TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

Macroarea di Ingegneria
Dipartimento di Ingegneria Civile e Ingegneria Informatica

Container orchestration: Kubernetes

Corso di Sistemi Distribuiti e Cloud Computing
A.A. 2022/23

Valeria Cardellini

Laurea Magistrale in Ingegneria Informatica

Container orchestration

- Platforms for managing deployment of multi-container packaged applications in large-scale clusters
- Allow to configure, provision, deploy, monitor, and dynamically control containerized apps
  – Used to integrate and manage *containers at scale*
- Examples
  – **Docker Swarm**
  – **Kubernetes**
  – Marathon (container orchestration platform for Mesos)
  – Nomad

Container management systems at Google

- Application-oriented shift

  "Containerization transforms the data center from being machine-oriented to being application-oriented"

- Goal: let container technology operate at Google scale
  - Everything at Google runs as a container
  - Google launches several billions of containers per week

- Borg -> Omega -> Kubernetes
  - Borg and Omega: purely Google-internal systems, precede Kubernetes, see Borg, Omega, and Kubernetes paper
  - Kubernetes: open-source

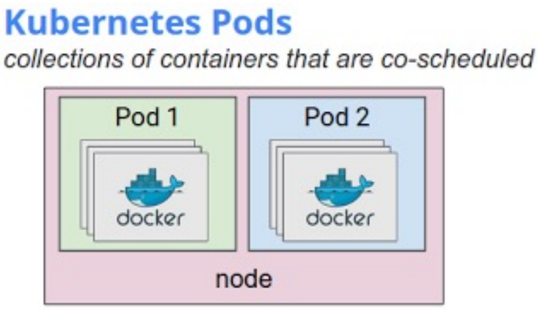
Kubernetes

- Google's open-source platform for automating deployment, scaling, and management of containerized apps across clusters of hosts

  http://kubernetes.io
- Features:
  - Portable: public, private, hybrid, multi-cloud
  - Extensible: modular, pluggable, hookable, composable
  - Self-healing: auto-placement, auto-restart, auto-replication, auto-scaling of containers
- Can run on public or private cloud platforms (e.g., AWS, OpenStack), and also on bare metal machines
- Offered as Cloud service by main providers
  - Kubernetes management and deployment on underlying infrastructure is up to Cloud provider

Pod

- **Pod**: smallest deployable compute object in Kubernetes
  - Set of (tightly coupled) containers with shared storage/network, and a specification for how to run the containers
  - Pod containers are bundled and scheduled together, and run in a shared context

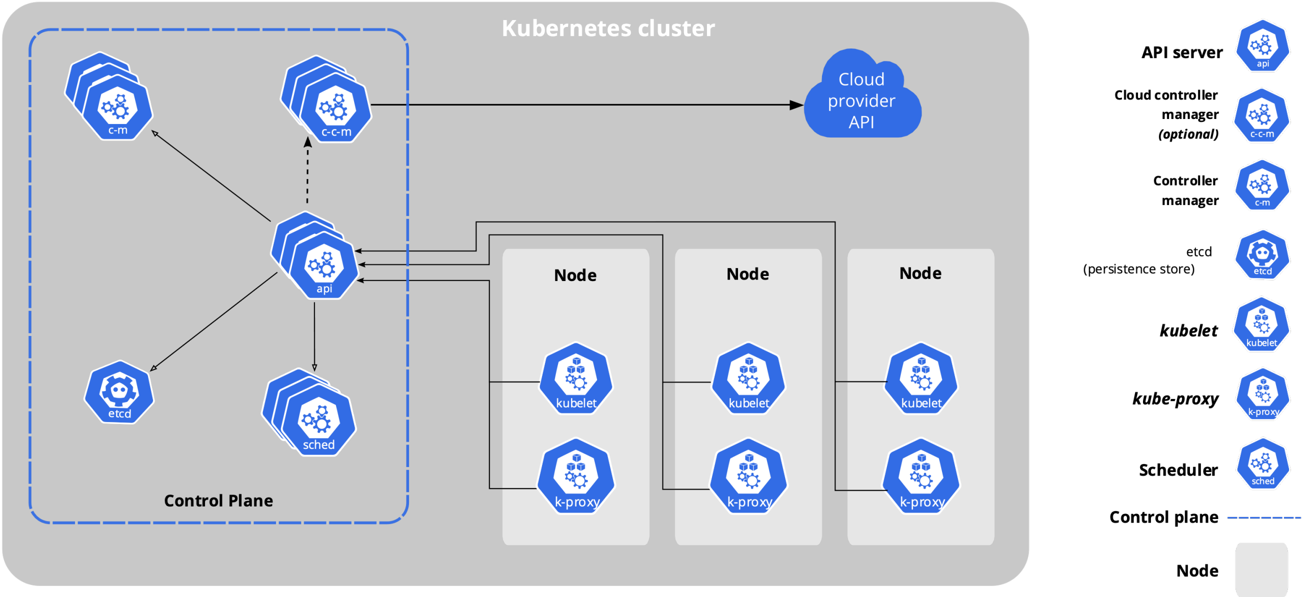


  - Kubernetes gives pods their own IP addresses and a single DNS name for a set of pods, and can load-balance across them
- Users organize pods using labels
  - Label: arbitrary key/value pair attached to pod
  - E.g., `role=frontend` and `stage=production`

Architecture

- When you deploy Kubernetes, you get a cluster
- Kubernetes cluster: set of worker machines, called nodes, that run containerized applications
- Architecture organized according to master-worker pattern
- Every cluster has at least one worker node
- Worker nodes host pods
- Kubernetes supports multiple container runtimes, including containerd (used by Docker Engine)

Architecture



https://kubernetes.io/docs/concepts/overview/components/

Architecture: control plane

- **Kubernetes control plane**: cluster's master, takes global decision about cluster (e.g., scheduling) as well as detects and responds to cluster events (e.g., starting up a new pod)
  – In production environments, control plane usually runs across multiple machines for failover and high availability
- Main components of control plane
  – **kube-apiserver**: API server that exposes Kubernetes API, front end for Kubernetes' control plane
  – **kube-scheduler**: decides how to assign newly created pods to nodes using a *placement (or scheduling)* policy
  – **kube-controller-manager**: runs controller processes (e.g., Node controller which is responsible for noticing and responding when nodes go down)

Architecture: control plane

- Main components of control plane
  - etcd: distributed key-value data store with strong consistency and high availability
    - Written in Go
    - Uses Raft consensus algorithm to manage a highly-available replicated log
    - How used in Kubernetes? Backing store for all cluster data

Architecture: nodes

- **Kubernetes nodes**: worker nodes (can be VM or physical machines) that maintain multiple running pods and provide Kubernetes' runtime environment
- Main components on worker nodes
  - ***kubelet***: agent ensuring that pods running on node are healthy and running
  - ***kube-proxy***: network proxy that maintains network rules on nodes

Some Kubernetes terminology

- ***Workload***: containerized application running on Kubernetes
- ***Deployment***: tells Kubernetes how to create or modify instances of the pods that hold a workload; deployments can help to:
  - efficiently scale number of replica pods
  - enable rollout of updated code in a controlled manner
  - roll back to earlier deployment version if necessary
- Kubernetes deployment:
  - described in YAML file
  - created using `kubectl apply`
    - `kubectl` is Kubernetes' CLI tool
  - Example: https://kubernetes.io/docs/concepts/workloads/controllers/deployment/

Some Kubernetes terminology

- Each pod gets its own unique cluster-wide IP address, but in a deployment the set of pods can change at runtime (e.g., due to node crash or pod replication)
  - In a containerized application running with multiple pods, how to keep track of which IP address to connect to?
- ***Service***: abstraction that defines a logical set of pods and a policy by which to access them to expose application running on a set of pods as a network service
  - Pod IPs are not exposed outside the cluster without a service

Pod placement

- *kube-scheduler:* default Kubernetes scheduler

https://kubernetes.io/docs/concepts/scheduling-eviction/kube-scheduler/

- Scheduler watches for newly created pods that have no node assigned and finds best node for each new pod
- Kubernetes' default placement policy selects node in 2 steps: *filtering* and *scoring*
  - *Filtering*: finds set of nodes where it is feasible to schedule pod
  - *Scoring:* scheduler ranks the remaining nodes that survived filtering to choose the most suitable pod placement. The scheduler assigns a score to each node, basing the score on active scoring rules
  - Finally, kube-scheduler assigns pod to node with highest ranking (if more than one node with highest score, kube-scheduler selects one of these at random)

Pod placement

- Other heuristic placement policies that can be easily integrated into Kubernetes
  - *Round robin:* organize nodes in a circular list, saving the latest node used for scheduling; allocate each pod on next node with enough resources, starting from current position on list
  - *Greedy first fit:* popular heuristic solution used to solve bin packing problem; consider pods as items to be greedily allocated in bins, representing worker nodes; add nodes to a list and sort them in ascending order of available resources; place each item into *the first bin* in which it will fit

Pod placement

- Limitations of default placement policy and other heuristics
  - Not well-suited to place pods in geo-distributed environments with non-negligible network delays
  - Do not consider energy consumption
  - Do not take into account security requirements

- Opportunity for thesis topics!

Auto-scaling in Kubernetes

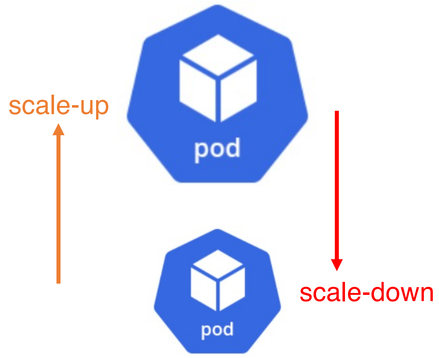
- Multiple auto-scalers at different control layers
  - Cluster auto-scaling with node granularity
  - Horizontal auto-scaling with pod granularity
  - Vertical auto-scaling with pod granularity
- Organized as MAPE loops

  https://github.com/kubernetes/autoscaler

- Cluster Autoscaler: adjusts size of Kubernetes cluster when one of the following conditions is true:
  - There are pods that failed to run in the cluster due to insufficient resources
  - There are nodes in the cluster that have been underutilized for an extended period of time and their pods can be placed on other existing nodes

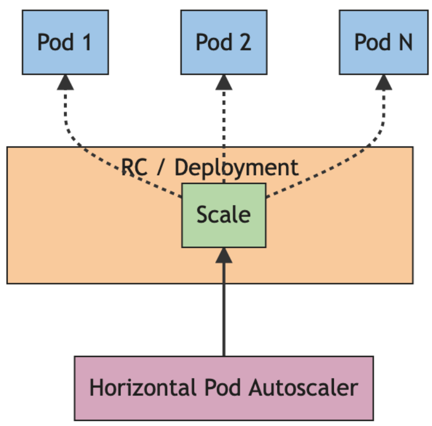
Auto-scaling: VPA

- Vertical Pod Autoscaler (VPA): scales amount of pod resources (CPU, memory)
  – Based on historical resource usage of pods: decaying histogram of weighted CPU and memory usage
  ✗ Whenever VPA updates pod resources, the pod is recreated: this disrupts the application availability



Auto-scaling: HPA

- Horizontal Pod Autoscaler (HPA): scales number of pods in a deployment, replica set or stateful set
  https://kubernetes.io/docs/tasks/run-application/horizontal-pod-autoscale/
  – Based on observed CPU utilization (or, with custom metrics support, on some other application-provided metrics)
  – Creates new pods without affecting existing ones

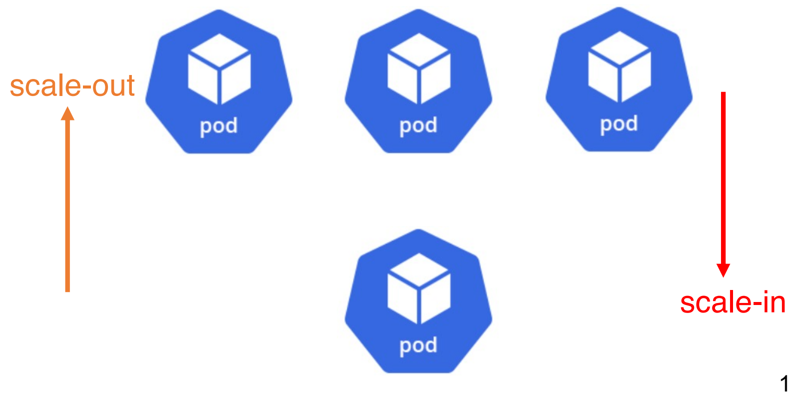


Auto-scaling: HPA

- HPA policy: heuristic policy, variant of threshold-based policy
  – Scales number of pods according to ratio between observed value and target value

$$desiredReplicas = \left\lceil currentReplicas \frac{currentMetricValue}{desiredMetricValue} \right\rceil$$

- Stabilization time window to limit fluctuations in replicas number



Distributions

- Multiple options

1. Install Kubernetes from source code
2. Pure distributions: pre-built Kubernetes
   – E.g., Charmed Kubernetes
3. Plus distributions: platforms that integrate Kubernetes with other specific technologies (e.g., container runtimes, host OSs or control-plane add-ons)
   – E.g., Red Hat OpenShift
4. Limited-purpose distributions: intended for a specific and limited purpose (e.g., single-node, DevOps, edge & IoT)
   – E.g., kind, minikube, MicroK8s, K3S
5. Kubernetes-as-a-service: Kubernetes fully managed by Cloud provider
   – E.g., AWS EKS, Azure AKS, Google GKE

Kubernetes tools

- Some useful tools
- kubectl: Kubernetes command-line tool to run commands against Kubernetes cluster
  - Use `kubectl` to deploy applications, inspect and manage cluster resources, and view logs
- Metrics Server: scalable, efficient source of container resource metrics
  - Collects resource metrics from kubelets and exposes them in kube-apiserver through Metrics API for use by HPA and VPA
- Helm: packet manager for Kubernetes
  - Helps to automate Kubernetes applications lifecycle