Middleware Architectures 1

Lecture 5: Cloud Native and Kubernetes

doc. Ing. Tomáš Vitvar, Ph.D.

tomas@vitvar.com • @TomasVitvar • https://vitvar.com

Czech Technical University in Prague

Faculty of Information Technologies • Software and Web Engineering • https://vitvar.com/lectures

Modified: Sun Oct 26 2025, 20:49:01

Humla v1.0

Overview

- Cloud Native
- Kubernetes

Overview

- The Cloud Native Computing Foundation (CNCF)
  – *Motto: Building sustainable ecosystems for cloud native software*
  – *CNCF is part of the nonprofit Linux Foundation*
- Cloud Native = scalable apps running in modern cloud environments
  – *containers, service mashes, microservices*
  – *Apps must be usually re-built from scratch or refactored*
  – *Benefits:*
    → *loosely coupled systems that are resilient, manageable, and observable*
    → *automation allowing for predictable and frequent changes with minimal effort*
  – *Trail Map*
    → *provides an overview for enterprises starting their cloud native journey*
- Lift and Shift
  – *Cloud transition program in organizations*
  – *Move app from on-premise to the cloud*
  – *Benefits*
    → *Infrastructure cost cutting (OPEX vs. CAPEX)*
    → *Improved operations (scaling up/down if possible can be faster)*

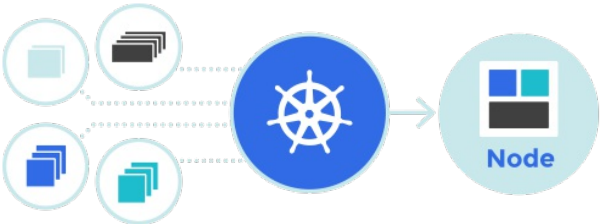
CNCF Trail Map

Overview

- Cloud Native
- Kubernetes
  - *Basic Concepts*
  - *Core Concepts and Architecture*
  - *Workloads*
  - *Beyond the Basics*

Overview

- In your architecture...
  - *Containers are atomic pieces of application architecture*
  - *Containers can be linked (e.g. web server, DB)*
  - *Containers access shared resources (e.g. disk volumes)*
- Kubernetes
  - *Automation of deployments, scaling, management of containerized applications across number of nodes*
  - *Based on Borg, a parent project from Goolge*

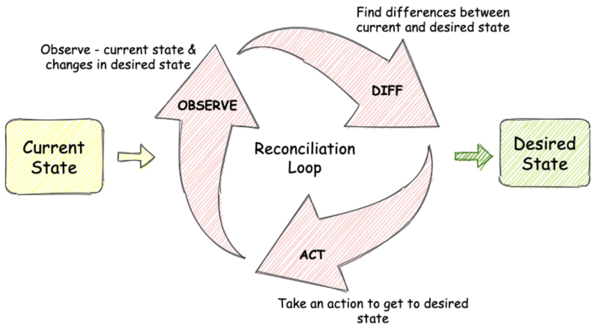


Key Design Principles

- Kubernetes provides abstractions that separate application deployment from the underlying infrastructure details
- Application workloads and infrastructure decoupling
  – ***Compute:*** *Define what to run without specifying where it runs*
  – ***Storage:*** *Applications request storage independent of storage backend*
  – ***Networking:*** *Stable access to applications regardless of IPs or location*
- Benefits
  – *Portability across on-prem and cloud environments*
  – *Scalability and resilience through dynamic scheduling*
  – *Consistency and standardization of deployment model*
  – *Reduced vendor lock-in thanks to open standards*

Desired State and Reconciliation

- Kubernetes operates on a **desired state** model
  – *Users define the state they want through object specifications (YAML)*
  – *Example: "there should be 3 replicas of this application"*
- Actual State vs. Desired State
  – *Kubernetes constantly monitors the cluster*
  – *If the actual state drifts from the desired state, it takes action to fix it*
- Reconciliation Loop
  – *Controllers continuously compare desired vs. actual state*
  – *Automatically performs actions such as restarting, rescheduling, or scaling Pods*



Features

- Automatic binpacking
  - *Automatically places containers onto nodes based on their resource requirements and other constraints.*
- Horizontal scaling
  - *Scales your application up and down with a simple command, with a UI, or automatically based on CPU usage.*
- Automated rollouts and rollbacks
  - *Progressive rollout out of changes to application/configuration, monitoring application health and rollback when something goes wrong.*
- Storage orchestration
  - *Automatically mounts the storage system (local or in the cloud)*
- Self-healing
  - *Restarts containers that fail, replaces and reschedules containers when nodes die, kills containers that don't respond to user-defined health checks.*
- Service discovery and load balancing
  - *Gives containers their own IP addresses and a single DNS name for a set of containers, and can load-balance across them.*

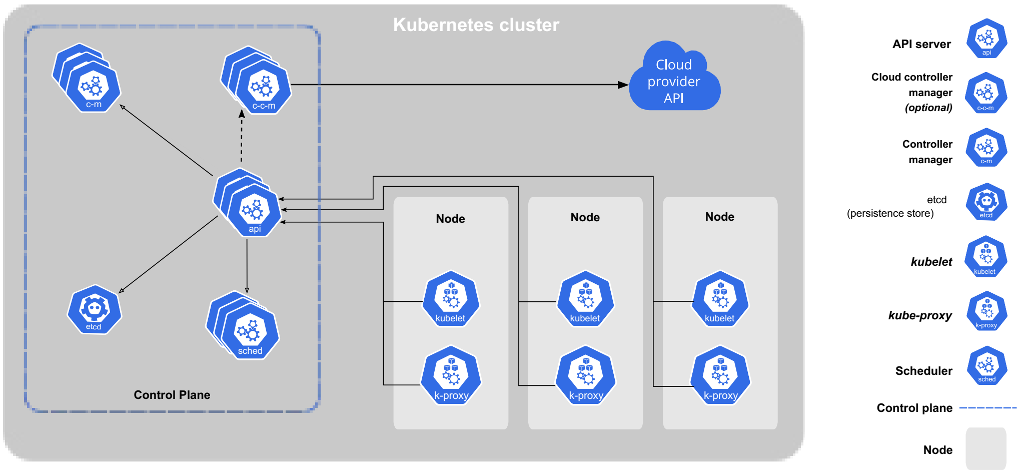
Overview

- Cloud Native
- Kubernetes
  - *Basic Concepts*
  - *Core Concepts and Architecture*
  - *Workloads*
  - *Beyond the Basics*

Core Building Blocks

- **Cluster**
  – *A set of worker nodes and a control plane*
  – *Runs and manages containerized applications*
- **Node**
  – *A worker machine in Kubernetes (VM or physical)*
  – *Runs Pods scheduled by the control plane*
- **Control Plane**
  – *Manages the overall state of the cluster*
  – *Schedules workloads and responds to cluster events*
- **Pod**
  – *The smallest deployable unit in Kubernetes*
  – *One or more tightly-coupled containers*
  – *Containers share networking and storage within a Pod*

Architecture



Control Plane Components (Part 1)

- Global decisions about the cluster
  - *Schedulling*
  - *Detecting and responding to cluster events, starting up new pods*
- kube-apiserver
  - *exposes the Kubernetes API*
  - *The API server is the front end for the Kubernetes control plane.*
- etcd
  - *highly-available key value store used to store all cluster data*
- kube-scheduler
  - *watches for newly created Pods with no assigned node*
  - *selects a node for Pods to run on.*
  - *Decision factors: resource requirements, hardware/software/policy constraints, affinity and anti-affinity specifications*

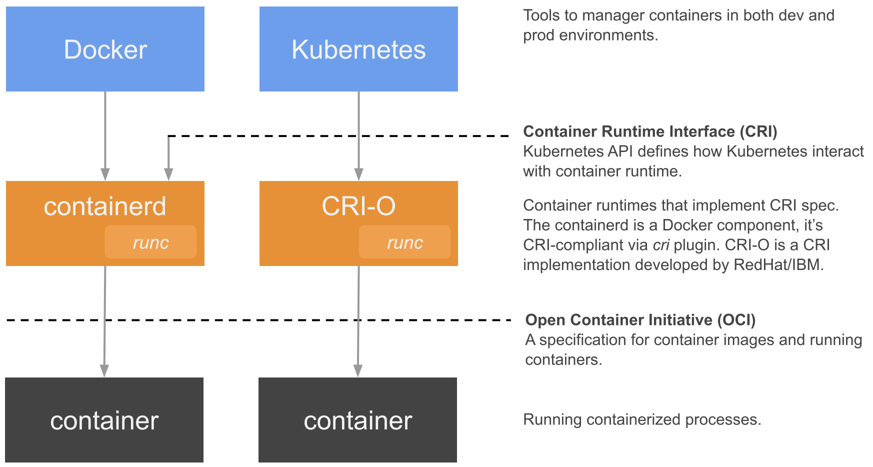
Control Plane Components (Part 2)

- kube-controller-manager
  - *runs controller to ensure the desired state of cluster objects*
  - ***Node controller***
    → *noticing and responding when nodes go down*
  - ***Job controller***
    → *creates Pods to run one-off tasks to completion.*
  - ***Endpoints controller***
    → *Populates the Endpoints object (that is, joins Services, Pods).*
- cloud-controller-manager
  - *Integration with cloud services (when the cluster is running in a cloud)*
  - ***Node controller***
    → *checks if a node has been deleted in the cloud after it stops responding*
  - ***Route controller***
    → *For setting up routes in the underlying cloud infrastructure*
  - ***Service controller***
    → *For creating, updating and deleting cloud provider load balancers*

Node

- Kubernetes runtime environment
  - *Run on every node*
  - *Maintaining running pods*
- kubelet
  - *An agent that runs on each node in the cluster*
  - *It makes sure that containers are running in a Pod.*
- kube-proxy
  - *maintains network rules on nodes*
  - *network rules allow network communication to Pods from inside or outside of the cluster*
  - *uses the operating system packet filtering layer or forwards the traffic itself.*
- Container runtime
  - *Responsible for running containers*
  - *Kubernetes supports several container runtimes (containerd, CRI-O)*
  - *Any implementation of the Kubernetes CRI (Container Runtime Interface)*

Container Stack



Overview

- Cloud Native
- Kubernetes
  - *Basic Concepts*
  - *Core Concepts and Architecture*
  - *Workloads*
  - *Beyond the Basics*

Namespaces

- Logical grouping of cluster resources
  - *Allow you to organize and separate objects within a Kubernetes cluster*
  - *Useful when multiple teams, environments, or projects share the same cluster*
- Rationale
  - *Provide isolation and boundaries between workloads*
  - *Prevent name collisions*
    - → *Objects can have the same name if in different namespaces*
  - *Enable resource limits and access control per namespace*
- Usage
  - *Common namespaces:* `default`, `kube-system`, `kube-public`, `kube-node-lease`
  - *Create separate namespaces for e.g. dev, test, prod*
  - *Commands run in a namespace unless another is specified*

Pod

- Pod
  – *A group of one or more tightly-coupled containers.*
  – *Containers share storage and network resources.*
  – *A Pod runs a single instance of a given application*
  – *Pod's containers are always co-located and co-scheduled*
  – *Pod's containers run in a shared context, i.e. in a set of Linux namespaces*
- Pods are created using workload resources
  – *You do not create them directly*
- Pods in a Kubernetes cluster are used in two main ways
  – *Run a single container, the most common Kubernetes use case*
  – *Run multiple containers that need to work together*

Workloads

- An application running on Kubernetes
- Workloads run in a set of Pods
- Pre-defined workload resources to manage lifecylce of Pods
  – ***Deployment** and ReplicaSet*
    → *managing a stateless application workload*
    → *any Pod in the Deployment is interchangeable and can be replaced if needed*
  – ***StatefulSet***
    → *one or more related Pods that track state*
    → *For example, if a workload records data persistently, run a StatefulSet that matches each Pod with a persistent volume.*
  – *DaemonSet*
    → *Ensures that all (or some) Nodes run a copy of a Pod*
    → *Such as a cluster storage daemon, logs collection, node monitoring running on every node*
  – *Job and CronJob*
    → *Define tasks that run to completion and then stop.*
    → *Jobs represent one-off tasks, whereas CronJobs recur according to a schedule.*

Deployment Spec Example

- Deployment spec

```yaml
apiVersion: apps/v1
kind: Deployment
metadata:
  name: nginx-deployment
spec:
  selector:
    matchLabels:
      app: nginx
  replicas: 3 # tells deployment to run 3 pods matching the template
  template:
    metadata:
      labels:
        app: nginx
    spec:
      containers:
      - name: nginx
        image: nginx:1.14.2
        ports:
        - containerPort: 80
```

  – *A desired state of an application running in the cluster*
  – *Kubernetes reads the Deployment spec and starts three app instances*
  – *If an instance fails, Kubernetes starts a replacement app instance*

Service

- Networking
  – *Containers within a Pod use networking to communicate via loopback*
  – *Cluster networking provides communication between different Pods.*
- Service resource
  – *An abstract way to expose an application running on a set of Pods*
  – *Example: a set of Pods with a label* `app=nginx`*, each listens on* `tcp/9376`

```yaml
apiVersion: v1
kind: Service
metadata:
  name: my-service
spec:
  selector:
    app: nginx
  ports:
    - protocol: TCP
      port: 80
      targetPort: 9376
```

  – *This specification creates a new Service object named* `my-service`
  – *The servive targets* `tcp/9376` *on any Pod with the* `app=nginx` *label.*
  – *Kubernetes assigns this Service a cluster IP address, which is used by the Service proxies.*

Overview

- Cloud Native
- Kubernetes
  – *Basic Concepts*
  – *Core Concepts and Architecture*
  – *Workloads*
  – *Beyond the Basics*

Advanced Topics

- Custom APIs and Controllers
  – *CRDs, Operators, reconciliation loops*
  – *Admission webhooks (mutating/validating)*
- Security
  – *RBAC, Namespaces, Pod Security (seccomp, capabilities, rootless)*
  – *Image signing and supply chain (SBOM, cosign), Secret management (Vault/CSI)*
  – *Policy engines: OPA Gatekeeper, Kyverno*
- Networking
  – *CNI, eBPF (Cilium), NetworkPolicies, Ingress*
  – *Gateway API, Service Mesh (mTLS, traffic shaping)*
- Storage
  – *CSI drivers, snapshots, expansion, topology-aware PVs*
  – *Backup/DR (e.g., Velero), StatefulSet patterns*
- Scaling and Scheduling
  – *HPA/VPA/KEDA (event-driven), Cluster Autoscaler*
  – *Affinity/anti-affinity, taints/tolerations, topology spread*
- Ops and Delivery