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Cluster Resource Management

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Why do we need resource management?

Diverse applications:
- Web service
- Data processing
- Machine learning
- …

Small Application 1

Mediuem Application 2

....

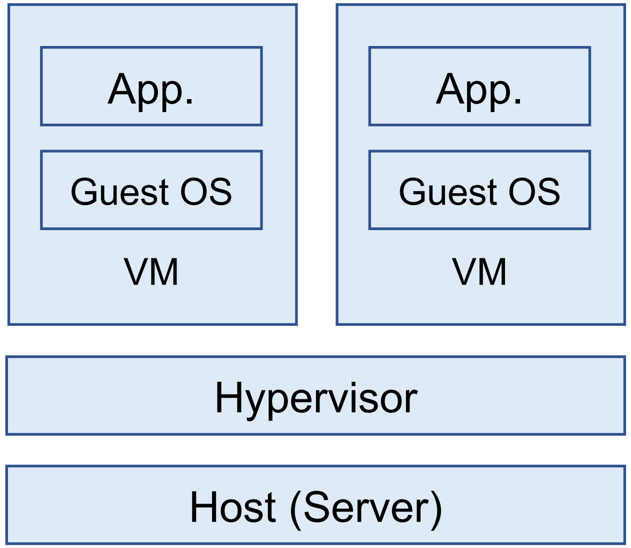
Large Application 3

"One size does not fit all"
- Virtualisation!

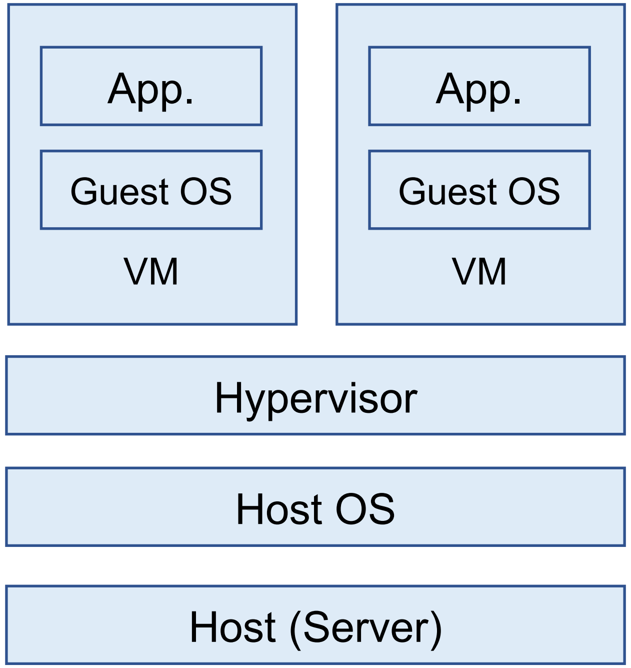
Servers in clusters:
- Homogeneous server configuration
- A server can have affluent resources (e.g., 256 CPUs, 8 GPUs, 1TB memory, 8TB SSD)

Virtual Machines

A **Virtual Machine (VM)** is an emulation of a physical computer. A **hypervisor** is a type of computer software, firmware or hardware that creates and runs VMs.



Type 1 - Native



Type 2 - Hosted

Type 1 hypervisors (Native)

- KVM, VMWare vSphere, …

Type 2 hypervisors (Hosted)

- Virtualbox, VMWare Fusion

Type 1 vs. Type 2

- Cost / Scale
- Portability

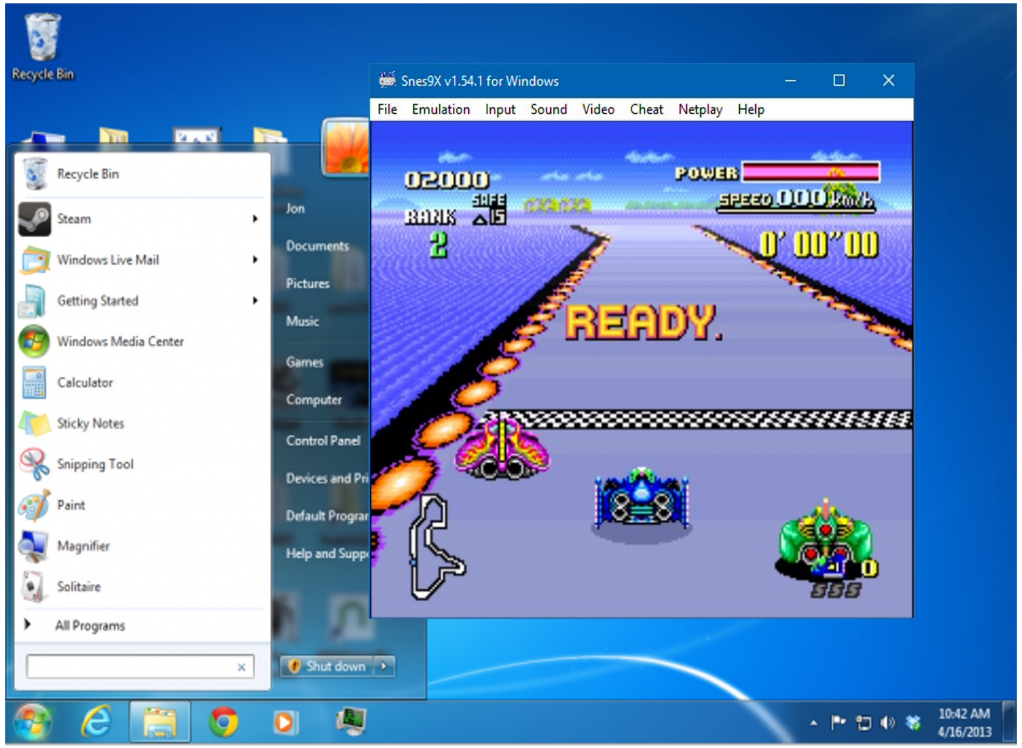
Types of Virtualisation

Different types of virtualisation shift the focus on different properties such as **execution speed**, **flexibility** and **security**.

- Software Emulation (e.g., QEMU)
- Hardware Virtualisation (e.g., KVM)
- Paravirtualisation (e.g., Xen [1] - Optional reading)

[1] Xen and the Art of Virtualization, SOSP 2003

Software Emulation

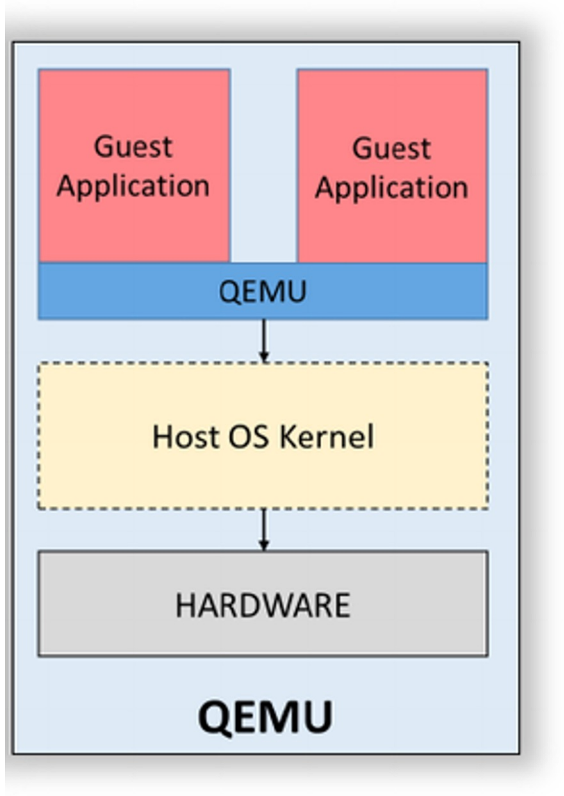


Execution of each guest instruction is emulated in software

- **highly flexible**, e.g. cross-architecture simulation
- **slow to run** - high overhead

speedup can be achieved using binary translation

Software Emulation



Qemu is a hosted hypervisor

- emulates hardware
- uses binary translation to speed up execution
- allows cross-architecture virtualisation supporting many architecture models

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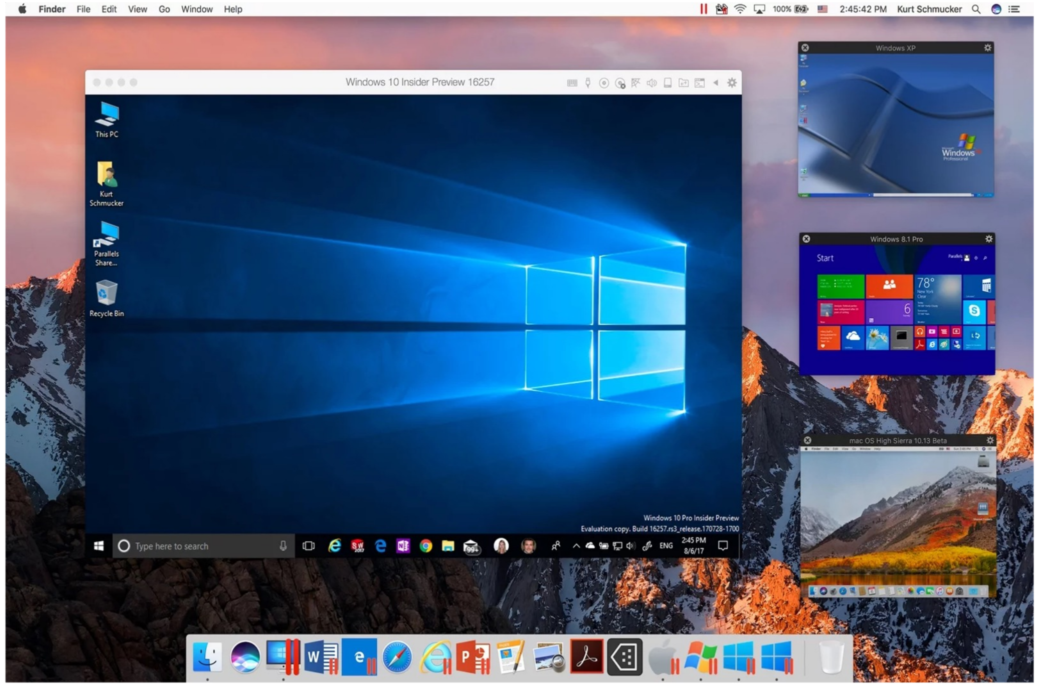
Full System or Hardware Virtualisation



Guest OS instructions can be executed natively on the host CPU

- **Near native speed**
- **Less flexible** - same architecture simulation

How can you make sure a guest OS does not disturb the underlying host when directly running on Hardware?

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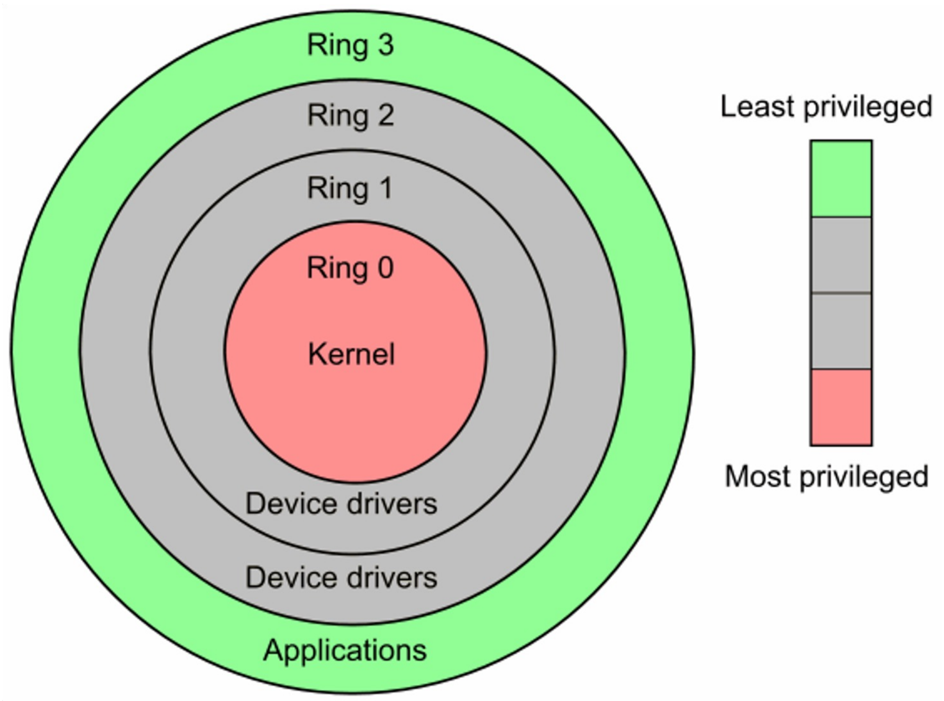
Kernel Mode vs. User Mode in Guest OS



OS Privilege Levels

Kernel Mode

- Code has unrestricted access to hardware
- Reserved for the lowest level, most trusted functions of OS

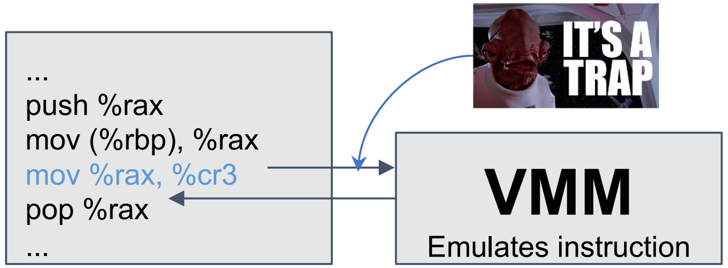
User Mode

- Code has no ability to directly access hardware or reference memory

How to handle privileged instructions?

Trap-and-Emulate

- The guest operating system runs “de-privileged”, all non-privileged instructions execute natively on the host.
- All privileged instructions trap to the Virtual Machine Manager (VMM) which implements the ”Hypervisor”
- VMM emulates these privileged operations.
- Guest resumes execution after emulation.

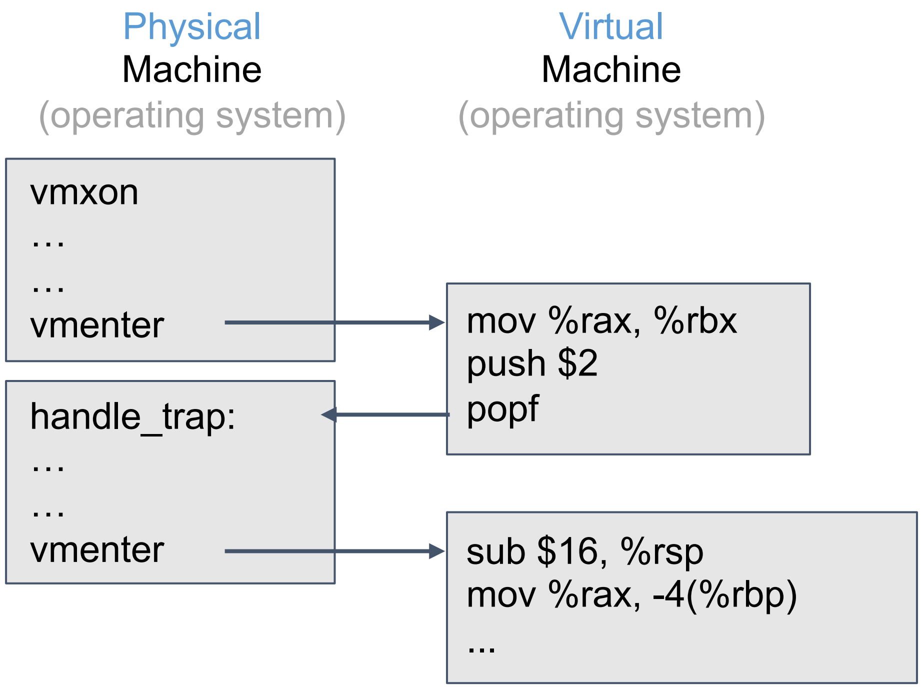


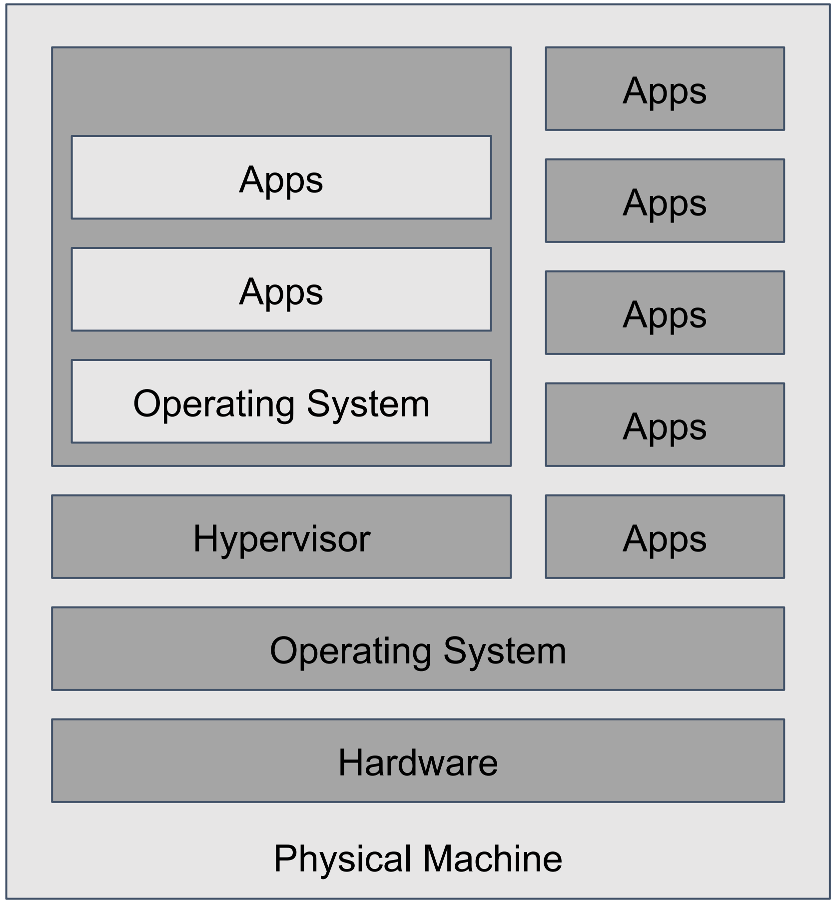
Problem: Not all privileged x86 instructions trap properly!

Virtualising x86

- Originally x86 was not "classically" virtualisable.
  - Some privileged instructions did not "trap", and so could not be emulated correctly.
- Interpretation is too slow
- Code Patching leaves traces of virtualisation
- Binary Translation is better but still incurs overhead.
- Since 2005, x86 processors now support virtualisation in hardware.
  - Intel-VT
  - AMD-V
- This enables trap-and-emulate style virtualisation.
- Unmodified operating systems can run natively on host machines.

Virtualising x86 on modern hardware





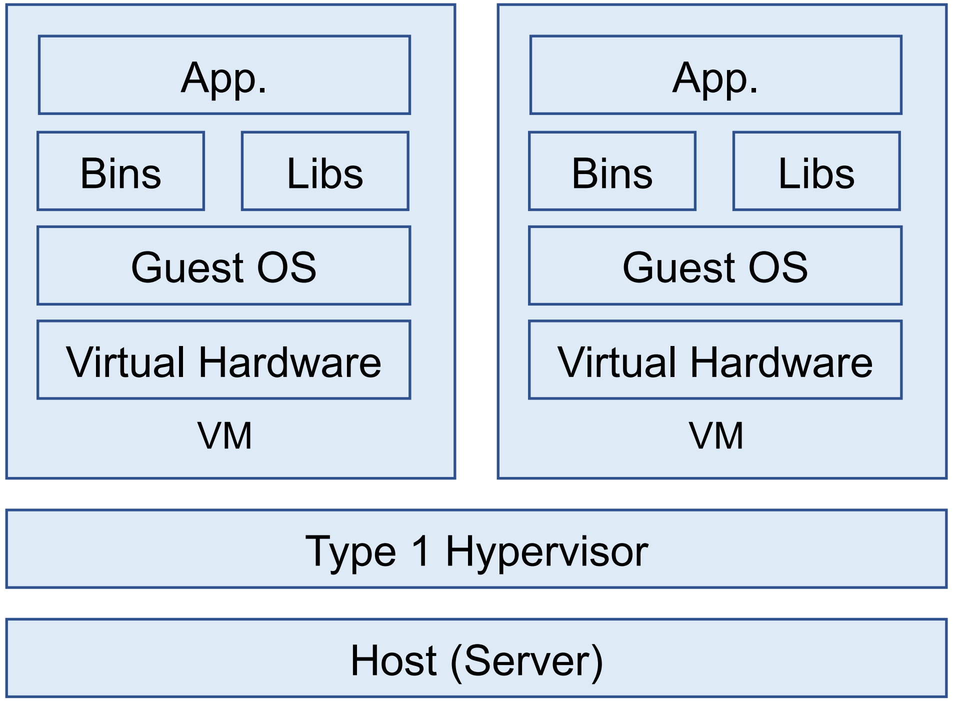
Benefits and Pricing Models of Cloud VMs

Benefits

- Cost savings
- Flexibility + Speed
- Lower downtime
- Security

Pricing models

- Pay-as-you-go
- Spot/Transient instances
- Reserved instances



Questions?

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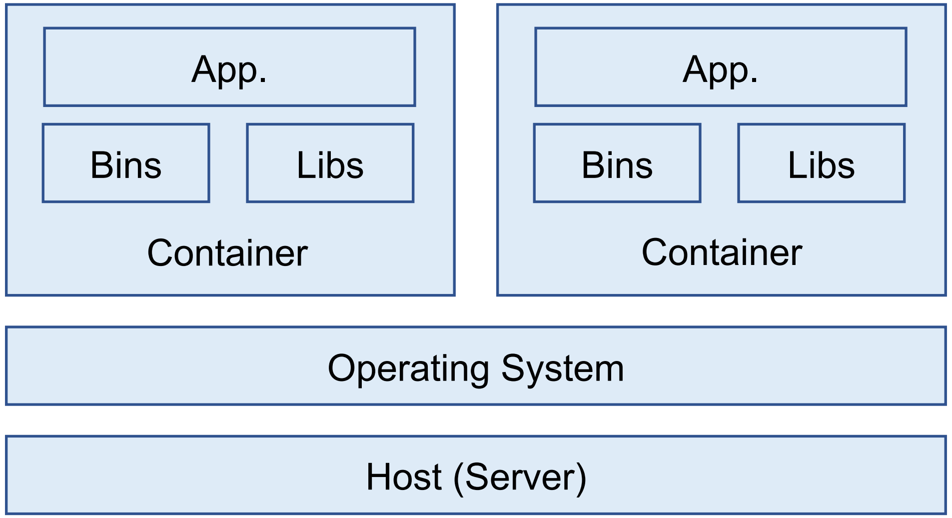
Containers – OS-Level Virtualisation

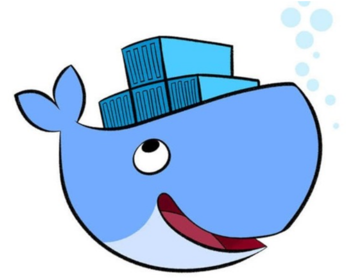
Containers are a lighter-weight, more agile way of handling virtualization — since they don't use a hypervisor, you can enjoy faster resource provisioning and speedier availability of new applications.



How can containerisation be achieved?

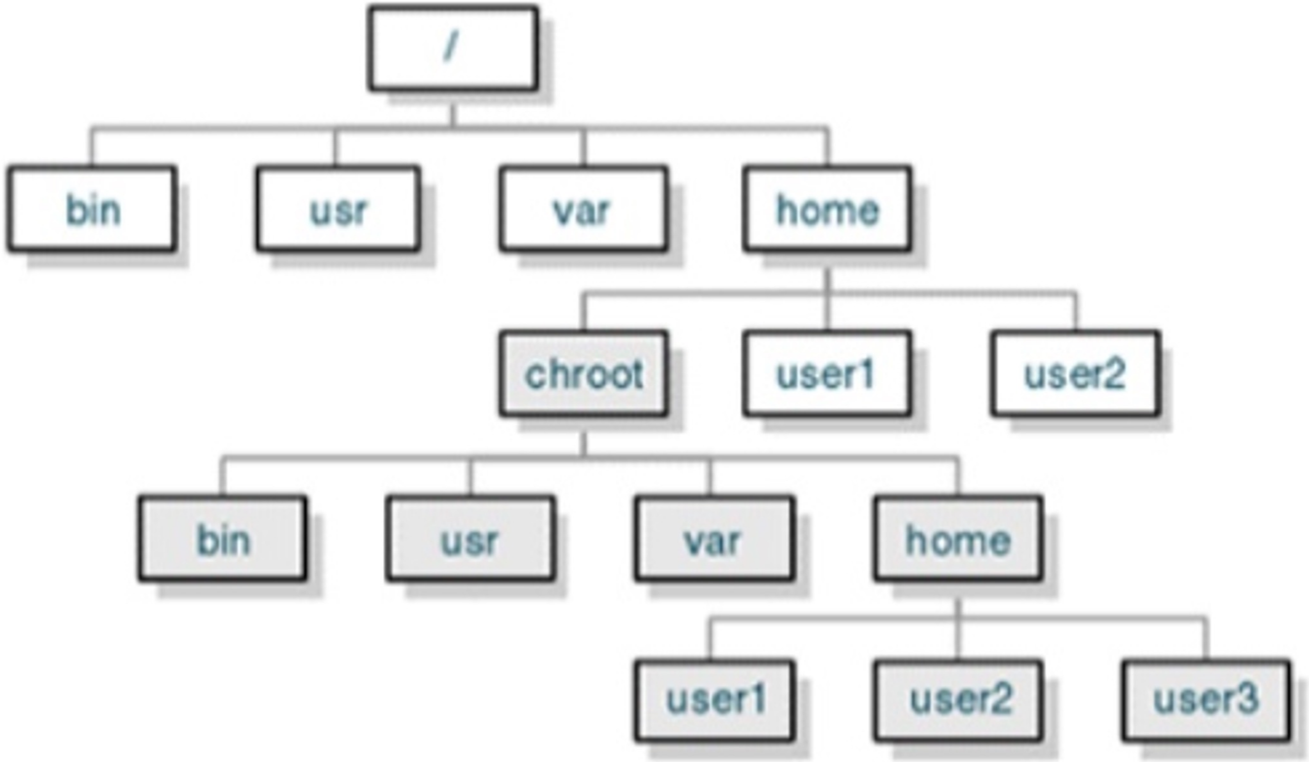
- provide user space abstraction for each container
  - isolated view at the system for container content

- provide a container management system to manage container instances and standardised access to contents



Chroot

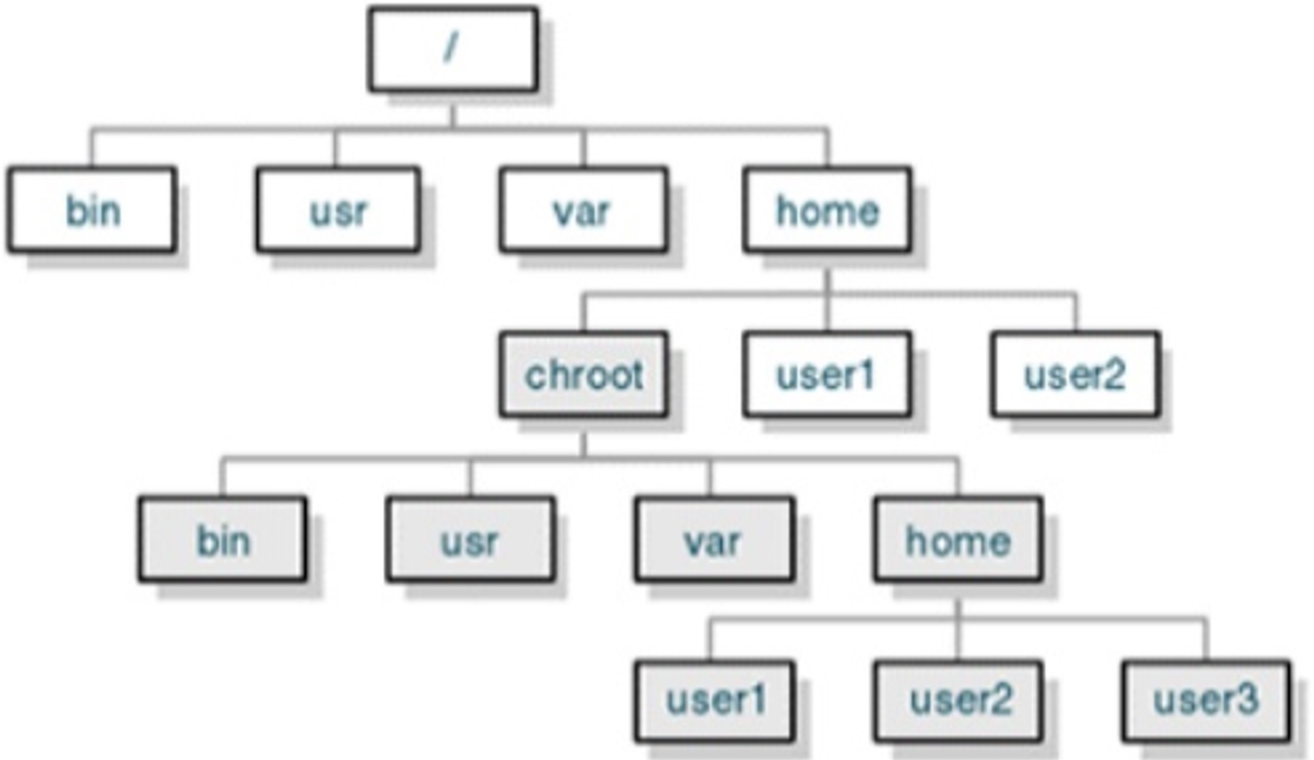
- Linux processes have a root directory
- chroot changes the root directory for a new process and its children
- such a jailed process cannot access files outside its root directory structure



Chroot

Limitations

- you can break out of a chroot jail with root privileges
- no resource limits
  - memory, cpu
- no isolation
  - network, devices, processes



Not a secure sandbox!

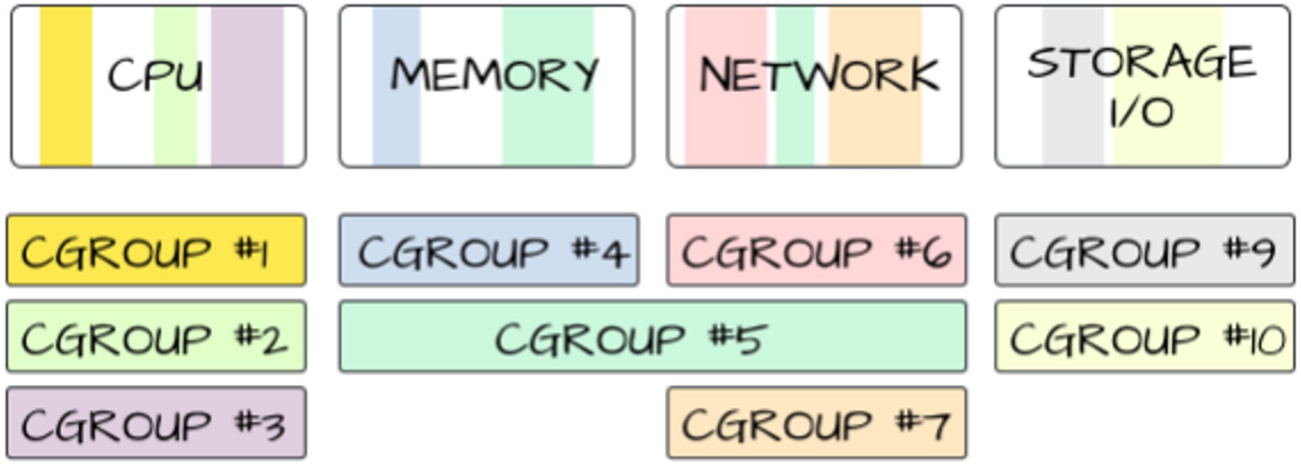
How to limit resources and achieve isolation?

- **control groups** - limit what you can use
  - resource control
- **namespaces** - limit what you can see
  - isolated view at system

Resource control through cgroups

Linux kernel feature to limit account and isolate resource usage for groups of processes

- cpu
- memory
- disk I/O
- devices
- network
- etc. ...

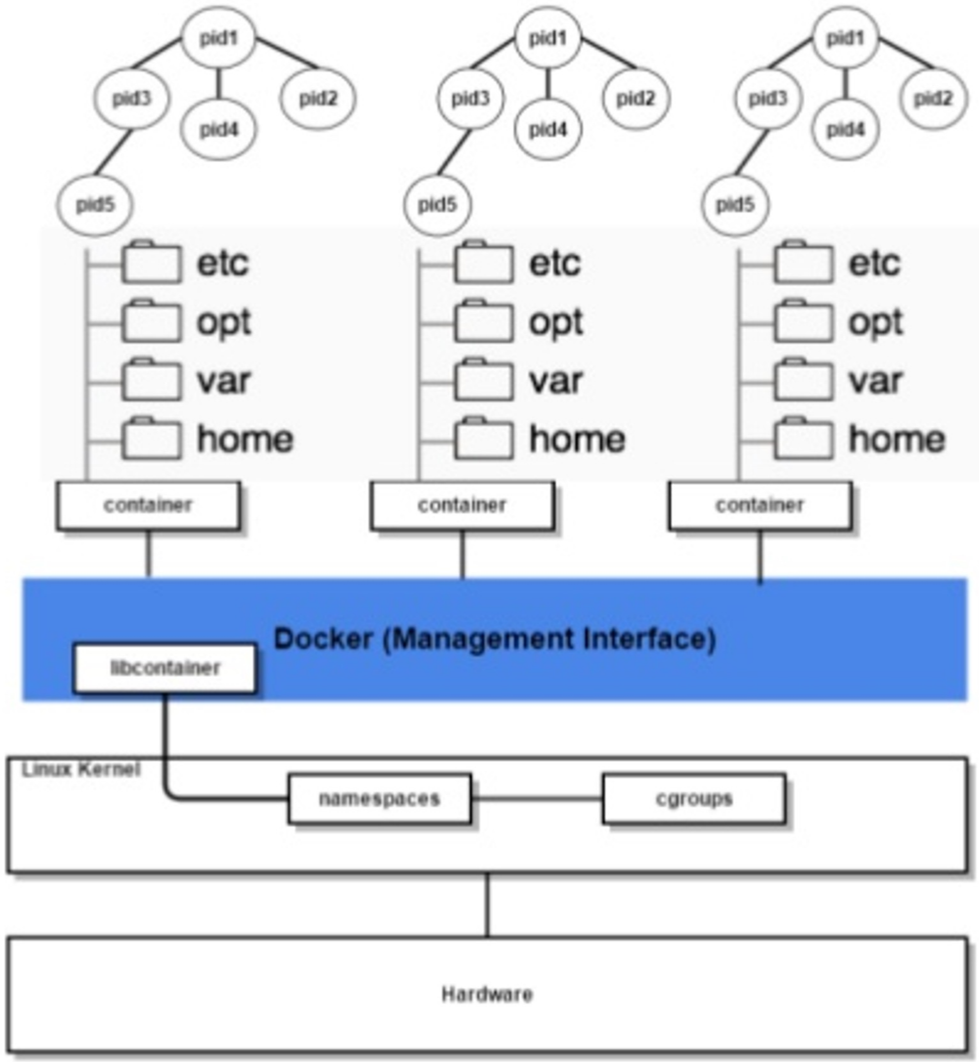


Isolation through namespaces

Namespaces provide containers with their own view of the underlying Linux system.

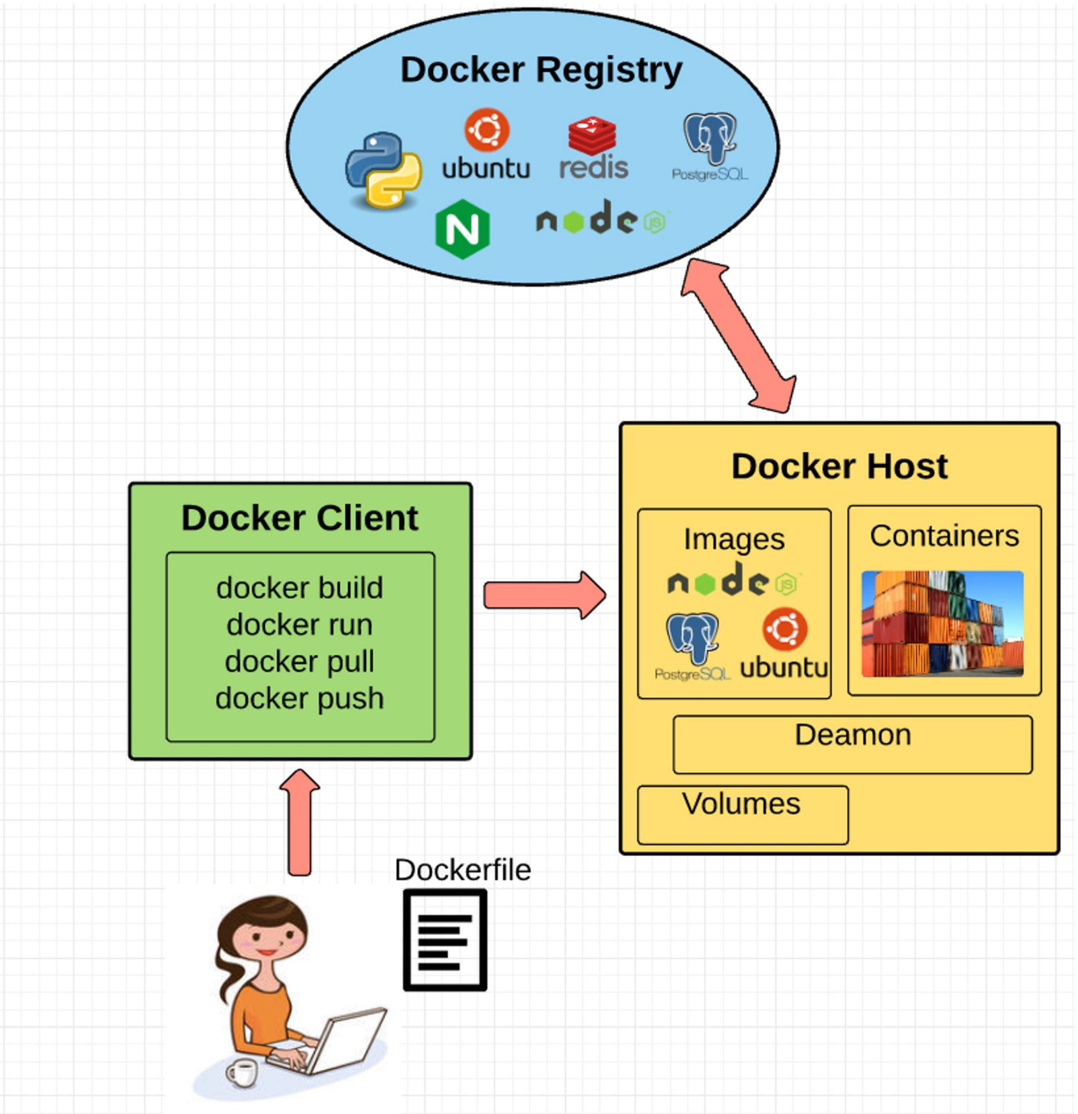
- **NET**: IP addresses, IP routing tables, port numbers
- **PID**: process IDs
- **MNT**: system mounts
- **UTS**: host name
- **IPC**: inter process communication resources
- **USER**: user ids

Docker Container under the hood



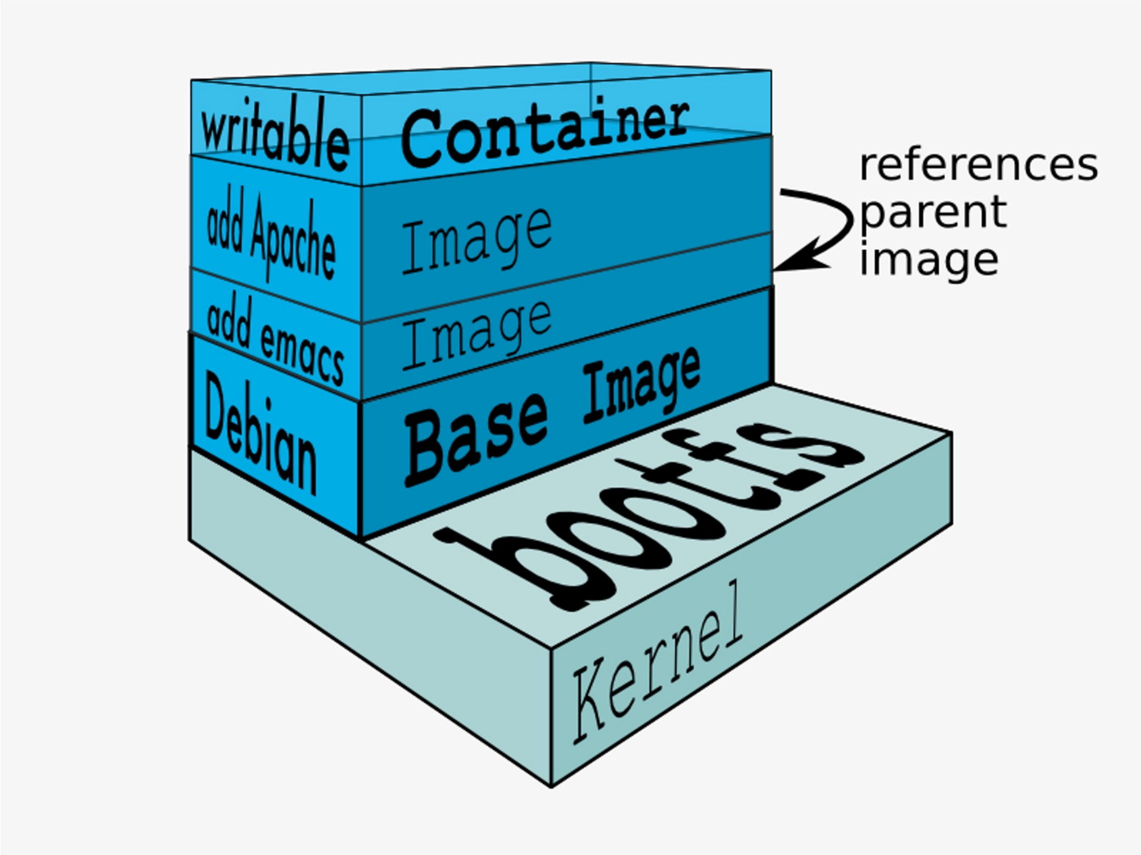
The Docker Eco-System

- **Docker Engine**: docker runtimer containing: Deamon, Client and API for remote access
- **Dockerfile**: contains instructions to build a docker image
- **Image:** layered read-only file system described by dockerfile
- **Volumes:** shared "data" part of a container
- **Container:** wraps application code and dependencies as described in image
- **Docker Registry:** server side app to share and distribute images



Docker Images

- Docker file describes docker image
- start with a base image
- layer dependencies on top
- Union file system



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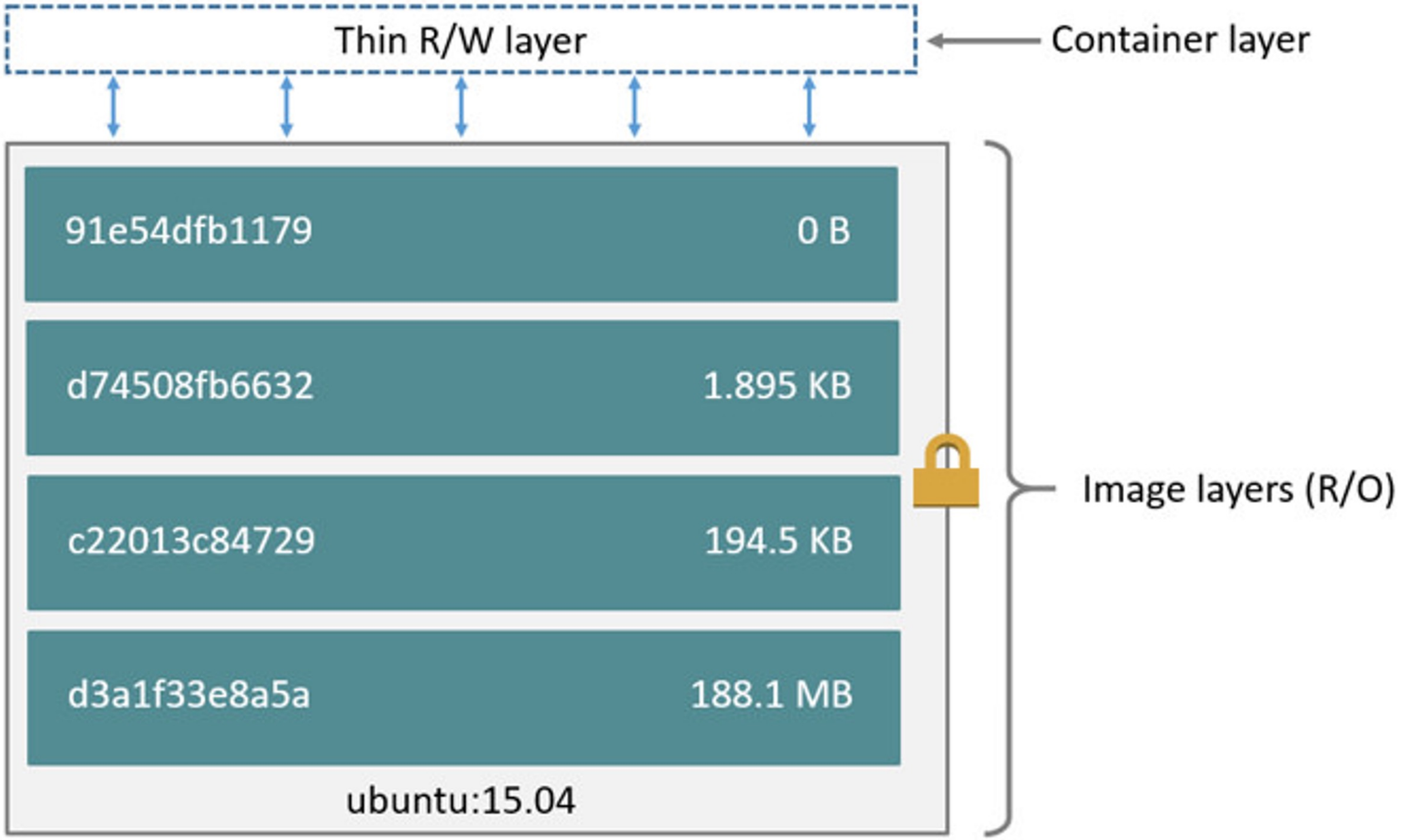
Docker Images

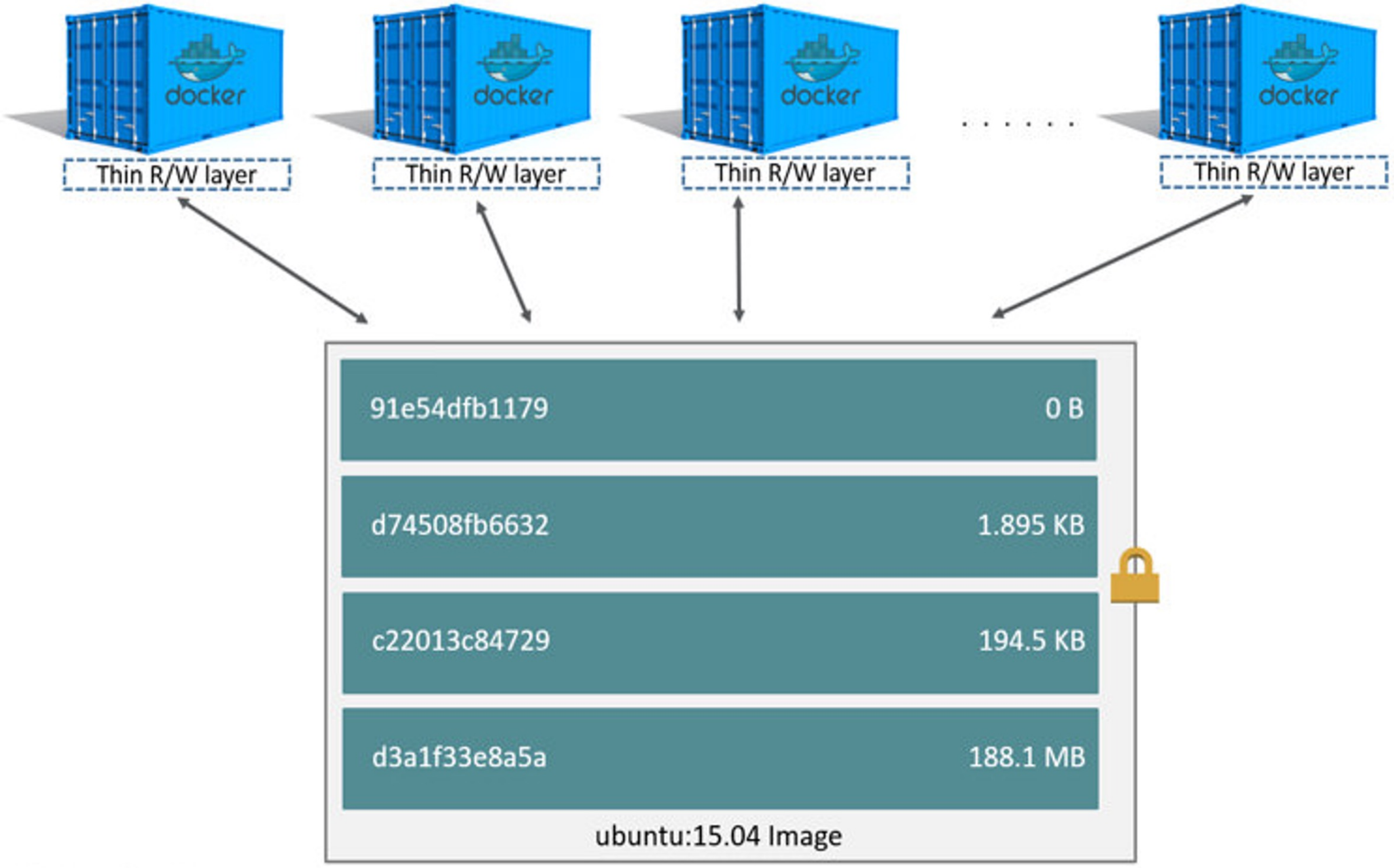
Docker File

```
FROM ubuntu:15.04
COPY . /app
RUN make /app
CMD python /app/app.py
```



Container
(based on ubuntu:15.04 image)

Docker Images



VMs vs. Containers

VM

- Heavy-weight in terms of layers of system software (GBs in size)
- Take minutes to start
- Allows multiple OS to execute concurrently
- Provide a high level of isolation
  - Fault
  - Resource

Containers

- Light-weight (MBs in size)
- Take seconds to start
- Share a common OS and kernel
- Don't offer the same level of isolation
  - A kernel crash caused by one guest will affect everyone else
- The interface offered is at the level of system calls and ABI – much more prone to security problems than the API exposed by the Hypervisor

How to choose virtualisation?

	Without Container	With Conatiner
Without VM	Bare-mantal	Contrainer
With VM	VM	Container in VM

Considerations

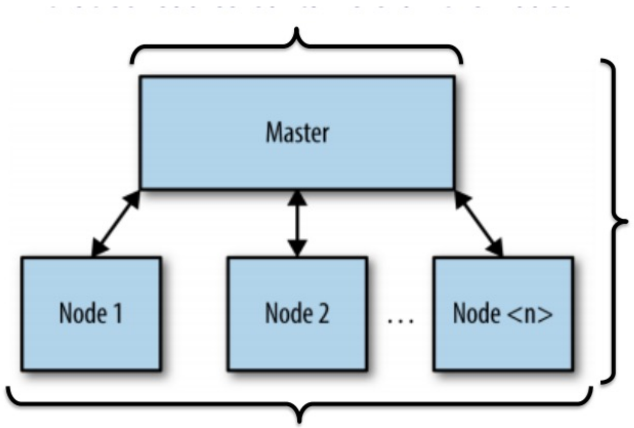
- Virtualisation costs
  - Some hardware does not support virtualisation
  - Virtualisation is not free
- Scale
  - What is the best way to communicate? NVLink, shared memory, socket, REST
- Security
  - What if your container or VM is compromised?
- Isolation
  - Multi-user vs. Single-user with multi-job
- Flexibility
  - Multi-OS vs. Single-OS

Questions?

Kubernetes - Container Orchestration

Kubernetes — also known as “k8s” — is a container orchestration platform for scheduling and automating the deployment, management, and scaling of containerized applications.

- Masters run special coordinating software that schedules containers on the nodes.

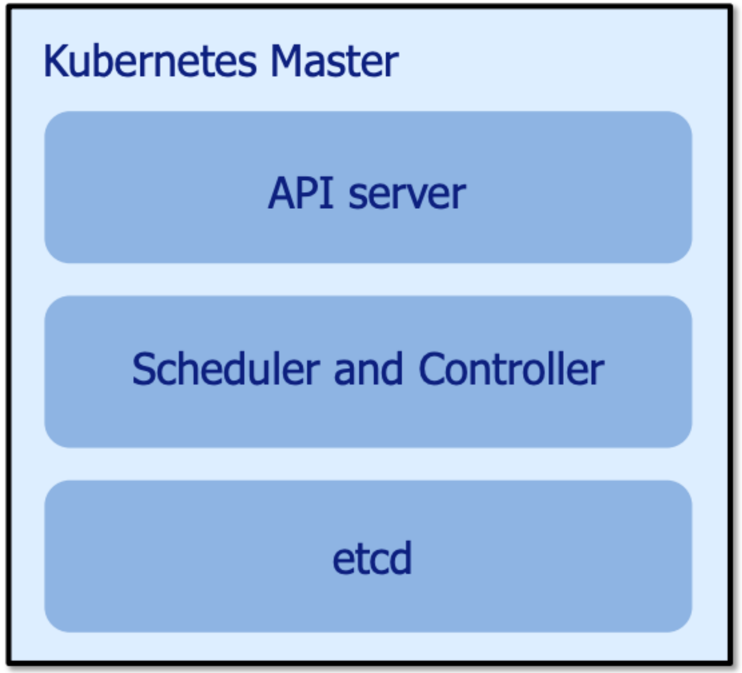


A bunch of machines sit networked together in many data centres.

The collection of masters and nodes is known as a cluster.

- Worker machines are called nodes.
- Each machine hosts 1+ Docker container.

The Master

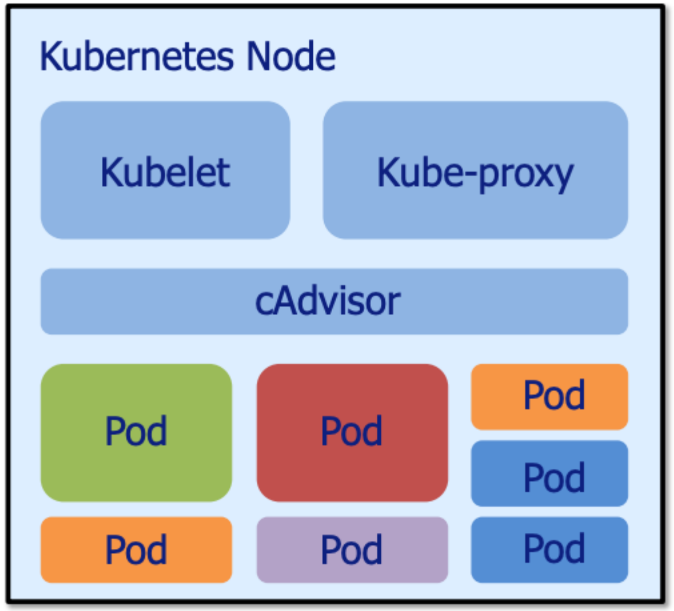


1. **API server**
    1. Nearly all components of the master and nodes accomplish their tasks by making API calls.
    2. These calls are handled by the API server running on the master.

2. **Scheduler and Controller Manager**
    1. Processes that schedule containers (i.e., pods) onto target nodes.
    2. Make sure that the correct number of these things are always running.

3. **etcd – distributed reliable key-value store**
    1. Responsible to keep and replicate the current configuration and run state of the cluster.
    2. Implemented as light-weight distributed KV store.

The nodes

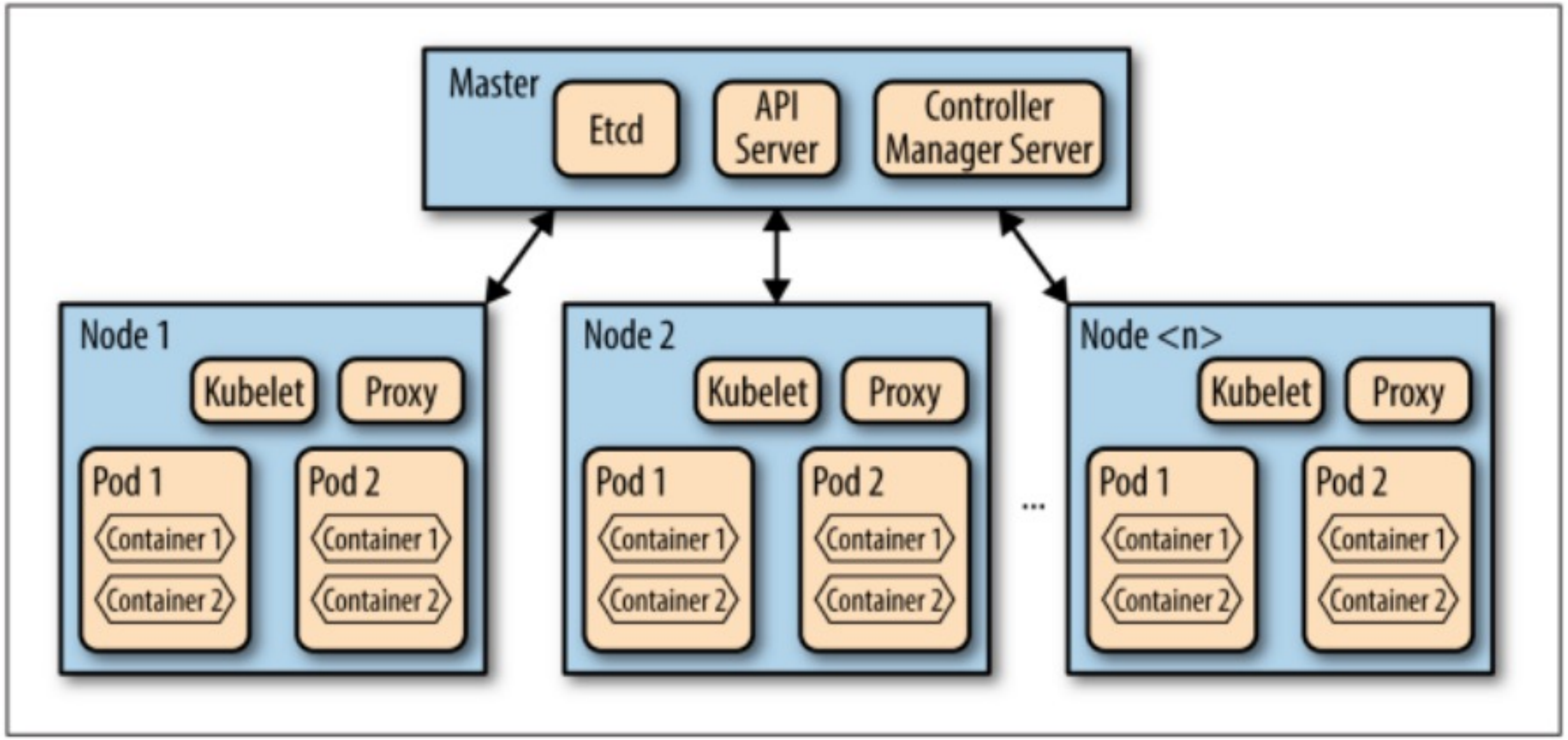


1. **Kubelet**
   1. special background process (daemon)
   2. execute commands from the master to create, destroy, and monitor containers on that host.

2. **Kube-proxy**
   1. simple network proxy to separate the IP address of target container from the name of the service it provides.

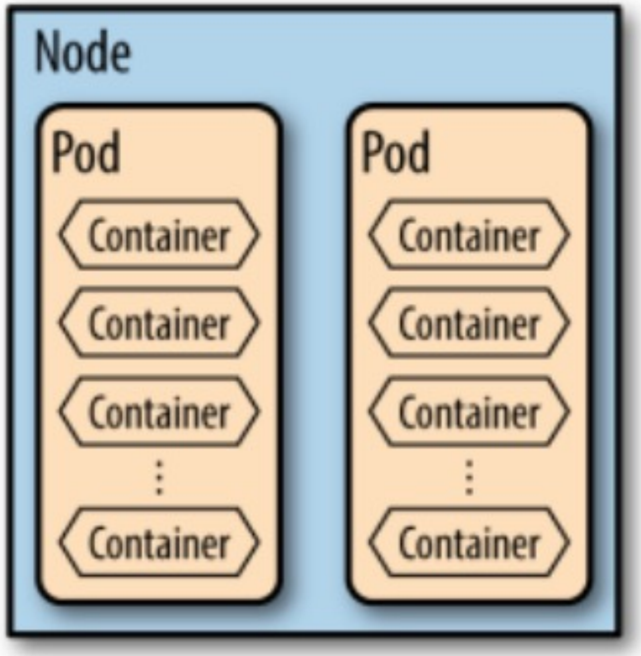
3. **cAdvisor (optional)**
   1. is a special daemon that collects, aggregates, processes, and exports information about the running containers.

Full picture of a Kubenetes cluster



src: Kubernetes – Scheduling the future at Cloud Scale, David K. Rensin

Pod



- A pod is a collection of containers that are bundled and scheduled together because they share a common resource – usually a file system or IP address.
- Pod serves as Kubernetes' core unit of management.
- Pods make up the difference between containerization and virtualization by making it possible to run multiple dependent processes together.
- At runtime, pods can be scaled by creating replica sets.

Why not just run multiple programs in a single container?

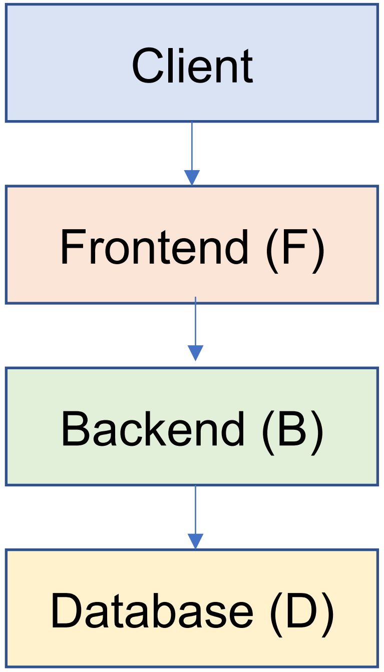
1. **Transparency**
   1. 1+ process in a container – you are responsible for monitoring and managing the resources each uses.
   2. By separating logical units of work into separate containers – Kubernetes can manage for you
   3. Makes things easier to debug and fix.

2. **Deployment and Maintenance**
   1. Individual containers can be rebuilt and redeployed by you whenever you make a software change.
   2. This decoupling of deployment dependencies will make your development and testing faster.
   3. It also makes it super easy to rollback in case there is a problem.

3. **Efficiency**
   1. The infrastructure takes on more responsibility, so the containers can be lighter-weight.

Cluster Management Example with k8s

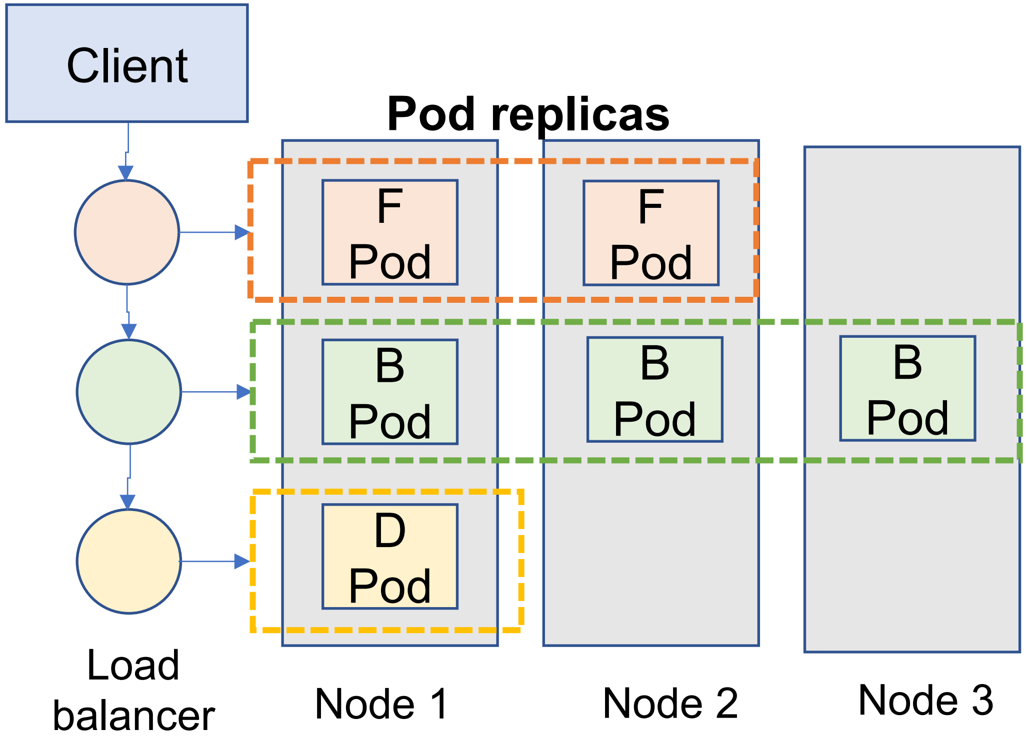
Web Service (Logical View)



K8s functionalities:

- Deployment
- Rollouts
- Service discovery
- Storage & networking
- Load balancing & scaling
- Failure recovery

Web Service (Physical View)



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