# Methods of Cloud Computing

## Chapter 3: Management of Virtual Resources


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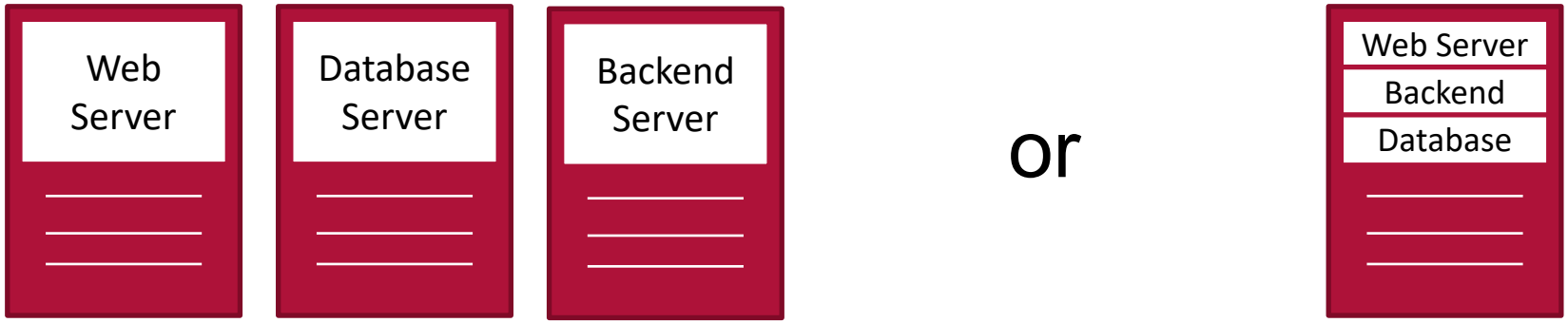
# Overview

- **Intro**
- Cloud Operating Systems
  - OpenStack
- Infrastructure-as-Code
  - Ansible
- Container Orchestration
  - Kubernetes
- DevOps, Continuous Integration, and Continuous Delivery

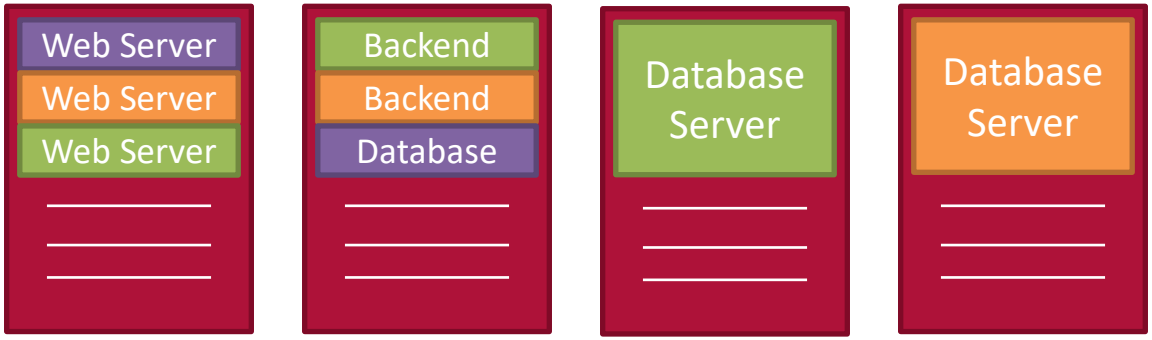
# “Iron Age”: Bare-Metal Servers




- Running components of an application on one or multiple physical servers:
  - Costs and agility: Purchase, housing, maintenance
  - Fault tolerance: Servers are single points of failure
  - Resource utilization: Servers were often underutilized, but sometimes also bottlenecks (i.e. w/ dynamic load)

# Bare-Metal Servers in one Organization

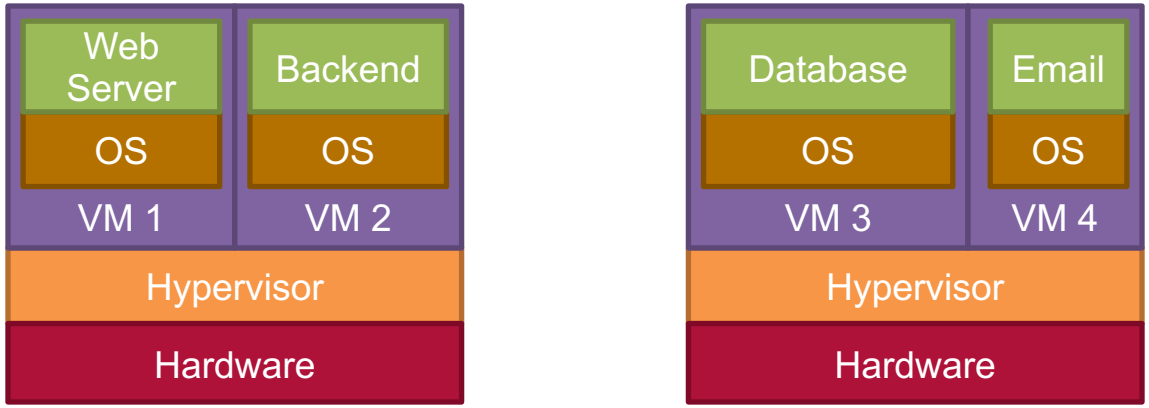
- Server consolidation: Manually assign components from different applications to set of physical nodes




- Only possible within one organization without isolation
- And static assignment, while loads may vary over time

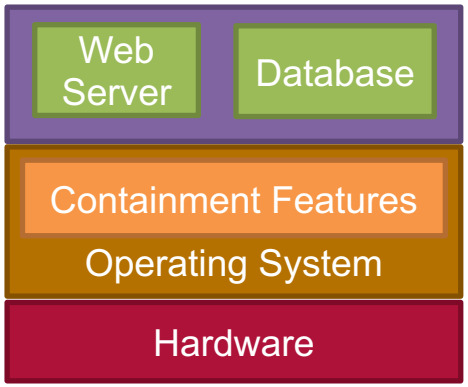
# Recap: Virtual Machines

- Hardware virtualization: Same architecture, but possibly different OS and resource configuration (#cores, RAM, storage) plus isolation
- Same physical host can run multiple virtual machines
- VMs can be migrated dynamically and snapshots can provide fault tolerance



# Recap: Container

- Motivation: VM images are large (contain OS) and starting VMs takes longer than processes (10x)
- Containers: Same OS kernel, but different resource configuration + isolation between contained processes
- Containment using Linux kernel features such as cgroups and namespaces



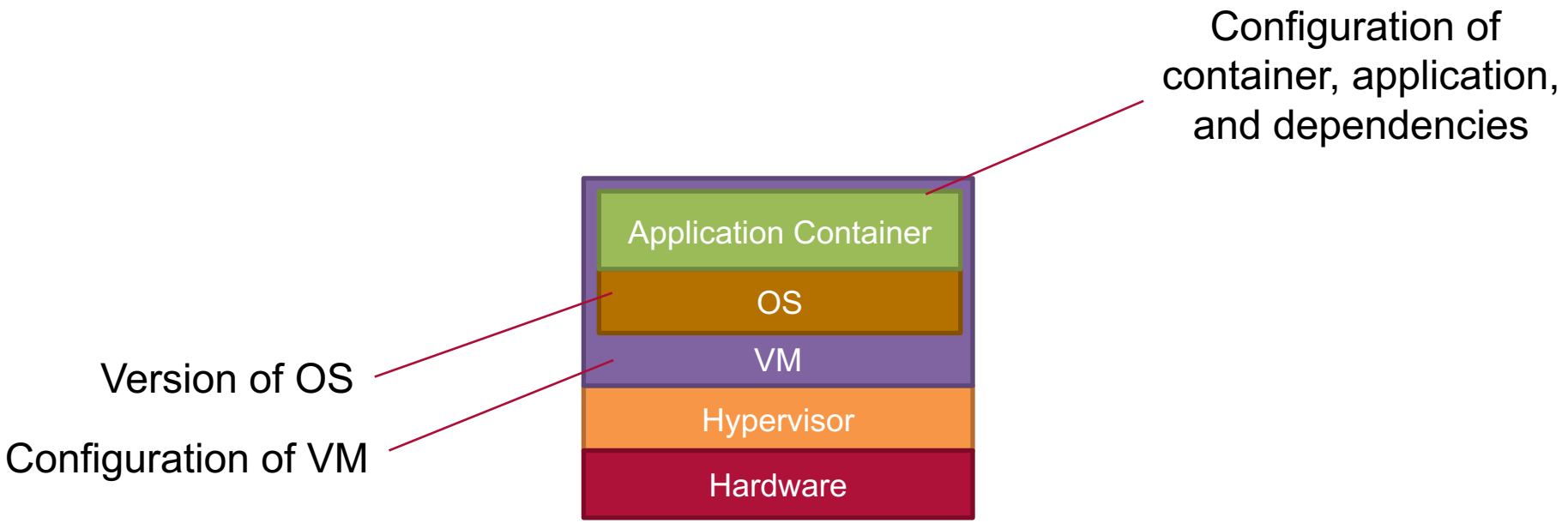
# Management of Resources (1/2)

- Now we can create VMs and containers, but management of large sets of resources is still difficult:
  - Provisioning of VMs and containers
  - Configuration of systems
  - Monitoring and failure handling
  - Replication and load balancing

- Cloud Operating Systems: manage large sets of virtual resources running on large sets of physical resources

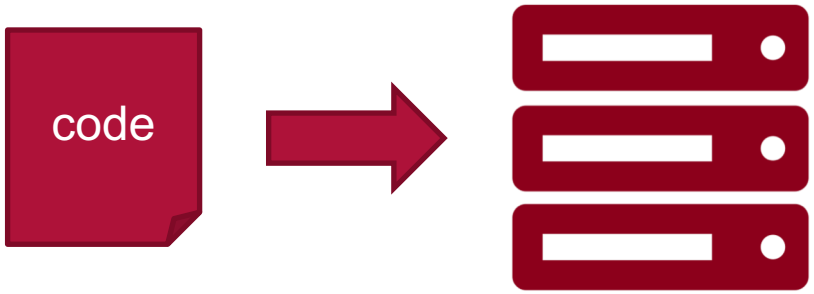
# Management of Resources (2/2)

- Major remaining problems in the “Cloud Age”: server sprawl, configuration drift, snowflake servers… → Technical debt!



# Infrastructure-as-Code

- Define servers, networking, and other infrastructure elements in source code:
  - Configuration of environments
  - Dependencies with specific versions




- Automation tools built around infrastructure definitions ➔ easily rebuild servers (instead of updating running servers: “immutable infrastructure”)
- Versioning and sharing of infrastructure definitions

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# Cloud Operating Systems (1/3)

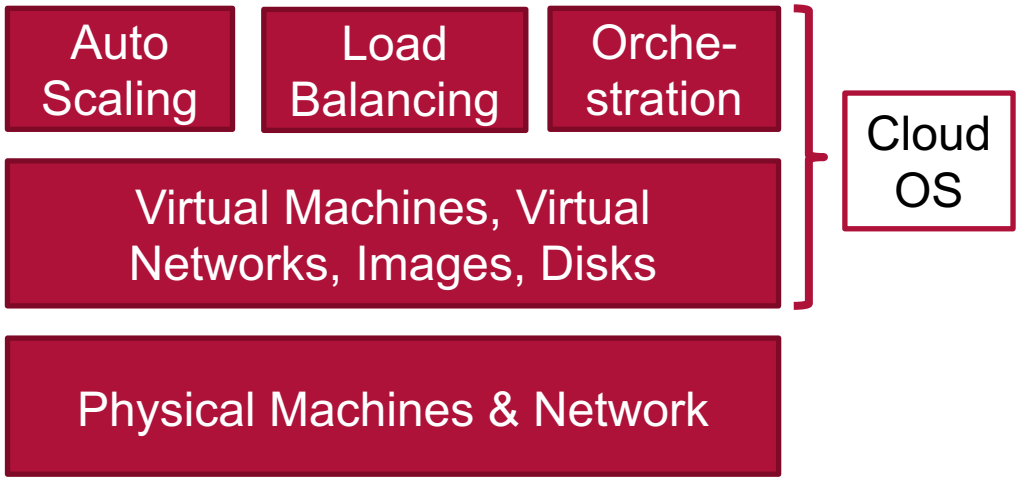
- Virtualization is immensely useful, but managing many virtual machines manually is impractical
- Therefore: Cloud Operating systems
  - Control large pools of compute, storage, and networking resources
  - Provides dashboards and APIs for datacenter operators (administration) and users (provisioning)

- Open Source cloud systems: OpenStack, OpenNebula
- Commercial public clouds: AWS EC2, GCE, Azure, Digital Ocean

# Cloud Operating Systems (2/3)

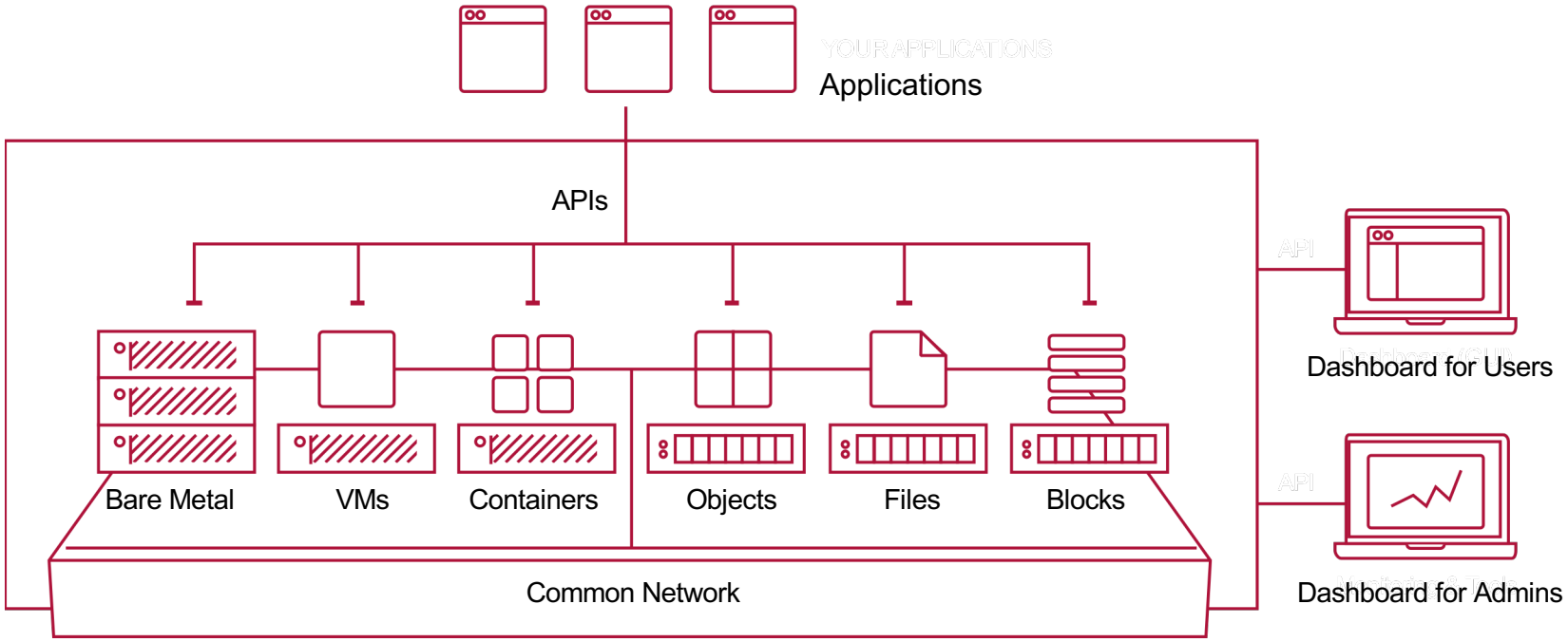
- User Interface and APIs for
  - spawn & maintain VMs,
  - virtual networking,
  - manage images & virtual disks

- Advanced features
  - load balancing,
  - auto scaling,
  - and orchestration



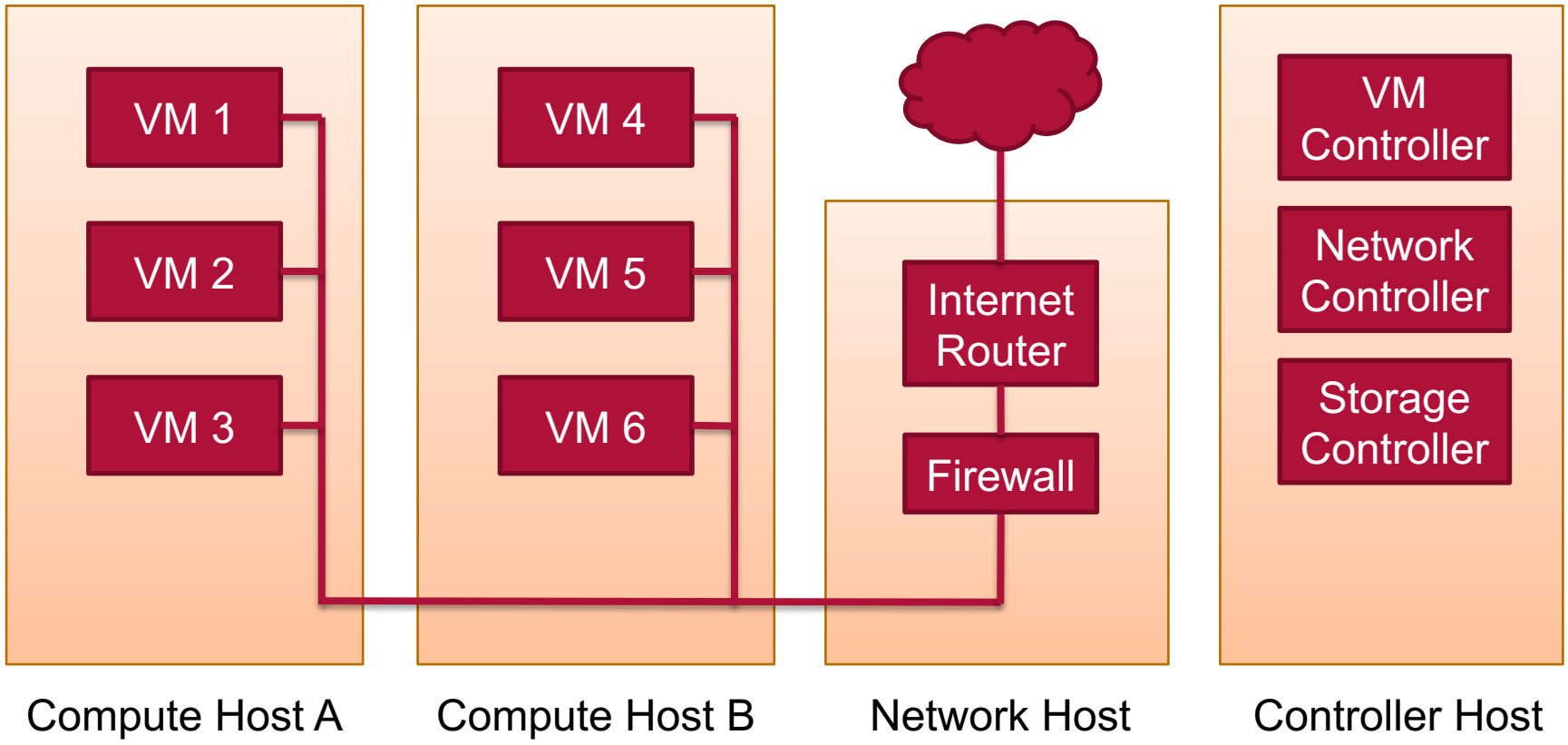
# Cloud Operating Systems (3/3)

- Interfaces to manage and provision virtual resources



# Managed Cloud Environment

- Different roles for physical hosts: compute hosts, storage hosts, network hosts, and controller host



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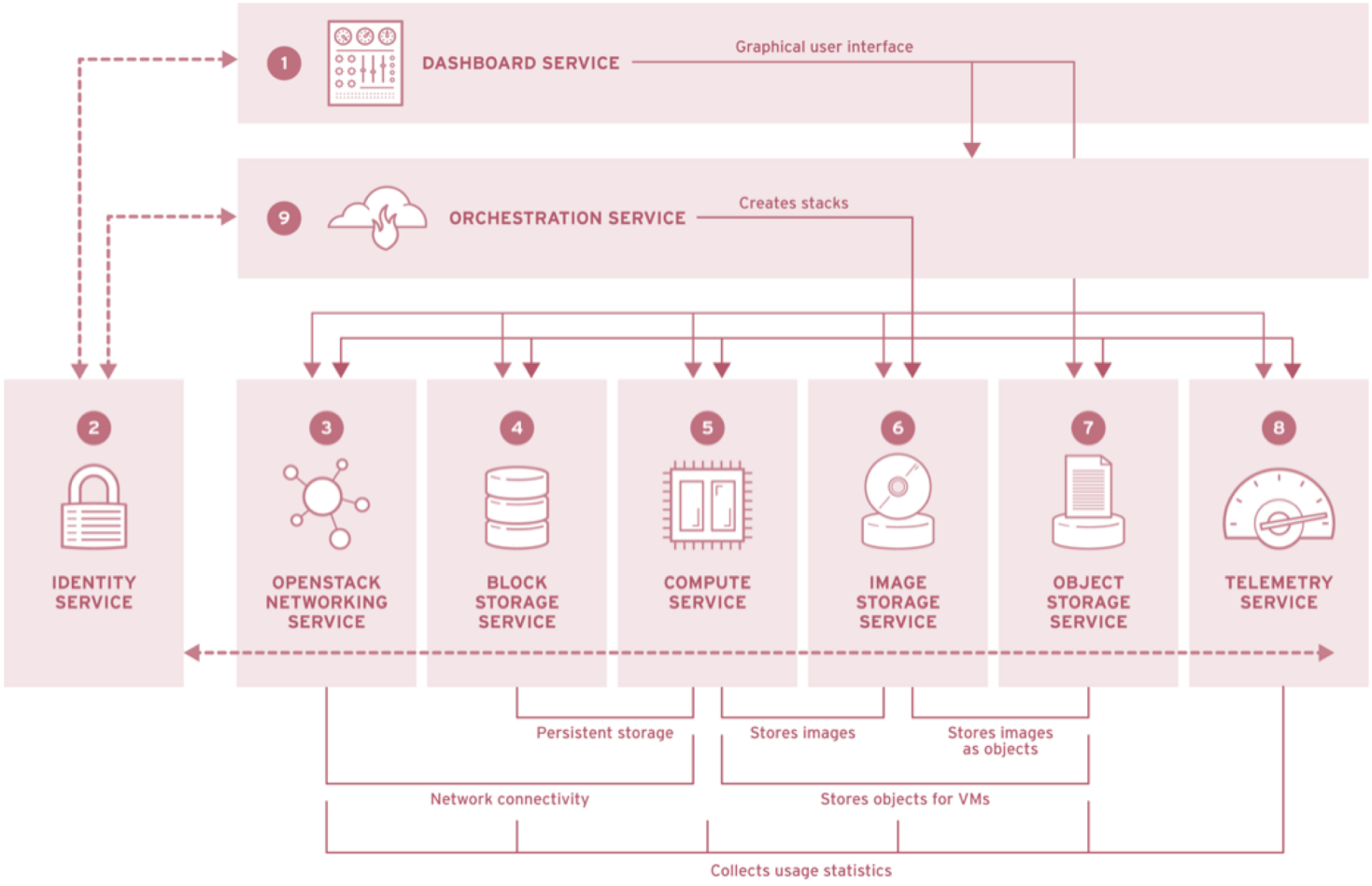
# OpenStack

- Open source cloud operating system
- Mostly deployed as IaaS, providing virtual machines and other resources to users


- Started in 2010 by Rackspace Hosting and NASA
- Contributions from IBM, Red Hat, HP, Cisco, Google, Oracle, EMC, VMware

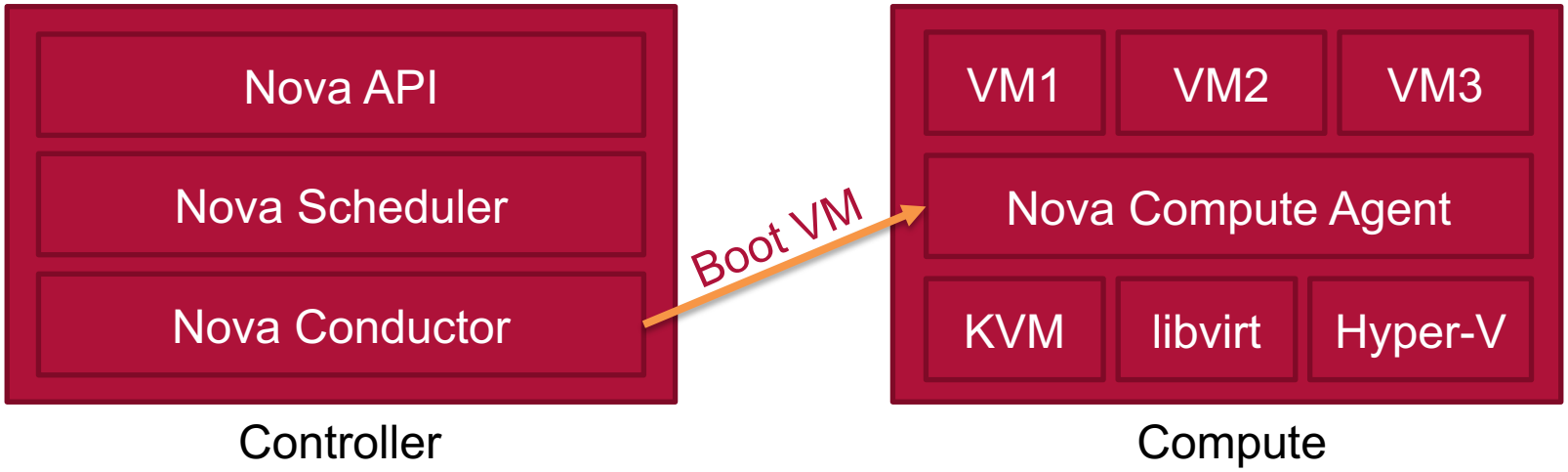
- Most popular open cloud platform in both industry and academia

# Core Components of OpenStack



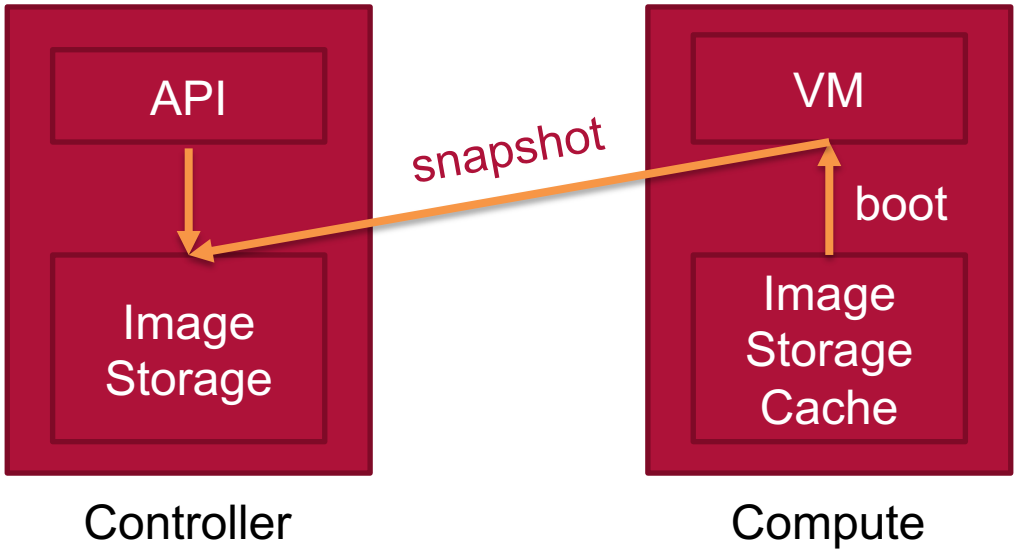
# Compute Service: Nova

- Allows to create and manage virtual machines on demand from images
- Schedules virtual machines to run on physical nodes
- Defines drivers that interact with underlying virtualization mechanisms



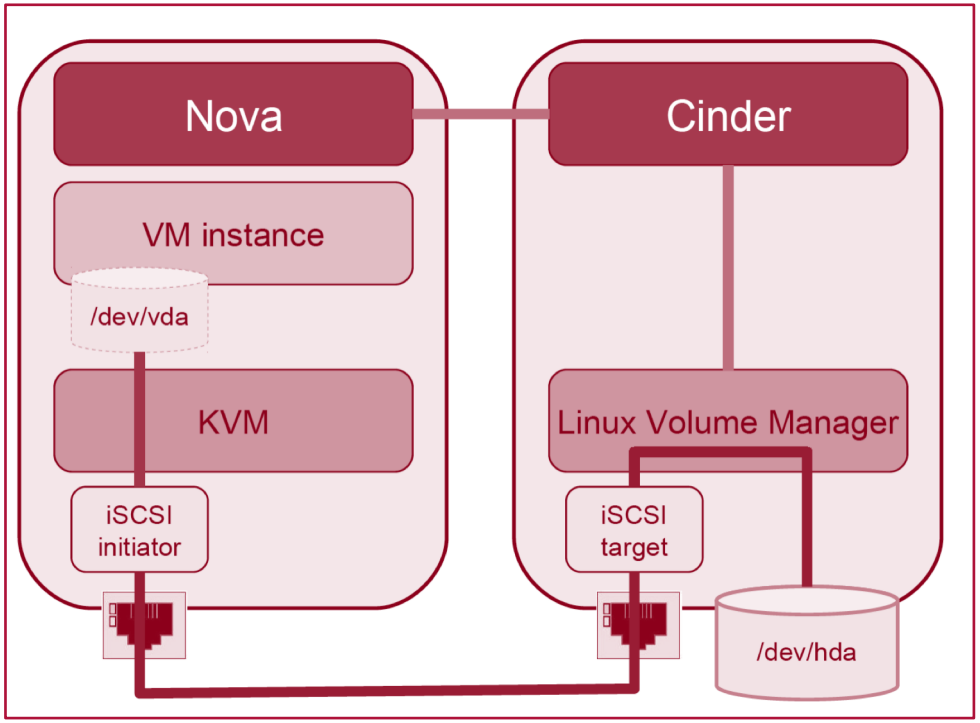
# Image Service: Glance

- Registry for virtual disk images
- Users can add new images or take snapshots of existing VMs
- Snapshots can be used as templates for new servers



# Block Storage Service: Cinder

- Provides network-backed virtual block storage volumes
- Enables live migration of VMs, supports replication
- Multiple storage backends



# Virtual Switches & SDN

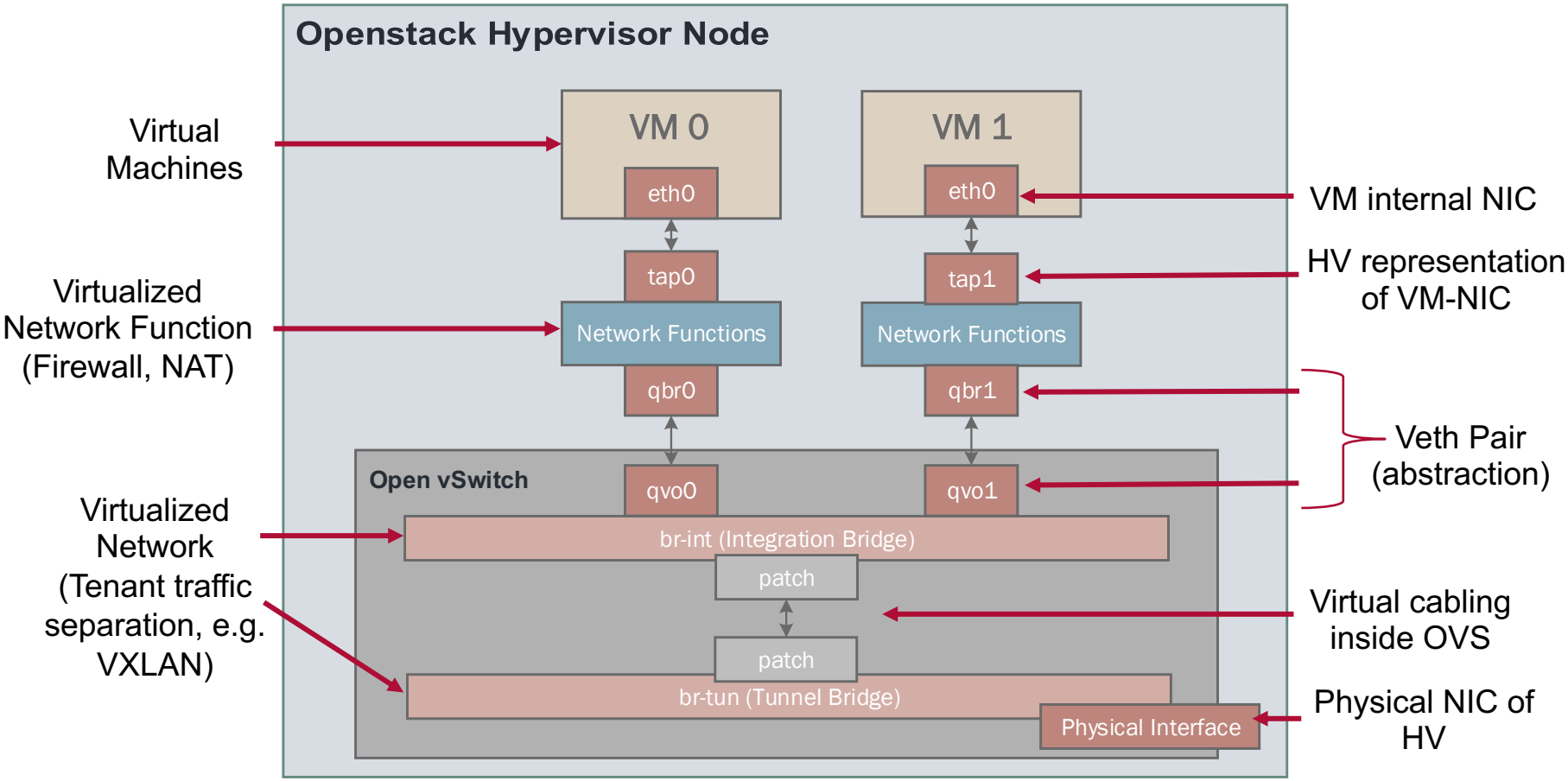
- Virtual Switches: Virtual switching stack that enables network automation through programmatic extensions and standard protocols (e.g. OpenFlow)

- Software-Defined Networking (SDN)
  - Goal: Simplify network administration
  - Separation of control plane from data plane
  - Allows on the fly configuration of switches (controller-based decision making)

# Virtual Networking

- Networking between virtual machines and physical network
- Interconnects virtual machines
  - within one hypervisor
  - between several hypervisors
  - with the Internet
- Provide additional network functions
  - Like DNS, DHCP, Firewalls …

# Virtual Networking in OpenStack



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# Motivation

- Manual configuration of servers usually leads to
  - *Configuration Drift*: change configuration of single servers manually over time (without documentation)
  - *Snowflake Servers*:
    - Unique configuration
    - Not reproducible when hardware dies
    - Difficult to mirror for a test environment
    - Deliberate vs. default configuration
    - Host-specific vs. general configuration

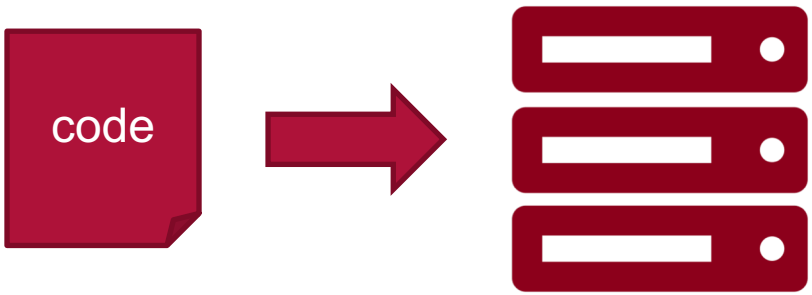
# Open Questions

- What if a server fails?
- How to mirror a production environment for testing?
- How to keep a cluster of servers consistent?

- Disk snapshots allow to recover and mirror servers, but
  - not straightforward to understand the state of servers
  - don’t allow managing multiple servers that are mostly similar, but specific in a few configurations

# Infrastructure as Code

- Goal: Make systems easily reproducible
- Solution: One single source of truth with a clear declaration of host-specific configuration → infrastructure definition files
  - That can be executed
  - That can be versioned
  - That can be shared




- Only use these definitions and automation tools, without manually updating single servers

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# Ansible

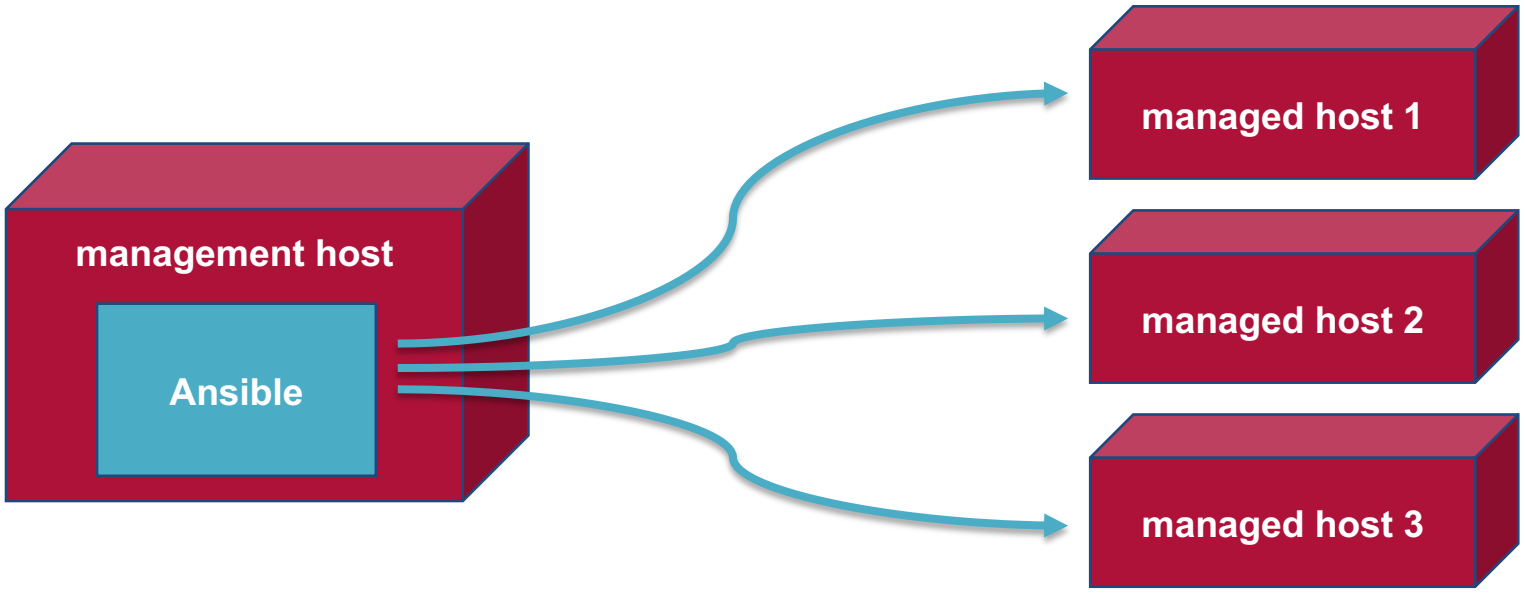
- Automation language and engine
- Configuration management
  - i.e. configure existing servers
- Orchestration
  - i.e. allocate and provision new servers


- Since 2012, acquired by Red Hat in October 2015
- Well-documented conventions and best practices, but no artificial limitations, so users can choose to ignore

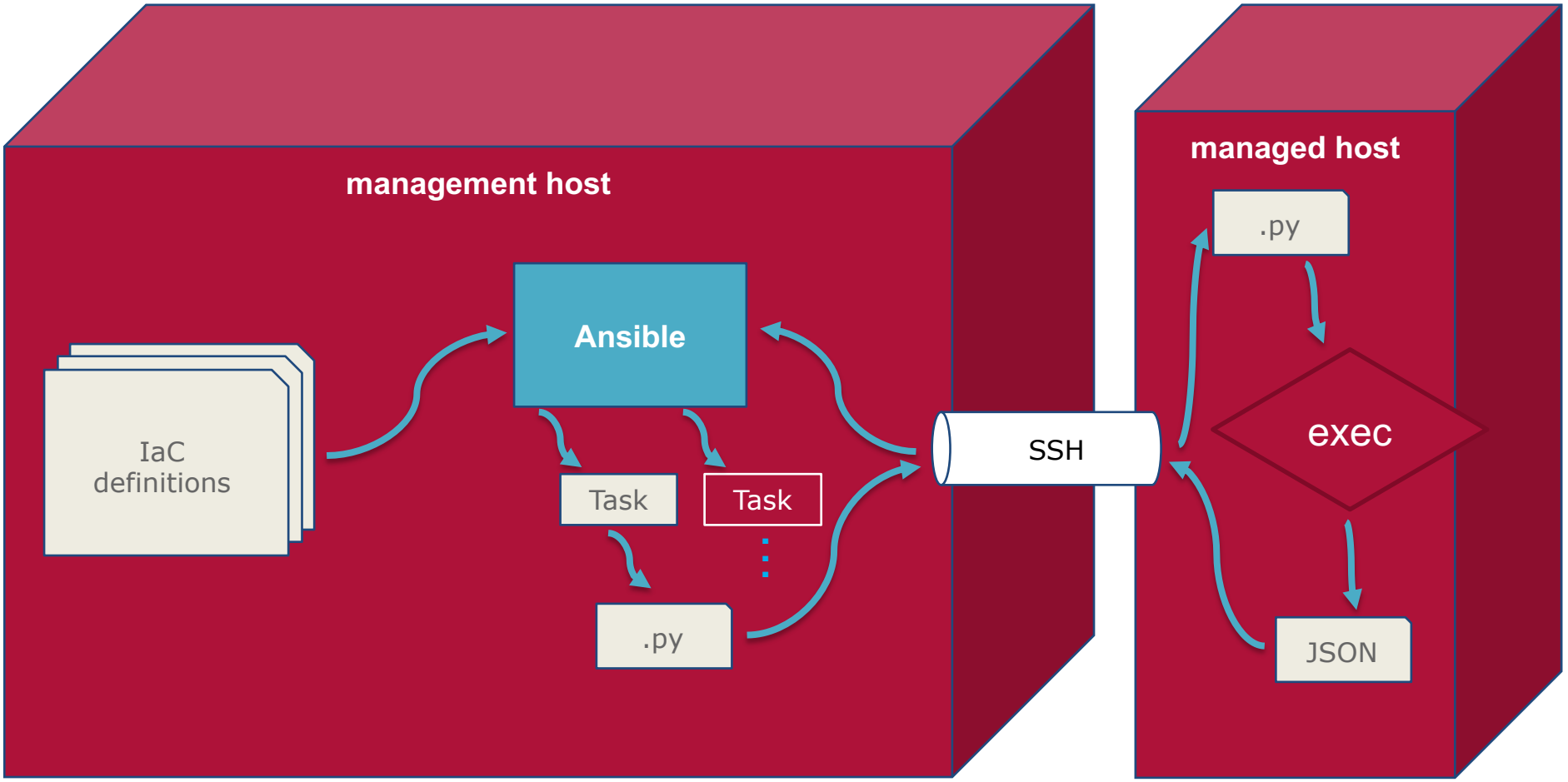
# Ansible

- Multi-platform
  - Operating systems: Linux, Unix-like, MacOS
  - Orchestration-related tools: LXC, libvirt, VMware, …
  - IaaS platforms: AWS, Azure, OpenStack, …
- Well-established technologies as foundation
  - Python
  - SSH (PowerShell remoting, respectively)
  - YAML + Jinja templating
- Design: Declarative and agent-less

# Agent-Less Architecture (1/2)



# Agent-Less Architecture (2/2)



# Ansible Tasks (1/2)

- Declarative
  - I.e., define the desired state
- Opposed to imperative
  - I.e., define how to achieve the desired state
- Implies idempotency
  - I.e., applying the configuration again leads to same state
    - # that's the intention; you can, of course, create non-idempotent tasks

```
# an example "task":
- name: "enforce permissions for .ssh directory of {{ ansible_user_id }}"
  # ↑ "name" is optional but strongly encouraged
  file: # ← the module name, ↓ followed by module parameters
    dest: "{{ ansible_user_dir }}/.ssh"
    state: directory
    mode: u+rX,go-rwx
    recurse: yes
```

# Ansible Tasks (2/2)

But to which hosts should this task be applied to?

```
# an example "task":
- name: "enforce permissions for .ssh directory of {{ ansible_user_id }}"
  # ↑ "name" is optional but strongly encouraged
  file: # ← the module name, ↓ followed by module parameters
    dest: "{{ ansible_user_dir }}/.ssh"
    state: directory
    mode: u+rX,go-rwx
    recurse: yes
```

# Ansible Playbooks (1/2)

- Playbooks map everything to hosts
  - Tasks
  - Roles
  - Variables

```
# file: my_playbook.yml

# a "Play":
- name: configure internal Web servers
  hosts: webservers
  roles:
    - webserver
  tasks:
    - name: forbid external connections
      iptables:
        chain: INPUT
        source: !192.168.1.1/24
        jump: DROP
```

- Further features include:
  - Rolling updates
    - Configure only n hosts at a time
    - Configure only x% of host at a time
  - Tolerate percentage of hosts where configuration fails
  - …

# Ansible Playbooks (2/2)

But how does Ansible know the hosts "webservers"?

```
# file: my_playbook.yml

# a “Play”:
- name: configure internal Web servers
  hosts: webservers
  roles:
    - webserver
  tasks:
    - name: forbid external connections
      iptables:
        chain: INPUT
        source: !192.168.1.1/24
        jump: DROP
```

# Ansible Inventory

```
# no FQDNs required, as long as
# ``ssh <hostname>`` works (~/.ssh/config)
mail

[webservers]
w1.example.com
w2.example.com


[dbservers]
d1.example.com
d2.example.com

[appservers]
# we can override variables:
a01.example.com www_user=web
# we can use a pattern-like syntax:
a[02-12].example.com

# we can define variables for groups:
[appservers:vars]
www_user=www-data

# a group of groups
[rootservers:children]
appservers
dbservers
```

```
# alternatively, we can use YAML:

all:
  hosts:
    mail.example.com:
  children:
    webservers:
      hosts:
        w1.example.com:
        w2.example.com:
    dbservers:
      hosts:
        d1.example.com:
        d2.example.com:
  ...
```

- Inventories can also be obtained from external scripts / executables (think: IaaS)

# Ansible Variables (1/2)

- Variables can be defined in many many places
  - Playbooks, Tasks, Inventory, CLI args, roles, facts, …
  - But, scattering variables all over the place is discouraged, of course
  - e.g., using role, group and host variables can suffice
- "facts"
  - A heap of auto-detected variables: e.g., Uptime, chroot?, user home, SSH host key, Python version, total and free memory, host name, FQDN, environment variables, block devices, mounts, interfaces, BIOS version, processor specs, OS name and version, …
- Jinja templating also in variables files
  - e.g., app_user: "{{ ansible_env.SUDO_USER|default(ansible_user_id) }}"

# Ansible Variables (2/2)

- Host and group variables
  - e.g., in project directory:

```
# e.g., set inventory to ./inventory.ini:
.ansible.cfg
inventory.ini
my_playbook.yml
group_vars/
  # applies to all hosts:
  all.yml
  webservers.yml
host_vars/
  mail.yml
```

```
# no FQDNs required, as
# ``ssh <hostname>`` w
mail

[webservers]
w1.example.com
w2.example.com


[dbservers]
d1.example.com
d2.example.com

[appservers]
# we can override variabl
a01.example.com www_u
# we can use a pattern-li
a[02-12].example.com

# we can define variables
[appservers:vars]
www_user=www-data

# a group of groups
[rootservers:children]
appservers
dbservers
```

# Ansible Roles (1/2)

- Roles
  - e.g., in project directory:

```
roles/webserver
  # default variables:
  defaults/main.yml
  # tasks to be executed:
  tasks/
    main.yml
    # ↑ might include:
    certbot.yml
  ...
```

# Ansible Roles (2/2)

- Roles
  - e.g., in project directory:

```
roles/webserver
  ...
  # e.g., restart service on
  # configuration changes:
  handlers/main.yml
  # e.g., declare dependencies to
  # other roles:
  meta/main.yml
```

# Summary of IaC in Ansible

- Inventory
  - List of managed hosts
  - Groups and groups of groups
- Roles
  - Concept to reuse tasks and variables for similar hosts
  - Usually contain (default) variables
- Host and group variables
  - This is where variables should go
- Playbooks (Ansible's execution unit)
  - "map" roles, tasks, variables to hosts from inventory

# Run a Playbook

**$ cat my_playbook.yml**

```
- name: test SSH connection
  hosts: pim:static
  tasks:
    - name: test if logging into host and running a module remotely works
      ping: # does not require any arguments
```

**$ ansible-playbook my_playbook.yml**

```
PLAY [test SSH connection] ****************************************************
TASK [Gathering Facts] ********************************************************
ok: [static]
ok: [pim]

TASK [test if logging in and running a module remotely works] ***************
ok: [pim]
ok: [static]

PLAY RECAP ********************************************************************
pim                        : ok=2    changed=0    unreachable=0    failed=0
static                     : ok=2    changed=0    unreachable=0    failed=0
```

# Run adhoc commands

**$ ansible vs2_and_containers -m file -a "path=/run/log/mylogs state=directory"**

```
vs2 | FAILED! => {
    "changed": false,
    "msg": "There was an issue creating …: [Errno 13] Permission denied: '/run/log/mylogs'",
    "path": "/run/log/mylogs",
    "state": "absent"
}
static | CHANGED => {
    "changed": true,
    "gid": 0,
    "group": "root",
    "mode": "0700",
    "owner": "root",
    …
}
rproxy | SUCCESS => {
    "changed": false,
    …
}
…
lists | UNREACHABLE! => {
    "changed": false,
    "msg": "SSH Error: data could not be sent …. Make sure this host can be reached over ssh",
    "unreachable": true
}
```

# "But my task is dead-simple …

*… using Ansible would be overkill."*

- How does your shell script handle …
  - … all the return codes?
  - … whitespaces in variables and undefined variables?
    - e.g., `$ rm -rf /$x`
  - … being re-run – do we still get the desired result?
  - … changes in e.g. CLI APIs?
  - … host-specific configurations?
  - … shell interoperability?
  - … different platforms?

# "But my task is dead-simple …

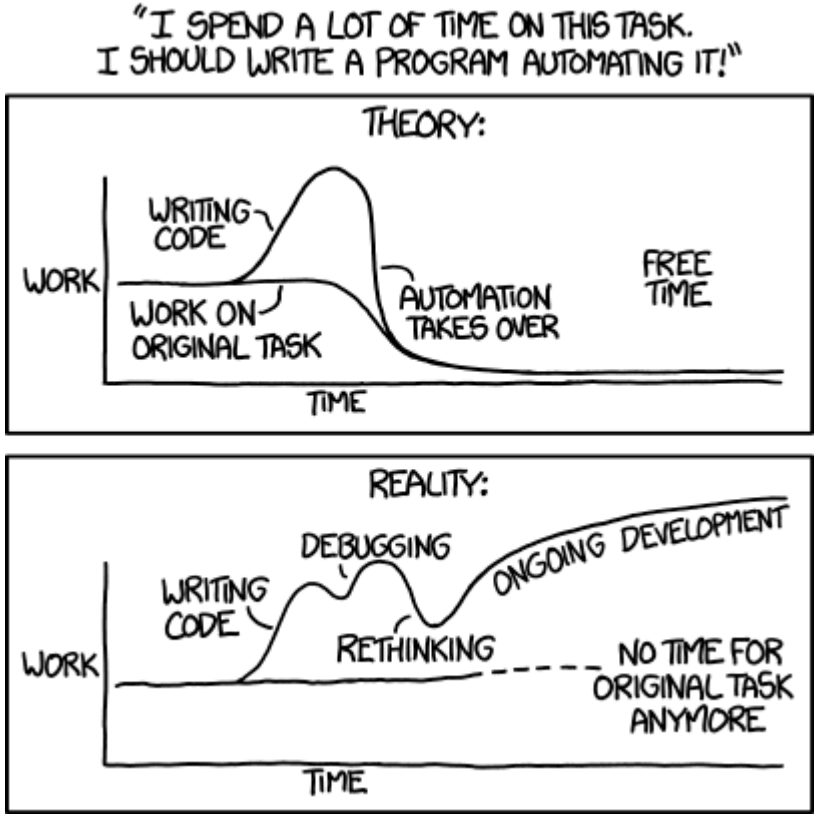
- How does your shell script handle …
  - … if you need to run it only partially?
  - … if it needs to be understood by humans?
  - … if it needs to be run sequentially on multiple hosts?
  - … if it needs to be run on multiple hosts in parallel?
  - …
- → simple tasks usually turn out harder than expected

# we're talking about Ansible here, but other configuration management/IaC tools would get the job done as well – a matter of requirements and taste

# Open Questions

# not specific to Ansible

- When to automate?
  - When expected to do task more than two times?
  - Depends on complexity
- Programming vs. markup
  - When to write a, e.g., Python program instead of using, e.g., Ansible?




https://xkcd.com/1319/

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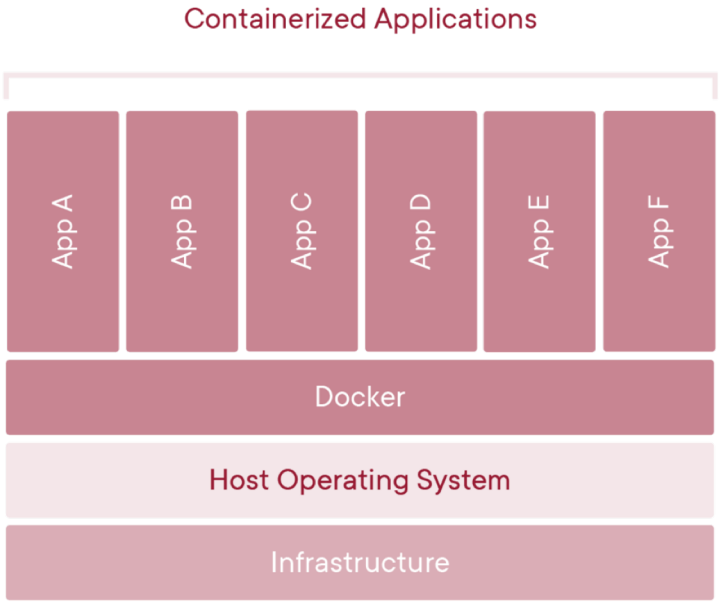
# Container Analogy

- Containers
  - Standardized
  - Easy to move
  - Isolated
  - Many containers fit hosts


- Dependency management: libs and config bundled with the application, to run it everywhere → build your app in a container, test the container locally or your staging environment, then ship the container

# Recap: Docker

- Container instance: running isolated process, started from a Docker image
- Docker image: snapshot of a container, packaging the application code and all dependencies
- Docker file: instructions for creating images
- Multiple containers share single OS kernel, isolated by kernel containment features (e.g. cgroups)



# Dockerfiles

- Creating docker images from configuration files
- Example: Dockerfile for an Express web server image using NodeJS

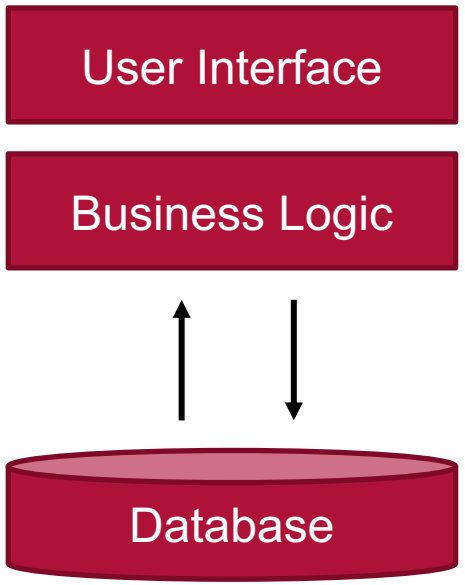
```
$ docker build --tag hello .

$ docker run --rm hello
```

```
# Create image based on the official Node 6 image from dockerhub
FROM node:9

# Create a dir where our app will be placed
RUN mkdir -p /usr/src/app

# Change dir so that our commands run inside this new dir
WORKDIR /usr/src/app

# Copy dependency definitions
COPY package.json /usr/src/app

# Install dependecies
RUN npm install

# Get all the code needed to run the app
COPY . /usr/src/app

# Expose the port the app runs in
EXPOSE 3000

# Serve the app
CMD ["npm", "start"]
```

# Container Composition

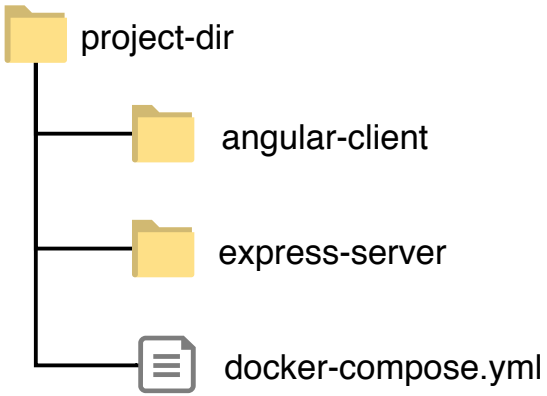
- Applications typically consist of multiple connected components intended to run as a single service

- e.g. Web Application
  - Front-end framework
  - Back-end framework
  - Persistent data store



# Docker Compose

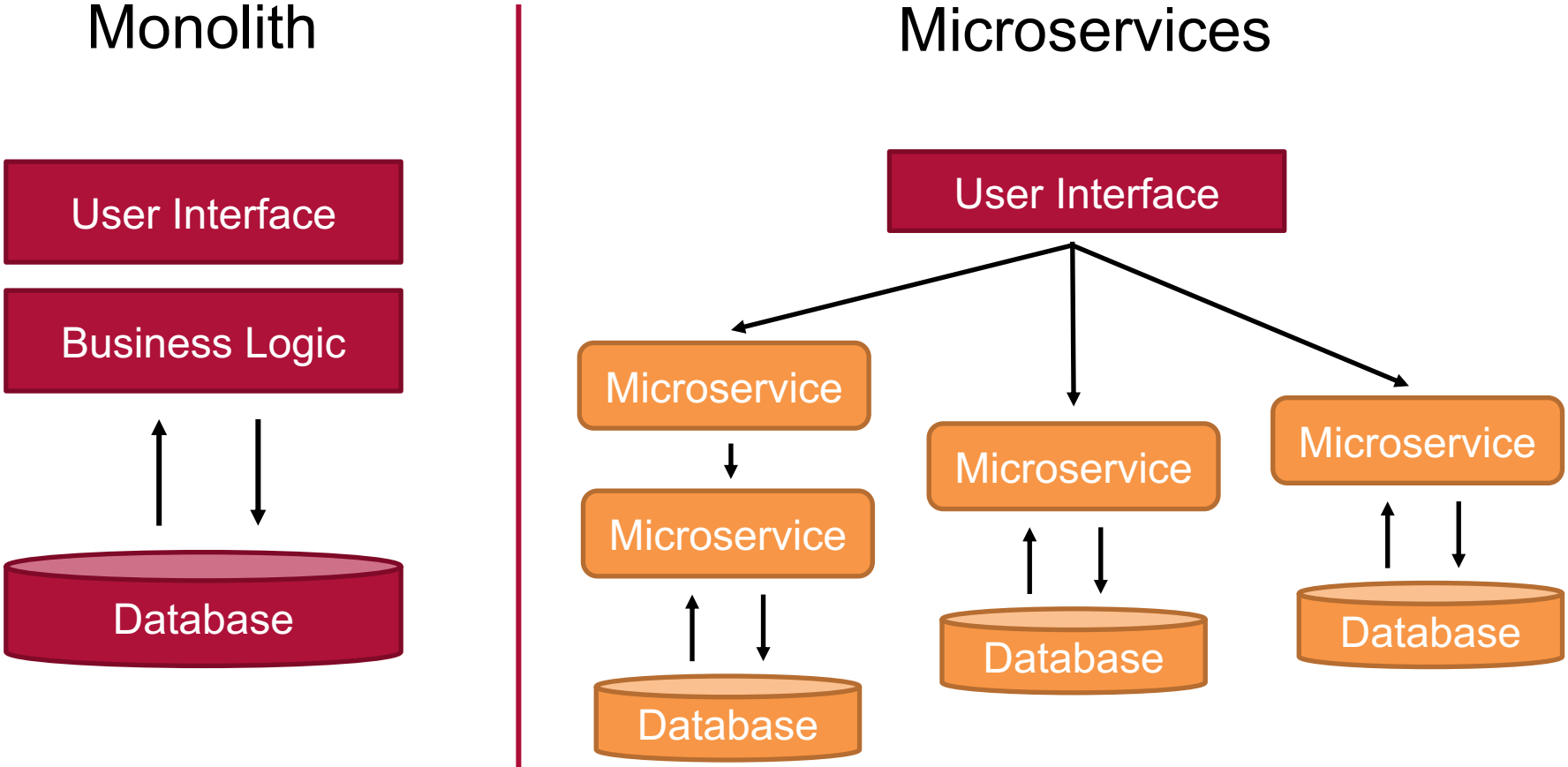
- Tool for defining and running multi-container Docker applications




```
$ docker-compose up
```

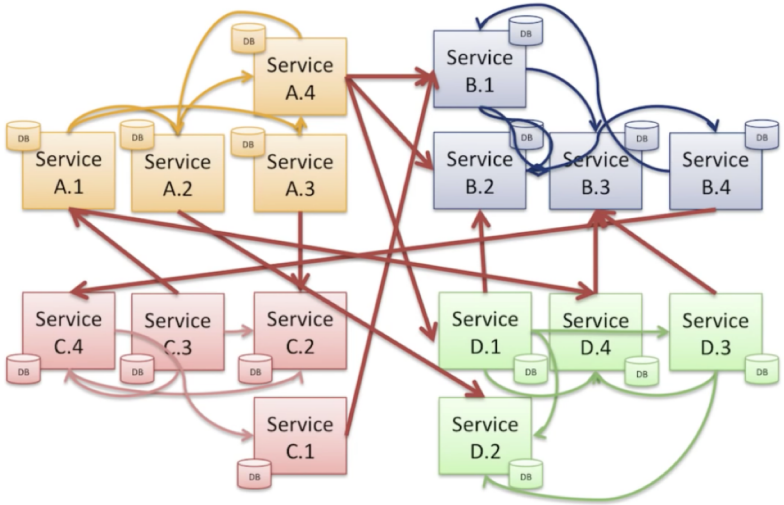
```
version: '2' # specify docker-compose version

# Define the services/containers to be run
services:
  angular:
    build: angular-client # Dockerfile directory
    ports:
      - "4200:4200" # port forewarding

  express:
    build: express-server # Dockerfile directory
    ports:
      - "3000:3000" # ports forewarding

  database:
    image: mongo # image to build container from
    ports:
      - "27017:27017" # port forewarding
```

# Microservices (1/2)



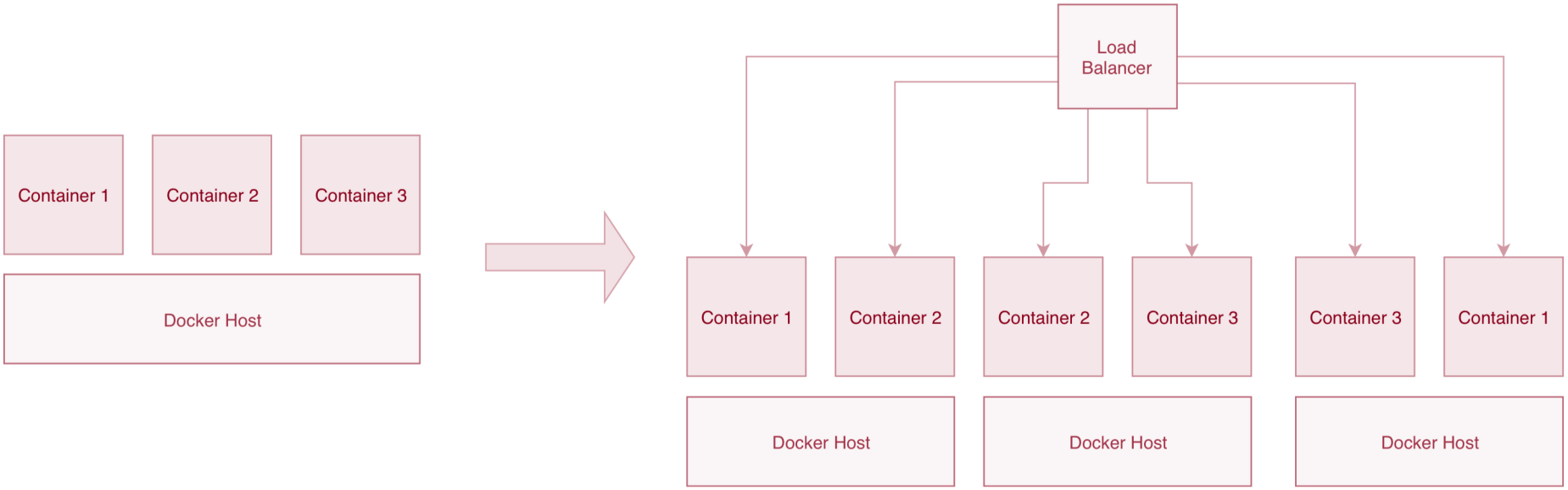
# Microservices (2/2)

- Advantages
  - Independent development
  - Small teams
  - Fault isolation
  - Scalable!
- Disadvantages
  - Overhead (duplicated tech)
  - Management of services and networking



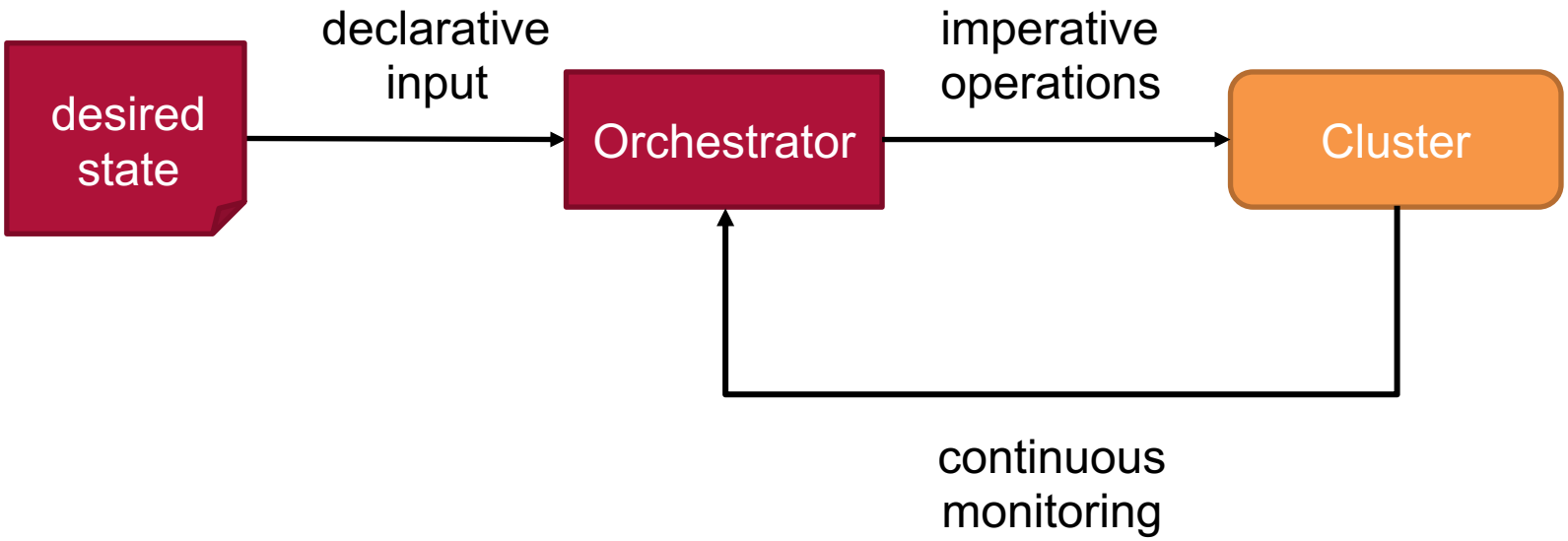
# Docker Cluster

- Running an application on a cluster of docker hosts for fault tolerance and scalability



# Orchestration

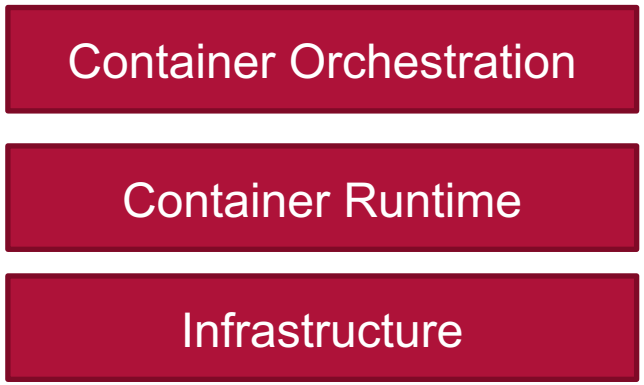
- Orchestration tools: Control systems for clusters



# Main Orchestration Tasks

- Scheduling and placement
- Service configuration
- Networking and storage management
- Monitoring and logging
- Replication and scaling
- Re-scheduling and load balancing
- Rolling updates

# Container Orchestration




- Distributed container management
- Local container management
- Container-agnostic infrastructure

- Provisioning and deployment of containers
- Replication and availability of containers
- Configuration and networking of containers
- Load balancing across replicated containers
- Monitoring of replicated containers

# Overview

- Intro
- Cloud Operating Systems
  - OpenStack
- Infrastructure-as-Code
  - Ansible
- Container Orchestration
  - **Kubernetes**
- DevOps, Continuous Integration, and Continuous Delivery

# Kubernetes

- Greek for “helmsman” or “pilot”, abbreviated ”k8s”
- Open-sourced by Google in 2014
- Version 1.0 released in July 2015
- Google and the Linux Foundation created the Cloud Native Computing Foundation (CNCF) to offer k8s as an open standard
- Google Kubernetes Engine (GKE), Azure Container Service (AKS), AWS Elastic Container Service (EKS)

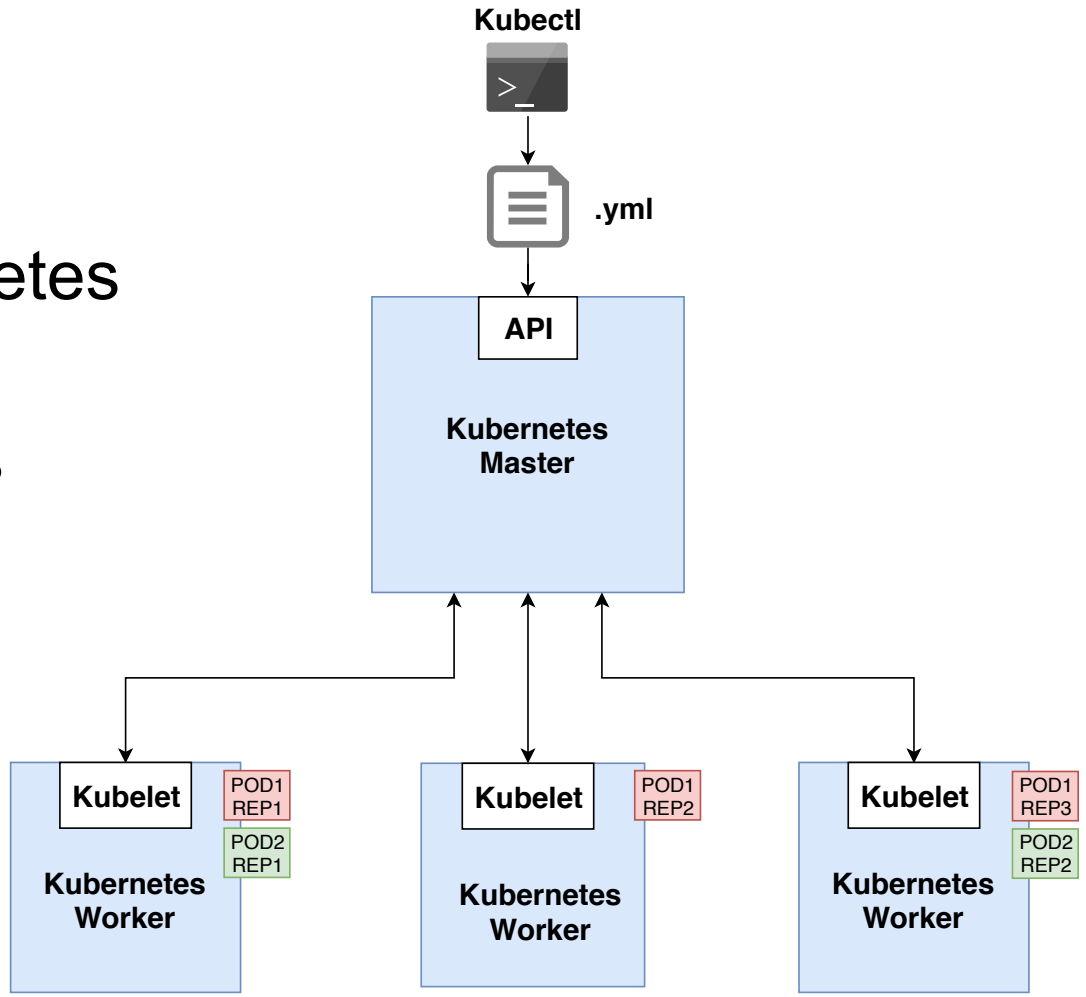
# What Does k8s Do for You?

- Automation engine for cluster management, from a declarative description of the desired cluster state

- Deploying, monitoring, and scaling
  - Instantiating sets of containers
  - Linking containers together through agreed interfaces
  - Exposing services to machines outside the cluster
  - Monitoring, logging, and rescheduling of failed containers
  - Scaling out or down the cluster by adding or removing containers

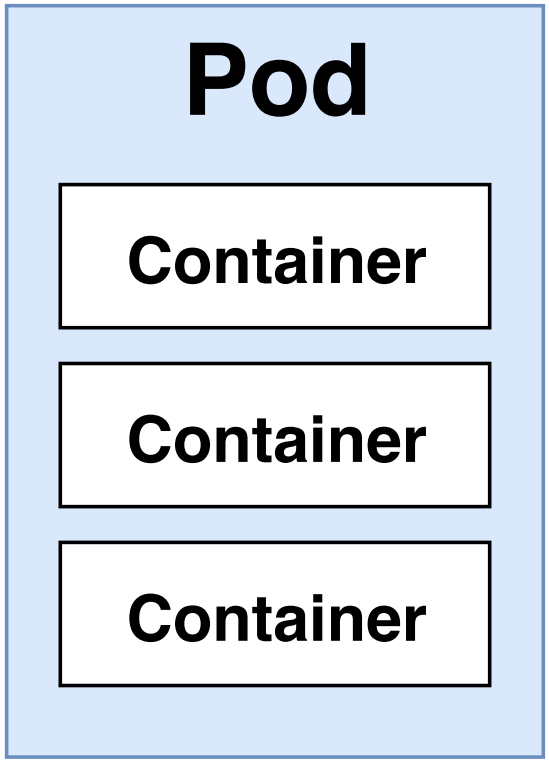
# Kubernetes Cluster

- Collection of nodes (either bare-metal or virtual machines), managed by Kubernetes
- Runs groups of replicated containers (called *Pods*)



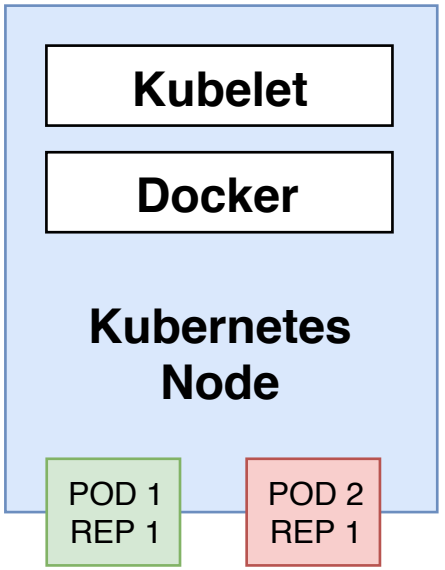
# Kubernetes Pods

- Pods consist of
  - Group of containers
  - Container configurations
  - Shared storage
- Containers in a pod
  - are scheduled together
  - are guaranteed to be on the same node
- Replicas of pods



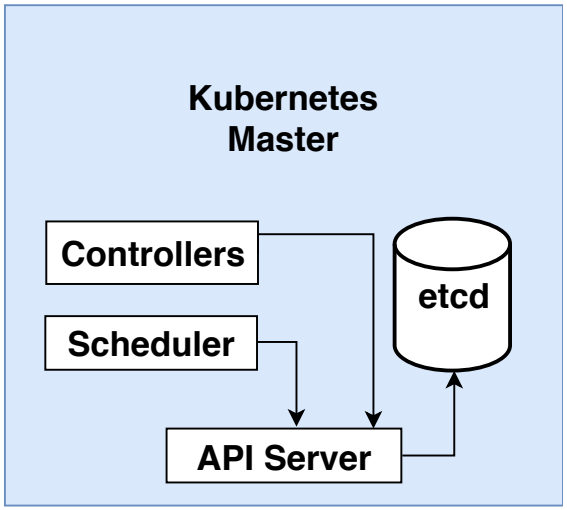
# Kubernetes Nodes

- Each worker node in the cluster runs two processes:
  - `kubelet`: communicates with the Kubernetes master
  - `kube-proxy`: reflects Kubernetes networking on each node



# Kubernetes Master

- Collection of processes managing the server state on a single node of the cluster



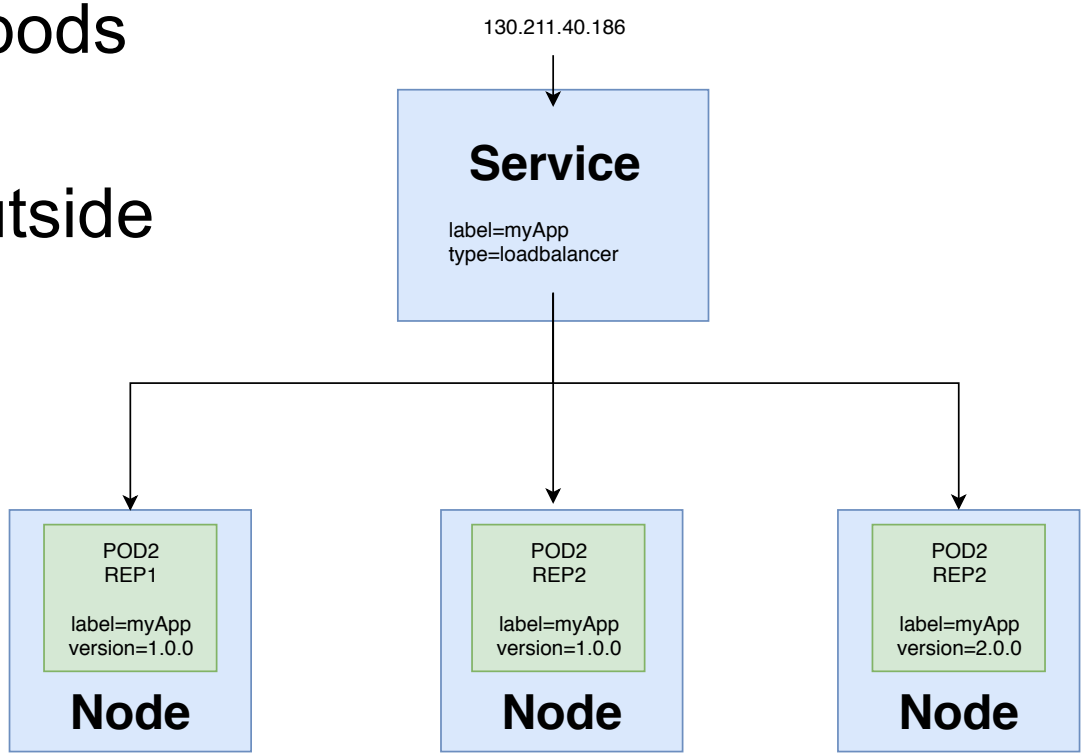

- Controllers, e.g. replication controller
- Scheduler: places pods based on resource requirements, hardware and software constraints, data locality, deadlines…

- etcd: key-value store for cluster state

# Kubernetes Services

- Services handle and load-balance requests to pods
- Services expose functionality to the outside

```
apiVersion: v1
kind: Service
metadata:
  name: myApp-service
spec:
  type: LoadBalancer
  ports:
  - protocol: TCP
    # accessible externally
    nodePort: 80
    # port in Pod
    targetPort: 8080
  selector:
    app: myApp
```



# Kubernetes Deployment

- Defines desired state, k8s then establishes and re-establishes it

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: nginx-deployment
  labels:
    app: nginx
spec:
  replicas: 3
  selector:
    matchLabels:
      app: nginx
  template:
    metadata:
      labels:
        app: nginx
    spec:
      containers:
      - name: nginx
        image: nginx:1.15.4
        ports:
        - containerPort: 80
```

```
$ kubectl create -f nginx-deployment.yaml
```

```
$ kubectl get deployments
```

```
NAME               DESIRED   CURRENT   UP-TO-DATE   AVAILABLE   AGE
nginx-deployment   3         3         3            3           18s
```

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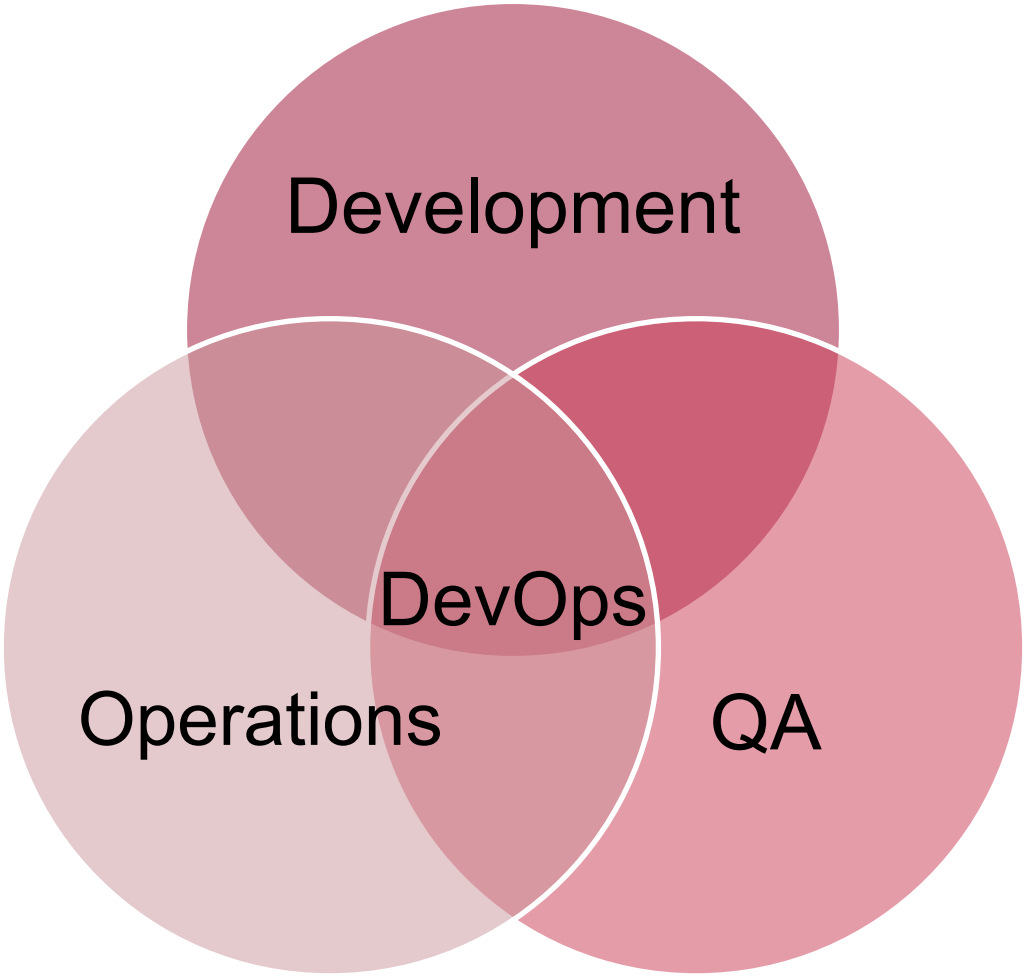
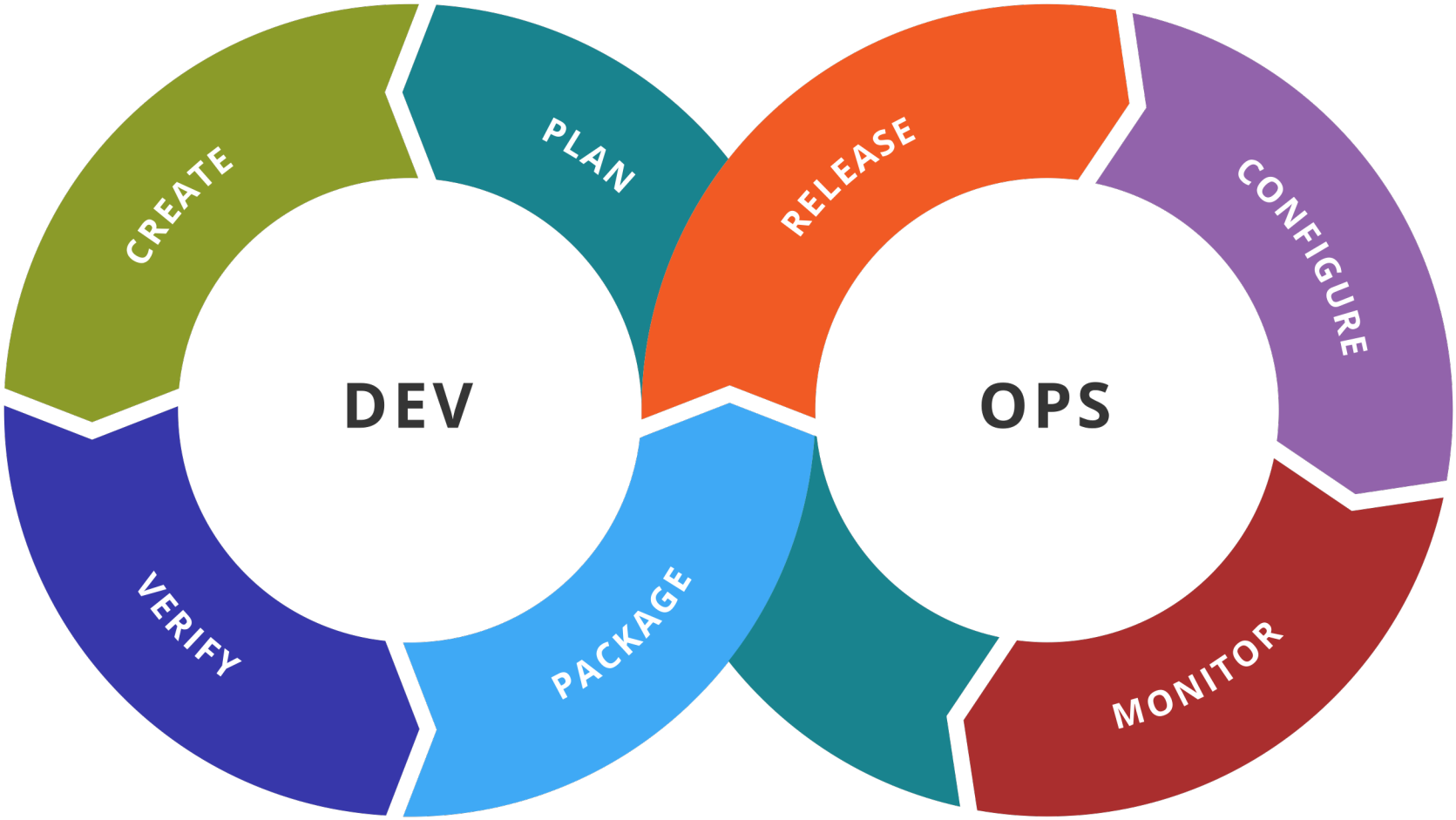
- **DevOps, Continuous Integration, and Continuous Delivery**

# DevOps



# DevOps


CREATE
PLAN
RELEASE
CONFIGURE
DEV
OPS
VERIFY
PACKAGE
MONITOR

# Continuous Integration

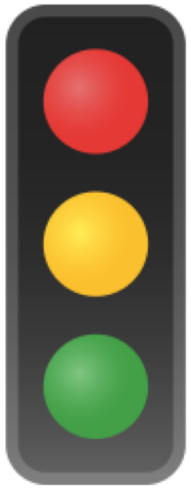
- Automation of integration *and testing* of software

- First proposed by Booch, 1991
- Adopted and popularized as part of XP

- Motivation:
  - Evade “integration hell”: Find bugs early, while still easy to fix
  - Immediate feedback on system-wide impact of local changes
  - Team has a common view of the state of a software project

# Continuous Integration: Practices

- One common (versioned) code repository
- Build automation (and short builds)
- Self-testing builds
- Regular commits
- Building every commit (usually on a CI server)
- Test & production environments as similar as possible
- Test results visible for everyone



# Continuous Delivery

- Fast and reproducible software releases
- From the first principle of the agile manifesto:

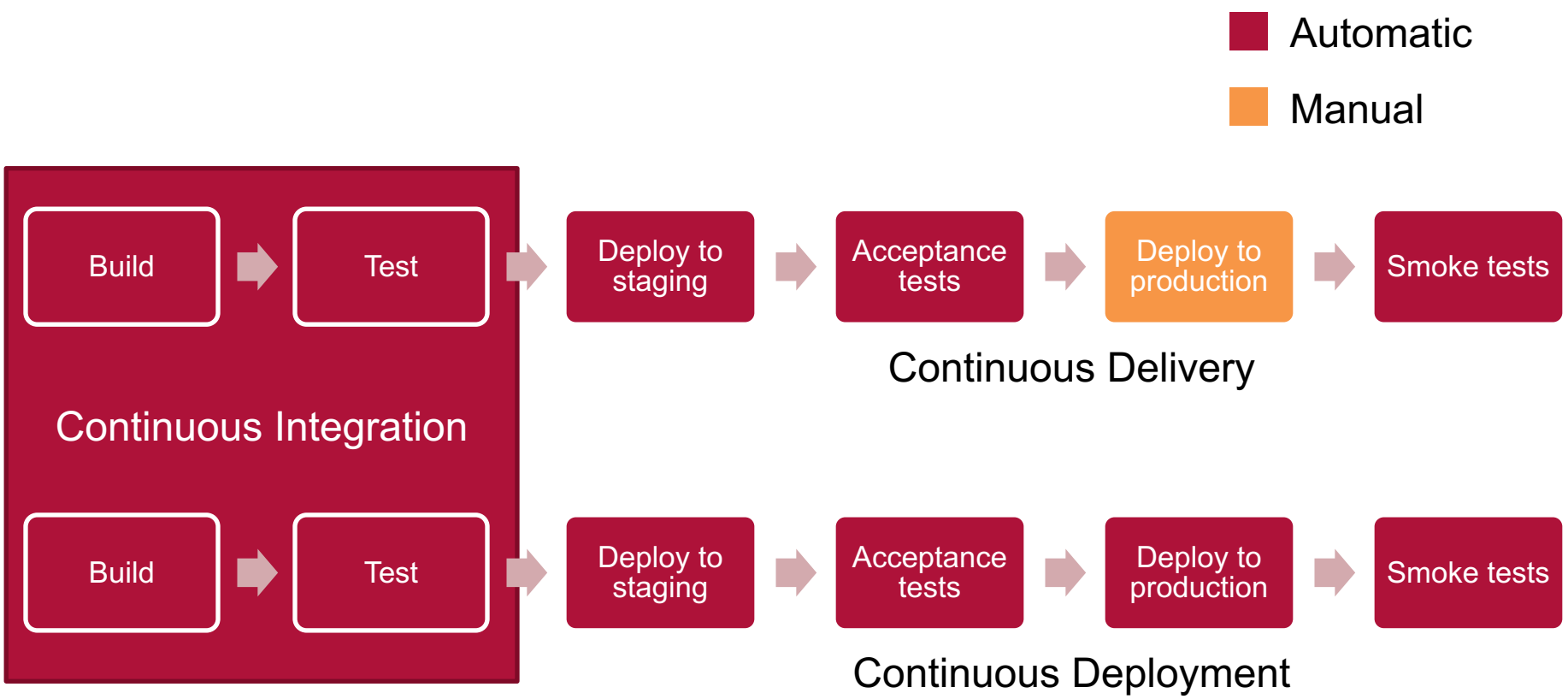
  *"Our highest priority is to satisfy the customer through early and continuous delivery of valuable software."*

- CD Metric: How long does it take to release a single-line-code-change to production? *(cycle time)*
- Business case: Software development as investment → optimizing ROI through small cycle time

# Continuous Delivery: Problems of Delivering Software

- Antipatterns
  - Deploying software manually
  - Deploying to a production-like environment only after development is complete
  - Manual configuration management of production environments

# Continuous Delivery vs. Continuous Deployment



# Continuous Delivery: Principles

- Parts of a working software application:
  - Executable code
  - Configuration
  - Host environment
  - Data
- Feedback on changes to any part
- Feedback as fast as possible: unit tests, acceptance tests, capacity tests

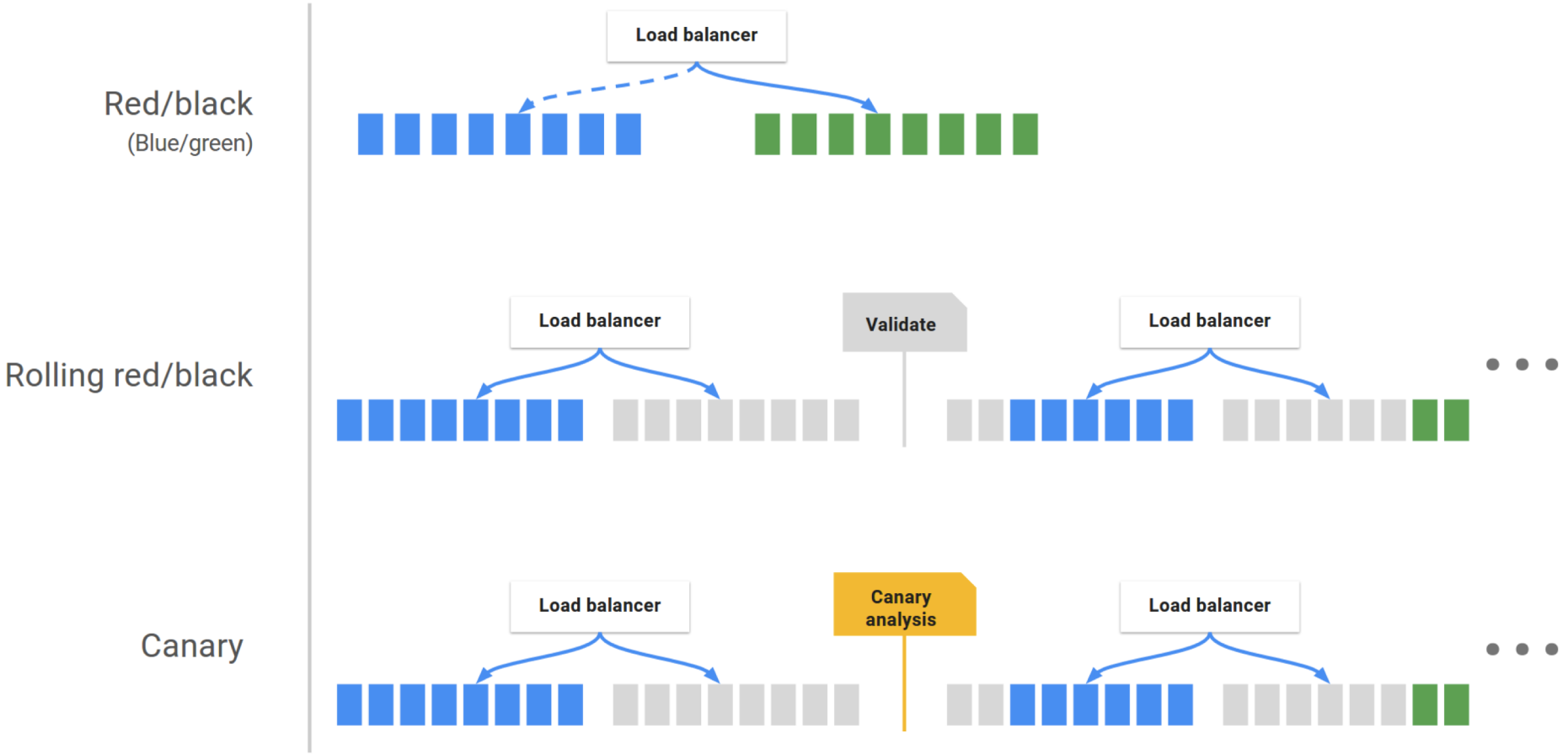
# Deployment Strategies: Blue/Green

- Strategy to deploy an upgrade
- Two production environments: Blue and green
- Only one environments is active at a time

1. Deploy to the non-active environment
2. Switch the traffic coming through the load balancer over to the new environment
3. Monitor new version, maybe switch back

- One environment always runs the last version, the other the newest version: easy roll-backs

# Deployment Strategies

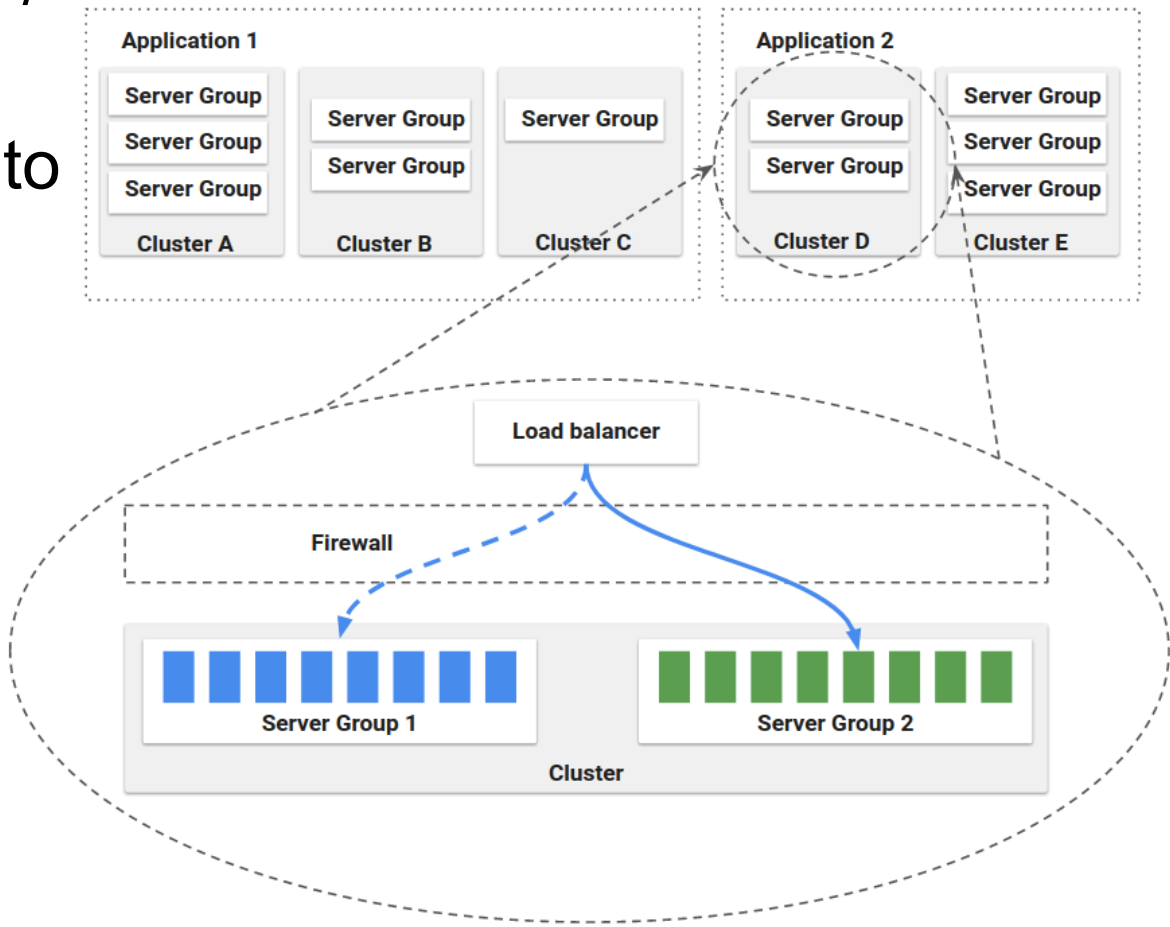


# Spinnaker

- Continuous delivery platform
- Started by Netflix, collaboration with Google
  - Successor to Asgard, a web interface to manage AWS
  - From baking to cloud deployment
- Support and common abstractions for EC2, GCE, Kubernetes, Azure, ...

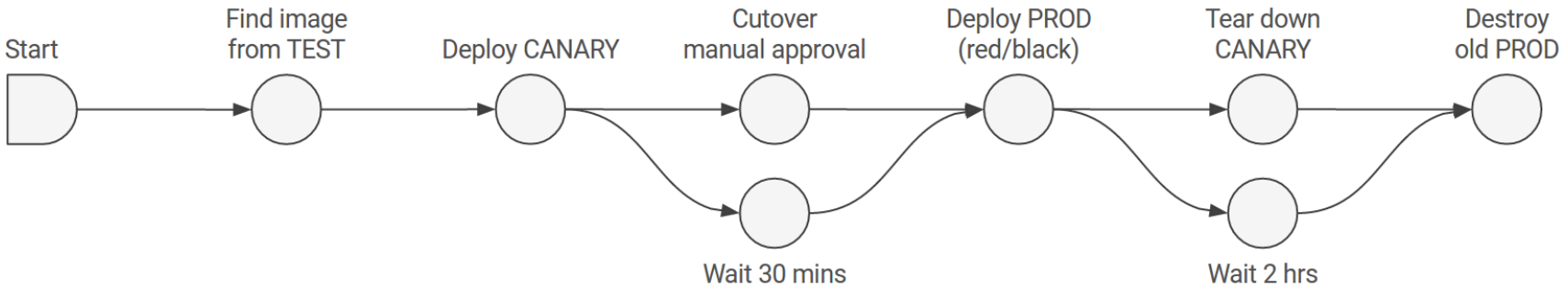
# Spinnaker

- Deploy applications / (micro)services
- Organize servers into
  - Clusters
  - Server groups

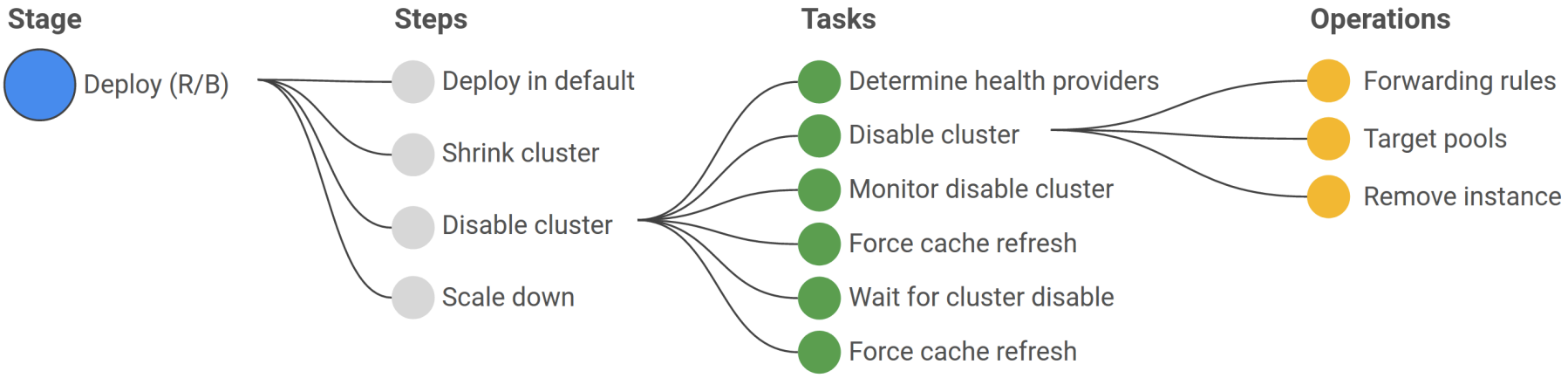


# Spinnaker Pipeline

- Deployment happens via pipelines
- Pipelines are built from stages
- Predefined stages exist for many things
  - Bake
  - Manual Judgement
  - Clone server group
  - Deploy



# Spinnaker Stage Example



# GitLab

- Includes a CI/CD system
- CI Jobs are defined in .gitlab-ci.yml

```
#gitlab-ci.yml

image: blang/latex
build:
    script:
        - latexmk –pdf
    only:
        - master
    artifacts:
        paths:
            - "*.pdf"
```

Job Name

Commands for this job; required property

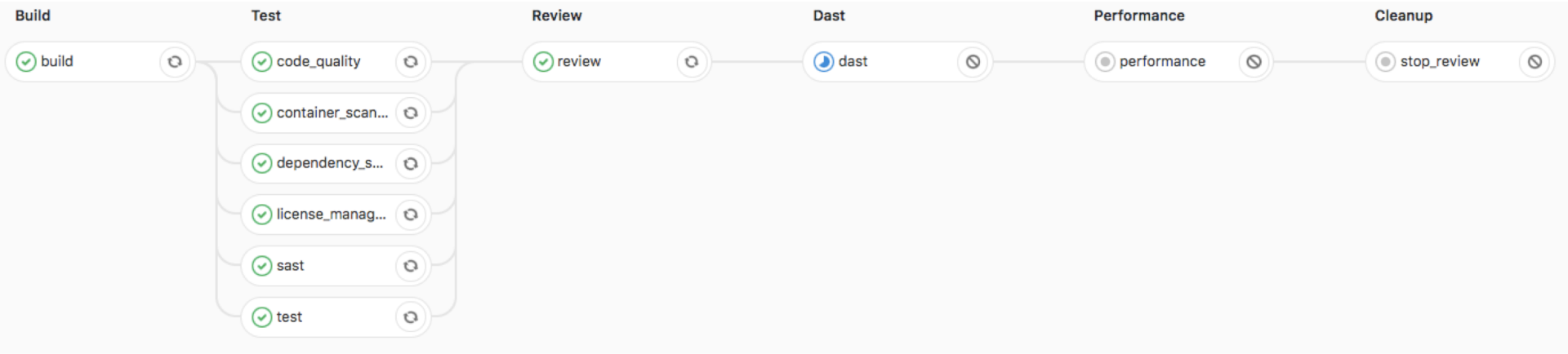
Only execute on certain branches

Save these artifacts back to server

# GitLab: Auto DevOps

- Based on Docker, Kubernetes and Gliderlabs Herokuish
- Defined as one long .gitlab-ci.yml
- Builds based on
  - Dockerfile or
  - Herokuish buildpacks
- Tests
  - Code Quality
  - Dependencies
  - Static and dynamic application security testing
  - Test via buildpacks
- Deploy to production or new review app

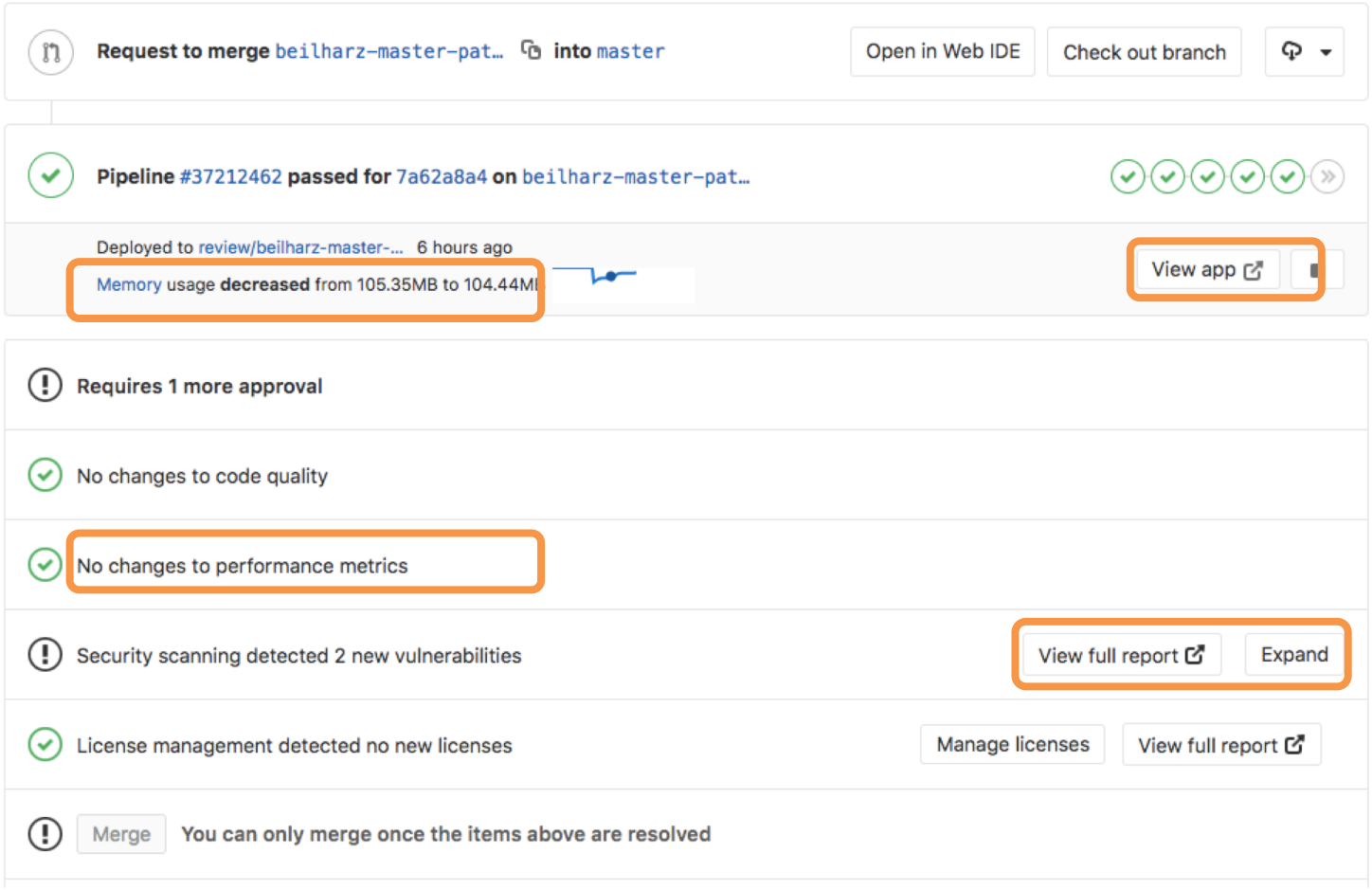
# GitLab: Auto DevOps, Example




Pipeline for Branches

# GitLab: Auto DevOps

- Integrated with the merge request flow



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# Summary

- Virtual machines and containers allow to quickly provision new servers, i.e. by using the interface of a Cloud OS
- Yet, server management and configuration remain very challenging (server sprawl, configuration drift, snowflake servers)
- Central Ideas
  - Infrastructure-as-Code: executable, understandable, and versioned descriptions of desired states as input to automation and orchestration tools
  - Cultural change to DevOps, for continuously and automatically deploying new versions to production

# References


- Humble, Jez, and David Farley. *Continuous Delivery: Reliable Software Releases through Build, Test, and Deployment Automation*. Addison Wesley, 2010.
- https://martinfowler.com/bliki/SnowflakeServer.html
- https://martinfowler.com/bliki/BlueGreenDeployment.html
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- https://www.spinnaker.io/reference/architecture/
- https://docs.gitlab.com/ee/ci/
- https://docs.gitlab.com/ee/topics/autodevops/index.html