Table of Contents

Definitions & Core Concepts

Container Runtime Fundamentals

What is a Container Runtime?

A **Container Runtime** is the software responsible for running containers on a host system. It manages the complete container lifecycle from creation to destruction.

Docker vs Containerd

- **Docker**: Complete container platform with CLI, API, image management, volumes, networking, and security features
- **Containerd**: Lightweight, industry-standard container runtime focused on core container operations
- **CRI (Container Runtime Interface)**: Kubernetes standard for communicating with container runtimes
- **OCI (Open Container Initiative)**: Industry standards for container formats and runtimes

CLI Tools Comparison

Tool	Purpose	Target Runtime	Use Case
docker	General container management	Docker daemon	Development, general use
ctr	Basic containerd control	Containerd	Limited debugging
nerdctl	Docker-compatible CLI	Containerd	Docker replacement
crictl	CRI debugging	Any CRI runtime	Kubernetes troubleshooting

Key Commands

```
# Docker
docker run --name redis redis:alpine docker
ps -a

# Containerd (ctr)
ctr images pull docker.io/library/redis:alpine ctr
run docker.io/library/redis:alpine redis

# Nerdctl (Docker-like for containerd)
nerdctl run --name redis redis:alpine nerdctl
ps -a
```

```
# CRI debugging
crictl pull busybox
crictl images
crictl ps -a crictl
pods
```

Pod Fundamentals

What is a Pod?

A **Pod** is the smallest deployable unit in Kubernetes that represents one or more containers sharing the same network and storage.

Pod Characteristics

- **Shared Network**: All containers in a pod share the same IP address and port space
- **Shared Storage**: Containers can share volumes mounted in the pod
- **Lifecycle Coupling**: All containers start and stop together
- **Ephemeral**: Pods are disposable and replaceable

Multi-Container Pod Patterns

- **Sidecar**: Helper container alongside main application (logging, monitoring)
- **Ambassador**: Proxy container for external connections
- **Adapter**: Container that standardizes output from main container

Pod Creation

```
# Imperative kubectl run nginx -
-image=nginx

# Declarative
kubectl apply -f pod-definition.yaml
```

```
apiVersion: v1
kind: Pod metadata:
  name: myapp-pod
labels:
    app: myapp spec:
  containers:
  - name: nginx-container
image: nginx
```

Controllers and Workload Management

What is a Controller?

A **Controller** is a Kubernetes component that watches the cluster state and makes changes to move the current state toward the desired state.

ReplicationController vs ReplicaSet

Feature	ReplicationController	ReplicaSet
API Version	v1	apps/v1
Selector	Equality-based only	Set-based (matchLabels)
Feature	ReplicationController	ReplicaSet
Status	Legacy	Current standard
Used by	Older deployments	Deployments

What is a Deployment?

A **Deployment** provides declarative updates for pods and ReplicaSets, enabling rolling updates, rollbacks, and scaling.

Deployment Strategies

- **RollingUpdate** (Default): Gradually replace old pods with new ones
- **Recreate**: Kill all old pods before creating new ones

Key Commands

```
# Create deployment kubectl create deployment
nginx --image=nginx

# Scale deployment kubectl scale deployment
nginx --replicas=5

# Update image kubectl set image deployment/nginx
nginx=nginx:1.18

# Rollback kubectl rollout undo
deployment/nginx
```

```
# Check rollout status kubectl rollout
status deployment/nginx

### Example Deployment YAML with RollingUpdate Strategy

# API version for Deployment resource (apps/v1 is the current stable version)
apiVersion: apps/v1
# Resource type - Deployment manages ReplicaSets and provides declarative
updates kind: Deployment metadata:
  # Unique name for this deployment
name: nginx-deployment
  # Labels for organizing and selecting resources
labels:
    app: nginx spec:
  # Number of replicas (pods) to maintain
replicas: 3

  # Deployment strategy configuration
strategy:
    # RollingUpdate: Gradually replace old pods with new ones (default)
# Alternative: Recreate (kills all old pods before creating new ones)
type: RollingUpdate     rollingUpdate:
      # maxSurge: Maximum number of pods above desired replicas during update
# 25% means with 3 replicas, up to 1 additional pod (3 * 0.25 = 0.75, rounded
up to 1)
      # Can be absolute number (e.g., 2) or percentage (e.g., 25%)
maxSurge: 25%

      # maxUnavailable: Maximum number of pods unavailable during update
# 25% means with 3 replicas, minimum 2 pods available (3 * 0.25 = 0.75,
rounded down to 0)
      # Can be absolute number (e.g., 1) or percentage (e.g., 25%)
maxUnavailable: 25%

  # Pod selector - determines which pods this deployment manages
selector:     matchLabels:       app: nginx

  # Pod template - defines the desired state for pods created by this
deployment   template:     metadata:
      # Labels that pods created by this deployment will have
labels:
```

```
        app: nginx
spec:
containers:       -
name: nginx
        # Container image to use
image: nginx:1.18

        # Ports that the container exposes
ports:
        - containerPort: 80

        # Resource requirements and limits
resources:
          # Minimum resources the container needs to run
requests:
            cpu: "100m"        # 0.1 CPU cores (100 millicores)
memory: "128Mi"    # 128 megabytes           # Maximum
resources the container can use           limits:
            cpu: "500m"        # 0.5 CPU cores (500 millicores)
memory: "512Mi"    # 512 megabytes
        # Health check to determine if container is alive
livenessProbe:           httpGet:             path: /
# HTTP path to check             port: 80          # Port to
check           initialDelaySeconds: 30  # Wait 30s before first
probe           periodSeconds: 10        # Check every 10
seconds

        # Health check to determine if container is ready to receive traffic
readinessProbe:           httpGet:             path: /            # HTTP path
to check            port: 80          # Port to check
initialDelaySeconds: 5   # Wait 5s before first probe
periodSeconds: 5         # Check every 5 seconds
```

RollingUpdate Strategy Parameters

Parameter	Description	Default	Example
maxSurge	Maximum number of pods above desired replicas during update. Controls how many extra pods can be created during rollout.	25%	`maxSurge: 2` or `maxSurge: 25%`

maxUnavailable Maximum number of pods 25% `maxUnavailable: 1` or unavailable during update. Ensures `maxUnavailable: 25%` minimum availability during rollout.

Example Calculation with 3 replicas:

- **maxSurge: 25%** = Up to 1 extra pod (3 × 0.25 = 0.75, rounded up to 1)
- **maxUnavailable: 25%** = Minimum 2 pods available (3 × 0.25 = 0.75, rounded down to 0 unavailable)
- **Result**: During update, you can have 1-4 pods total, with minimum 2 always available

Namespaces and Resource Isolation

What is a Namespace?

A **Namespace** provides virtual clustering within a physical Kubernetes cluster, enabling resource isolation and multi-tenancy.

Default Namespaces

- **default**: Default namespace for objects with no specified namespace
- **kube-system**: Namespace for Kubernetes system components
- **kube-public**: Publicly readable namespace for cluster information
- **kube-node-lease**: Namespace for node heartbeat objects

DNS in Namespaces

```
# Same namespace service-name

# Different namespace service-name.namespace-name.svc.cluster.local
```

Resource Quotas

Resource Quota limits the total resource consumption within a namespace.

```
apiVersion: v1 kind:
ResourceQuota
metadata:   name:
compute-quota
namespace: dev spec:
hard:
    pods: "10"
requests.cpu: "4"
```

```
requests.memory: 5Gi
limits.cpu: "10"
limits.memory: 10Gi
```

LimitRange

LimitRange sets minimum and maximum resource constraints for individual objects in a namespace.

```
apiVersion: v1 kind:
LimitRange metadata:
name: resource-limits
spec:  limits:  -
default:
      cpu:        "500m"
memory:          "512Mi"
defaultRequest:
cpu: "100m"      memory:
"128Mi"            type:
Container
```

Services and Networking

What is a Service?

A **Service** is an abstraction that defines a logical set of pods and provides stable network access to them.

Service Types

ClusterIP (Default)

- **Purpose**: Internal cluster communication only
- **IP Range**: Cluster-internal IP addresses
- **Access**: Only accessible from within the cluster

NodePort

- **Purpose**: External access via node ports • **Port Range**: 30000-32767
- **Access**: :

LoadBalancer

- **Purpose**: Cloud provider load balancer
- **Requirements**: Cloud provider integration
- **Access**: External IP provided by cloud provider

Service Port Definitions

Port Type	Definition	Example
targetPort	Port on the pod where traffic is sent	80 (nginx container port)
port	Port on the service where it accepts traffic	80 (service port)
nodePort	Port on the node for external access	30008 (external access)

Service Example

```yaml
apiVersion: v1
kind: Service
metadata:
  name: myapp-service
spec:
  type: NodePort
  selector:
    app: myapp
  ports:
    - targetPort: 80      # Pod port
      port: 80            # Service port
      nodePort: 30008     # Node port
```

What is a Node IP?

Node IP is the IP address of the physical or virtual machine that runs Kubernetes worker nodes. External traffic reaches services through NodeIP:NodePort combination.

Configuration Management

What are ConfigMaps?

ConfigMaps store non-confidential configuration data in key-value pairs that can be consumed by pods as environment variables, command-line arguments, or configuration files.

```yaml
apiVersion: v1
kind: ConfigMap
metadata:
  name: app-config
data:
  database.host: "postgres"
  database.port: "5432"
  app.properties: |
    debug=true
    log.level=info
```

What are Secrets?

Secrets store sensitive information like passwords, tokens, and keys in base64-encoded format with additional security measures.

```
apiVersion: v1 kind: Secret metadata:   name:
db-secret type: Opaque data:   username:
cG9zdGdyZXM=  # postgres (base64)   password:
cGFzc3dvcmQ=  # password (base64)
```

Using ConfigMaps and Secrets

```
apiVersion: v1
kind: Pod metadata:
  name: myapp-pod spec:
containers:   - name:
myapp     image:
myapp:latest     env:
    - name: DB_HOST
valueFrom:
configMapKeyRef:
name: app-config
key: database.host     - name:
DB_PASSWORD       valueFrom:
secretKeyRef:           name:
db-secret           key:
password
```

Kubernetes Control Plane Components

What is etcd?

etcd is a distributed, reliable key-value store that stores all Kubernetes cluster data and state information.

Data Stored in etcd

- Nodes, pods, deployments, services
- ConfigMaps, secrets
- Network policies, RBAC rules
- All cluster configuration

What is the API Server?

kube-apiserver is the central management component that exposes the Kubernetes API and handles all cluster communications.

API Server Responsibilities

- **Authentication**: Verify user identity
- **Authorization**: Check user permissions (RBAC)
- **Admission Control**: Validate and modify requests
- **Persistence**: Store data in etcd

What is the Scheduler?

kube-scheduler assigns pods to nodes based on resource requirements, constraints, and policies.

Scheduling Process

1. **Filtering**: Remove unsuitable nodes
2. **Scoring**: Rank remaining nodes
3. **Binding**: Assign pod to highest-scoring node

What is the Controller Manager?

kube-controller-manager runs various controllers that regulate cluster state.

Key Controllers

- **Node Controller**: Monitors node health
- **Replication Controller**: Maintains desired pod replicas
- **Deployment Controller**: Manages rolling updates
- **Service Account Controller**: Creates default service accounts

What is Kubelet?

kubelet is the node agent that manages pod lifecycle on worker nodes.

Kubelet Responsibilities

- **Pod Management**: Create, update, delete pods
- **Health Monitoring**: Report node and pod status
- **Resource Reporting**: Send resource usage to API server
- **Container Runtime Interface**: Communicate with container runtime

What is Kube-proxy?

kube-proxy maintains network rules and enables service communication within the cluster.

Kube-proxy Functions

- **Service Discovery**: Route traffic to service endpoints
- **Load Balancing**: Distribute traffic across pod replicas
- **Network Rules**: Manage iptables or IPVS rules

Resource Management

What are Resource Requests?

Resource Requests specify the minimum amount of CPU and memory a container needs to run.

What are Resource Limits?

Resource Limits specify the maximum amount of CPU and memory a container can consume.

```
resources:
requests:
    cpu: "100m"         # 0.1 CPU core minimum
memory: "128Mi"    # 128 megabytes minimum   limits:
    cpu: "500m"         # 0.5 CPU core maximum
memory: "512Mi"    # 512 megabytes maximum
```

Resource Units

- **CPU**: Measured in millicores (1000m = 1 core)
- **Memory**: Measured in bytes (Ki, Mi, Gi, Ti)

Best Practices

Declarative vs Imperative

Declarative (Recommended)

- **Definition**: Describe desired state in YAML files
- **Command**: `kubectl apply -f file.yaml`
- **Benefits**: Version control, reproducibility, collaboration

Imperative

- **Definition**: Direct commands to modify cluster state
- **Commands**: `kubectl run`, `kubectl create`, `kubectl scale`
- **Use Cases**: Quick testing, debugging, learning

Essential kubectl Commands

```
# Resource management
kubectl get  kubectl
describe   kubectl
create -f  kubectl
apply -f  kubectl
delete

#   Debugging   kubectl    logs
kubectl exec -it  -- /bin/bash
kubectl port-forward  8080:80

# Cluster information
kubectl cluster-info
kubectl get nodes kubectl
get events
```

Kubernetes Scheduling

DaemonSets

What is a DaemonSet?

A **DaemonSet** ensures that a copy of a pod runs on all (or specific) nodes in the cluster.

DaemonSet Use Cases

- **Node monitoring**: Monitoring agents on every node
- **Log collection**: Log collectors like Fluentd or Filebeat
- **Storage daemons**: Distributed storage solutions
- **Network components**: CNI plugins, kube-proxy

DaemonSet vs Deployment

Feature	DaemonSet	Deployment
Replica Logic	One per node	Total replica count
Scheduling	Node-based	Cluster-wide
Use Case	Node-level services	Application services
Updates	Rolling update per node	Rolling update by replica

DaemonSet Definition

```
apiVersion: apps/v1
kind:     DaemonSet
metadata:
  name: monitoring-daemon
labels:
    app: monitoring-daemon
spec:   selector:
matchLabels:
      app: monitoring-agent
template:    metadata:
labels:
        app: monitoring-agent
spec:       containers:
      - name: monitoring-agent
image: monitoring-agent
resources:           requests:
cpu: 100m             memory:
128Mi           limits:
cpu: 200m             memory:
256Mi
```

DaemonSet Scheduling Evolution

- **Before v1.12**: Used nodeName to bypass scheduler
- **v1.12+**: Uses NodeAffinity with default scheduler

DaemonSet Commands

```
# Create DaemonSet kubectl create -f daemon-
set-definition.yaml

# View DaemonSets kubectl
get daemonsets

# Describe DaemonSet
kubectl describe daemonset monitoring-daemon

#  View  DaemonSet  pods  kubectl  get  pods  -l
app=monitoring-agent -o wide
```

Static Pods

What are Static Pods?

Static Pods are pods managed directly by the kubelet on a specific node, without requiring the Kubernetes API server or any controllers like ReplicaSets or Deployments.

Key Characteristics

- **Managed by kubelet only**: No involvement of kube-apiserver or controllers
- **Node-specific**: Created and managed on the node where kubelet runs
- **Automatic restart**: kubelet automatically restarts static pods if they fail
- **Mirror pods**: API server creates read-only mirror pods for visibility

Static Pod Configuration

Method 1: Pod Manifest Path

```
# Configure kubelet with --pod-manifest-path
ExecStart=/usr/local/bin/kubelet \
--container-runtime=remote \
--container-runtime-endpoint=unix:///var/run/containerd/containerd.sock \
--pod-manifest-path=/etc/kubernetes/manifests \
--kubeconfig=/var/lib/kubelet/kubeconfig \
--network-plugin=cni \
--register-node=true \
--v=2
```

Method 2: Kubelet Configuration File

```
# kubeconfig.yaml staticPodPath:
/etc/kubernetes/manifests

# Use config file
ExecStart=/usr/local/bin/kubelet \
--config=kubeconfig.yaml \
--kubeconfig=/var/lib/kubelet/kubeconfig \
--network-plugin=cni \
--register-node=true \ --v=2
```

Static Pod Use Cases

Control Plane Components

Static pods are commonly used to run control plane components on master nodes:

- **kube-apiserver**: API server pod

- **kube-controller-manager**: Controller manager pod
- **kube-scheduler**: Scheduler pod
- **etcd**: Database pod

Static Pod Lifecycle

1. **Creation**: Place YAML file in `/etc/kubernetes/manifests/`
2. **Detection**: kubelet monitors the directory and detects new files
3. **Pod Creation**: kubelet creates the pod directly
4. **Mirror Pod**: API server creates a read-only mirror for visibility
5. **Management**: kubelet handles restarts, updates, and deletion

Static Pod Example

```
# /etc/kubernetes/manifests/static-web.yaml
apiVersion: v1 kind: Pod metadata:
  name: static-web
labels:
    app: static-web
spec:  containers:
- name: web
image: nginx
ports:
    - containerPort: 80
```

Static Pods vs DaemonSets

Feature	Static Pods	DaemonSets
Creation	kubelet directly	kube-apiserver (DaemonSet Controller)
Management	Node-level	Cluster-level
Use Case	Control plane components	Monitoring agents, log collectors
Scheduler	Ignored by scheduler	Uses scheduler
API Visibility	Mirror pods only	Full API objects

Viewing Static Pods

```
# View static pods (will show mirror pods) kubectl
get pods -n kube-system

# Example output showing static pods with node names
```

```
NAME                                READY   STATUS    RESTARTS   AGE etcd-master
1/1     Running   0          15m kube-apiserver-master            1/1
Running   0          15m kube-controller-manager-master   1/1     Running   0
15m kube-scheduler-master            1/1     Running   0          15m
```

Taints and Tolerations

What are Taints and Tolerations?

Taints are applied to nodes to repel pods, while **tolerations** are applied to pods to allow them to be scheduled on tainted nodes.

Taint Effects

Effect	Description
NoSchedule	Prevents new pods from being scheduled
PreferNoSchedule	Avoids scheduling if possible
NoExecute	Evicts existing pods and prevents new ones

Applying Taints

```
# Taint a node kubectl taint nodes node1
app=myapp:NoSchedule

# Remove a taint kubectl taint nodes node1
app=myapp:NoSchedule-

# View node taints kubectl describe node
node1 | grep Taint
```

Pod Tolerations

```
apiVersion:    v1
kind:         Pod
metadata:   name:
myapp-pod   spec:
containers:
  - name: nginx-container
image: nginx
tolerations:   - key:
"app"    operator:
"Equal"    value:
"myapp"    effect:
"NoSchedule"
```

Master Node Taints

Master nodes are typically tainted to prevent regular workloads:

```
kubectl describe node master | grep Taint
# Output: Taints: node-role.kubernetes.io/master:NoSchedule
```

Toleration Operators

- **Equal**: Key/value must match exactly
- **Exists**: Only key must match (ignores value)

Node Selectors and Node Affinity

What is Node Selection?

Node selection mechanisms allow you to constrain pods to run on specific nodes based on node labels.

Node Selectors (Simple Method)

Label Nodes
```
# Label a node kubectl label
nodes node-1 size=Large

# View node labels kubectl get
nodes --show-labels
```

Use Node Selector
```
apiVersion: v1
kind: Pod
metadata: name:
myapp-pod spec:
containers:
  - name: data-processor
image: data-processor
nodeSelector: size:
Large
```

Node Selector Limitations

- **Simple equality only**: Cannot handle complex logic
- **No OR conditions**: Cannot select “Large OR Medium”
- **No negation**: Cannot specify “NOT Small”

Node Affinity (Advanced Method)

Required Node Affinity

```
apiVersion:     v1
kind: Pod metadata:
  name: myapp-pod spec:
  containers:
- name: data-processor     image: data-processor
  affinity:    nodeAffinity:
  requiredDuringSchedulingIgnoredDuringExecution:
        nodeSelectorTerms:
- matchExpressions:
- key: size             operator: In
  values:             - Large
- Medium
```

Preferred Node Affinity

```
apiVersion:  v1 kind:  Pod metadata:
name:  myapp-pod spec:    affinity:       nodeAffinity:
preferredDuringSchedulingIgnoredDuringExecution:
- weight: 100         preference:
  matchExpressions:           - key: size
  operator: In             values:             - Large
```

Node Affinity Operators

- **In**: Value must be in the list
- **NotIn**: Value must not be in the list
- **Exists**: Key must exist (ignores values)
- **DoesNotExist**: Key must not exist
- **Gt**: Greater than (numeric values)
- **Lt**: Less than (numeric values)

Node Affinity Types

Type	DuringScheduling	DuringExecution
requiredDuringSchedulingIgnoredDuringExecution	Required	Ignored
preferredDuringSchedulingIgnoredDuringExecution	Preferred	Ignored
requiredDuringSchedulingRequiredDuringExecution	Required	Required (Planned)

Lifecycle Phases

- **DuringScheduling**: Rules applied when pod is first scheduled
- **DuringExecution**: Rules applied to running pods when node labels change

Manual Scheduling

What is Manual Scheduling?

Manual Scheduling is the process of assigning pods to specific nodes without using the Kubernetes scheduler.

When Manual Scheduling is Needed

- **No scheduler available**: Scheduler is down or not configured
- **Custom placement logic**: Specific node requirements
- **Troubleshooting**: Testing pod placement
- **Static pods**: Control plane components

Manual Scheduling Methods

Method 1: NodeName in Pod Spec

```
apiVersion: v1
kind: Pod
metadata:
name: nginx
spec:
containers:   -
name: nginx
image: nginx
ports:
    - containerPort: 80   nodeName: node02
# Direct node assignment
```

Method 2: Binding API (Post-Creation)

```
# Pod without nodeName (will remain Pending)
apiVersion: v1 kind: Pod metadata:   name:
nginx spec:   containers:   - name: nginx
image: nginx

# Binding object
apiVersion: v1
kind: Binding
metadata:
```

```
name: nginx
target:
  apiVersion: v1
kind: Node   name:
node02
# Create binding via API curl --header
"Content-Type:application/json" \
     --request POST \
     --data '{"apiVersion":"v1", "kind": "Binding", "metadata": {"name":
"nginx"}, "target": {"apiVersion": "v1", "kind": "Node", "name": "node02"}}'
\
     http://$SERVER/api/v1/namespaces/default/pods/nginx/binding/
```

Multiple Schedulers

What are Multiple Schedulers?

Kubernetes supports running **multiple schedulers** simultaneously, allowing different scheduling policies for different types of workloads.

Use Cases for Multiple Schedulers

- **Specialized workloads**: GPU, high-memory, or compute-intensive tasks
- **Custom scheduling logic**: Business-specific placement rules
- **Multi-tenancy**: Different schedulers for different teams
- **Performance optimization**: Specialized algorithms for specific use cases

Deploying Custom Scheduler

Binary Deployment

```
# Download scheduler binary
wget
https://storage.googleapis.com/kubernetesrelease/release/v1.12.0/bin/linux/am
d64/kube-scheduler

# Configure custom scheduler service
# my-custom-scheduler.service
ExecStart=/usr/local/bin/kube-scheduler \
--config=/etc/kubernetes/config/kube-scheduler.yaml \
--scheduler-name=my-custom-scheduler
kubeadm   Deployment   #   my-custom-
scheduler.yaml apiVersion:  v1 kind:
Pod metadata:
```

```
  name: my-custom-scheduler
namespace: kube-system spec:
  containers:
- command:
- kube-scheduler
- --address=127.0.0.1
- --kubeconfig=/etc/kubernetes/scheduler.conf
- --leader-elect=true
- --scheduler-name=my-custom-scheduler
- --lock-object-name=my-custom-scheduler     image: k8s.gcr.io/kube-
  scheduler-amd64:v1.11.3     name: my-custom-scheduler
```

Using Custom Scheduler

```
apiVersion: v1 kind: Pod metadata:   name: nginx spec:   containers:
- name: nginx    image: nginx   schedulerName: my-custom-scheduler
# Specify custom scheduler
```

Monitoring Multiple Schedulers

```
# View all schedulers kubectl get pods -
-namespace=kube-system

# View scheduler events kubectl
get events

# View scheduler logs kubectl logs my-custom-scheduler --
namespace=kube-system
```

Network Policies

What are Network Policies?

Network Policies are Kubernetes resources that control network traffic between pods, providing micro-segmentation at the application level.

Network Policy Components

- **podSelector**: Selects pods the policy applies to
- **policyTypes**: Ingress, Egress, or both
- **ingress**: Rules for incoming traffic
- **egress**: Rules for outgoing traffic

Basic Network Policy Example

```
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy metadata:
  name: db-policy spec:
  podSelector:
matchLabels:
role: db
policyTypes:   -
Ingress
ingress:
- from:     -
  podSelector:
  matchLabels:
  name: api-pod
  ports:     -
  protocol: TCP
  port: 3306
```

Network Policy Rules

Ingress Rules (Incoming Traffic)

```
spec:
  ingress:
- from:
    # Pod selector - allow from specific pods
- podSelector:         matchLabels:
app: frontend
    # Namespace selector - allow from specific namespaces
- namespaceSelector:         matchLabels:
          name: production
    # IP block - allow from specific IP ranges
- ipBlock:
        cidr: 192.168.1.0/24
except:         -
192.168.1.5/32     ports:
- protocol: TCP       port:
80
```

Egress Rules (Outgoing Traffic)

```
spec:
  policyTypes:
- Egress
egress:
  - to:     - ipBlock:
cidr: 10.0.0.0/24
```

```
ports:     - protocol:
TCP       port: 5432
```

Ingress

What is Ingress?

Ingress is a Kubernetes resource that manages external access to services, typically HTTP/HTTPS, providing load balancing, SSL termination, and name-based virtual hosting.

Ingress Components

- **Ingress Controller**: Implements ingress functionality (nginx, traefik, etc.)
- **Ingress Resource**: Configuration defining routing rules

Ingress vs Services

Feature	Service (NodePort/LoadBalancer)	Ingress
Layer	Layer 4 (TCP/UDP)	Layer 7 (HTTP/HTTPS)
Routing	Simple port-based	Path/host-based routing
SSL/TLS	External configuration	Built-in SSL termination
Cost	Multiple load balancers	Single entry point

Ingress Controller Deployment

```
apiVersion:  apps/v1 kind:
Deployment metadata:
  name: nginx-ingress-controller
spec:   replicas: 1   selector:
matchLabels:       name: nginx-
ingress   template:     metadata:
labels:
        name: nginx-ingress
spec:       containers:
- name: nginx-ingress-controller
        image: quay.io/kubernetes-ingress-controller/nginx-
ingresscontroller:0.21.0         args:
- /nginx-ingress-controller
- --configmap=$(POD_NAMESPACE)/nginx-configuration         env:
- name: POD_NAME           valueFrom:             fieldRef:
              fieldPath: metadata.name
- name: POD_NAMESPACE           valueFrom:
fieldRef:               fieldPath:
metadata.namespace         ports:         -
```

```
name: http           containerPort: 80
- name: https           containerPort: 443
```

Ingress Resource Examples

Simple Ingress apiVersion: networking.k8s.io/v1 kind: Ingress metadata:

```
  name: ingress-wear
spec:  rules:  - http:
paths:      - path: /
pathType: Prefix
backend:
service:
            name: wear-service
port:               number: 80
```

Path-based Routing apiVersion: networking.k8s.io/v1 kind: Ingress metadata:

```
  name: ingress-wear-watch
spec:  rules:  - http:
paths:      - path: /wear
pathType: Prefix
backend:
service:
            name: wear-service
port:               number: 80
- path: /watch
pathType: Prefix
backend:          service:
            name: watch-service
port:               number: 80
```

Host-based Routing apiVersion: networking.k8s.io/v1 kind: Ingress metadata:

```
  name: ingress-wear-watch
spec:  rules:
  - host: wear.my-online-store.com
http:      paths:      - path: /
pathType: Prefix        backend:
service:
```

```
            name: wear-service
port:
              number: 80   - host:
watch.my-online-store.com    http:
paths:       - path: /
pathType: Prefix         backend:
service:
            name: watch-service
port:               number: 80
```

Key Commands

Static Pods

```
# Check static pod directory ls
/etc/kubernetes/manifests/

# View kubelet configuration systemctl
status kubelet
```

Taints and Tolerations

```
# Apply taint kubectl taint nodes node1
key=value:NoSchedule

# Remove taint kubectl taint nodes node1
key=value:NoSchedule-

# Check node taints kubectl describe
node node1 | grep Taint
```

Node Affinity

```
#  Label  nodes kubectl  label  nodes
node1 size=Large

# View node labels kubectl get
nodes --show-labels
```

DaemonSets

```
# Create DaemonSet kubectl
create -f daemonset.yaml # View
DaemonSets
kubectl get daemonsets
```

```
# View DaemonSet pods kubectl get pods -l
app=monitoring-agent -o wide
```

Multiple Schedulers

```
# View schedulers
kubectl get pods -n kube-system

# View scheduler events kubectl
get events

# View scheduler logs kubectl logs
scheduler-name -n kube-system
```

Network Policies

```
# Create network policy
kubectl create -f network-policy.yaml

# View network policies kubectl
get networkpolicies

# Describe network policy kubectl describe
networkpolicy policy-name
```

Ingress

```
# Create ingress
kubectl create -f ingress.yaml

# View ingress kubectl
get ingress

# Describe ingress kubectl describe
ingress ingress-name
```

Logging and Monitoring

Container Logging

What is Container Logging?

Container Logging is the process of collecting, storing, and accessing application logs generated by containers running in pods.

Docker vs Kubernetes Logging

Docker Logging

```
# Run container and view logs directly
docker run kodekloud/event-simulator

# Run in detached mode and view logs docker
run -d kodekloud/event-simulator docker
logs -f
```

Kubernetes Logging

```
# Create pod and view
logs kubectl create -f event-
simulator.yaml kubectl logs -f event-
simulator-pod
```

Log Access Methods

Single Container Pod

```
# View logs from single container pod kubectl
logs

# Follow logs in real-time kubectl
logs -f

# View previous container logs (after restart) kubectl
logs --previous
```

Multi-Container Pod

```
# Specify container name for multi-container pods kubectl
logs -f

# Example with multi-container pod kubectl logs -f
event-simulator-pod event-simulator
```

Pod Definition for Logging

```
# Single container pod
apiVersion: v1 kind:
Pod metadata:
  name: event-simulator-pod spec:
```

```
  containers:   - name: event-
simulator     image:
kodekloud/event-simulator

# Multi-container pod
apiVersion: v1 kind: Pod
metadata:   name: event-
simulator-pod spec:
containers:
- name: event-simulator
    image: kodekloud/event-simulator
- name: image-processor     image: some-image-
  processor
```

Log Storage Locations

- **Container Runtime**: Docker stores logs in `/var/lib/docker/containers/`
- **Kubelet**: Manages log rotation and cleanup
- **Node-level**: Logs accessible via kubectl from any cluster node

Log Limitations

- **Ephemeral**: Logs are lost when pods are deleted
- **No centralized storage**: Logs stored locally on nodes
- **Limited retention**: Subject to log rotation policies
- **No aggregation**: No built-in cross-pod log correlation

Kubernetes Monitoring

What is Monitoring in Kubernetes?

Monitoring is the continuous observation of cluster and application performance through metrics collection, storage, and analysis.

Key Metrics to Monitor

Node-Level Metrics

- **CPU Usage**: Processor utilization across nodes
- **Memory Usage**: RAM consumption and availability
- **Disk Usage**: Storage utilization and I/O performance
- **Network**: Traffic, latency, and packet loss

Pod-Level Metrics

- **Resource Consumption**: CPU, memory usage per pod
- **Restart Count**: Pod failure and restart frequency
- **Health Status**: Pod readiness and liveness states

Cluster-Level Metrics

- **API Server Performance**: Request latency and throughput
- **Scheduler Performance**: Pod placement efficiency
- **Controller Performance**: Reconciliation loop metrics

Monitoring Solutions

Built-in Solutions

- **Metrics Server**: Lightweight, resource metrics collection
- **cAdvisor**: Container-level resource usage statistics

Third-Party Solutions

- **Prometheus**: Open-source monitoring and alerting
- **Elastic Stack**: Log aggregation and analysis
- **Datadog**: Commercial monitoring platform
- **Dynatrace**: Application performance monitoring

Metrics Server

What is Metrics Server?

Metrics Server is a cluster-wide aggregator of resource usage data that provides CPU and memory metrics for nodes and pods.

Metrics Server vs Heapster

Feature	Heapster (Deprecated)	Metrics Server
Status	Deprecated in K8s 1.11	Current standard
Storage	Persistent storage	In-memory only
Scope	Full monitoring solution	Resource metrics only
Performance	Heavier resource usage	Lightweight
API	Custom API	Standard Metrics API

Metrics Server Architecture

Components

- **Metrics Server Pod**: Collects and aggregates metrics
- **Kubelet Integration**: Pulls metrics from kubelet on each node
- **cAdvisor**: Provides container-level metrics to kubelet
- **API Server**: Exposes metrics via Kubernetes API

Data Flow `cAdvisor → Kubelet → Metrics Server → Kubernetes API → kubectl top`

Metrics Server Installation

Minikube

```
# Enable metrics-server addon minikube
addons enable metrics-server
```

Manual Installation

```
# Clone metrics-server repository
git clone https://github.com/kubernetes-incubator/metrics-server.git

# Deploy metrics-server kubectl
create -f deploy/1.8+/
```

Installation Output

```
clusterrolebinding "metrics-server:system:auth-delegator" created
rolebinding "metrics-server-auth-reader" created apiservice
"v1beta1.metrics.k8s.io" created serviceaccount "metrics-server"
created deployment "metrics-server" created service "metrics-
server" created clusterrole "system:metrics-server" created
clusterrolebinding "system:metrics-server" created
```

Using Metrics Server

View Node Metrics `kubectl top node`

```
NAME          CPU(cores)   CPU%   MEMORY(bytes)   MEMORY%
kubemaster    166m         8%     1337Mi          70% kubenode1
36m          1%     1046Mi          55% kubenode2     39m
1%     1048Mi          55%
```

View Pod Metrics `kubectl top pod`

```
NAME    CPU(cores)   MEMORY(bytes)
nginx   5m           10Mi redis
2m          15Mi
```

Namespace-Specific Metrics

```
# View pods in specific namespace kubectl
top pod -n kube-system

# View all namespaces kubectl
top pod --all-namespaces
```

Metrics Server Data Storage

- **In-Memory Only**: No persistent storage of historical data
- **Real-Time**: Provides current resource usage only
- **Aggregation Period**: Typically 15-60 second intervals
- **Retention**: Limited to current metrics only

Advanced Monitoring Concepts

Resource Requests vs Usage

- **Requests**: Resources guaranteed by scheduler
- **Usage**: Actual resources consumed by container
- **Monitoring Value**: Usage vs requests comparison shows over/under-provisioning

Horizontal Pod Autoscaler (HPA) Integration

```
apiVersion: autoscaling/v2
kind: HorizontalPodAutoscaler
metadata:  name: webapp-hpa
spec:  scaleTargetRef:
apiVersion: apps/v1    kind:
Deployment    name: webapp
minReplicas: 2  maxReplicas:
10  metrics:  - type:
Resource    resource:
name: cpu      target:
type: Utilization
averageUtilization: 70
```

Custom Metrics

- **Application Metrics**: Business-specific measurements
- **Custom Resource Metrics**: GPU, network bandwidth

- **External Metrics**: Cloud provider metrics, external services

Logging Best Practices

Application Logging

- **Structured Logging**: Use JSON format for easier parsing
- **Log Levels**: Implement DEBUG, INFO, WARN, ERROR levels
- **Contextual Information**: Include request IDs, user IDs, timestamps

Container Logging Standards

- **Stdout/Stderr**: Write logs to standard output streams
- **Avoid File Logging**: Don't write logs to container filesystem
- **Single Process**: One main process per container for log clarity

Log Management

```
# View logs with timestamps kubectl
logs  --timestamps

# Limit log output
kubectl logs  --tail=100

# Filter logs by time kubectl
logs  --since=1h
```

Monitoring Best Practices

Metrics Collection

- **Resource Limits**: Set appropriate CPU/memory limits
- **Health Checks**: Implement liveness and readiness probes
- **Service Monitoring**: Monitor service endpoints and response times

Alerting Strategy

- **Threshold-Based**: CPU > 80%, Memory > 90%
- **Trend-Based**: Resource usage growing over time
- **Service-Level**: Application-specific metrics and SLAs

Dashboard Design

- **Node Overview**: Cluster-wide resource utilization
- **Application Metrics**: Service-specific performance

- **Infrastructure Health**: Node status, pod distribution

Troubleshooting Common Issues

Metrics Server Issues

```
# Check metrics-server status
kubectl get pods -n kube-system | grep metrics-server

# View metrics-server logs
kubectl logs -n kube-system deployment/metrics-server

# Verify metrics API kubectl get --raw
/apis/metrics.k8s.io/v1beta1/nodes
```

Logging Issues

```
# Pod not generating logs kubectl
describe pod

# Container exit codes kubectl
get pods -o wide

# Previous container logs after restart kubectl
logs  --previous
```

Performance Troubleshooting

```
# High CPU usage investigation
kubectl top pods --sort-by=cpu

# Memory pressure analysis kubectl
top pods --sort-by=memory

# Node resource availability
kubectl describe node
```

Version Compatibility Notes

Kubernetes Version Support

- **Metrics Server**: Supported in K8s 1.8+
- **Heapster**: Deprecated since K8s 1.11
- **Play-with-K8s**: Uses K8s 1.8, may require Heapster

Migration Considerations

- **Legacy Clusters**: May still use Heapster
- **Upgrade Path**: Migrate from Heapster to Metrics Server
- **API Changes**: Update monitoring tools to use Metrics API

Key Commands Summary

Logging Commands

```
# Basic log viewing kubectl logs
kubectl logs -f   # Follow logs
kubectl logs  -c   # Multi-container

#  Advanced  log  options  kubectl  logs    --
timestamps kubectl logs  --tail=50 kubectl logs
--since=2h kubectl logs  --previous  # Previous
container
```

Monitoring Commands

```
# Resource usage kubectl top
nodes kubectl top pods kubectl top
pods --all-namespaces
kubectl top pods --sort-by=cpu

# Metrics server
kubectl get pods -n kube-system | grep metrics kubectl
get apiservice | grep metrics
```

Troubleshooting Commands

```
# Pod investigation kubectl
describe pod
kubectl get events --sort-by=.metadata.creationTimestamp

# Node investigation kubectl
describe node  kubectl get
nodes -o wide
```

Application Lifecycle Management

Rolling Updates and Rollbacks

What is a Rollout?

A **Rollout** is the process of deploying a new version of an application in Kubernetes. Each rollout creates a new **revision** that can be tracked and managed.

Rollout Revisions

- **Revision 1**: Initial deployment (e.g., nginx:1.7.0)
- **Revision 2**: Updated deployment (e.g., nginx:1.7.1)
- **Revision History**: Kubernetes maintains a history of all revisions

Deployment Strategies

Strategy	Description	Downtime	Use Case
Recreate	Kill all old pods, then create new ones	Yes	Development, non-critical new apps
RollingUpdate	Gradually replace old pods with new ones	No	Production applications (default)

Rolling Update Process

1. **Create new ReplicaSet** with updated image
2. **Scale up new ReplicaSet** gradually
3. **Scale down old ReplicaSet** simultaneously
4. **Maintain desired replica count** throughout process

Rollout Commands

```
# Check rollout status kubectl rollout status
deployment/myapp-deployment

# View rollout history kubectl rollout history
deployment/myapp-deployment

# Trigger rollout with record
kubectl apply -f deployment-definition.yml --record

# Update image and trigger rollout kubectl set image
deployment/myapp-deployment nginx=nginx:1.9.1
```

Example Rollout Output

```
kubectl rollout status deployment/myapp-deployment
# Output:
```

```
Waiting for rollout to finish: 0 of 10 updated replicas are available...
Waiting for rollout to finish: 1 of 10 updated replicas are available...
...
deployment "myapp-deployment" successfully rolled out
```

Rollback Operations

```
# Rollback to previous revision kubectl rollout
undo deployment/myapp-deployment

# View ReplicaSets during rollback kubectl
get replicasets

# Before rollback:
# myapp-deployment-67c749c58c    0    0    0    22m  (old)
# myapp-deployment-7d57dbdb8d    5    5    5    20m  (current)

# After rollback:
# myapp-deployment-67c749c58c    5    5    5    22m  (restored)
# myapp-deployment-7d57dbdb8d    0    0    0    20m  (scaled down)
```

Deployment Definition

```
apiVersion: apps/v1
kind:    Deployment
metadata:
  name: myapp-deployment
labels:
    app: myapp
type: front-end
spec:
  replicas: 3
selector:
    matchLabels:
      type: front-end
template:
metadata:
      name: myapp-pod
labels:
        app: myapp
type: front-end
spec:       containers:
      - name: nginx-container
image: nginx:1.7.1
```

Commands and Arguments

Docker Container Behavior

- **Default Command**: Containers run default command specified in Dockerfile
- **Override Command**: Can override default command at runtime
- **Process Lifecycle**: Container exits when main process completes

Docker Command Examples

```
# Default ubuntu behavior (exits immediately)
docker run ubuntu docker ps -a
# STATUS: Exited (0) 41 seconds ago

# Override with custom command docker
run ubuntu sleep 5
```

Dockerfile Instructions

CMD Instruction

CMD specifies the default command to run when container starts:

```
FROM Ubuntu
CMD sleep 5

# Shell form
CMD command param1

# Exec form (preferred)
CMD ["command", "param1"]
```

ENTRYPOINT Instruction

ENTRYPOINT specifies the command that always executes:

```
FROM Ubuntu
ENTRYPOINT ["sleep"]

# Usage docker run ubuntu-
sleeper 10 # Command at
startup: sleep 10
```

ENTRYPOINT + CMD Combination

```
FROM Ubuntu
```

```
ENTRYPOINT ["sleep"]
CMD ["5"]
```

Benefits:

- **Default behavior**: `docker run ubuntu-sleeper` → `sleep 5`
- **Override parameter**: `docker run ubuntu-sleeper 10` → `sleep 10`
- **Override entrypoint**: `docker run --entrypoint sleep2.0 ubuntu-sleeper 10`

Kubernetes Commands and Arguments

Pod Command Override

```
apiVersion: v1 kind: Pod
metadata: name: ubuntu-
sleeper-pod spec:
containers:
  - name: ubuntu-sleeper image: ubuntu-
sleeper command: ["sleep2.0"] # Overrides
ENTRYPOINT args: ["10"] # Overrides
CMD
```

Docker vs Kubernetes Mapping

Docker	Kubernetes	Purpose
ENTRYPOINT	**command**	Main executable
CMD	**args**	Default arguments

Environment Variables

What are Environment Variables?

Environment Variables are key-value pairs that provide configuration data to applications at runtime.

Flask Application Example

```
# app.py import
os
from flask import Flask

app = Flask(__name__)
color = os.environ.get('APP_COLOR')  # Read from environment
```

```
@app.route("/") def
main():
    print(color)
    return render_template('hello.html', color=color)

if __name__ == "__main__":
app.run(host="0.0.0.0", port="8080")
```

Setting Environment Variables

Docker

```
# Set environment variable
docker run -e APP_COLOR=blue simple-webapp-color
docker run -e APP_COLOR=green simple-webapp-color docker
run -e APP_COLOR=pink simple-webapp-color
```

Kubernetes Pod

```
apiVersion: v1
kind: Pod metadata:   name:
simple-webapp-color   spec:
containers:
-     name: simple-webapp-
color     image: simple-
webapp-color     ports:
-     containerPort: 8080
env:
-     name: APP_COLOR
value: pink
```

Environment Variable Value Types

1. Plain Key-Value

```
env:
- name: APP_COLOR
value: pink
```

2. ConfigMap Reference

```
env:
- name: APP_COLOR
valueFrom:
configMapKeyRef:
name: app-config
key: APP_COLOR
```

3. Secret Reference

```
env:
```

```
- name: APP_COLOR
valueFrom:
secretKeyRef:
name: app-secret
key: APP_COLOR
```

ConfigMaps

What are ConfigMaps?

ConfigMaps store configuration data in key-value pairs that can be consumed by pods as environment variables, command-line arguments, or configuration files.

ConfigMap Use Cases

- **Application settings**: Database URLs, feature flags
- **Configuration files**: Application config, logging config
- **Non-sensitive data**: Any configuration that's not secret

Creating ConfigMaps

Imperative Method

```
# From literal values
kubectl create configmap app-config \
  --from-literal=APP_COLOR=blue \
  --from-literal=APP_MODE=prod

# From file kubectl create configmap
app-config \   --from-
file=app_config.properties
```

Declarative Method

```
# config-map.yaml
apiVersion: v1 kind:
ConfigMap metadata:
  name: app-config data:
APP_COLOR: blue   APP_MODE: prod
app.properties: |     debug=true
log.level=info kubectl create -f
config-map.yaml
```

Viewing ConfigMaps

```
#    List    ConfigMaps
kubectl get configmaps
```

```
# Detailed view kubectl describe
configmap app-config
```

Using ConfigMaps in Pods

Environment Variables (All Keys)

```
apiVersion:  v1 kind:  Pod
metadata:
  name: simple-webapp-color
spec:  containers:
-     name: simple-
webapp-color     image:
simple-webapp-color
envFrom:
-     configMapRef:
name: app-config
```

Single Environment Variable `env:`

```
-     name: APP_COLOR
valueFrom:
configMapKeyRef:
name: app-config
key: APP_COLOR
```

Volume Mount `volumes:`

```
-     name: app-config-
volume   configMap:
name: app-config
```

Secrets

What are Secrets?

Secrets store sensitive information like passwords, tokens, and keys in base64-encoded format with additional security measures.

Secret vs ConfigMap

Feature	ConfigMap	Secret
Data Type	Non-sensitive configuration	Sensitive information
Encoding	Plain text	Base64 encoded
Security	Standard	Enhanced (encryption at rest)

Use Cases App config, feature flags Passwords, tokens, certificates

Creating Secrets

Imperative Method kubectl create secret
generic app-secret \
  --from-literal=DB_Host=mysql \
  --from-literal=DB_User=root \
  --from-literal=DB_Password=paswrd

Declarative Method

```
# secret-data.yaml
apiVersion: v1 kind:
Secret metadata:
  name: app-secret data:
  DB_Host: bXlzcWw=     # mysql (base64)
  DB_User: cm9vdA==     # root (base64)
  DB_Password: cGFzd3Jk # paswrd (base64)
```

Base64 Encoding/Decoding

```
# Encode echo -n 'mysql'
| base64
# Output: bXlzcWw=

# Decode echo -n 'bXlzcWw=' | base64
--decode # Output: mysql
```

Viewing Secrets

```
#   List   secrets
kubectl get secrets

# Describe secret (shows size, not values) kubectl
describe secret app-secret

# View secret YAML (shows base64 values) kubectl
get secret app-secret -o yaml
```

Using Secrets in Pods

Environment Variables (All Keys)

```
spec:   containers:   - name:
simple-webapp-color     image:
simple-webapp-color
```

```
envFrom:          -  secretRef:
name: app-secret
```

Single Environment Variable

```
env:      -       name:
DB_PASSWORD
valueFrom:
secretKeyRef:
name:        app-secret
key: DB_Password
```

Volume Mount

```
volumes:
- name: app-secret-volume
secret:     secretName:
app-secret
```

Secrets as Volumes

When mounted as volumes, each key becomes a file:

```
# Inside container ls
/opt/app-secret-volumes #
Output: DB_Host
DB_Password  DB_User

cat /opt/app-secret-volumes/DB_Password #
Output: paswrd
```

Multi-Container Pods

What are Multi-Container Pods?

Multi-Container Pods contain multiple containers that share the same lifecycle, network, and storage.

Multi-Container Patterns

Sidecar Pattern

- **Main container**: Application
- **Sidecar container**: Supporting functionality (logging, monitoring)
- **Example**: Web server + log agent

Ambassador Pattern

- **Main container**: Application
- **Ambassador container**: Proxy for external connections
- **Example**: App + database proxy

Adapter Pattern

- **Main container**: Application
- **Adapter container**: Transforms/standardizes output
- **Example**: App + log format converter

Shared Resources in Multi-Container Pods

Lifecycle

- **Start together**: All containers start simultaneously
- **Stop together**: Pod termination affects all containers
- **Restart policy**: Applied to entire pod

Network

- **Shared IP**: All containers share same IP address
- **Localhost communication**: Containers communicate via localhost
- **Port sharing**: Containers must use different ports

Storage

- **Shared volumes**: Containers can share mounted volumes
- **Data exchange**: File-based communication between containers

Multi-Container Pod Definition

```
apiVersion: v1
kind: Pod metadata:
  name: simple-webapp
spec:  containers:  -
name: simple-webapp
image: simple-webapp
ports:
    - containerPort: 8080
- name: log-agent
image: log-agent
```

Use Cases for Multi-Container Pods

- **Logging**: Main app + log collection sidecar
- **Monitoring**: Application + metrics collection

- **Service mesh**: App + proxy (Istio, Linkerd)
- **Data synchronization**: App + data sync agent
- **Security scanning**: App + security agent

Application Lifecycle Commands Summary

Rolling Updates and Rollbacks

```
# Deployment management
kubectl create -f deployment-definition.yml kubectl
get deployments
kubectl apply -f deployment-definition.yml
kubectl set image deployment/myapp-deployment nginx=nginx:1.9.1

# Rollout operations
kubectl rollout status deployment/myapp-deployment kubectl
rollout history deployment/myapp-deployment kubectl
rollout undo deployment/myapp-deployment
```

ConfigMaps and Secrets

```
# ConfigMap operations
kubectl create configmap app-config --from-literal=key=value kubectl
get configmaps
kubectl describe configmap app-config

# Secret operations
kubectl create secret generic app-secret --from-literal=key=value
kubectl get secrets kubectl describe secret app-secret
```

Pod Management

```
# Create and manage pods kubectl create
-f  pod-definition.yaml  kubectl  get
pods kubectl describe pod  kubectl logs
-c  kubectl exec -it  -c  -- /bin/bash
```

Horizontal Pod Autoscaler (HPA) and Vertical Pod Autoscaler (VPA)

Horizontal Pod Autoscaler (HPA)

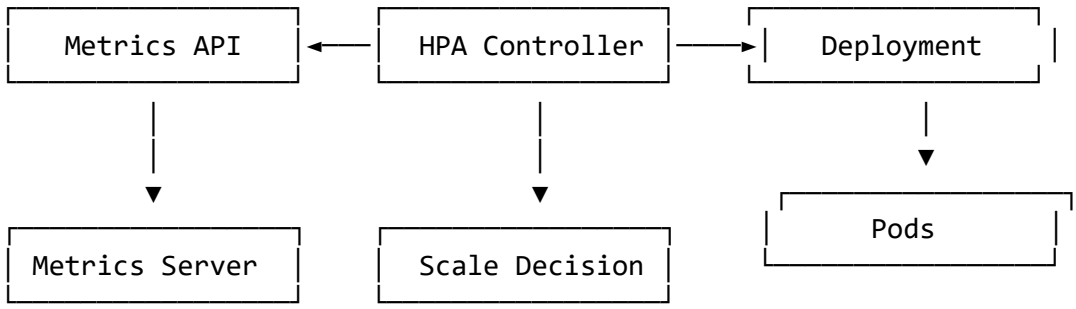
What is HPA?

Horizontal Pod Autoscaler (HPA) automatically scales the number of pods in a deployment, replica set, or stateful set based on observed CPU utilization, memory usage, or custom metrics.[1][2]

Key Concepts

- **Horizontal Scaling**: Adding/removing pod replicas
- **Metrics-based**: Decisions based on resource utilization
- **Target Utilization**: Desired resource usage percentage
- **Scale Up/Down**: Automatic pod count adjustment
- **Control Loop**: Continuous monitoring and adjustment

HPA Architecture



HPA Prerequisites

1. Metrics Server

```
# Check if metrics server is running kubectl get pods
-n kube-system | grep metrics-server

# If not installed, deploy metrics server
kubectl apply -f https://github.com/kubernetes-
sigs/metricsserver/releases/latest/download/components.yaml

# Verify metrics are available
kubectl top nodes kubectl top
pods
```

2. Resource Requests

```
# Pods MUST have resource requests defined
apiVersion: apps/v1 kind: Deployment
metadata:
  name: web-app
spec:  replicas:
3  selector:
matchLabels:
app: web-app
template:
metadata:
labels:
        app: web-app    spec:      containers:      - name:
web-app            image: nginx:latest           resources:
requests:             cpu: 100m         # Required for CPU-
based HPA            memory: 128Mi    # Required for memory-
based HPA         limits:          cpu: 200m          memory:
256Mi
```

Creating HPA

1. Imperative Creation

```
# CPU-based HPA (simple)
kubectl autoscale deployment web-app --cpu-percent=70 --min=2 --max=10

# View HPA kubectl get hpa
kubectl describe hpa web-app
```

2. Declarative Creation (CPU-based)

```
apiVersion:    autoscaling/v2
kind: HorizontalPodAutoscaler
metadata:
  name: web-app-hpa
spec:  scaleTargetRef:
apiVersion: apps/v1
kind: Deployment
name: web-app
minReplicas: 2
maxReplicas: 10
metrics:
```

```
      -     type:
      Resource
      resource:
      name: cpu
      target:
        type: Utilization
averageUtilization: 70
behavior:     scaleDown:
      stabilizationWindowSeconds: 300
policies:       - type: Percent
value: 10         periodSeconds: 60
scaleUp:
      stabilizationWindowSeconds: 0
policies:       - type: Percent
value: 100         periodSeconds:
15
```

3. Memory-based HPA

```
apiVersion:     autoscaling/v2
kind: HorizontalPodAutoscaler
metadata:
  name: memory-hpa
spec:   scaleTargetRef:
apiVersion: apps/v1
kind: Deployment
name: web-app
minReplicas: 2
maxReplicas: 8
metrics:   - type:
Resource     resource:
name: memory
target:
        type: Utilization
averageUtilization: 80
```

4. Multi-metric HPA

```
apiVersion:     autoscaling/v2
kind: HorizontalPodAutoscaler
metadata:
  name: multi-metric-hpa spec:
  scaleTargetRef:
apiVersion: apps/v1
kind: Deployment
```

```
name: web-app
minReplicas: 2
maxReplicas: 15
metrics:   - type:
Resource    resource:
name: cpu      target:
type: Utilization
averageUtilization: 70
      -     type:
      Resource
      resource:
      name: memory     target:
type:              Utilization
averageUtilization: 80
```

HPA Behavior Configuration

Scaling Policies

```
apiVersion: autoscaling/v2
kind: HorizontalPodAutoscaler
metadata:   name: advanced-
hpa spec:   scaleTargetRef:
apiVersion: apps/v1    kind:
Deployment    name: web-app
minReplicas: 2   maxReplicas:
20   metrics:   - type:
Resource    resource:
name: cpu      target:
        type: Utilization
averageUtilization: 70
behavior:    scaleDown:
      stabilizationWindowSeconds: 300  # Wait 5 minutes before scaling down
policies:      - type: Percent
        value: 10                      # Scale down by max 10% of current
replicas        periodSeconds: 60              # Per minute
      - type: Pods
        value: 2                       # Or max 2 pods per minute
periodSeconds: 60
      selectPolicy: Min                # Use the policy that removes fewer
pods
    scaleUp:
```

```
      stabilizationWindowSeconds: 60   # Wait 1 minute before scaling up
policies:       - type: Percent
        value: 50                      # Scale up by max 50% of current
replicas         periodSeconds: 60              # Per minute
      - type: Pods
        value: 4                       # Or max 4 pods per minute
periodSeconds: 60       selectPolicy: Max               # Use the policy
that adds more pods
```

Behavior Parameters

- **stabilizationWindowSeconds**: Time to wait before making scaling decisions
- **selectPolicy**:
  - `Max`: Use policy that allows highest scaling – `Min`: Use policy that allows lowest scaling
  - `Disabled`: Disable scaling in this direction

Custom Metrics HPA

Prerequisites for Custom Metrics

```
# Install custom metrics API server (example with Prometheus)
# 1. Deploy Prometheus
kubectl apply -f
https://raw.githubusercontent.com/prometheusoperator/prometheus-
operator/main/bundle.yaml

# 2. Deploy Prometheus Adapter
helm repo add prometheus-community
https://prometheuscommunity.github.io/helm-charts helm install
prometheus-adapter prometheus-community/prometheus-adapter
```

Custom Metrics HPA Example

```
apiVersion:    autoscaling/v2
kind: HorizontalPodAutoscaler
metadata:
  name: custom-metrics-hpa spec:
  scaleTargetRef:
apiVersion: apps/v1
kind: Deployment
name: web-app
minReplicas: 2
maxReplicas: 10
```

```
metrics:  # CPU metric
- type: Resource
resource:      name:
cpu
      target:
        type: Utilization
averageUtilization: 70   # Custom
metric: requests per second
-     type: Pods
pods:
metric:
        name: http_requests_per_second
target:
        type: AverageValue
averageValue: "100"   # External
metric: SQS queue length
-     type:
External
external:
metric:
        name: sqs_queue_length
selector:
matchLabels:
            queue: worker-queue
target:         type: Value
value: "30"
```

Object Metrics

```
apiVersion:    autoscaling/v2
kind: HorizontalPodAutoscaler
metadata:
  name: object-metrics-hpa
spec:  scaleTargetRef:
apiVersion: apps/v1
kind: Deployment    name:
web-app  minReplicas: 1
maxReplicas: 5  metrics:
- type: Object    object:
metric:
        name: requests-per-second
describedObject:        apiVersion:
networking.k8s.io/v1        kind:
```

```
Ingress          name: main-route
target:          type: Value
value: "2k"
```

Vertical Pod Autoscaler (VPA)

What is VPA?

Vertical Pod Autoscaler (VPA) automatically adjusts CPU and memory requests for containers in pods to optimize resource utilization and improve cluster efficiency.[1][2]

VPA vs HPA

Feature	HPA	VPA
Scaling Type	Horizontal (replica count)	Vertical (resource requests)
Pod Recreation	No	Yes (in most cases)
Use Case	Handle load spikes	Optimize resource allocation
Compatibility	Works with HPA	Can conflict with HPA

VPA Components

- **VPA Recommender**: Analyzes resource usage and provides recommendations
- **VPA Updater**: Applies recommendations by evicting pods
- **VPA Admission Controller**: Sets resource requests on new pods

Installing VPA

VPA Installation

```
# Clone VPA repository
git clone https://github.com/kubernetes/autoscaler.git cd
autoscaler/vertical-pod-autoscaler/

# Install VPA
./hack/vpa-install.sh

# Verify installation kubectl get pods -n
kube-system | grep vpa
```

Check VPA Components

```
# VPA components should be running kubectl
get pods -n kube-system
# vpa-admission-controller-xxx
```

```
# vpa-recommender-xxx
# vpa-updater-xxx
```

VPA Modes

1. Off Mode (Recommendation Only)

```
apiVersion: autoscaling.k8s.io/v1
kind:       VerticalPodAutoscaler
metadata:
  name: vpa-off-mode spec:
  targetRef:     apiVersion: apps/v1     kind:
Deployment     name: web-app   updatePolicy:
updateMode: "Off"  # Only provide recommendations
```

2. Initial Mode (Set on Pod Creation)

```
apiVersion: autoscaling.k8s.io/v1
kind:       VerticalPodAutoscaler
metadata:
  name: vpa-initial-mode spec:   targetRef:     apiVersion:
apps/v1     kind: Deployment     name: web-app   updatePolicy:
updateMode: "Initial"  # Set requests only on pod creation
```

3. Auto Mode (Automatic Updates)

```
apiVersion: autoscaling.k8s.io/v1
kind:       VerticalPodAutoscaler
metadata:
  name: vpa-auto-mode
spec:  targetRef:
apiVersion: apps/v1
kind: Deployment
name: web-app
updatePolicy:
    updateMode: "Auto"  # Automatically update running pods
resourcePolicy:
    containerPolicies:     -
containerName: web-app
minAllowed:         cpu:
100m         memory: 50Mi
maxAllowed:         cpu:
1000m         memory: 500Mi
      controlledResources: ["cpu", "memory"]
controlledValues: "RequestsAndLimits"
```

VPA Resource Policies

Comprehensive Resource Policy

```
apiVersion: autoscaling.k8s.io/v1
kind:       VerticalPodAutoscaler
metadata:
  name: advanced-vpa
spec:  targetRef:
apiVersion: apps/v1
kind: Deployment
name: web-app
updatePolicy:
    updateMode: "Auto"   resourcePolicy:
containerPolicies:     - containerName: web-
app       minAllowed:         cpu: 100m
memory: 128Mi       maxAllowed:         cpu:
2000m         memory: 1Gi
controlledResources: ["cpu", "memory"]
controlledValues: "RequestsAndLimits"
mode: Auto
    - containerName: sidecar       mode: "Off"  #
Don't adjust sidecar container
```

Resource Policy Options

- **controlledResources**: `["cpu"]`, `["memory"]`, `["cpu", "memory"]`
- **controlledValues**:
  - `RequestsOnly`: Only adjust requests
  - `RequestsAndLimits`: Adjust both requests and limits
- **mode**: `Auto`, `Off`

VPA Recommendations

Viewing VPA Recommendations

```
# Get VPA status and recommendations
kubectl describe vpa vpa-name

# View VPA recommendations in detail kubectl
get vpa vpa-name -o yaml
```

Sample VPA Output

```
status:
```

```
  conditions:   - status: "True"
type: RecommendationProvided
recommendation:
    containerRecommendations:
- containerName: web-app
lowerBound:         cpu: 50m
        memory:  262144k
target:        cpu: 250m
memory:          262144k
uncappedTarget:
cpu: 250m        memory:
262144k      upperBound:
cpu: 366m        memory:
262144k
```

HPA + VPA Combination

Safe Combination (Different Metrics)

```
# HPA for horizontal scaling based on custom metrics
apiVersion: autoscaling/v2 kind:
HorizontalPodAutoscaler metadata:
  name: custom-hpa
spec:   scaleTargetRef:
apiVersion: apps/v1
kind: Deployment
name: web-app
minReplicas: 2
maxReplicas: 10
metrics:   - type: Pods
pods:       metric:
        name: http_requests_per_second
target:         type: AverageValue
averageValue: "100"
---
# VPA for vertical scaling based on resource usage
apiVersion: autoscaling.k8s.io/v1 kind:
VerticalPodAutoscaler metadata:
  name: resource-vpa spec:
  targetRef:
    apiVersion: apps/v1
kind: Deployment
name: web-app
```

```
updatePolicy:
updateMode: "Auto"
```

Avoiding Conflicts

- **Don't use HPA with CPU/Memory + VPA together**
- **Use VPA in "Off" mode for recommendations only when using HPA**
- **Use different metrics for HPA (custom) and VPA (resources)**

Monitoring and Observability

HPA Monitoring

```
# Watch HPA in real-time kubectl
get hpa --watch

# Check HPA events
kubectl describe hpa web-app-hpa

# View scaling events kubectl get events --sort-
by=.metadata.creationTimestamp
```

VPA Monitoring

```
# Check VPA recommendations
kubectl describe vpa web-app-vpa

# Monitor VPA events kubectl get events | grep
VerticalPodAutoscaler

# Check resource usage kubectl
top pods
```

Metrics to Monitor

```
# CPU and memory usage
kubectl   top   nodes
kubectl top pods

# Pod resource requests vs usage kubectl describe pod
pod-name | grep -A 10 "Requests:"
```

Troubleshooting

Common HPA Issues

```
1. HPA Not Scaling # Check
  metrics server
kubectl get pods -n kube-system | grep metrics-server kubectl
logs -n kube-system deployment/metrics-server

# Check resource requests kubectl describe deployment web-
app | grep -A 5 "Requests:"

# Check HPA status kubectl
describe hpa web-app-hpa
2. Unable to get Resource Metrics
# Verify metrics API kubectl get apiservice
v1beta1.metrics.k8s.io -o yaml

# Check metrics server logs kubectl logs -n kube-
system -l k8s-app=metrics-server

# Test metrics availability
kubectl top nodes kubectl
top pods

3. Thrashing (Rapid Scaling) #
  Add stabilization windows
  behavior:  scaleDown:
    stabilizationWindowSeconds: 300
scaleUp:
stabilizationWindowSeconds: 60
```

Common VPA Issues

```
1. VPA Not Updating Pods # Check VPA components kubectl get pods -n kube-system |
  grep vpa

# Check VPA status
kubectl describe vpa web-app-vpa

# Verify admission controller kubectl logs -n kube-system -
l app=vpa-admission-controller

2. Pods Being Evicted Too Often
# Use "Initial" mode instead of "Auto" updatePolicy:
  updateMode: "Initial"
```

```
# Or use "Off" mode for recommendations only
updatePolicy:  updateMode: "Off"
```

3. Resource Recommendations Too High/Low

```
# Set resource limits in VPA
resourcePolicy:
containerPolicies:  -
containerName: web-app
minAllowed:      cpu: 100m
memory: 128Mi
maxAllowed:
      cpu:      1000m
memory: 512Mi
```

Real-World Examples

E-commerce Application Scaling

```
# Deployment
apiVersion: apps/v1
kind: Deployment
metadata:
  name: ecommerce-app spec:
replicas: 3  selector:
matchLabels:      app:
ecommerce  template:
metadata:      labels:
app: ecommerce    spec:
containers:      - name:
web-server        image:
nginx:latest
resources:
requests:            cpu:
200m            memory:
256Mi          limits:
cpu: 500m
memory: 512Mi      - name:
app-server        image:
myapp:latest
resources:
requests:            cpu:
300m            memory:
```

```
512Mi          limits:
cpu: 1000m
memory: 1Gi
---
# HPA for handling traffic spikes
apiVersion: autoscaling/v2 kind:
HorizontalPodAutoscaler metadata:
  name: ecommerce-hpa
spec:  scaleTargetRef:
apiVersion: apps/v1
kind: Deployment
name: ecommerce-app
minReplicas: 3
maxReplicas: 20
metrics:  - type:
Resource    resource:
name: cpu      target:
type: Utilization
averageUtilization: 70
  - type: Pods
pods:
metric:
        name: http_requests_per_second
target:        type: AverageValue
averageValue: "200"  behavior:
scaleDown:
      stabilizationWindowSeconds: 300
scaleUp:
      stabilizationWindowSeconds: 60
---
# VPA for resource optimization (recommendations only) apiVersion:
autoscaling.k8s.io/v1 kind: VerticalPodAutoscaler metadata:  name:
ecommerce-vpa spec:  targetRef:    apiVersion: apps/v1    kind:
Deployment    name: ecommerce-app  updatePolicy:    updateMode: "Off"
# Only recommendations to avoid conflicts with HPA
```

Batch Processing Application

```
# For batch processing, VPA is more appropriate than HPA
apiVersion: autoscaling.k8s.io/v1 kind:
VerticalPodAutoscaler metadata:
  name: batch-processor-vpa
spec:  targetRef:
```

```
apiVersion: apps/v1
kind: Deployment     name:
batch-processor
updatePolicy:
    updateMode: "Auto"
resourcePolicy:
containerPolicies:
- containerName:
processor
minAllowed:
cpu: 500m
memory: 1Gi
maxAllowed:
cpu: 4000m
memory: 8Gi
controlledResources:
["cpu", "memory"]
controlledValues:
"RequestsAndLimits"
```

CKA Exam Scenarios

Scenario 1: Create HPA for Deployment

```
# Given: deployment 'web-app' with resource requests
# Task: Create HPA to scale between 2-8 replicas at 80% CPU

# Solution:
kubectl autoscale deployment web-app --cpu-percent=80 --min=2 --max=8

# Verify:
kubectl get hpa kubectl
describe hpa web-app
```

Scenario 2: Multi-metric HPA with Custom Behavior

```
# Task: Create HPA with CPU and memory metrics, custom scaling behavior
apiVersion: autoscaling/v2 kind: HorizontalPodAutoscaler metadata:
name: advanced-hpa   namespace: production spec:   scaleTargetRef:
apiVersion: apps/v1     kind: Deployment     name: api-server
minReplicas: 3   maxReplicas: 15   metrics:   - type: Resource
resource:       name: cpu       target:
        type: Utilization
averageUtilization: 70
```

```
  - type: Resource
resource:
      name: memory
target:         type:
Utilization
averageUtilization: 80
behavior:     scaleDown:
      stabilizationWindowSeconds: 300
policies:       - type: Percent
value: 25         periodSeconds: 60
scaleUp:
      stabilizationWindowSeconds: 60
policies:       - type: Pods
value: 3         periodSeconds: 60
```

Scenario 3: VPA for Resource Optimization

```
# Task: Create VPA to optimize resources for 'database' deployment

# Solution:
kubectl apply -f - <<EOF apiVersion:
autoscaling.k8s.io/v1 kind:
VerticalPodAutoscaler metadata:
  name: database-vpa
spec:   targetRef:
apiVersion: apps/v1
kind: Deployment
name: database
updatePolicy:
    updateMode: "Auto"
resourcePolicy:
containerPolicies:     -
containerName: mysql
minAllowed:         cpu:
500m         memory: 1Gi
maxAllowed:         cpu:
2000m         memory: 4Gi
EOF

# Check recommendations:
kubectl describe vpa database-vpa
```

Best Practices

HPA Best Practices

1. **Always set resource requests** on containers
2. **Use stabilization windows** to prevent thrashing
3. **Monitor scaling events** and adjust policies
4. **Test scaling behavior** under load
5. **Use multiple metrics** for better decision making
6. **Set appropriate min/max replicas**

VPA Best Practices

1. **Start with "Off" mode** to analyze recommendations
2. **Set resource limits** to prevent runaway resource allocation
3. **Use "Initial" mode** for predictable workloads
4. **Monitor eviction frequency** in "Auto" mode
5. **Avoid VPA + HPA conflicts** on same resources
6. **Review recommendations regularly**

General Autoscaling Best Practices

1. **Monitor resource utilization** patterns
2. **Set up proper monitoring** and alerting
3. **Test autoscaling** in non-production environments
4. **Document scaling policies** and decisions
5. **Regular review** of autoscaling configurations
6. **Capacity planning** for maximum scale scenarios

Commands Summary

HPA Commands

```
# Create HPA kubectl autoscale deployment NAME --cpu-percent=70 --
min=2 --max=10

# Manage HPA kubectl get
hpa kubectl describe hpa
NAME kubectl delete hpa
NAME

# Monitor scaling kubectl get hpa --watch kubectl top
pods kubectl get events --sort-
by=.metadata.creationTimestamp
```

VPA Commands

```
# Install VPA (if needed)
git clone https://github.com/kubernetes/autoscaler.git cd
autoscaler/vertical-pod-autoscaler/
./hack/vpa-install.sh

# Manage VPA kubectl
get vpa kubectl
describe vpa NAME
kubectl delete vpa
NAME

# Monitor VPA kubectl get
vpa NAME -o yaml kubectl
describe vpa NAME
```

Metrics and Debugging

```
# Check metrics server
kubectl get pods -n kube-system | grep metrics-server
kubectl top nodes kubectl top pods

# Debug autoscaling kubectl
describe hpa NAME kubectl
describe vpa NAME kubectl
get events | grep -E
"(HorizontalPodAutoscaler|VerticalPodAutoscaler)"
```

Key Points for CKA Exam

Must Know Concepts

1. **HPA scales replicas** horizontally based on metrics
2. **VPA adjusts resource requests** vertically
3. **Resource requests are required** for HPA/VPA to work
4. **Metrics server is prerequisite** for resource-based scaling
5. **Behavior policies control** scaling rate and timing

Common Exam Tasks

- Create HPA for deployments
- Configure multi-metric HPA
- Set up VPA for resource optimization

- Troubleshoot scaling issues
- Monitor autoscaling behavior

Critical Configuration

- **minReplicas/maxReplicas** for HPA
- **updateMode** for VPA (Off/Initial/Auto)
- **Resource requests** in deployments
- **Stabilization windows** for smooth scaling
- **Resource policies** for VPA boundaries

Security

Security Primitives

What is Kubernetes Security?

Kubernetes Security encompasses the protection of cluster infrastructure, applications, and data through multiple layers of defense including authentication, authorization, network policies, and encryption.

Core Security Components

- **Authentication**: Verifying identity of users and services
- **Authorization**: Determining what authenticated entities can do
- **Admission Control**: Validating and potentially modifying requests
- **Network Security**: Controlling traffic flow between components
- **Secrets Management**: Protecting sensitive data

Authentication Mechanisms

What is Authentication?

Authentication is the process of verifying the identity of users, service accounts, or external systems attempting to access the Kubernetes cluster.

Authentication Methods

1. Static Token Files

```
# Create user-details.csv password123,user1,u0001,group1
password123,user2,u0002,group1
password123,user3,u0003,group2
```

```
# Configure API server
--token-auth-file=user-details.csv
```

2. X.509 Client Certificates

```
# Generate user certificate openssl genrsa -out user.key 2048 openssl req -new -key user.key -out user.csr -subj "/CN=john/O=developers" openssl x509 -req -in user.csr -CA ca.crt -CAkey ca.key -out user.crt
```

3. Service Account Tokens

- **Automatic**: Created for each namespace
- **JWT-based**: JSON Web Tokens for pod authentication
- **Projection**: Mounted into pods automatically

API Server Configuration

```
# API Server Authentication Flags
--client-ca-file=/var/lib/kubernetes/ca.pem
--tls-cert-file=/var/lib/kubernetes/apiserver.crt
--tls-private-key-file=/var/lib/kubernetes/apiserver.key
--service-account-key-file=/var/lib/kubernetes/service-account.pem
```

TLS Certificates

What are TLS Certificates?

TLS Certificates provide cryptographic proof of identity and enable encrypted communication between Kubernetes components.

Certificate Types

Server Certificates

- **API Server**: `apiserver.crt` - Serves HTTPS API endpoints
- **ETCD Server**: `etcdserver.crt` - Encrypts cluster data storage
- **Kubelet**: `kubelet.crt` - Secures node agent communication

Client Certificates

- **Admin Users**: `admin.crt` - Administrator access to cluster
- **Scheduler**: `scheduler.crt` - Scheduler to API server communication
- **Controller Manager**: `controller-manager.crt` - Controller authentication
- **Kube-proxy**: `kube-proxy.crt` - Network proxy authentication

Certificate Generation Process

```
# 1. Generate CA Key and Certificate openssl
genrsa -out ca.key 2048
openssl req -new -x509 -key ca.key -subj "/CN=KUBERNETES-CA" -out ca.crt days
10000

# 2. Generate Server Certificate (API Server) openssl
genrsa -out apiserver.key 2048
openssl req -new -key apiserver.key -subj "/CN=kube-apiserver" -out
apiserver.csr -config openssl.cnf
openssl x509 -req -in apiserver.csr -CA ca.crt -CAkey ca.key -out
apiserver.crt -days 365

# 3. Generate Client Certificate (Admin) openssl
genrsa -out admin.key 2048
openssl req -new -key admin.key -subj "/CN=kube-admin/O=system:masters" -out
admin.csr openssl x509 -req -in admin.csr -CA ca.crt -CAkey ca.key -out
admin.crt -days
365
```

Certificate Requirements

```
# Subject Alternative Names for API Server
DNS.1 = kubernetes
DNS.2 = kubernetes.default
DNS.3 = kubernetes.default.svc
DNS.4 = kubernetes.default.svc.cluster.local
IP.1 = 10.96.0.1
IP.2 = 172.17.0.87
```

Certificate Inspection

```
# View certificate details openssl x509 -in
/etc/kubernetes/pki/apiserver.crt -text -noout

# Check certificate expiration openssl x509
-in apiserver.crt -noout -dates
```

Authorization

What is Authorization?

Authorization determines what actions an authenticated user or service account can perform within the Kubernetes cluster.[3][4]

Authorization Modes

1. Node Authorization

- **Purpose**: Authorizes requests from kubelets
- **Scope**: Limited to node-specific resources
- **Certificate Group**: `system:nodes`

2. ABAC (Attribute-Based Access Control)

```
{"apiVersion": "abac.authorization.kubernetes.io/v1beta1", "kind": "Policy",
"spec": {"user": "alice", "namespace": "projectCaribou", "resource": "pods",
"readonly": true}}
```

3. RBAC (Role-Based Access Control)

Most recommended authorization method for production clusters.[4][3]

4. Webhook Mode

- **External**: Delegates authorization to external services
- **Custom Logic**: Allows complex authorization rules
- **Integration**: Works with external identity providers

API Server Authorization Configuration

```
# Enable multiple authorization modes
--authorization-mode=Node,RBAC,Webhook
```

Role-Based Access Control (RBAC)

What is RBAC?

RBAC regulates access to Kubernetes resources based on the roles assigned to users, groups, or service accounts.[3][4]

RBAC Components

1. Role (Namespace-scoped)

```
apiVersion: rbac.authorization.k8s.io/v1
kind: Role metadata:   namespace:
development   name: pod-reader rules:
-     apiGroups: [""]
resources: ["pods"]
  verbs: ["get", "watch", "list"]
-     apiGroups: [""]
resources: ["configmaps"]
verbs: ["create"]
```

2. ClusterRole (Cluster-wide)

```
apiVersion: rbac.authorization.k8s.io/v1
kind: ClusterRole metadata:
  name: secret-reader rules:
- apiGroups: [""]  resources:
["secrets"]  verbs: ["get",
"watch", "list"]
```

3. RoleBinding (Namespace-scoped)

```
apiVersion: rbac.authorization.k8s.io/v1
kind: RoleBinding metadata:  name: read-
pods  namespace: development subjects: -
kind:  User  name:  jane  apiGroup:
rbac.authorization.k8s.io  roleRef:
kind: Role  name: pod-reader
  apiGroup: rbac.authorization.k8s.io
```

4. ClusterRoleBinding (Cluster-wide)

```
apiVersion: rbac.authorization.k8s.io/v1
kind: ClusterRoleBinding metadata:
  name: read-secrets-global subjects:
- kind: User  name: manager
apiGroup: rbac.authorization.k8s.io
roleRef:  kind: ClusterRole  name:
secret-reader  apiGroup:
rbac.authorization.k8s.io
```

RBAC Verbs

- **get**: Retrieve specific resource
- **list**: List resources of a type
- **watch**: Watch for resource changes
- **create**: Create new resources
- **update**: Modify existing resources
- **patch**: Partially update resources
- **delete**: Remove resources

Resource Names (Specific Resource Access)

```
rules:
- apiGroups: [""]  resources: ["pods"]
verbs: ["get", "update"]  resourceNames:
["blue-pod", "green-pod"]
```

RBAC Management Commands

```
# Check user permissions
kubectl auth can-i create deployments --as=dev-user
kubectl auth can-i delete nodes --as=dev-user --namespace=development

# View RBAC resources kubectl
get roles,rolebindings
kubectl get clusterroles,clusterrolebindings
kubectl describe role pod-reader kubectl
describe rolebinding read-pods
```

KubeConfig Files

What is KubeConfig?

KubeConfig files contain cluster access information including clusters, users, and contexts for kubectl authentication.[2][1]

KubeConfig Structure

```
apiVersion: v1 kind: Config current-context:
dev-user@development-cluster clusters:
- name: development-cluster cluster:
certificate-authority: /path/to/ca.crt
server: https://dev-cluster:6443 - name:
production-cluster cluster:
certificate-authority: /path/to/ca.crt
server: https://prod-cluster:6443
contexts:
- name: dev-user@development-cluster
context: cluster: development-cluster
user: dev-user namespace: development -
name: admin@production-cluster context:
cluster: production-cluster user:
admin users:
- name: dev-user user: client-
certificate: /path/to/dev-user.crt
client-key: /path/to/dev-user.key
- name: admin user: client-
certificate: /path/to/admin.crt
client-key: /path/to/admin.key
```

Certificate Data Encoding

```
# Instead of file paths, embed base64-encoded data
clusters: - name: my-cluster   cluster:
certificate-authority-data: LS0tLS1CRUdJTi...
    server: https://cluster:6443 users: - name:
my-user   user:    client-certificate-data:
LS0tLS1CRUdJTi...    client-key-data:
LS0tLS1CRUdJTi...
```

What are Contexts?

Contexts combine cluster, user, and namespace information into a named configuration that allows easy switching between different Kubernetes environments.[1][2]

Context Components

- **Cluster**: Which Kubernetes cluster to connect to
- **User**: Which user credentials to use for authentication
- **Namespace**: Default namespace for kubectl commands (optional)

Context Structure

```
contexts:
-    name: dev-user@development-cluster   context:
cluster: development-cluster    # Which cluster to
use    user: dev-user                # Which user
credentials to use    namespace: development
# Default namespace (optional)
-    name: admin@production-cluster   context:
    cluster: production-cluster
user: admin    namespace:
production
```

Context Management Commands

```
# View all contexts
kubectl config get-contexts

# View current context kubectl
config current-context

# Switch to a different context kubectl config use-
context dev-user@development-cluster

# Switch to production context kubectl config use-
context admin@production-cluster
```

```
# View detailed configuration kubectl
config view

# View only current context details kubectl
config view --minify
```

Creating and Modifying Contexts

```
# Create a new context kubectl config
set-context my-context \
  --cluster=my-cluster \
  --user=my-user \
  --namespace=my-namespace

# Modify existing context namespace kubectl config set-context dev-
user@development-cluster --namespace=testing

# Set namespace for current context
kubectl config set-context --current --namespace=production

# Create context with cluster and user kubectl
config set-context staging-context \
  --cluster=staging-cluster \
  --user=staging-user
```

Context Examples

```
# Development environment context kubectl
config set-context development \
  --cluster=dev-cluster \
  --user=dev-user \
  --namespace=development

# Production environment context   kubectl
config set-context production \
  --cluster=prod-cluster \
  --user=admin-user \
  --namespace=production

# Testing environment context kubectl
config set-context testing \
  --cluster=test-cluster \
```

```
  --user=test-user \
  --namespace=testing
```

Context Best Practices

- **Descriptive naming**: Use clear context names like `dev-user@development`
- **Environment separation**: Different contexts for dev, staging, production
- **Namespace defaults**: Set appropriate default namespaces
- **Regular cleanup**: Remove unused contexts periodically
- **Backup configs**: Keep backup copies of important kubeconfig files

Context Switching Workflows

```
# Daily workflow example # Start with
development kubectl config use-context
development
kubectl get pods  # Shows pods in development namespace

# Switch to production for deployment kubectl
config use-context production kubectl apply -
f production-deployment.yaml

# Quick check in staging kubectl
config use-context staging kubectl
get services

# Back to development
kubectl config use-context development
```

Advanced Context Operations

```
# Delete a context kubectl config delete-
context old-context

# Rename context (delete and recreate) kubectl
config delete-context old-name
kubectl config set-context new-name --cluster=cluster --user=user

# Export specific context
kubectl config view --context=production --minify --flatten > prodconfig.yaml

# Use temporary context without switching
kubectl --context=production get pods kubectl -
-context=development apply -f app.yaml
```

Multi-Cluster Context Setup

```
# Example: Managing multiple environments
apiVersion: v1 kind: Config
current-context: development

# Development cluster clusters: - name: dev-
cluster   cluster:     server: https://dev-
api.company.com:6443     certificate-
authority-data: LS0tLS...

# Staging cluster   - name: staging-cluster
cluster:     server: https://staging-
api.company.com:6443     certificate-authority-
data: LS0tLS...

# Production cluster -
name: prod-cluster
cluster:
    server: https://prod-api.company.com:6443     certificate-authority-
data: LS0tLS...

# Users for different environments
users: - name: dev-user   user:
    client-certificate-data: LS0tLS...
client-key-data: LS0tLS... - name:
staging-user   user:
    client-certificate-data: LS0tLS...     client-key-
data: LS0tLS...
- name: prod-admin   user:     client-
certificate-data: LS0tLS...
    client-key-data: LS0tLS...

# Contexts combining clusters and users
contexts: - name: development   context:
cluster: dev-cluster     user: dev-user
namespace: development - name: staging
context:     cluster: staging-cluster
user: staging-user     namespace:
staging - name: production   context:
cluster: prod-cluster     user: prod-
admin     namespace: production
```

Context Security Considerations

- **User isolation**: Use different users for different environments
- **Namespace boundaries**: Set appropriate default namespaces
- **Access control**: Ensure users only have access to appropriate clusters
- **Audit trails**: Context switches can be logged for security auditing
- **Credential management**: Rotate certificates and tokens regularly

Troubleshooting Context Issues

```
# Check context configuration kubectl config view
--context=problematic-context

# Verify cluster connectivity
kubectl --context=production cluster-info

# Test authentication kubectl --
context=development auth can-i get pods

# Debug certificate issues kubectl
config view --raw -o
jsonpath='{.contexts[?(@.name=="production")].context}'

# Check current context settings
kubectl config get-contexts $(kubectl config current-context)
```

Image Security

What is Image Security?

Image Security involves securing container images and controlling access to private registries.[1][2]

Private Registry Authentication

```
#  Login  to  private  registry
docker login private-registry.io
Username: registry-user
Password: registry-password

# Create secret for registry authentication kubectl
create secret docker-registry regcred \
  --docker-server=private-registry.io \   --docker-username=registry-
user \
  --docker-password=registry-password \
```

```
  --docker-email=user@company.com
```

Using Image Pull Secrets

```
apiVersion: v1 kind:
Pod metadata:
  name: private-app spec:  containers:  - name:
app    image: private-
registry.io/apps/internal-app
imagePullSecrets:  - name: regcred
```

Image Security Best Practices

- **Scan images** for vulnerabilities before deployment
- **Use specific tags** instead of `latest`
- **Minimize base images** to reduce attack surface
- **Regular updates** of base images and dependencies

Security Contexts

What are Security Contexts?

Security Contexts define privilege and access control settings for pods and containers.[2][1]

Pod Security Context

```
apiVersion:    v1
kind:         Pod
metadata:
  name: security-context-demo spec:
securityContext:    runAsUser: 1000
runAsGroup: 3000    fsGroup: 2000
runAsNonRoot: true  containers:  -
name: sec-ctx-demo    image: busybox
securityContext:
allowPrivilegeEscalation: false
runAsUser: 2000      capabilities:
add: ["NET_ADMIN", "SYS_TIME"]
drop: ["ALL"]
readOnlyRootFilesystem: true
```

Security Context Options

- **runAsUser**: User ID for running containers
- **runAsGroup**: Primary group ID for containers

- **runAsNonRoot**: Prevents running as root user
- **fsGroup**: Group ownership for mounted volumes
- **allowPrivilegeEscalation**: Controls privilege escalation
- **capabilities**: Linux capabilities to add/drop
- **readOnlyRootFilesystem**: Makes root filesystem read-only

Network Policies

What are Network Policies?

Network Policies control network traffic flow between pods, providing microsegmentation at the application layer.[1][2]

Default Behavior

- **All Allow**: By default, all pods can communicate with all other pods
- **No Isolation**: No network restrictions until policies are applied

Network Policy Components

- **podSelector**: Which pods the policy applies to
- **policyTypes**: Ingress, Egress, or both
- **ingress**: Rules for incoming traffic
- **egress**: Rules for outgoing traffic

Basic Network Policy Example

```
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy
metadata:
  name: test-network-policy
namespace: default spec:
podSelector:
matchLabels:       role: db
policyTypes:   - Ingress   -
Egress   ingress:
-     from:     -
ipBlock:
        cidr: 172.17.0.0/16
except:
-     172.17.1.0/24
- namespaceSelector:
matchLabels:
```

```
name: prod     -
podSelector:
matchLabels:
role: frontend
ports:     - protocol:
TCP       port: 6379
egress:
-     to:     -
ipBlock:         cidr:
10.0.0.0/8     ports:
- protocol: TCP
port: 5978
```

Network Policy Selectors

Pod Selector `ingress:`

```
-     from:   -
podSelector:
matchLabels:
app: frontend
```

Namespace Selector `ingress:`

```
-     from:   -
namespaceSelector:
matchLabels:
name: production
```

IP Block `ingress:`

```
-     from:   -
ipBlock:
      cidr: 192.168.1.0/24
except:       -
192.168.1.5/32
```

Deny All Policy

```
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy metadata:
  name: deny-all
spec:
podSelector: {}
policyTypes:   -
Ingress
  - Egress
```

CNI Plugin Requirements

Network Policies require a compatible CNI plugin:

- **Calico**: Full network policy support
- **Weave**: Supports network policies
- **Flannel**: Does **NOT** support network policies

ConfigMaps and Secrets Security

What are ConfigMaps?

ConfigMaps store non-confidential configuration data in key-value pairs that can be consumed by pods.[2]

What are Secrets?

Secrets store sensitive information such as passwords, tokens, and keys with additional security measures.[2]

Security Differences

Feature	ConfigMap	Secret
Data Type	Non-sensitive configuration	Sensitive information
Encoding	Plain text	Base64 encoded
Storage	etcd (plain text)	etcd (can be encrypted at rest)
Access	Standard RBAC	Enhanced RBAC controls

Secret Types

- **Opaque**: General-purpose secrets (default)
- **kubernetes.io/service-account-token**: Service account tokens
- **kubernetes.io/dockercfg**: Docker registry authentication
- **kubernetes.io/tls**: TLS certificates and keys

Creating Secrets

```
# Imperative creation kubectl create secret
generic app-secret \
  --from-literal=DB_Host=mysql \
  --from-literal=DB_User=root \
  --from-literal=DB_Password=password
```

```
# Declarative creation
apiVersion: v1 kind:
Secret metadata:
name: app-secret type:
Opaque data:
  DB_Host: bXlzcWw=     # mysql (base64)
  DB_User: cm9vdA==     # root (base64)
  DB_Password: cGFzc3dvcmQ= # password (base64)
```

Using Secrets in Pods

```
apiVersion:     v1
kind:          Pod
metadata:
  name: secret-pod
spec:
containers:   -
name: app
image: myapp
env:
-     name: DB_PASSWORD
valueFrom:
secretKeyRef:
          name: app-secret
key: DB_Password
volumeMounts:     - name:
secret-volume
mountPath: /etc/secrets
volumes:
-     name: secret-volume
secret:       secretName:
app-secret
```

ConfigMap Security Best Practices

- **Separate sensitive data**: Never store passwords in ConfigMaps
- **Use RBAC**: Control access to ConfigMaps
- **Namespace isolation**: Keep ConfigMaps in appropriate namespaces
- **Regular audits**: Review ConfigMap contents regularly

Secret Security Best Practices

- **Encryption at rest**: Enable etcd encryption
- **RBAC controls**: Strict access controls for secrets

- **Secret rotation**: Regular rotation of sensitive data
- **Avoid logging**: Prevent secrets from appearing in logs
- **Image security**: Don't embed secrets in container images

Certificate API

What is the Certificates API?

The **Certificates API** allows you to provision TLS certificates signed by a Certificate Authority (CA) that you control.[1][2]

Certificate Signing Request (CSR)

```
apiVersion: certificates.k8s.io/v1 kind:
CertificateSigningRequest metadata: name: john-
developer spec: request: LS0tLS1CRUdJTi... #
base64 encoded CSR signerName:
kubernetes.io/kube-apiserver-client usages: -
client auth
```

CSR Workflow

```
# 1. Generate private key
openssl genrsa -out john.key 2048

# 2. Create certificate signing request openssl req -new -key john.key -
subj "/CN=john/O=developers" -out john.csr

# 3. Submit CSR to Kubernetes cat
john.csr | base64 | tr -d '\n'

# 4. Create CSR object kubectl
apply -f john-csr.yaml

# 5. Approve CSR kubectl certificate
approve john-developer

# 6. Get certificate
kubectl get csr john-developer -o jsonpath='{.status.certificate}' | base64 d
> john.crt
```

Controller Manager Configuration

```
# Controller manager handles certificate signing
```

```
--cluster-signing-cert-file=/etc/kubernetes/pki/ca.crt
--cluster-signing-key-file=/etc/kubernetes/pki/ca.key
```

Security Best Practices

Cluster Security

- **Regular updates**: Keep Kubernetes and components updated
- **Network segmentation**: Use network policies for micro-segmentation
- **Least privilege**: Apply minimal necessary permissions
- **Audit logging**: Enable comprehensive audit logging
- **Resource limits**: Set appropriate resource quotas and limits

Authentication Security

- **Strong certificates**: Use proper key lengths and algorithms
- **Certificate rotation**: Regular rotation of certificates
- **Multi-factor authentication**: Where possible, implement MFA
- **Service accounts**: Use dedicated service accounts for applications

Authorization Security

- **RBAC enforcement**: Use RBAC over other authorization modes
- **Regular reviews**: Audit permissions regularly
- **Namespace isolation**: Use namespaces for logical separation
- **Avoid wildcards**: Be specific in permission grants

Secret Management

- **External secret management**: Consider tools like HashiCorp Vault
- **Encryption at rest**: Enable etcd encryption
- **Secret scanning**: Scan for secrets in code and images
- **Rotation policies**: Implement automated secret rotation

Troubleshooting Security Issues

Common Authentication Problems

```
# Check API server configuration
kubectl get pods -n kube-system
kubectl logs kube-apiserver-master -n kube-system

# Verify certificate details
openssl x509 -in client.crt -text -noout
```

```
# Test authentication
kubectl auth can-i get pods --as=system:serviceaccount:default:default
```

Common Authorization Problems

```
# Check RBAC configuration kubectl get
roles,rolebindings -A kubectl describe
role developer kubectl describe
rolebinding dev-binding

# Test permissions
kubectl auth can-i create deployments --as=dev-user kubectl
auth can-i list secrets --as=dev-user -n production
```

Network Policy Debugging

```
# Check if network policies are applied kubectl
get networkpolicies
kubectl describe networkpolicy deny-all

# Test connectivity
kubectl exec -it test-pod -- nc -zv target-service 80
kubectl exec -it test-pod -- nslookup target-service
```

Key Commands Summary

Authentication & Certificates

```
# Certificate operations openssl genrsa -out user.key 2048 openssl req
-new -key user.key -out user.csr -subj "/CN=user" openssl x509 -req -
in user.csr -CA ca.crt -CAkey ca.key -out user.crt

# CSR management kubectl get csr
kubectl certificate approve user-csr
kubectl certificate deny user-csr
```

RBAC Management

```
# Create RBAC resources
kubectl create role developer --verb=get,list,create --resource=pods kubectl
create rolebinding dev-binding --role=developer --user=dev-user kubectl
create clusterrole cluster-reader --verb=get,list --resource=nodes kubectl
create clusterrolebinding cluster-reader-binding -clusterrole=cluster-
reader --user=admin
```

Secrets and ConfigMaps

```
# Secret operations
kubectl create secret generic app-secret --from-literal=key=value kubectl
get secrets
kubectl describe secret app-secret

# ConfigMap operations
kubectl create configmap app-config --from-literal=key=value kubectl
get configmaps
kubectl describe configmap app-config
```

Network Policies

```
# Network policy management kubectl
apply -f network-policy.yaml kubectl
get networkpolicies kubectl describe
networkpolicy deny-all
```

Service Accounts

What are Service Accounts?

Service Accounts are special types of accounts in Kubernetes that provide an identity for processes running in pods. Unlike user accounts (which are for humans), service accounts are designed for applications and system components.[1][2]

Key Characteristics

- **Pod Identity**: Every pod runs with a service account
- **API Access**: Service accounts enable pods to interact with the Kubernetes API
- **Namespace Scoped**: Each service account belongs to a specific namespace
- **Automatic Creation**: Every namespace gets a default service account
- **Token-Based**: Authentication uses JWT tokens

Default Service Account

Automatic Behavior

```
# Every namespace gets a default service account
kubectl get serviceaccounts kubectl get sa  #
Short form

# Output shows:
```

```
# NAME      SECRETS   AGE #
default   1         5d
```

Default Service Account Properties

- **Name**: `default`
- **Automatic Mounting**: Token automatically mounted to all pods
- **Limited Permissions**: Can only access basic API discovery endpoints
- **Location**: `/var/run/secrets/kubernetes.io/serviceaccount/`

Default Token Structure

```
# Inside a pod, check mounted service account ls
/var/run/secrets/kubernetes.io/serviceaccount/
# ca.crt    namespace    token

# View the token cat
/var/run/secrets/kubernetes.io/serviceaccount/token #
View the namespace cat
/var/run/secrets/kubernetes.io/serviceaccount/namespac
e
```

Creating Service Accounts

Imperative Creation

```
# Create a service account
kubectl create serviceaccount my-service-account kubectl
create sa my-app-sa  # Short form

# Create in specific namespace kubectl create
serviceaccount my-sa -n development

# List service accounts kubectl
get serviceaccounts -A kubectl
get sa --all-namespaces
```

Declarative Creation

```
apiVersion: v1 kind: ServiceAccount metadata:  name:
my-app-service-account      namespace:  production
labels:     app: my-application     tier: backend
automountServiceAccountToken: true  # Default: true
```

Service Account with Secrets

```
apiVersion:   v1   kind:
ServiceAccount metadata:
  name: build-robot
secrets:
- name: build-robot-secret imagePullSecrets:
- name: private-registry-secret
```

Service Account Tokens

What are Service Account Tokens?

Service Account Tokens are JWT (JSON Web Token) credentials that pods use to authenticate with the Kubernetes API server.[2][1]

Token Types

1. Automatic Tokens (Legacy)

```
# Kubernetes < 1.24: Automatic secret creation kubectl
create serviceaccount token-test kubectl get secrets
# Shows: token-test-token-xxxxx

# View token secret kubectl describe secret
token-test-token-xxxxx
```

2. Projected Tokens (Current)

```
apiVersion:  v1 kind:  Pod
  metadata:
  name: nginx spec:   serviceAccountName:
my-service-account   containers:   -
image: nginx     name: nginx
volumeMounts:
      - mountPath:
        /var/run/secrets/kubernetes.io/serviceaccount
        name: kube-api-access-xxxxx       readOnly: true
        volumes:
      - name: kube-api-access-xxxxx     projected:
        sources:
      - serviceAccountToken:
          expirationSeconds: 3607
path: token       - configMap:
items:           - key: ca.crt
path: ca.crt           name:
kube-root-ca.crt       -
downwardAPI:
```

```
          items:
- fieldRef:
              apiVersion: v1
              fieldPath: metadata.namespace
path: namespace
```

Manual Token Creation (Kubernetes 1.24+)

```
# Create long-lived token secret kubectl
create token my-service-account

# Create token with expiration kubectl create token
my-service-account --duration=1h

# Create token for specific audience kubectl create token my-service-account
--audience=https://my-api.example.com

# Create permanent token secret (legacy style)
kubectl apply -f - <<EOF
apiVersion: v1 kind:
Secret metadata:
  name: my-sa-token   annotations:
kubernetes.io/service-account.name: my-service-account
type: kubernetes.io/service-account-token EOF
```

Using Service Accounts in Pods

Specifying Service Account

```
apiVersion: v1 kind: Pod metadata:   name:
my-pod spec:     serviceAccountName:  my-
service-account    containers:    - name:
app     image: my-app:latest
```

Deployment with Service Account

```
apiVersion:   apps/v1  kind:
Deployment metadata:   name:
my-app spec:
  replicas: 3
selector:
matchLabels:
app: my-app
template:
```

```
metadata:
labels:
        app: my-app
spec:
      serviceAccountName: my-app-service-account
containers:       - name: app         image: my-
app:latest
```

Disabling Automatic Token Mounting

```
apiVersion: v1
kind: Pod metadata:
  name: no-token-pod spec:
  serviceAccountName: my-service-account   automountServiceAccountToken: false
containers:   - name: app     image: my-app:latest

# Disable at service account level
apiVersion: v1 kind: ServiceAccount
metadata:    name: no-auto-mount-sa
automountServiceAccountToken: false
```

Service Accounts and RBAC

What is Service Account RBAC?

Service accounts integrate with Kubernetes RBAC to define what API operations pods can perform.[3][4]

Creating Role for Service Account

```
apiVersion: rbac.authorization.k8s.io/v1
kind:   Role  metadata:       namespace:
development   name: pod-reader rules:
-     apiGroups: [""]
resources: ["pods",
"pods/log"]   verbs: ["get",
"watch", "list"]
-     apiGroups: [""]
resources: ["configmaps"]
verbs: ["get"]
```

Binding Service Account to Role

```
apiVersion: rbac.authorization.k8s.io/v1
kind: RoleBinding metadata:
```

```
  name: read-pods
namespace: development
subjects:
-     kind: ServiceAccount
name: my-app-service-account
namespace: development
roleRef:
  kind: Role
name: pod-reader
  apiGroup: rbac.authorization.k8s.io
```

ClusterRole for Service Account

```
apiVersion: rbac.authorization.k8s.io/v1
kind: ClusterRole metadata:
  name: node-reader rules: -
apiGroups: [""]   resources:
["nodes"]   verbs: ["get",
"watch", "list"]

apiVersion: rbac.authorization.k8s.io/v1
kind: ClusterRoleBinding metadata:
  name: read-nodes-global subjects:
-     kind: ServiceAccount   name: node-reader-sa
namespace: monitoring roleRef:   kind:
ClusterRole   name: node-reader   apiGroup:
rbac.authorization.k8s.io
```

Service Account Subject Format

```
# In RoleBinding/ClusterRoleBinding
subjects:
-     kind: ServiceAccount   name: service-
account-name   namespace: namespace-name  #
Required for service accounts
```

Advanced Service Account Usage

Multiple Service Accounts Example

```
# Development service account
apiVersion:      v1     kind:
ServiceAccount metadata:
  name: dev-app-sa
namespace: development
---
```

```
# Production service account
apiVersion: v1 kind:
ServiceAccount metadata:
  name: prod-app-sa
namespace: production
---
# Different permissions for each environment
apiVersion: rbac.authorization.k8s.io/v1 kind:
Role
metadata:   namespace:
development   name: dev-
permissions rules: -
apiGroups: [""]
  resources: ["pods", "configmaps", "secrets"]
verbs: ["*"] ---
apiVersion: rbac.authorization.k8s.io/v1
kind: Role metadata:   namespace:
production   name: prod-permissions
rules: - apiGroups: [""]   resources:
["pods", "configmaps"]   verbs: ["get",
"list"]
```

Service Account with Image Pull Secrets

```
apiVersion: v1 kind:
ServiceAccount
metadata:   name:
registry-sa
imagePullSecrets:
- name: private-registry-secret
--- apiVersion:
v1 kind: Pod
metadata:
  name: private-image-pod spec:
serviceAccountName: registry-sa
containers:   - name: app     image: private-
registry.io/my-app:latest
```

Service Account Labels and Annotations

```
apiVersion: v1 kind:
ServiceAccount
metadata:
```

```
  name: labeled-sa
namespace: production
labels:
    app: my-application
environment: production
team: backend   annotations:
    description: "Service account for backend application"
owner: "backend-team@company.com"     compliance.requirement:
"high-security"
```

Service Account Security Best Practices

Principle of Least Privilege

```
# ❌ BAD: Too broad permissions
apiVersion: rbac.authorization.k8s.io/v1
kind: ClusterRoleBinding metadata:
  name: bad-binding
subjects:
- kind: ServiceAccount   name: app-sa
namespace: default roleRef:   kind:
ClusterRole   name: cluster-admin   # Too
much access!   apiGroup:
rbac.authorization.k8s.io

# ☑ GOOD: Specific permissions apiVersion:
rbac.authorization.k8s.io/v1 kind: Role metadata:
namespace: default   name: specific-permissions
rules: - apiGroups: [""]   resources: ["configmaps"]
verbs: ["get"]   resourceNames: ["app-config"]   #
Specific resource
```

Namespace Isolation

```
# Create dedicated namespaces kubectl
create namespace app-production kubectl
create namespace app-development

# Create service accounts per namespace
kubectl create serviceaccount prod-app-sa -n app-production kubectl
create serviceaccount dev-app-sa -n app-development
```

Disable Default Service Account

```
# Patch default service account to disable auto-mounting kubectl
patch serviceaccount default -p
'{"automountServiceAccountToken":false}'

# Or create pod without service account
apiVersion: v1 kind: Pod metadata:
  name: no-service-account-pod spec:
  automountServiceAccountToken: false
  containers:   - name:
app     image: my-
app:latest
```

Token Security

```
# Use short-lived tokens
kubectl create token my-sa --duration=1h

# Avoid long-lived tokens in secrets
# Use projected service account tokens instead
```

Service Account Troubleshooting

Common Issues and Solutions

1. Permission Denied Errors

```
# Check service account permissions kubectl auth can-i get pods --
as=system:serviceaccount:default:my-sa

# Check what the service account can do kubectl auth can-i --list
--as=system:serviceaccount:default:my-sa

# Debug RBAC kubectl get rolebindings,clusterrolebindings -A -o wide
| grep my-sa
```

2. Token Not Found

```
# Check if service account exists
kubectl get serviceaccount my-sa

# Check token mounting kubectl describe pod my-pod | grep -
A5 -B5 "service-account"

# Manually create token kubectl
create token my-sa
```

3. Wrong Namespace

```
# Check service account namespace kubectl get
serviceaccount my-sa -n correct-namespace

# Service accounts are namespace-scoped kubectl
get sa -A | grep my-sa
```

Debugging Commands

```
# View service account details
kubectl describe serviceaccount my-sa

# Check mounted token in pod kubectl
exec -it my-pod -- ls -la
/var/run/secrets/kubernetes.io/serviceaccount/

# View token content (be careful with sensitive data) kubectl
exec -it my-pod -- cat
/var/run/secrets/kubernetes.io/serviceaccount/token

# Test API access from within pod kubectl exec -it my-pod --
curl -H "Authorization: Bearer $(cat
/var/run/secrets/kubernetes.io/serviceaccount/token)"
https://kubernetes.default.svc/api/v1/namespaces/default/pods --cacert
/var/run/secrets/kubernetes.io/serviceaccount/ca.crt
```

CKA Exam Scenarios

Scenario 1: Create Service Account and Bind to Role

```
# 1. Create service account kubectl create serviceaccount app-
service-account -n production

# 2. Create role
kubectl create role app-role --verb=get,list,create -resource=pods,configmaps
-n production

# 3. Create role binding
kubectl create rolebinding app-binding --role=app-role -
serviceaccount=production:app-service-account -n production

# 4. Test permissions
```

```
kubectl auth can-i get pods --as=system:serviceaccount:production:appservice-
account -n production
```

Scenario 2: Fix Pod Service Account Issue

```
# Problem: Pod cannot access API kubectl
describe pod failing-pod

# Solution: Check and fix service account
kubectl get serviceaccount kubectl create
serviceaccount correct-sa kubectl patch
deployment my-app -p
'{"spec":{"template":{"spec":{"serviceAccountName":"correct-sa"}}}}'
```

Scenario 3: Security Hardening

```
# Disable default service account auto-mount kubectl
patch serviceaccount default -p
'{"automountServiceAccountToken":false}'

# Create minimal permission service account kubectl
create serviceaccount minimal-sa
kubectl create role minimal-role --verb=get --resource=configmaps --
resourcename=app-config
kubectl create rolebinding minimal-binding --role=minimal-role -
serviceaccount=default:minimal-sa
```

Service Account Commands Summary

Basic Operations

```
# Create service account kubectl
create serviceaccount NAME kubectl
create sa NAME -n NAMESPACE

# List service accounts
kubectl get serviceaccounts
kubectl get sa kubectl get
sa -A

# Describe service account kubectl
describe serviceaccount NAME kubectl
describe sa NAME
```

```
# Delete service account kubectl
delete serviceaccount NAME kubectl
delete sa NAME
```

Token Operations

```
# Create token (Kubernetes 1.24+) kubectl create
token SERVICE_ACCOUNT_NAME kubectl create token
SA_NAME --duration=1h kubectl create token SA_NAME
--audience=my-audience

# View mounted token in pod kubectl
exec POD_NAME -- cat
/var/run/secrets/kubernetes.io/serviceaccount/token
```

RBAC Integration

```
# Create role and binding for service account
kubectl create role ROLE_NAME --verb=VERBS --resource=RESOURCES kubectl
create rolebinding BINDING_NAME --role=ROLE_NAME -
serviceaccount=NAMESPACE:SA_NAME

# Create cluster role and binding
kubectl create clusterrole CLUSTER_ROLE_NAME --verb=VERBS -resource=RESOURCES
kubectl create clusterrolebinding BINDING_NAME --
clusterrole=CLUSTER_ROLE_NAME --serviceaccount=NAMESPACE:SA_NAME

# Test service account permissions
kubectl auth can-i VERB RESOURCE --as=system:serviceaccount:NAMESPACE:SA_NAME
kubectl auth can-i --list --as=system:serviceaccount:NAMESPACE:SA_NAME
```

Debugging

```
# Check service account in pod kubectl describe pod
POD_NAME | grep -i "service account"

# View service account tokens kubectl get
secrets | grep service-account-token

# Check RBAC bindings kubectl get
rolebindings,clusterrolebindings -A | grep SA_NAME
```

Key Points for CKA Exam

Must Know Concepts

1. **Default Behavior**: Every pod gets the default service account if none specified
2. **Namespace Scope**: Service accounts are namespace-scoped resources
3. **RBAC Integration**: Service accounts work with RBAC for authorization
4. **Token Mounting**: Tokens automatically mounted at `/var/run/secrets/kubernetes.io/serviceaccount/`
5. **Security**: Follow least privilege principle

Common Exam Tasks

- Create service accounts
- Bind service accounts to roles/cluster roles
- Configure pods to use specific service accounts
- Troubleshoot permission issues
- Disable automatic token mounting
- Create manual tokens

Important File Paths

- **Token**: `/var/run/secrets/kubernetes.io/serviceaccount/token`
- **CA Certificate**: `/var/run/secrets/kubernetes.io/serviceaccount/ca.crt`
- **Namespace**: `/var/run/secrets/kubernetes.io/serviceaccount/namespace`

Critical Commands

```
kubectl create serviceaccount NAME
kubectl create role NAME --verb=VERBS --resource=RESOURCES kubectl create
rolebinding NAME --role=ROLE --serviceaccount=NAMESPACE:SA kubectl auth
can-i VERB RESOURCE --as=system:serviceaccount:NAMESPACE:SA
```

Storage

Volumes

What are Volumes in Kubernetes?

Volumes provide persistent storage for pods that survives container restarts. Unlike the container's ephemeral filesystem, volumes persist data even when containers are recreated or restarted.[1]

Volume Purpose and Benefits

- **Data persistence**: Maintains data across container restarts
- **Data sharing**: Enables multiple containers in a pod to share data
- **External storage**: Connects pods to external storage systems

- **Decoupling**: Separates storage concerns from container lifecycle

Container Storage Behavior

When containers are created, Kubernetes creates a temporary filesystem that gets destroyed when the container is removed. Volumes solve this problem by providing persistent storage that exists independently of container lifecycle.[1]

Volume Types

What are Volume Types?

Volume Types determine where and how data is stored. Kubernetes supports numerous volume types to accommodate different storage requirements and infrastructure setups.[1]

Host-Based Volume Types *hostPath Volume* **hostPath** mounts a directory from the node's filesystem into the pod:

```
apiVersion: v1
kind: Pod metadata:
  name: random-number-generator spec:
  containers:   - image: alpine     name: alpine
command: ["/bin/sh","-c"]     args: ["shuf -i 0-100
-n 1 >> /opt/number.out;"]     volumeMounts:     -
mountPath: /opt       name: data-volume   volumes:
  -  name:  data-volume
hostPath:          path:
/data              type:
Directory       hostPath
```

Characteristics:

- **Node-specific**: Data tied to specific node
- **Not portable**: Pods scheduled on different nodes can't access data
- **Development use**: Suitable for single-node testing
- **Production caution**: Not recommended for multi-node clusters

Network-Based Volume Types

```
NFS (Network File System) volumes: -
name: nfs-volume   nfs:     server:
nfs-server.example.com       path:
/path/to/nfs/share
```

Cloud Provider Volumes **AWS**

Elastic Block Store (EBS):

```
volumes:
-     name: data-volume
awsElasticBlockStore:
volumeID: vol-
1234567890abcdef0
fsType: ext4
```

Google Cloud Persistent Disk:

```
volumes:
-     name: data-volume
gcePersistentDisk:
pdName: my-disk
fsType: ext4 Azure Disk:
```

```
volumes:
-     name: data-volume
azureDisk:
    diskName: my-disk.vhd     diskURI:
https://myaccount.blob.core.windows.net/vhds/my-disk.vhd
```

Distributed Storage Volume Types

- **Ceph**: Distributed storage system
- **GlusterFS**: Scale-out network-attached storage
- **ScaleIO**: Software-defined storage platform
- **Flocker**: Container data volume manager

Volume Mounting Process

1. **Volume definition**: Specify volume in pod spec
2. **Container mounting**: Mount volume into container filesystem
3. **Path mapping**: Map volume to specific container directory 4. **Data persistence**: Data persists beyond container lifecycle

Volume Challenges in Large Deployments

Multi-User Environment Problems

In environments with many users creating pods with different volume requirements:

- **Configuration complexity**: Each user must configure volumes manually
- **Storage management**: Admins must provision storage for every pod
- **Resource conflicts**: Multiple users might try to use same storage
- **Inconsistent setup**: Different volume configurations across teams

The Need for Abstraction

Problem: Direct volume management becomes unmanageable at scale **Solution**: Kubernetes provides **Persistent Volumes** and **Persistent Volume Claims** to abstract storage management[1]

Persistent Volumes (PVs)

What are Persistent Volumes?

Persistent Volumes (PVs) are cluster-wide storage resources provisioned by administrators. They abstract the underlying storage implementation and provide a standardized interface for storage consumption.[1]

PV Benefits

- **Centralized management**: Admins manage storage pool centrally
- **User abstraction**: Users don't need to know storage details
- **Resource pooling**: Create pool of storage resources
- **Standardization**: Consistent storage interface across cluster

Persistent Volume Definition

```
apiVersion:    v1   kind:
PersistentVolume
metadata:
  name: pv-vol1 spec:
  accessModes:
- ReadWriteOnce
capacity:
    storage: 1Gi
persistentVolumeReclaimPolicy: Retain
awsElasticBlockStore:     volumeID:
vol-1234567890abcdef0     fsType: ext4
```

PV Specification Components

Access Modes

Access Modes define how the volume can be mounted:

Mode	Description	Use Case
ReadWriteOnce	Single node read-write	Databases, single-instance apps **(RWO)**
ReadOnlyMany (ROX)	Multiple nodes read-only	Static content, shared configuration
ReadWriteMany (RWX)	Multiple nodes read-write	Shared filesystems, collaborative apps

Capacity
```
capacity:   storage: 1Gi   # Available storage space
```

Reclaim Policy

Reclaim Policy determines what happens when PV is released:

Policy	Behavior	Description
Retain	Manual cleanup	Admin must manually reclaim
Delete	Automatic deletion	Storage resource deleted automatically
Recycle	Data scrubbing	Volume scrubbed and made available (deprecated)

Creating and Viewing PVs
```
# Create PV kubectl create -f pv-definition.yaml

# List PVs
kubectl get persistentvolume kubectl get pv

# Detailed PV information kubectl describe pv pv-vol1
```

PV Status States

Status	Description
Available	Ready for use, not yet claimed

Status	Description

Bound Bound to a PVC

Released PVC deleted, but not yet reclaimed **Failed** Reclamation failed

Persistent Volume Claims (PVCs)

What are Persistent Volume Claims?

Persistent Volume Claims (PVCs) are requests for storage by users. They specify storage requirements and are matched with available Persistent Volumes.[1]

PVC Purpose

- **User interface**: Simple way for users to request storage
- **Resource claiming**: Claims available PVs based on requirements
- **Abstraction**: Users don't need to know underlying storage details
- **Automatic binding**: Kubernetes handles PV-PVC binding

PVC Definition

```yaml
apiVersion: v1
kind: PersistentVolumeClaim
metadata:
  name: myclaim
spec:  accessModes:
- ReadWriteOnce
resources:
requests:
storage: 500Mi
```

Creating and Managing PVCs

```
# Create PVC kubectl create -f pvc-
definition.yaml

# List PVCs
kubectl get persistentvolumeclaim kubectl
get pvc

# Describe PVC kubectl
describe pvc myclaim

# Delete PVC
kubectl delete persistentvolumeclaim myclaim
```

PV and PVC Binding Process

What is PV-PVC Binding?

Binding is the process where Kubernetes automatically matches PVCs with suitable PVs based on specified criteria.[1]

Binding Criteria

Kubernetes considers multiple factors when binding PVCs to PVs:

1. Sufficient Capacity
```
# PVC requests 500Mi
resources:
  requests:
    storage: 500Mi

# PV provides 1Gi (sufficient)
capacity:
  storage: 1Gi
```

2. Access Modes Compatibility
```
# Both must have compatible access modes
# PVC
accessModes:
  - ReadWriteOnce

# PV
accessModes:
  - ReadWriteOnce
```

3. Volume Modes
```
# Block or Filesystem mode compatibility
volumeMode: Filesystem
```

4. Storage Class
```
# Must match storage class (if specified)
storageClassName: fast-ssd
```

5. Selector Labels
```
# PV with labels
metadata:
  labels:
    name: my-pv
    environment: production

# PVC with selector
spec:
  selector:
    matchLabels:
```

```
name: my-pv
environment: production
```

Binding Examples

```
Successful Binding #
Before binding
kubectl get pv,pvc
NAME                      CAPACITY   ACCESS MODES   RECLAIM POLICY   STATUS
persistentvolume/pv-vol1  1Gi        RWO            Retain           Available

NAME                           STATUS    VOLUME   CAPACITY   ACCESS MODES
persistentvolumeclaim/myclaim Pending

# After binding
NAME                      CAPACITY   ACCESS MODES   RECLAIM POLICY   STATUS
CLAIM
persistentvolume/pv-vol1  1Gi        RWO            Retain           Bound
default/myclaim

NAME                           STATUS   VOLUME    CAPACITY   ACCESS MODES
persistentvolumeclaim/myclaim Bound    pv-vol1   1Gi        RWO
```

Failed Binding (Pending State)

If no suitable PV is available, PVC remains in **Pending** status:

```
NAME                           STATUS    VOLUME   CAPACITY   ACCESS MODES
persistentvolumeclaim/myclaim Pending
```

One-to-One Relationship

- **Exclusive binding**: Each PV can bind to only one PVC
- **Capacity allocation**: Entire PV capacity allocated to PVC (even if PVC requests less)
- **No sharing**: PVs cannot be shared between multiple PVCs

Using PVCs in Pods

Mounting PVCs in Pods

Once a PVC is bound to a PV, pods can use the PVC to access persistent storage:

```
apiVersion: v1
kind: Pod metadata:
```

```
  name: mypod
spec:
containers:   -
name: frontend
image: nginx
volumeMounts:
- mountPath:
"/var/www/html"
name: mypd
volumes:   - name:
mypd
persistentVolumeCl
aim:
claimName: myclaim
```

PVC Lifecycle in Pods

1. **PVC creation**: User creates PVC
2. **Binding**: Kubernetes binds PVC to suitable PV
3. **Pod usage**: Pod references PVC in volume definition
4. **Mount**: Container mounts PVC at specified path
5. **Data persistence**: Data persists across pod restarts

Imperative Commands for Storage

PV Management Commands

```
# Create PV from YAML
kubectl create -f pv-definition.yaml

# List all PVs kubectl
get pv
kubectl get persistentvolumes

# Describe specific PV kubectl
describe pv pv-vol1

# Delete PV
kubectl delete pv pv-vol1

# Edit PV
kubectl edit pv pv-vol1
```

```
# View PV in different output formats
kubectl get pv -o wide kubectl get pv
-o yaml kubectl get pv -o json
```

PVC Management Commands

```
# Create PVC imperatively kubectl create
pvc my-pvc --size=1Gi --access-modes=ReadWriteOnce

# Create from YAML kubectl create -f
pvc-definition.yaml

# List PVCs kubectl
get pvc
kubectl get persistentvolumeclaims

# Describe PVC kubectl
describe pvc myclaim

# Delete PVC kubectl
delete pvc myclaim

# View PVC details kubectl get
pvc -o wide kubectl get pvc
myclaim -o yaml
```

Combined PV/PVC Operations

```
# View both PVs and PVCs
kubectl get pv,pvc

# Monitor binding status kubectl
get pv,pvc -w

# Check events related to storage
kubectl get events --field-selector involvedObject.kind=PersistentVolume
kubectl get events --field-selector involvedObject.kind=PersistentVolumeClaim
```

Declarative Configurations

Complete PV-PVC-Pod Example

```
# pv-definition.yaml
apiVersion: v1 kind:
```

```
PersistentVolume
metadata:
  name: task-pv-volume
labels:
    type: local spec:
  storageClassName: manual
capacity:
    storage: 10Gi
accessModes:    -
ReadWriteOnce
hostPath:
    path: "/tmp/data"

---
# pvc-definition.yaml
apiVersion: v1 kind:
PersistentVolumeClaim
metadata:   name: task-pv-
claim spec:
storageClassName: manual
accessModes:    -
ReadWriteOnce   resources:
requests:       storage:
3Gi

---
# pod-definition.yaml
apiVersion: v1 kind:
Pod metadata:
  name: task-pv-pod spec:
volumes:   - name: task-pv-
storage
persistentVolumeClaim:
claimName: task-pv-claim
containers:   - name: task-pv-
container     image: nginx
ports:    - containerPort: 80
name: "http-server"
volumeMounts:
    - mountPath: "/usr/share/nginx/html"
name: task-pv-storage
```

Deployment with PVC

```
apiVersion: apps/v1
kind:    Deployment
metadata:
  name: webapp-deployment spec:
  replicas: 3   selector:
matchLabels:       app: webapp
template:     metadata:
labels:         app: webapp
spec:       containers:       -
name: webapp         image: nginx
volumeMounts:         - name:
webapp-storage
mountPath: /var/www/html
volumes:       - name: webapp-
storage
persistentVolumeClaim:
claimName: webapp-pvc
```

Storage Classes (Dynamic Provisioning)

What are Storage Classes?

Storage Classes enable dynamic provisioning of storage resources, automatically creating PVs when PVCs are created.[1]

Storage Class Benefits

- **Automatic provisioning**: No need to pre-create PVs
- **On-demand storage**: Storage created when needed
- **Different tiers**: Support multiple storage performance tiers
- **Cloud integration**: Seamless integration with cloud storage services

Storage Class Definition

```
apiVersion: storage.k8s.io/v1
kind: StorageClass metadata:
  name: fast-ssd provisioner:
kubernetes.io/aws-ebs parameters:
type: gp2
  zones: us-west-2a, us-west-2b
encrypted: "true" reclaimPolicy: Delete
allowVolumeExpansion: true
volumeBindingMode: WaitForFirstConsumer
```

Using Storage Classes with PVCs

```
apiVersion: v1 kind:
PersistentVolumeClaim
metadata:
  name: dynamic-pvc spec:
  storageClassName: fast-ssd
accessModes: -
ReadWriteOnce resources:
requests: storage: 100Gi
```

Reclaim Policies in Detail

Understanding Reclaim Policies

Reclaim Policies determine what happens to a PV after its associated PVC is deleted.[1]

Retain Policy `persistentVolumeReclaimPolicy: Retain`

- **Manual intervention**: Admin must manually handle PV
- **Data preservation**: Data remains intact
- **Status change**: PV status changes to “Released”
- **Reuse restriction**: Cannot be claimed by new PVC until manually cleaned

Delete Policy `persistentVolumeReclaimPolicy: Delete`

- **Automatic cleanup**: PV and underlying storage deleted automatically
- **Data loss**: All data permanently lost
- **Cloud storage**: Actual cloud storage resources deleted
- **Default**: Often default for dynamically provisioned volumes

Recycle Policy (Deprecated) `persistentVolumeReclaimPolicy: Recycle`

- **Data scrubbing**: Basic scrub (rm -rf /thevolume/*)
- **Availability**: PV becomes available for new claims
- **Deprecation**: Replaced by dynamic provisioning

Storage Best Practices

PV/PVC Design Principles

- **Right-size storage**: Request appropriate storage amounts

- **Access mode selection**: Choose correct access modes for use case
- **Storage class strategy**: Use storage classes for different performance tiers
- **Backup planning**: Implement backup strategies for critical data

Security Considerations

- **Access controls**: Use RBAC to control PVC creation
- **Namespace isolation**: Keep storage resources in appropriate namespaces
- **Data encryption**: Enable encryption for sensitive data
- **Network policies**: Secure storage network communications

Performance Optimization

- **Storage location**: Consider data locality for performance
- **IOPS requirements**: Match storage type to performance needs
- **Caching strategies**: Implement appropriate caching layers
- **Monitoring**: Monitor storage performance and usage

Troubleshooting Storage Issues

Common PVC Problems

```
# PVC stuck in Pending kubectl describe pvc problematic-pvc # Look for events and error messages

# Check available PVs kubectl get pv
# Verify capacity, access modes, storage class

# Check storage class kubectl get storageclass kubectl describe storageclass fast-ssd
```

PV Binding Issues

```
# Check PV labels and selectors
kubectl describe pv my-pv kubectl describe pvc my-pvc

# Verify access modes compatibility kubectl get pv my-pv -o yaml | grep accessModes
kubectl get pvc my-pvc -o yaml | grep accessModes
```

```
# Check storage capacity kubectl describe
pv my-pv | grep Capacity kubectl describe
pvc my-pvc | grep storage
```

Pod Mount Failures

```
# Check pod
events kubectl describe pod
my-pod
kubectl get events --field-selector involvedObject.name=my-pod

# Verify PVC status kubectl
get pvc
kubectl describe pvc my-claim

# Check volume mounts kubectl describe pod my-pod
| grep -A 5 "Mounts"
```

Key Storage Commands

Summary

Essential PV Commands

```
# PV lifecycle
kubectl create -f pv-definition.yaml
kubectl get pv kubectl describe pv
kubectl delete pv
```

Essential PVC Commands

```
# PVC lifecycle
kubectl create -f pvc-definition.yaml
kubectl get pvc kubectl describe pvc
kubectl delete pvc
```

Storage Monitoring Commands

```
# Combined view kubectl
get pv,pvc
kubectl get pv,pvc -o wide

# Storage events
kubectl get events | grep -i volume kubectl
get events | grep -i persistent

# Storage class information
kubectl get storageclass kubectl
describe storageclass
```

Networking

Networking Fundamentals

What is Kubernetes Networking?

Kubernetes Networking is the mechanism by which different resources within and outside your cluster are able to communicate with each other. It provides the foundation for understanding how containers, pods, and services within Kubernetes communicate seamlessly across the cluster.[1][2]

Core Networking Principles

Kubernetes networking is built on several fundamental principles that ensure consistent and reliable communication:[3][1]

- **Every pod gets its own IP address**: Each pod receives a unique cluster-wide IP address
- **Containers within a pod share the pod IP address**: All containers in a pod communicate via localhost
- **Pods can communicate with all other pods**: Direct communication without NAT across the entire cluster
- **Network isolation**: Defined using network policies rather than network structure

Why Kubernetes Networking Matters

Understanding Kubernetes networking is crucial for:[2]

- **Proper environment configuration**: Setting up production-ready clusters
- **Complex networking scenarios**: Implementing advanced traffic management
- **Security implementation**: Controlling communication flows
- **Troubleshooting**: Diagnosing connectivity issues

The Kubernetes Network Model

What is the Kubernetes Network Model?

The **Kubernetes Network Model** specifies how different components communicate within a cluster. It provides a flat network structure that makes pod-to-pod communication simple and predictable.[1]

Network Model Components

Pod Network (Cluster Network)

The **Pod Network** handles communication between pods across the cluster:[3]

```
# Every pod gets a unique IP from the cluster CIDR
apiVersion: v1 kind: Pod metadata:
  name: web-pod
spec:
containers:   -
name: nginx
image: nginx
ports:
    - containerPort: 80 Key
```

characteristics:

- **Cluster-wide IP addressing**: All pods can reach each other using IP addresses
- **No NAT required**: Direct pod-to-pod communication
- **Cross-node communication**: Pods on different nodes communicate seamlessly
- **Network namespace sharing**: Containers in same pod share network namespace

Service Network

Services provide stable network identities for accessing groups of pods:[3]

```
apiVersion: v1
kind: Service
metadata:   name:
web-service spec:
selector:     app:
web   ports:
  - port: 80
targetPort: 80   type:
ClusterIP
```

Network Model Implementation

The Kubernetes network model is implemented using:[4]

- **Container Runtime**: Sets up network namespaces for containers
- **CNI Plugin**: Configures networking rules and policies
- **Kube-proxy**: Handles service networking and load balancing

Container Network Interface (CNI)

What is CNI?

Container Network Interface (CNI) is a standard interface specification for network plugins in container orchestration systems. It defines how container runtimes collaborate with networking plugins to configure networking for containers and pods.[4]

CNI Responsibilities

CNI plugins handle several critical networking tasks:[4]

- **IP address assignment**: Allocating unique IPs to containers
- **Network interface setup**: Configuring network interfaces
- **Route definition**: Setting up routing tables
- **Network policy enforcement**: Implementing security rules

Popular CNI Plugins

Weave Net

Weave Net creates a virtual network that connects containers across multiple hosts:

```
# Deploy Weave Net
kubectl apply -f "https://cloud.weave.works/k8s/net?k8s-version=$(kubectl
version | base64 | tr -d '\n')"
```

Features:

- **Automatic IP allocation**: Dynamic IP address management
- **Encryption**: Secure pod-to-pod communication
- **Network policies**: Traffic filtering capabilities
- **Multi-cloud support**: Works across different cloud providers *Calico*

Calico provides networking and network security for containers:

```
# Deploy Calico kubectl apply -f
https://docs.projectcalico.org/manifests/calico.yaml
```

Features:

- **Network policies**: Advanced traffic filtering
- **BGP routing**: Efficient inter-node communication
- **Network security**: Built-in firewall capabilities
- **Performance**: High-performance networking

Flannel

Flannel is a simple overlay network for Kubernetes:

```
# Deploy Flannel
kubectl apply -f
https://raw.githubusercontent.com/flannelio/flannel/master/
Documentation/kube-flannel.yml
```

Features:

- **Simplicity**: Easy to deploy and manage
- **Overlay networking**: VXLAN-based networking
- **Cross-platform**: Works on various operating systems

CNI Configuration

CNI is configured through the kubelet:[5]

```
# Kubelet CNI configuration
ExecStart=/usr/local/bin/kubelet \
  --network-plugin=cni \
  --cni-bin-dir=/opt/cni/bin  \
--cni-conf-dir=/etc/cni/net.d
```

Configuration files:

```
{
  "cniVersion": "0.2.0",
  "name": "mynet",
  "type": "bridge",
  "bridge": "cni0",
  "isGateway": true,
  "ipMasq": true,
  "ipam": {
    "type": "host-local",
    "subnet": "10.244.0.0/16",
    "routes": [
      { "dst": "0.0.0.0/0" }
    ]
  }}
```

IP Address Management (IPAM)

What is IPAM?

IP Address Management (IPAM) ensures that each pod receives a unique IP address within the cluster. It prevents IP conflicts and manages IP allocation across nodes.[5]

IPAM Plugins

Host-Local IPAM

Host-local maintains IP allocation on each node locally:

```
{
  "ipam": {
    "type": "host-local",
    "subnet": "10.244.0.0/16",
    "routes": [
      { "dst": "0.0.0.0/0" }
    ]
  }}
```

Characteristics:

- **Node-specific allocation**: Each node manages its own IP range
- **Persistent storage**: IP allocations stored locally
- **Simple configuration**: Easy to set up and manage

DHCP IPAM

DHCP uses external DHCP servers for IP allocation:

```
{
  "ipam": {
    "type": "dhcp"
  }
}
```

IP Range Planning

Proper IP range planning is crucial for large clusters:[5]

```
# Cluster CIDR configuration kube-apiserver --service-
cluster-ip-range=10.96.0.0/12 Common IP ranges:
```

- **Pod Network**: `10.244.0.0/16` (65,534 IPs)
- **Service Network**: `10.96.0.0/12` (1,048,574 IPs)
- **Node Network**: `192.168.1.0/24` (254 IPs)

Services and Service Discovery

What are Services?

Services provide stable network endpoints for accessing groups of pods. They abstract away the dynamic nature of pod IP addresses and provide load balancing.[6]

Service Types

ClusterIP Service

ClusterIP exposes the service internally within the cluster:

```
apiVersion: v1 kind:
Service metadata:   name:
internal-service spec:
type: ClusterIP
selector:
    app:     backend
ports:   - port: 80
targetPort: 8080 Use
cases:
```

- **Internal communication**: Service-to-service communication
- **Database access**: Backend services accessing databases
- **Microservices**: Communication between microservices

NodePort Service

NodePort exposes the service on each node's IP at a static port:

```
apiVersion: v1 kind:
Service metadata:
  name: nodeport-service
spec:   type: NodePort
selector:
    app: frontend
ports:   - port: 80
targetPort: 80
nodePort: 30080
```

Characteristics:

- **External access**: Accessible from outside the cluster
- **Port range**: 30000-32767 by default

- **All nodes**: Service accessible on all nodes

LoadBalancer Service

LoadBalancer provisions an external load balancer:

```
apiVersion: v1 kind:
Service metadata:
  name: loadbalancer-service
spec:   type: LoadBalancer
selector:     app: web
ports:   - port: 80
targetPort: 80 Features:
```

- **Cloud integration**: Works with cloud provider load balancers
    - **Automatic provisioning**: Load balancer created automatically
- **High availability**: Built-in load balancing and failover Service Discovery

Kubernetes provides automatic service discovery through:[5]

DNS-Based Discovery

Every service gets a DNS name:

```
# Service DNS format
..svc.cluster.local

# Examples
web-service.default.svc.cluster.local database.production.svc.cluster.local
```

Environment Variables

Services are exposed as environment variables:

```
# Service environment variables
WEB_SERVICE_HOST=10.96.1.100
WEB_SERVICE_PORT=80
WEB_SERVICE_PORT_80_TCP=tcp://10.96.1.100:80
```

Ingress and Ingress Controllers

What is Ingress?

Ingress manages external access to services in a cluster, typically HTTP and HTTPS. It provides URL-based routing, SSL termination, and load balancing.[5]

Ingress Components

Ingress Resource

Ingress Resource defines the routing rules:

```
apiVersion: networking.k8s.io/v1 kind: Ingress
metadata:  name: web-ingress  annotations:
nginx.ingress.kubernetes.io/rewrite-target: /
spec:  rules:
  - host: example.com
http:      paths:
- path: /app
pathType: Prefix
backend:
service:
            name: app-service
port:               number:
80      - path: /api
pathType: Prefix
backend:          service:
            name: api-service
port:               number:
8080
```

Ingress Controller

Ingress Controller implements the ingress rules:

```
# Deploy NGINX Ingress Controller
kubectl apply -f
https://raw.githubusercontent.com/kubernetes/ingressnginx/controller-
v1.8.1/deploy/static/provider/cloud/deploy.yaml
```

Advanced Ingress Features

SSL/TLS Termination `apiVersion:`
`networking.k8s.io/v1 kind:`
`Ingress metadata:`
`  name: tls-ingress spec:`
`tls:  - hosts:  -`
`example.com`

```
secretName: tls-secret
rules:   - host:
example.com     http:
paths:       - path: /
pathType: Prefix
backend:
service:
            name: web-service
port:               number:
80
```

Path-Based Routing

```
spec:
rules:          -    host:
api.example.com     http:
paths:        - path: /v1
pathType:           Prefix
backend:          service:
            name: api-v1-service
port:               number: 80
- path: /v2         pathType:
Prefix         backend:
service:
            name: api-v2-service
port:               number: 80
```

Kubernetes Gateway API

What is the Gateway API?

The **Kubernetes Gateway API** is a modern, extensible approach to managing ingress and traffic routing in Kubernetes. It provides more expressive, structured routing capabilities compared to traditional Ingress resources.[7]

Gateway API Benefits

The Gateway API offers several advantages over Ingress:[8]

- **More expressive**: Rich traffic management capabilities
- **Role separation**: Clear separation between infrastructure and application concerns
- **Extensibility**: Built-in extension points for custom functionality
- **Protocol support**: Native support for HTTP, HTTPS, TCP, UDP, and gRPC
- **Implementation agnostic**: Works with different gateway controllers

Gateway API Architecture

GatewayClass

GatewayClass defines a set of gateways implemented by a specific controller:[7]

```
apiVersion: gateway.networking.k8s.io/v1
kind: GatewayClass metadata:
  name: nginx spec:   controllerName:
nginx.org/gateway-controller   description:
"NGINX Gateway Controller" Purpose:
```

- **Decouples configuration from implementation**: Allows switching between different gateway implementations
- **Multi-controller support**: Multiple gateway implementations can coexist
- **Administrative control**: Platform administrators control available implementations

Gateway

Gateway defines how traffic enters the cluster:[7]

```
apiVersion: gateway.networking.k8s.io/v1
kind: Gateway metadata:
  name: nginx-gateway
namespace: default
spec:
gatewayClassName: nginx
listeners:   - name:
http     protocol: HTTP
port: 80
allowedRoutes:
namespaces:
from: All   - name:
https     protocol:
HTTPS     port: 443
tls:       mode:
Terminate
certificateRefs:
- kind: Secret
name: tls-secret
allowedRoutes:
namespaces:
from: All Key features:
```

- **Multiple protocols**: HTTP, HTTPS, TCP, UDP support
    - **TLS termination**: Built-in SSL/TLS handling
- **Namespace control**: Fine-grained route permissions

HTTP Routing with Gateway API

Basic HTTP Routing

HTTPRoute defines how HTTP traffic is routed to services:

```
apiVersion: gateway.networking.k8s.io/v1
kind: HTTPRoute metadata:
  name: basic-route
namespace: default spec:
  parentRefs:   - name:
nginx-gateway
hostnames:   -
"api.example.com"
rules:
- matches:
- path:
        type: PathPrefix
value: /api/v1
backendRefs:     - name:
api-v1-service
      port: 80      weight:
100  Advanced  HTTP  Routing
```

Features

Header-Based Routing:

```
rules:
- matches:
- headers:     - name:
  "version"
  value: "v2"     path:
      type:   PathPrefix
value:               /api
backendRefs:     -  name:
api-v2-service     port:
80 Method-Based Routing:
```

```
rules: -
matches:   -
method: GET
path:
      type: PathPrefix
value: /api/users
backendRefs:   - name:
user-read-service     port:
80 - matches:   - method:
POST     path:
      type: PathPrefix
value: /api/users
backendRefs:   - name: user-
write-service     port: 80
```

Traffic Management with Gateway API

HTTP Redirects **HTTP to**

HTTPS Redirect:

```
apiVersion: gateway.networking.k8s.io/v1
kind: HTTPRoute metadata:
  name: https-redirect
namespace: default
spec:   parentRefs:
- name: nginx-gateway
  hostnames:   -
  "example.com"   rules:   -
  filters:     - type:
  RequestRedirect
  requestRedirect:
  scheme: https
  statusCode: 301 Path
  Redirects:
```

```
rules:
- matches:
- path:       type:
  PathPrefix       value:
  /old-api   filters:   -
  type: RequestRedirect
  requestRedirect:
```

```
  path:        type:
  ReplacePrefixMatch
  replacePrefixMatch: /new-
  api       statusCode: 302
```

URL Rewriting **Path**

Rewriting:

```
apiVersion: gateway.networking.k8s.io/v1
kind: HTTPRoute metadata:
  name: rewrite-path
namespace: default spec:
  parentRefs:   - name:
nginx-gateway   rules:
- matches:
- path:        type:
  PathPrefix         value:
  /external-api     filters:
  - type: URLRewrite
  urlRewrite:         path:
          type: ReplacePrefixMatch
replacePrefixMatch: /internal-api
backendRefs:     - name: internal-service
port: 80
```

Header Modification **Request**

Header Modification:

```
rules: -
filters:
- type:
  RequestHeaderModifier
  requestHeaderModifier:
  add:
- name: "X-Environment"
  value: "production"       -
  name: "X-Request-ID"
  value: "generated-uuid"
  set:
- name: "Authorization"
  value: "Bearer token"
  remove:       - "X-Debug"
```

```
  backendRefs:   - name:
  backend-service     port:
  80
```
Response Header Modification:

```
filters:
- type:
  ResponseHeaderModifier
  responseHeaderModifier:
  add:
- name: "X-Cache-Status"
  value: "MISS"     set:
- name: "Cache-Control"
  value: "max-age=3600"
  remove:     - "Server"
```

Traffic Splitting

Canary Deployments:

```
apiVersion: gateway.networking.k8s.io/v1
kind: HTTPRoute metadata:
  name: canary-split
namespace: default
spec:   parentRefs:   -
name: nginx-gateway
rules:   - backendRefs:
- name: stable-service
      port: 80      weight:
90        -  name:  canary-
service           port:  80
weight: 10
```
A/B Testing:

```
rules:
- matches:
- headers:     - name: "X-
  User-Group"       value:
  "beta"   backendRefs:   -
  name: beta-service
  port: 80 - backendRefs:
  - name: stable-service
  port: 80
```

Request Mirroring

Traffic Mirroring for Testing:

```
apiVersion: gateway.networking.k8s.io/v1
kind: HTTPRoute metadata:  name: mirror-
traffic  namespace: default spec:
parentRefs:  - name: nginx-gateway
rules:  - filters:    - type:
RequestMirror      requestMirror:
backendRef:          name: test-service
port: 80    backendRefs:    - name:
production-service      port: 80
```

Advanced Gateway API Features

TCP and UDP Routing

TCP Route:

```
apiVersion: gateway.networking.k8s.io/v1alpha2
kind: TCPRoute metadata:
  name:       database-route
namespace:   default  spec:
parentRefs:    - name:  tcp-
gateway       rules:       -
backendRefs:        - name:
postgres-service       port:
5432
```

UDP Route:

```
apiVersion: gateway.networking.k8s.io/v1alpha2
kind: UDPRoute metadata:
  name: dns-route
namespace: default
spec:  parentRefs:  -
name: udp-gateway
rules:  - backendRefs:
- name: dns-service
port: 53
```

TLS Configuration **TLS**

Termination:

```
apiVersion: gateway.networking.k8s.io/v1
kind: Gateway metadata:
  name: tls-gateway
namespace: default spec:
  gatewayClassName: nginx
listeners:   - name:
https     protocol: HTTPS
port: 443     tls:
      mode:          Terminate
certificateRefs:       - kind:
Secret          name: example-
com-tls             namespace:
default         allowedRoutes:
namespaces:          from: All
```

TLS Passthrough:

```
listeners:
- name: tls-passthrough
protocol: TLS   port:
443   tls:     mode:
Passthrough
allowedRoutes:
namespaces:       from:
All
```

Installing NGINX Gateway Fabric

Prerequisites

Before installing NGINX Gateway Fabric:[9]

```
# Install Gateway API CRDs
kubectl kustomize "https://github.com/nginx/nginx-gateway-
fabric/config/crd/gateway-api/standard?ref=v1.6.2" | kubectl apply -f -

kubectl kustomize "https://github.com/nginx/nginx-
gatewayfabric/config/crd/gateway-api/experimental?ref=v1.6.2" | kubectl apply
-f -
```

Installation via Helm

Install NGINX Gateway Fabric:[9]

```
# Add NGINX Helm repository
```

```
helm repo add nginx-stable https://helm.nginx.com/stable helm
repo update

# Install NGINX Gateway Fabric helm install ngf
oci://ghcr.io/nginx/charts/nginx-gateway-fabric \
  --create-namespace \
  -n nginx-gateway \   --
wait
```

Verify Installation

```
# Check Gateway Fabric pods kubectl
get pods -n nginx-gateway

# Check GatewayClass kubectl
get gatewayclass

# Check Gateway API resources
kubectl get gateways kubectl
get httproutes
```

Practical Gateway API Examples

Multi-Service Application

Complete application setup:

```
# GatewayClass
apiVersion: gateway.networking.k8s.io/v1 kind:
GatewayClass metadata:   name: nginx spec:
controllerName: nginx.org/gateway-controller

--- #
Gateway
apiVersion: gateway.networking.k8s.io/v1
kind: Gateway metadata:
  name: app-gateway
namespace: default spec:
gatewayClassName: nginx
listeners:   - name: http
protocol: HTTP     port:
80   - name: https
protocol: HTTPS     port:
443     tls:       mode:
```

```
Terminate
certificateRefs:      -
kind: Secret
name: app-tls

--- # Frontend
Route
apiVersion: gateway.networking.k8s.io/v1
kind: HTTPRoute metadata:
  name: frontend-route
namespace: default spec:
  parentRefs:   -
name: app-gateway
hostnames:   -
"app.example.com"
rules:
- matches:
- path:        type:
  PathPrefix
  value: /
  backendRefs:
- name: frontend-
  service       port: 80

---
# API Route with versioning apiVersion:
gateway.networking.k8s.io/v1 kind:
HTTPRoute metadata:   name: api-route
namespace: default spec:   parentRefs:
- name: app-gateway   hostnames:   -
"api.example.com"   rules:
- matches:
- path:        type:
  PathPrefix
  value: /v1
  backendRefs:
- name: api-v1-service
  port: 80   - matches:
- path:        type:
  PathPrefix
  value: /v2
  backendRefs:
```

```
- name: api-v2-service
  port: 80
```

Network Policies

What are Network Policies?

Network Policies are Kubernetes resources that control traffic flow between pods, providing network-level security and segmentation. They act as a firewall for your pods, defining which traffic is allowed or denied.[6]

Network Policy Components

Pod Selector

Pod Selector determines which pods the policy applies to:

```
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy metadata:
  name: web-policy
namespace: production
spec:   podSelector:
matchLabels:       app:
web       tier:
frontend   policyTypes:
- Ingress   - Egress
```

Ingress Rules

Ingress Rules control incoming traffic to selected pods:

```
spec:
ingress:
  - from:
    # Allow traffic from pods with specific labels
- podSelector:         matchLabels:           app:
api
    # Allow traffic from specific namespaces
- namespaceSelector:         matchLabels:
environment: production     # Allow traffic
from specific IP ranges     - ipBlock:
        cidr: 192.168.1.0/24
except:         -
192.168.1.100/32     ports:
```

```
- protocol: TCP       port:
80     - protocol: TCP
port: 443
```

Egress Rules

Egress Rules control outgoing traffic from selected pods:

```
spec:
egress:
  - to:
    # Allow traffic to database pods
- podSelector:         matchLabels:
app: database
    ports:     -
protocol: TCP
port: 5432   - to:
    # Allow traffic to external services
- ipBlock:
        cidr:  0.0.0.0/0
ports:    - protocol: TCP
port: 443  # HTTPS      -
protocol: TCP       port:
53   # DNS    - protocol:
UDP      port: 53   # DNS
```

Network Policy Examples

Default Deny All Policy

Deny all ingress and egress traffic:

```
apiVersion: networking.k8s.io/v1 kind: NetworkPolicy
metadata:   name: default-deny-all   namespace:
production spec:   podSelector: {}  # Applies to all
pods in namespace   policyTypes:   - Ingress   -
Egress
```

Allow Specific Traffic

Three-tier application policy:

```
# Frontend policy - allows ingress from anywhere, egress to API
apiVersion: networking.k8s.io/v1 kind: NetworkPolicy metadata:
name: frontend-policy   namespace: production spec:
```

```
  podSelector:
matchLabels:
tier: frontend
policyTypes:   -
Ingress   - Egress
ingress:
- {} # Allow all
  ingress
  egress:
- to:     - podSelector:
  matchLabels:
  tier: api     ports:
  - protocol: TCP
  port: 8080

---
# API policy - allows ingress from frontend, egress to database
apiVersion: networking.k8s.io/v1 kind: NetworkPolicy metadata:
name: api-policy   namespace: production spec:   podSelector:
matchLabels:       tier: api   policyTypes:   - Ingress   -
Egress   ingress:
- from:     -
  podSelector:
  matchLabels:
  tier: frontend
  ports:     - protocol:
  TCP       port: 8080
  egress:
- to:     - podSelector:
  matchLabels:
  tier: database
  ports:     - protocol:
  TCP       port: 5432

---
# Database policy - allows ingress from API only
apiVersion: networking.k8s.io/v1 kind:
NetworkPolicy metadata:
  name: database-policy
namespace: production
spec:   podSelector:
matchLabels:
```

```
      tier: database
policyTypes:   -
Ingress   ingress:
  - from:     -
podSelector:
matchLabels:
tier: api     ports:
- protocol: TCP
port: 5432
```

Network Policy Best Practices

Namespace Isolation

Isolate different environments:

```
# Production namespace policy
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy metadata:
name: production-isolation
namespace: production spec:
podSelector: {}   policyTypes:
- Ingress   ingress:
- from:
- namespaceSelector:
  matchLabels:
          environment: production     -
namespaceSelector:         matchLabels:          name:
ingress-nginx  # Allow ingress controller
```

DNS Access Policy **Allow**

DNS resolution:

```
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy metadata:
  name: allow-dns
namespace: production spec:
  podSelector: {}
policyTypes:   -
Egress   egress:
- to:
- namespaceSelector:
  matchLabels:
```

```
          name: kube-system
- podSelector:
matchLabels:
          k8s-app: kube-dns
ports:     - protocol: TCP
port: 53     - protocol:
UDP       port: 53
```

DNS in Kubernetes

What is Kubernetes DNS?

Kubernetes DNS provides service discovery and name resolution within the cluster. It automatically creates DNS records for services and pods, enabling communication using human-readable names instead of IP addresses.[5]

DNS Architecture

CoreDNS

CoreDNS is the default DNS server in Kubernetes:[5]

```
apiVersion: v1 kind:
ConfigMap metadata:
  name: coredns
namespace: kube-system
data:   Corefile: |
.:53 {         errors
health {
lameduck 5s
        }
ready
        kubernetes cluster.local in-addr.arpa ip6.arpa {
pods insecure
            fallthrough in-addr.arpa ip6.arpa
ttl 30         }
        prometheus :9153
forward . /etc/resolv.conf
cache 30         loop
reload
        loadbalance
}
```

DNS Records

Service DNS Records

Services get DNS records in the following format:[5]

```
# Service DNS format
..svc.cluster.local

# Examples
web-service.default.svc.cluster.local        # ClusterIP service
database.production.svc.cluster.local         # Database service
api-gateway.kube-system.svc.cluster.local      # System service
```

Service record types:

- **A Record**: Points to service ClusterIP
- **SRV Record**: Includes port information
- **CNAME Record**: For external services

Pod DNS Records

Pods get DNS records based on their IP addresses:[5]

```
# Pod DNS format
..pod.cluster.local

# Examples
10-244-1-5.default.pod.cluster.local     # Pod with IP 10.244.1.5
172-17-0-3.kube-system.pod.cluster.local # System pod
```

Headless Service Records

Headless Services create DNS records for individual pods:

```
apiVersion: v1 kind:
Service metadata:
  name: headless-service spec:
  clusterIP: None  # Makes service headless
selector:
    app: database
ports:   - port:
5432

# Headless service DNS records
```

```
database-0.headless-service.default.svc.cluster.local database-1.headless-
service.default.svc.cluster.local database-2.headless-
service.default.svc.cluster.local
```

DNS Configuration

Pod DNS Configuration

Pods automatically get DNS configuration:[5]

```
# /etc/resolv.conf in pod nameserver
10.96.0.10
search default.svc.cluster.local svc.cluster.local cluster.local options
ndots:5
```

Custom DNS Configuration Customize

DNS for specific pods:

```
apiVersion: v1
kind: Pod metadata:
  name: custom-dns-pod
spec:  dnsPolicy:
"None"  dnsConfig:
nameservers:    -
8.8.8.8    - 8.8.4.4
searches:    -
custom.local
options:    - name:
ndots      value: "2"
containers:  - name:
app    image: nginx
```

Load Balancing and Service Mesh

Service Load Balancing

Kubernetes provides built-in load balancing through Services:[5]

Service Load Balancing Algorithms

Round Robin (default):

```
apiVersion: v1 kind:
Service metadata:
```

```
  name: web-service spec:
  selector:      app: web    ports:    -
port:   80            targetPort:   8080
sessionAffinity:  None    # Round robin
```

Session Affinity:

```
spec:   sessionAffinity: ClientIP
sessionAffinityConfig:     clientIP:
timeoutSeconds: 10800  # 3 hours
```

External Load Balancers

Cloud Provider Load Balancers **AWS**

Application Load Balancer:

```
apiVersion: v1 kind: Service metadata:   name: aws-lb-service   annotations:
service.beta.kubernetes.io/aws-load-balancer-type:                    "nlb"
service.beta.kubernetes.io/aws-load-balancer-backend-protocol:      "http"
spec:   type: LoadBalancer   selector:      app: web   ports:   - port: 80
targetPort: 8080
```

Google Cloud Load Balancer:

```
metadata:
  annotations:
    cloud.google.com/load-balancer-type:                      "External"
cloud.google.com/backend-config:   '{"default":   "my-backendconfig"}'
```

Imperative Commands for Networking

Service Management Commands

```
# Create services
kubectl expose deployment nginx --port=80 --target-port=8080 --type=ClusterIP
kubectl expose pod nginx --port=80 --type=NodePort kubectl create service
loadbalancer web --tcp=80:8080

# View services kubectl
get services kubectl
get svc -o wide
kubectl describe service web-service

# Edit services
kubectl edit service web-service
kubectl patch service web-service -p '{"spec":{"type":"LoadBalancer"}}'
```

```
# Delete services kubectl delete
service web-service
```

Ingress Management Commands

```
# Create ingress
kubectl create ingress web-ingress --rule="example.com/api*=api-service:80"
kubectl create ingress tls-ingress --
rule="secure.com/*=webservice:80,tls=tls-secret"

# View ingress kubectl
get ingress
kubectl describe ingress web-ingress

# Edit ingress
kubectl edit ingress web-ingress
kubectl annotate ingress web-ingress
nginx.ingress.kubernetes.io/rewritetarget=/

# Delete ingress kubectl delete
ingress web-ingress
```

Network Policy Management Commands *#*

```
Create network policy (declarative only)
kubectl apply -f network-policy.yaml

# View network policies kubectl
get networkpolicies kubectl get
netpol
kubectl describe networkpolicy web-policy

# Delete network policies kubectl
delete networkpolicy web-policy kubectl
delete netpol --all
```

DNS and Service Discovery Commands

```
# DNS testing
kubectl run test-pod --image=busybox --rm -it -- nslookup web-service kubectl
exec -it test-pod -- dig web-service.default.svc.cluster.local

# Service endpoints
```

```
kubectl get endpoints web-service kubectl
describe endpoints web-service

# DNS debugging
kubectl exec -it dns-test -- cat /etc/resolv.conf kubectl
logs -n kube-system deployment/coredns
```

Gateway API Commands #

```
Install Gateway API CRDs
kubectl kustomize "https://github.com/kubernetes-
sigs/gatewayapi/config/crd?ref=v1.0.0" | kubectl apply -f -

# View Gateway API resources
kubectl get gatewayclasses
kubectl get gateways kubectl
get httproutes kubectl get
tcproutes

# Describe Gateway resources kubectl
describe gatewayclass nginx kubectl
describe gateway app-gateway kubectl
describe httproute api-route

# Gateway API debugging kubectl get gateway app-gateway -o yaml
kubectl get events --field-selector involvedObject.kind=Gateway
```

Declarative Configurations

Complete Network Stack Example

```
# Namespace
apiVersion: v1 kind:
Namespace metadata:
  name: ecommerce
labels:
    environment: production

---
# Network Policy - Default deny
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy metadata:
  name: default-deny
namespace: ecommerce
spec:   podSelector:
```

```
{}  policyTypes:  -
Ingress
- Egress

---
# Network Policy - Web tier
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy metadata:
name: web-policy  namespace:
ecommerce spec:  podSelector:
matchLabels:      tier: web
policyTypes:  - Ingress  -
Egress  ingress:
- from:    -
  namespaceSelector:
  matchLabels:
  name: ingress-nginx
  ports:    - protocol: TCP
  port: 80  egress:
- to:    - podSelector:
  matchLabels:
  tier: api    ports:    -
  protocol: TCP      port:
  8080  - to: {}  # Allow
  DNS    ports:    -
  protocol: UDP      port:
  53

--- # ClusterIP
Service apiVersion:
v1 kind: Service
metadata:
  name: web-service
namespace: ecommerce
spec:  selector:
app: web    tier: web
ports:  - port: 80
targetPort: 80  type:
ClusterIP

---
```

```
# LoadBalancer Service apiVersion: v1 kind: Service metadata:
name: web-external   namespace: ecommerce   annotations:
service.beta.kubernetes.io/aws-load-balancer-type: "nlb"
spec:   selector:     app: web     tier: web   ports:   -
port: 80     targetPort: 80   type: LoadBalancer

--- #
Ingress
apiVersion: networking.k8s.io/v1 kind: Ingress
metadata:   name: ecommerce-ingress   namespace:
ecommerce   annotations:
nginx.ingress.kubernetes.io/rewrite-target: /
nginx.ingress.kubernetes.io/ssl-redirect: "true"
cert-manager.io/cluster-issuer: "letsencrypt-prod"
spec:   tls:   - hosts:
-     shop.example.com     -
api.example.com
secretName: ecommerce-tls
rules:
-     host:
shop.example.com     http:
paths:       - path: /
pathType: Prefix
backend:           service:
            name: web-service
port:
              number: 80
- host: api.example.com
http:       paths:       -
path: /v1
pathType: Prefix
backend:
service:
            name:    api-v1-service
port:               number: 8080
```

Troubleshooting Networking Issues

Common Networking Problems

```
Service Discovery Issues # Check service
endpoints   kubectl    get    endpoints
```

```
service-name kubectl describe service
service-name

# Test DNS resolution
kubectl run debug --image=busybox --rm -it -- nslookup service-name kubectl
run debug --image=busybox --rm -it -- wget -qO- http://service-name

# Check CoreDNS
kubectl logs -n kube-system deployment/coredns kubectl
get configmap coredns -n kube-system -o yaml
```

Network Policy Problems # Check

```
network policies kubectl get
networkpolicies -A
kubectl describe networkpolicy policy-name

# Test connectivity
kubectl exec -it source-pod -- nc -zv target-service 80 kubectl
exec -it source-pod -- curl -v http://target-service

# Debug network policy kubectl get pods --show-
labels kubectl describe pod pod-name | grep -A 5
Labels
```

Ingress Issues

```
# Check ingress controller kubectl
get pods -n ingress-nginx
kubectl logs -n ingress-nginx deployment/ingress-nginx-controller

# Check ingress resources kubectl
get ingress -A
kubectl describe ingress ingress-name

# Test external access
curl -H "Host: example.com" http://ingress-ip/path
kubectl port-forward -n ingress-nginx service/ingress-nginx-controller
8080:80
```

Network Diagnostics Tools

Network Testing Pod

```
apiVersion:    v1
```

```
kind:         Pod
metadata:
  name: network-debug spec:
containers:   - name: debug
image: nicolaka/netshoot
command: ["sleep", "3600"]
securityContext:
capabilities:         add:
["NET_ADMIN"]
```

Common Debugging Commands

```
# Inside debug pod nslookup
service-name
dig service-name.namespace.svc.cluster.local
nc -zv service-name port traceroute service-
ip tcpdump -i any port 80

# Pod connectivity ping
pod-ip telnet service-
name port
wget -qO- http://service-name/health

# Network interface information
ip addr show ip route show
netstat -tlnp ss -tlnp
```

Key Networking Commands Summary

Essential Service Commands

```
# Service lifecycle
kubectl create service clusterip web --tcp=80:8080
kubectl expose deployment app --port=80 --type=NodePort
kubectl get services -o wide kubectl describe service
service-name kubectl delete service service-name
```

Essential Ingress Commands

```
# Ingress management
kubectl create ingress web --rule="host/path*=service:port"
kubectl get ingress -A kubectl describe ingress ingress-
name kubectl edit ingress ingress-name
```

Essential Network Policy Commands

```
# Network policy management kubectl apply
-f network-policy.yaml kubectl get
networkpolicies -A kubectl describe
networkpolicy policy-name kubectl delete
networkpolicy policy-name
```

Essential DNS Commands

```
# DNS
testing and debugging
kubectl run test --image=busybox --rm -it -- nslookup service-name
kubectl exec pod -- dig service.namespace.svc.cluster.local kubectl
logs -n kube-system deployment/coredns
```

Essential Gateway API Commands

```
# Gateway API resources kubectl get
gatewayclasses kubectl get gateways -
A kubectl get httproutes -A kubectl
describe gateway gateway-name kubectl
describe httproute route-name
```

Design and Install a Kubernetes Cluster HA (High Availability)

High Availability Overview

What is Kubernetes High Availability?

High Availability (HA) in Kubernetes ensures that the cluster remains operational even when individual components fail. HA Kubernetes clusters eliminate single points of failure and provide continuous service availability for production workloads.[1]

Why HA is Critical for Production

- **Business continuity**: Prevents costly downtime and service disruptions
- **Data protection**: Maintains cluster state and application data integrity
- **Scalability**: Supports enterprise-scale deployments up to 5,000 nodes[2]
- **Fault tolerance**: Automatic recovery from component failures
- **Regulatory compliance**: Meets enterprise availability requirements

HA Topology Options

Stacked Control Plane Topology

Stacked topology co-locates etcd members with control plane nodes:[3]

```
# Stacked HA Configuration apiVersion:
kubeadm.k8s.io/v1beta4 kind: ClusterConfiguration
kubernetesVersion: stable controlPlaneEndpoint:
"loadbalancer.example.com:6443" etcd:   local:
    dataDir: "/var/lib/etcd"
```

Advantages:

- **Simpler setup**: Fewer infrastructure components to manage
- **Lower cost**: Requires fewer nodes than external etcd topology
- **Easier management**: Co-located components simplify administration
- **Default approach**: Standard kubeadm topology for HA clusters[3]

Disadvantages:

- **Coupled failure risk**: Loss of one node affects both etcd and control plane
- **Resource contention**: etcd and API server compete for resources
- **Limited scalability**: Not ideal for very large clusters

External etcd Topology

External etcd topology separates etcd cluster from control plane nodes:[3]

```
# External etcd Configuration apiVersion:
kubeadm.k8s.io/v1beta4 kind: ClusterConfiguration
kubernetesVersion: stable controlPlaneEndpoint:
"loadbalancer.example.com:6443" etcd:   external:
endpoints:
        - "https://10.100.0.10:2379"
        - "https://10.100.0.11:2379"     -
          "https://10.100.0.12:2379"     caFile:
          "/etc/kubernetes/pki/etcd/ca.crt"
    certFile: "/etc/kubernetes/pki/apiserver-etcd-client.crt"
keyFile: "/etc/kubernetes/pki/apiserver-etcd-client.key"
```

Advantages:

- **Reduced risk**: Control plane and etcd failures are decoupled
- **Better performance**: Dedicated resources for etcd operations
- **Higher scalability**: Better suited for large-scale deployments
- **Independent maintenance**: Can maintain etcd and control plane separately

Disadvantages:

- **Complex setup**: Requires additional infrastructure and configuration
- **Higher cost**: More nodes required for full HA setup
- **Management overhead**: Multiple clusters to monitor and maintain

Design Considerations

Infrastructure Requirements

Based on cluster size and workload demands:[4]

Nodes	GCP Instance	AWS Instance	Use Case
1-5	N1-standard-1 (1 vCPU, 3.75GB)	M3.medium (1 vCPU, 3.75GB)	Development/Testing
6-10	N1-standard-2 (2 vCPU, 7.5GB)	M3.large (2 vCPU, 7.5GB)	Small Production
11-100	N1-standard-4 (4 vCPU,	M3.xlarge (4 vCPU, 15GB)	Medium Production 15GB)
101-250	N1-standard-8 (8 vCPU, 30GB)	M3.2xlarge (8 vCPU, 30GB)	Large Production
251-500	N1-standard-16 (16 vCPU, 60GB)	C4.4xlarge (16 vCPU, 30GB)	Enterprise
>500	N1-standard-32 (32 vCPU, 120GB)	C4.8xlarge (36 vCPU, 60GB)	Hyperscale

Network Architecture Planning

Load Balancer Configuration:

```
# HAProxy Load Balancer Configuration
global     daemon

defaults     mode http
timeout connect 5000ms
timeout client 50000ms
timeout server 50000ms

frontend kubernetes
bind *:6443     option
tcplog     mode tcp
    default_backend kubernetes-master-nodes

backend kubernetes-master-nodes     mode tcp     balance
roundrobin     option tcp-check     server master1
192.168.5.11:6443 check fall 3 rise 2     server master2
```

```
192.168.5.12:6443 check fall 3 rise 2    server master3
192.168.5.13:6443 check fall 3 rise 2
```

Node Distribution Strategy

Minimum HA Requirements:

- **Control Plane**: 3 master nodes for quorum
- **Worker Nodes**: Minimum 2 workers for workload distribution
- **Load Balancer**: 1-2 load balancers for API access
- **etcd Cluster**: 3 or 5 nodes for data consistency

Storage Considerations

High-Performance Storage Requirements:[2]

- **SSD-backed storage**: For high-performance applications
- **Network-based storage**: For multiple concurrent connections
- **Persistent volumes**: Shared access across multiple pods
- **Backup strategy**: Regular etcd and application data backups **etcd High**

Availability etcd Cluster Fundamentals **etcd** is a distributed key-value store that maintains cluster state:[4]

```
# etcd Service Configuration
ExecStart=/usr/local/bin/etcd \
  --name ${ETCD_NAME} \
  --cert-file=/etc/etcd/kubernetes.pem \
  --key-file=/etc/etcd/kubernetes-key.pem \
  --peer-cert-file=/etc/etcd/kubernetes.pem \
  --peer-key-file=/etc/etcd/kubernetes-key.pem \
  --trusted-ca-file=/etc/etcd/ca.pem \
  --peer-trusted-ca-file=/etc/etcd/ca.pem \
  --peer-client-cert-auth \
  --client-cert-auth \
  --initial-advertise-peer-urls https://${INTERNAL_IP}:2380 \
  --listen-peer-urls https://${INTERNAL_IP}:2380 \
  --listen-client-urls https://${INTERNAL_IP}:2379,https://127.0.0.1:2379 \
  --advertise-client-urls https://${INTERNAL_IP}:2379 \   --initial-cluster-
token etcd-cluster-0 \
```

```
  --initial-cluster controller-0=https://${CONTROLLER0_IP}:2380,controller-
1=https://${CONTROLLER1_IP}:2380,controller-2=https://${CONTROLLER2_IP}:2380
\
  --initial-cluster-state new \
--data-dir=/var/lib/etcd    etcd
```

Quorum and Fault Tolerance

Quorum Requirements:[4]

Instances	Quorum	Fault Tolerance	Recommendation
1	1	0	Development only
2	2	0	Not recommended
3	2	1	**Minimum for production**
4	3	1	Same as 3, higher cost
5	3	2	**Recommended for critical workloads**
6	4	2	Same as 5, higher cost 7 4 3 Maximum practical size

etcd Best Practices

Optimal Configuration:

- **Odd numbers**: Always use odd number of etcd instances
- **Fast storage**: Use SSD storage for etcd data directory
- **Network latency**: Keep etcd nodes in same data center
- **Resource isolation**: Dedicated CPU and memory for etcd
- **Regular backups**: Automated etcd snapshot backups

Control Plane High Availability

API Server HA Configuration

Multiple API Server Setup:[4]

```
# API Server Service Configuration
ExecStart=/usr/local/bin/kube-apiserver \
  --advertise-address=${INTERNAL_IP} \
  --allow-privileged=true \
  --apiserver-count=3 \
```

```
  --audit-log-maxage=30 \
  --audit-log-maxbackup=3 \
  --audit-log-maxsize=100 \
  --audit-log-path=/var/log/audit.log \
  --authorization-mode=Node,RBAC \
  --bind-address=0.0.0.0 \
  --client-ca-file=/var/lib/kubernetes/ca.pem \
  --enable-admission-
plugins=NamespaceLifecycle,NodeRestriction,LimitRanger,ServiceAccount,Default
StorageClass,ResourceQuota \
  --etcd-cafile=/var/lib/kubernetes/ca.pem \
  --etcd-certfile=/var/lib/kubernetes/kubernetes.pem \
  --etcd-keyfile=/var/lib/kubernetes/kubernetes-key.pem \
  --etcd-
servers=https://10.240.0.10:2379,https://10.240.0.11:2379,https://10.240.0.12
:2379 \
  --event-ttl=1h \
  --encryption-provider-config=/var/lib/kubernetes/encryption-config.yaml \
  --kubelet-certificate-authority=/var/lib/kubernetes/ca.pem \
  --kubelet-client-certificate=/var/lib/kubernetes/kubernetes.pem \
  --kubelet-client-key=/var/lib/kubernetes/kubernetes-key.pem \
  --runtime-config='api/all=true' \
  --service-account-key-file=/var/lib/kubernetes/service-account.pem \   --
service-account-signing-key-file=/var/lib/kubernetes/service-accountkey.pem \
  --service-account-issuer=https://${KUBERNETES_PUBLIC_ADDRESS}:6443 \
  --service-cluster-ip-range=10.32.0.0/24 \
  --service-node-port-range=30000-32767 \
  --tls-cert-file=/var/lib/kubernetes/kubernetes.pem \
  --tls-private-key-file=/var/lib/kubernetes/kubernetes-key.pem \   --
v=2
```

Controller Manager HA with Leader Election

Leader Election Configuration:[4]

```
# Controller Manager Service
ExecStart=/usr/local/bin/kube-controller-manager \
  --bind-address=0.0.0.0 \
  --cluster-cidr=10.200.0.0/16 \
  --cluster-name=kubernetes \
  --cluster-signing-cert-file=/var/lib/kubernetes/ca.pem \
```

```
  --cluster-signing-key-file=/var/lib/kubernetes/ca-key.pem \
  --kubeconfig=/var/lib/kubernetes/kube-controller-manager.kubeconfig \
  --leader-elect=true \
  --leader-elect-lease-duration=15s \
  --leader-elect-renew-deadline=10s \
  --leader-elect-retry-period=2s \
  --root-ca-file=/var/lib/kubernetes/ca.pem \
  --service-account-private-key-file=/var/lib/kubernetes/service-
accountkey.pem \
  --service-cluster-ip-range=10.32.0.0/24 \
  --use-service-account-credentials=true \
  --v=2
```

Scheduler HA with Leader Election

Scheduler Leader Election:[4]

```
# Scheduler Service
ExecStart=/usr/local/bin/kube-scheduler \
  --config=/etc/kubernetes/config/kube-scheduler.yaml \
  --leader-elect=true \
  --leader-elect-lease-duration=15s \
  --leader-elect-renew-deadline=10s \
  --leader-elect-retry-period=2s \   --
v=2
```

Installation Process

Prerequisites and Planning

Infrastructure Preparation:

1. **Node Requirements**:[4]
   - **Operating System**: Linux x86_64 architecture
   - **Container Runtime**: Docker 1.11.1, 1.12.1, 1.13.1, 17.03, 17.06, 17.09, 18.06
   - **Network**: All nodes must communicate on required ports
   - **Storage**: SSD storage recommended for etcd
2. **Network Configuration**:
   - **Pod Network**: `10.244.0.0/16` (default)

- **Service Network**: `10.96.0.0/12` (default)
- **DNS**: CoreDNS for service discovery

Step 1: Provision Infrastructure

Using Vagrant for Lab Setup:[4]

```
# Vagrantfile for HA Cluster
Vagrant.configure("2") do |config|
  # Load Balancer
  config.vm.define "loadbalancer" do |lb|
lb.vm.box = "ubuntu/bionic64"     lb.vm.hostname
= "loadbalancer"
    lb.vm.network "private_network", ip: "192.168.5.30"
lb.vm.provider "virtualbox" do |v|       v.name =
"loadbalancer"
      v.memory = 1024
      v.cpus = 1
end   end

  # Master Nodes
(1..3).each do |i|
    config.vm.define "master-#{i}" do |master|
master.vm.box = "ubuntu/bionic64"       master.vm.hostname
= "master-#{i}"       master.vm.network "private_network",
ip: "192.168.5.1#{i}"       master.vm.provider
"virtualbox" do |v|         v.name = "master-#{i}"
        v.memory = 2048
        v.cpus = 2
end     end   end

  # Worker Nodes   (1..2).each do |i|
config.vm.define "worker-#{i}" do |worker|
worker.vm.box = "ubuntu/bionic64"
worker.vm.hostname = "worker-#{i}"
      worker.vm.network "private_network", ip: "192.168.5.2#{i}"
worker.vm.provider "virtualbox" do |v|         v.name = "worker-
#{i}"
        v.memory = 2048
        v.cpus = 2
end     end   end
end
```

Step 2: Install Container Runtime

Docker Installation on All Nodes:

```
# Install Docker
curl -fsSL https://download.docker.com/linux/ubuntu/gpg | sudo apt-key add -
sudo add-apt-repository "deb [arch=amd64]
https://download.docker.com/linux/ubuntu $(lsb_release -cs) stable" sudo
apt-get update
sudo apt-get install -y docker-ce=5:18.09.7~3-0~ubuntu-bionic

# Configure Docker daemon
sudo tee /etc/docker/daemon.json  apiserver-csr.conf  kubeadm-config.yaml
apiVersion:     kubeadm.k8s.io/v1beta4    kind:     ClusterConfiguration
kubernetesVersion:   v1.21.0  controlPlaneEndpoint:   "192.168.5.30:6443"
networking:
  podSubnet: "10.244.0.0/16" etcd:
  external:
endpoints:
- "https://192.168.5.11:2379"
- "https://192.168.5.12:2379"    -
  "https://192.168.5.13:2379"    caFile:
  "/etc/kubernetes/pki/etcd/ca.crt"    certFile:
  "/etc/kubernetes/pki/apiserver-etcd-client.crt"
  keyFile: "/etc/kubernetes/pki/apiserver-etcd-client.key"
---
apiVersion: kubeadm.k8s.io/v1beta4
kind: InitConfiguration
localAPIEndpoint:
advertiseAddress: "192.168.5.11"
  bindPort: 6443
EOF

# Initialize first master node sudo kubeadm init --config
kubeadm-config.yaml --upload-certs
```

Step 6: Configure Load Balancer

HAProxy Configuration for API Server:

```
# Install HAProxy sudo apt-get
update sudo apt-get install -y
haproxy
```

```
# Configure HAProxy cat
\
  --discovery-token-ca-cert-hash  \
  --control-plane \
  --certificate-key
```

Step 8: Configure Networking

Install CNI Plugin (Flannel):

```
# Apply Flannel CNI
kubectl apply -f
https://raw.githubusercontent.com/flannelio/flannel/master/Documentation/kube
-flannel.yml
```

Step 9: Join Worker Nodes

Adding Worker Nodes to Cluster:

```
# On worker nodes sudo kubeadm join
192.168.5.30:6443 \
  --token  \
  --discovery-token-ca-cert-hash
```

Validation and Testing

Cluster Health Verification Basic

Health Checks:

```
# Check node status kubectl
get nodes -o wide # Check
control plane pods
kubectl get pods -n kube-system

# Check etcd cluster health kubectl -n kube-system exec
etcd-master-1     --     etcdctl     \             --ca-
file=/etc/kubernetes/pki/etcd/ca.crt \
  --cert-file=/etc/kubernetes/pki/etcd/server.crt \
  --key-file=/etc/kubernetes/pki/etcd/server.key \
--endpoints=https://127.0.0.1:2379  \     endpoint
health
```

```
# Test API server accessibility curl -k
https://192.168.5.30:6443/healthz
```

Application Deployment Testing Deploy

Test Application:

```
# Create test deployment kubectl create deployment test-nginx -
-image=nginx --replicas=3

# Expose deployment kubectl expose deployment test-nginx --
port=80 --type=NodePort

# Scale deployment kubectl scale deployment
test-nginx --replicas=6

# Check pod distribution kubectl
get pods -o wide
```

Failure Testing

Simulate Node Failures:

```
# Stop one master node sudo
systemctl stop kubelet
sudo systemctl stop docker

# Verify cluster continues to operate kubectl
get nodes

# Test application availability kubectl
get pods

# Restart failed node sudo
systemctl start docker sudo
systemctl start kubelet
```

Production Best Practices

Security Hardening

Essential Security Measures:

- **RBAC**: Enable role-based access control

- **Network Policies**: Implement pod-to-pod communication rules
- **TLS**: Use TLS for all component communication
- **Encryption**: Enable etcd encryption at rest
- **Regular Updates**: Keep Kubernetes components updated

Monitoring and Alerting

Monitoring Stack Setup:

```
# Prometheus monitoring configuration
apiVersion: v1 kind: ConfigMap
metadata:  name: prometheus-config
namespace: monitoring data:
prometheus.yml: |    global:
scrape_interval: 15s
scrape_configs:
    - job_name: 'kubernetes-apiservers'       kubernetes_sd_configs:       -
role: endpoints        scheme: https        tls_config:           ca_file:
/var/run/secrets/kubernetes.io/serviceaccount/ca.crt      bearer_token_file:
/var/run/secrets/kubernetes.io/serviceaccount/token Backup and Disaster Recovery
```

etcd Backup Strategy:

```
# Create etcd backup
ETCDCTL_API=3 etcdctl snapshot save snapshot.db \
  --endpoints=https://127.0.0.1:2379 \
  --cacert=/etc/kubernetes/pki/etcd/ca.crt \
  --cert=/etc/kubernetes/pki/etcd/server.crt \
  --key=/etc/kubernetes/pki/etcd/server.key

# Verify backup
ETCDCTL_API=3 etcdctl --write-out=table snapshot status snapshot.db

# Schedule automated backups
cat << EOF | sudo tee /etc/cron.d/etcd-backup
0 2 * * * root /usr/local/bin/backup-etcd.sh
EOF
```

Troubleshooting Common Issues

etcd Cluster Issues

Common etcd Problems:

```
# Check etcd cluster status
ETCDCTL_API=3 etcdctl endpoint status \
  --
endpoints=https://192.168.5.11:2379,https://192.168.5.12:2379,https://192.168
.5.13:2379 \
  --cacert=/etc/kubernetes/pki/etcd/ca.crt \
  --cert=/etc/kubernetes/pki/etcd/server.crt \
  --key=/etc/kubernetes/pki/etcd/server.key

# Check etcd member list
ETCDCTL_API=3 etcdctl member list \
  --endpoints=https://127.0.0.1:2379 \
  --cacert=/etc/kubernetes/pki/etcd/ca.crt \
  --cert=/etc/kubernetes/pki/etcd/server.crt \
  --key=/etc/kubernetes/pki/etcd/server.key

# View etcd logs sudo
journalctl -u etcd -f
```

API Server Connectivity Issues

Load Balancer Troubleshooting:

```
# Test load balancer connectivity nc
-zv 192.168.5.30 6443

# Check HAProxy status sudo
systemctl status haproxy

# View HAProxy logs sudo tail -f
/var/log/haproxy.log

# Test direct API server access curl -k
https://192.168.5.11:6443/healthz curl -k
https://192.168.5.12:6443/healthz curl -k
https://192.168.5.13:6443/healthz
```

Control Plane Recovery

Master Node Recovery Procedures:

```
# Recover from control plane failure sudo kubeadm init phase control-
plane all --config kubeadm-config.yaml
```

```
# Recreate admin kubeconfig sudo kubeadm init phase kubeconfig admin
--config kubeadm-config.yaml

#    Restart    kubelet    sudo
systemctl  restart  kubelet
```

Key

Commands Summary

Installation Commands

```
# Initialize HA cluster sudo kubeadm init -
-config kubeadm-config.yaml --upload-certs

# Join control plane node
sudo kubeadm join LOAD_BALANCER:6443 --token TOKEN --control-plane -
certificate-key KEY

# Join worker node
sudo kubeadm join LOAD_BALANCER:6443 --token TOKEN --discovery-token-ca-
certhash HASH

# Generate new join token kubeadm token
create --print-join-command
```

Health Check Commands

```
# Cluster status kubectl
cluster-info kubectl get
nodes
kubectl get componentstatuses

# Control plane health kubectl
get pods -n kube-system kubectl
top nodes

# etcd health kubectl -n kube-system exec etcd-master-1 -- etcdctl
endpoint health
```

Maintenance Commands

```
# Drain node for maintenance kubectl drain
node-name --ignore-daemonsets --delete-emptydir-data

# Uncordon node
kubectl uncordon node-name
```

```
# Upgrade cluster sudo kubeadm
upgrade plan sudo kubeadm upgrade
apply v1.21.1
```

Helm and Kustomize - CKAD Essentials

Helm - Package Manager for Kubernetes

What is Helm?

Helm is a package manager for Kubernetes that simplifies deploying and managing applications using templates and reusable packages called **Charts**.

Why Use Helm?

- **Templating**: Create reusable Kubernetes manifests
- **Package Management**: Install, upgrade, and rollback applications easily
- **Version Control**: Track application releases
- **Configuration Management**: Separate config from application logic

Helm Key Concepts

- **Chart**: A Helm package containing Kubernetes templates
- **Release**: An instance of a chart deployed to Kubernetes
- **Values**: Configuration data for charts
- **Repository**: A collection of charts

Basic Helm Usage

Installing Helm

```
Install Helm
curl https://raw.githubusercontent.com/helm/helm/main/scripts/get-helm-3 |
bash

# Verify installation helm
version
```

Working with Repositories

```
Add popular repositories
helm repo add bitnami https://charts.bitnami.com/bitnami helm
repo add nginx https://helm.nginx.com/stable
```

```
# Update repositories helm
repo update

# Search for charts helm
search repo nginx helm
search repo mysql
```

Essential Helm Commands

```
# Install a chart helm install
myapp bitnami/nginx # Install
with custom values helm install
myapp bitnami/nginx --set
replicaCount=3

# List releases helm
list

# Upgrade release helm upgrade myapp bitnami/nginx --
set image.tag=1.21

# Rollback release helm
rollback myapp 1

# Uninstall release helm
uninstall myapp

# Get release info helm
status myapp helm get values
myapp
```

Creating Simple Helm Charts

Chart Structure

```
# Create new chart
helm create webapp

# Basic chart structure webapp/
├── Chart.yaml          # Chart metadata
├── values.yaml         # Default values
└── templates/          # Kubernetes templates
    ├── deployment.yaml
    ├── service.yaml
```

```
    └── _helpers.tpl
```

Chart.yaml (Metadata)

```
apiVersion:      v2
name: webapp
description: Simple web application
version: 0.1.0 appVersion: "1.0.0"
```

values.yaml (Configuration)

```
# Simple configuration replicaCount:
3

image:   repository: nginx
tag: "1.21.0"
pullPolicy: IfNotPresent
service:   type: ClusterIP
port: 80

# Application config
app:   debug: false
logLevel: "info"
```

Simple Deployment Template #

```
templates/deployment.yaml
apiVersion:   apps/v1  kind:
Deployment metadata:
  name: {{ .Chart.Name }}
labels:
    app: {{ .Chart.Name }} spec:
replicas: {{ .Values.replicaCount }}
selector:     matchLabels:       app:
{{ .Chart.Name }}   template:
metadata:       labels:
        app: {{ .Chart.Name }}
spec:       containers:
- name: {{ .Chart.Name }}
        image: "{{ .Values.image.repository }}:{{ .Values.image.tag }}"
imagePullPolicy: {{ .Values.image.pullPolicy }}         ports:
- containerPort: 80         env:         -
  name: DEBUG
          value: "{{ .Values.app.debug }}"
```

```
- name: LOG_LEVEL           value: "{{
  .Values.app.logLevel }}"
```

Basic Template Functions

```
Common template functions
{{ .Values.name | upper }}           # Uppercase
{{ .Values.name | lower }}           # Lowercase
{{ .Values.replicas | int }}         # Convert to integer
{{ .Values.tag | default "latest" }} # Default value

# Conditionals
{{- if .Values.ingress.enabled }}
# ingress configuration
{{- end }}

# Loops
{{- range .Values.environments }}
- name: {{ .name }}
value: {{ .value }}{{-
end }}
```

Working with Your Chart # Test template rendering helm

```
template webapp ./webapp/

# Install your chart helm
install myapp ./webapp/

# Install with custom values helm install myapp
./webapp/ --set replicaCount=5

# Package chart helm
package webapp/
```

Kustomize - Kubernetes Native Configuration

What is Kustomize?

Kustomize is a Kubernetes-native tool for customizing YAML configurations without templates. It uses an overlay approach to modify base configurations.

Why Use Kustomize?

- **Template-free**: Works with standard Kubernetes YAML
- **Overlay approach**: Modify configs without changing originals
- **Built into kubectl**: No extra tools needed
- **GitOps friendly**: Easy version control

Basic Kustomize Structure

```
# Simple project structure app/
├── base/                    # Base configuration
│   ├── kustomization.yaml   # Base kustomization file
│   ├── deployment.yaml      # Base deployment
│   └── service.yaml         # Base service
└── overlays/                # Environment-specific changes
    ├── development/
    │   └── kustomization.yaml
    └── production/
        └── kustomization.yaml
```

Basic Kustomize Usage

Base Configuration

base/kustomization.yaml:

```
apiVersion: kustomize.config.k8s.io/v1beta1 kind:
Kustomization

resources:   -
deployment.yaml
  - service.yaml

commonLabels:   app:
webapp   namePrefix:
webapp-
```

base/deployment.yaml:

```
apiVersion: apps/v1
kind: Deployment
metadata:   name:
app spec:
  replicas: 3
selector:
matchLabels:
app: webapp
```

```
template:
metadata:
labels:
app: webapp
spec:
      containers:       -
name: app         image:
nginx:1.20.0         ports:
- containerPort: 80
```

base/service.yaml:

```
apiVersion: v1 kind:
Service metadata:
  name: app-service
spec:   selector:
app: webapp
ports:   - port: 80
    targetPort:  80      type:  ClusterIP
```

Development **Overlay**

overlays/development/kustomization.yaml:

```
apiVersion: kustomize.config.k8s.io/v1beta1 kind:
Kustomization

# Include base configuration
resources:   - ../../base

# Development-specific settings
namespace: development namePrefix:
dev-

# Change image tag for development
images:   - name: nginx
    newTag: latest

# Override replica count
replicas:   - name: app
count: 1

# Add development labels commonLabels:
environment:    development
```

Production

Overlay

overlays/production/kustomization.yaml:

```
apiVersion: kustomize.config.k8s.io/v1beta1 kind:
Kustomization

resources:   -
../../base

# Production settings namespace:
production namePrefix: prod-

# Use specific image version
images:   - name: nginx
newTag: 1.21.0

# Production replica count
replicas:   - name: app
count: 5

#       Production       labels
commonLabels:      environment:
production
```

Essential Kustomize Operations

Basic Commands

```
# Preview configuration
kubectl kustomize ./overlays/development/

# Apply configuration kubectl apply -k
./overlays/development/
kubectl apply -k ./overlays/production/

# Delete resources kubectl delete -k
./overlays/development/
```

Common Transformers

```
# Change image tags
images:   - name:
nginx     newTag:
1.21.0
```

```
# Modify replica counts
replicas:   - name: app-
deployment     count: 5

# Add name prefix/suffix
namePrefix: dev- nameSuffix:
-v1

# Set namespace namespace:
development

# Add common labels
commonLabels:
app: myapp
environment: dev

# Add common annotations
commonAnnotations:   description:
"Development deployment"
```

Simple Patches

```
# overlays/production/patch-resources.yaml
apiVersion: apps/v1 kind: Deployment
metadata:   name: app spec:   template:
spec:       containers:       - name: app
resources:           limits:
cpu: 500m             memory: 512Mi
requests:             cpu: 250m
memory: 256Mi

# Include patch in kustomization.yaml
patchesStrategicMerge:   - patch-
resources.yaml
```

ConfigMaps and Secrets with Kustomize

Generate ConfigMaps *#*

```
From  literal  values
configMapGenerator:
-   name:   app-config
literals:           -
DEBUG=true
      - LOG_LEVEL=info
```

```
# From files
configMapGenerator:   -
name: app-config
files:       -
config.properties       -
app.yaml
```

Generate Secrets `# From literal values`

```
secretGenerator:   - name:
app-secrets      literals:
- username=admin         -
password=secret123
type: Opaque
```

When to Use Helm vs Kustomize

Use Helm When:

- Need package management and distribution
- Complex templating requirements
- Want to use existing Helm charts
- Need dependency management
- Require release management features

Use Kustomize When:

- Managing multiple environments
- Want simple configuration overlays
- Prefer template-free approach
- Working with standard Kubernetes YAML
- Need built-in kubectl integration **Common Patterns**

Environment Management with Kustomize

```
# Development kubectl apply -k
./overlays/development/

# Staging   kubectl apply -k
./overlays/staging/

# Production kubectl apply -k
./overlays/production/
```

Application Distribution with Helm

```
# Add application repository helm repo add mycompany
https://charts.mycompany.com

# Install application helm install
myapp mycompany/webapp

# Upgrade application helm upgrade myapp
mycompany/webapp --version 2.0.0
```

Key Commands

Summary

Helm Commands

```
# Repository
management helm repo add
<name> <url> helm repo
update helm search repo
<term>

# Release management
helm install <name> <chart>
helm upgrade <name> <chart>
helm rollback <name> <revision>
helm uninstall <name> helm list

# Chart development helm
create <name> helm template
<name> <chart> helm package
<chart>
```

Kustomize Commands

```
# Build and apply kubectl
kustomize <directory> kubectl
apply -k <directory>
kubectl delete -k <directory>

# Validation kubectl apply -k <directory> --
dry-run=client
```

Best Practices

Helm Best Practices

- Use semantic versioning for charts
- Include resource limits and probes

- Organize values logically
- Test templates before releasing
- Document chart usage

Kustomize Best Practices

- Keep base configuration minimal
- Use meaningful directory structure
- Apply consistent labeling
- Use overlays for environment differences
- Version control all configurations