Virtualization: VMs and Containers

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Why do we need multiple servers?

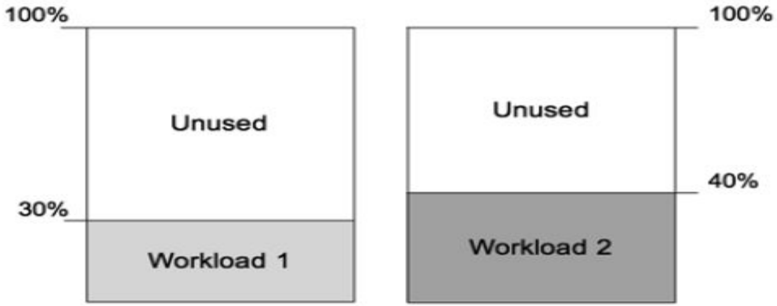
- Multiple applications
- Better performance
- Application isolation
- Load balancing
- Backup
- Failover

Server Consolidation

Server Sprawl: Server sprawl is a term used to describe the rapid and uncontrolled growth of servers in an organization. It occurs when an organization deploys too many servers for its needs, leading to inefficiencies and increased costs

- Multiple server take more space and energy comparing to the workload

- Underutilized machines



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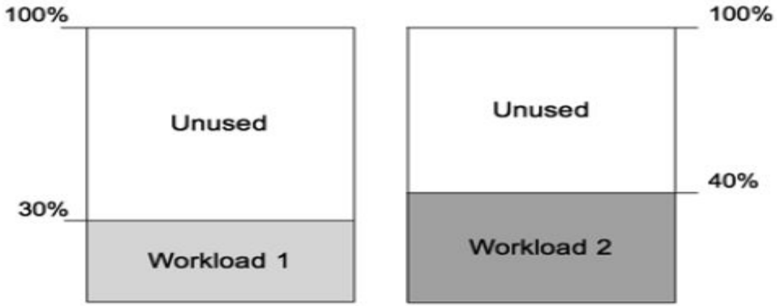


Why do we need multiple servers?

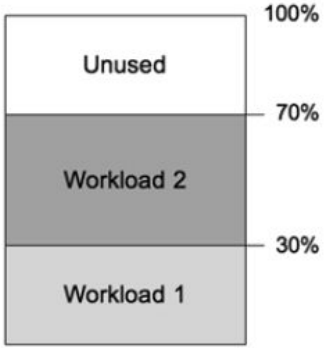
Server Sprawl (Cont.)

How about maintenance cost, energy consumption, and environmental issues?

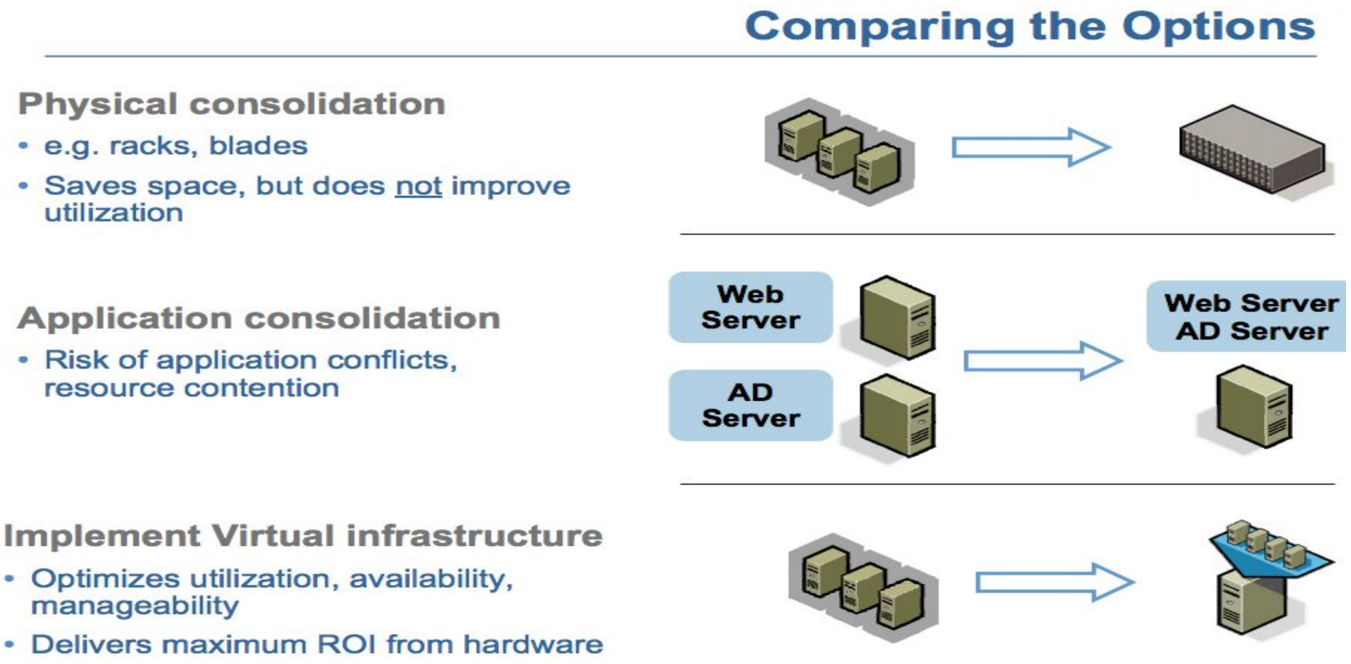
Server Consolidation

- Server consolidation is the process of reducing the number of servers in an organization in order to improve efficiency, reduce costs, and increase scalability.

- This can be achieved through a number of different strategies such as virtualization, cloud computing, application consolidation, automation & scripting, and capacity planning.



Server Consolidation (Cont.)



Comparing the Options

Physical consolidation

- e.g. racks, blades
- Saves space, but does not improve utilization

Application consolidation

- Risk of application conflicts, resource contention

Implement Virtual infrastructure

- Optimizes utilization, availability, manageability
- Delivers maximum ROI from hardware

Server Consolidation (Cont.)

What should be the strategy for server consolidation?

- Determine Priorities (Environmental, Financial, and Operational)
- Identify existing servers actual requirement through workload monitoring
- Buy/use powerful servers
- Enable virtualization
- Pilot consolidation project
- Migrate applications

Workload

Amount of processing given to system in a certain time duration.

Common bottlenecks due to workload?

Workload (Cont.)

Amount of processing given to system in a certain time duration.

Common bottlenecks due to workload?

- CPU
- I/O
- Memory
- Network Bandwidth

Workload (Cont.)

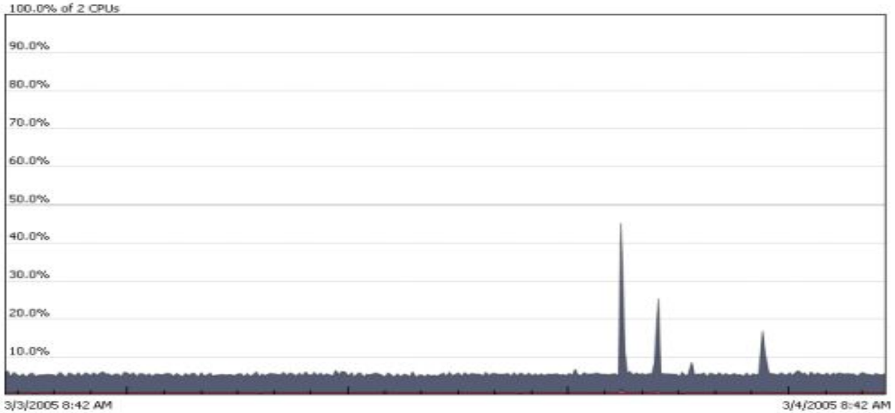
- Database Workload
  - Memory
  - I/O
  - Bandwidth/throughput

- File Server Workload
  - I/O
  - Bandwidth

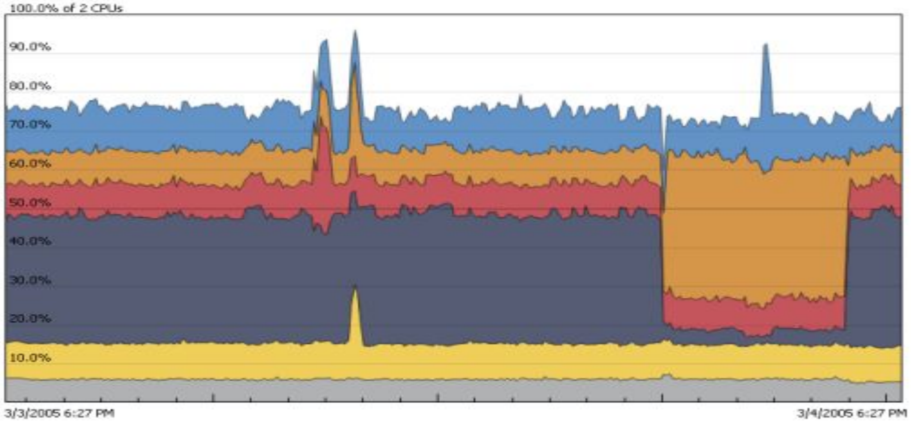
- Web Server Workload
  - CPU
  - Memory
  - Bandwidth

Server Consolidation

Before Virtualization



After Virtualization



Virtualization improved server utilization

Source: http://www.progression.com/casestudies/studies/VMware_Server_Consolidation_and_Containment.pdf

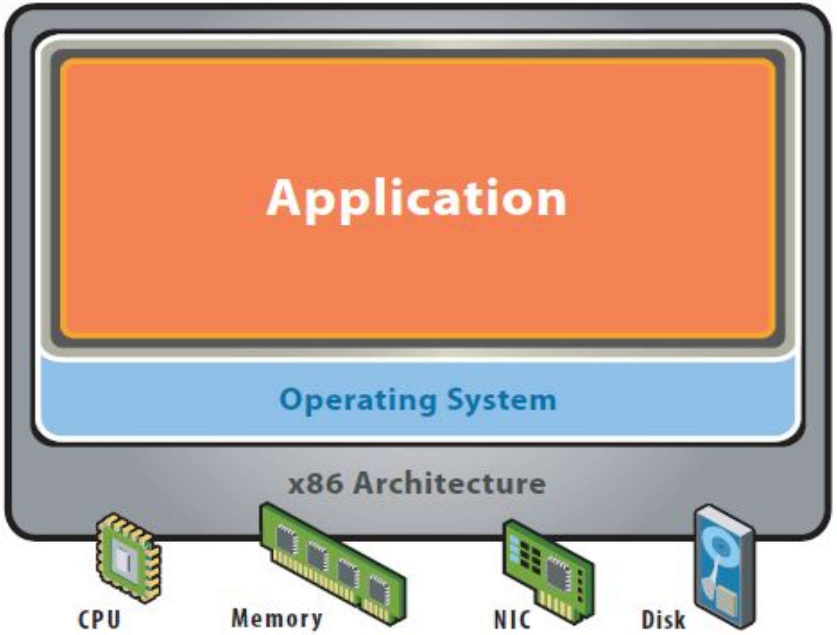
Virtualization

This part of presentation contains data and images from VMWare official material availably publically.

Virtualization

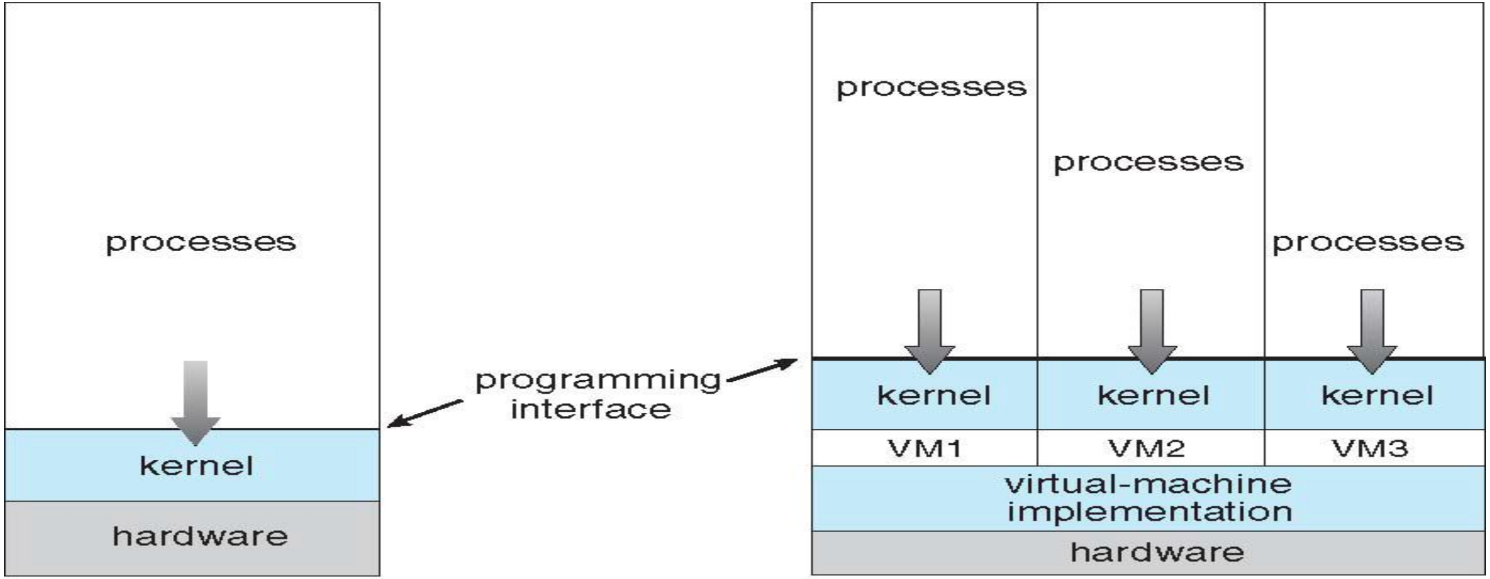
- **1960’s:** first track of virtualization
  - Time and resource sharing on expensive mainframes
  - IBM VM/370
- **Late 1970’s and early 1980’s:** became unpopular
  - Cheap hardware and multiprocessing OS
- **Late 1990’s:** became popular again
  - Wide variety of OS and hardware configurations
  - VMWare
- **Since 2000:** an important technology
  - Cloud Computing
  - Containers

Without Virtualization



- Single OS image per machine
- Software and hardware tightly coupled
- Running multiple applications on same machine often creates conflict
- Inflexible and costly infrastructure

Virtualization



(a) Non virtual machine

(b) virtual machine

Source: Silberschatz, Galvin, and Gagne (2008), Fig 2.17

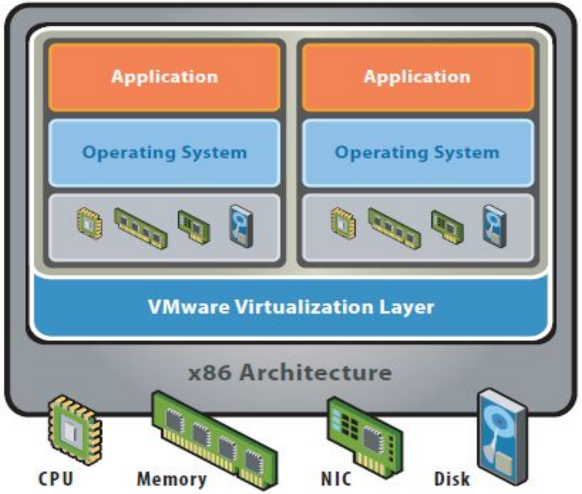
Virtualization (Cont.)

- Virtualization allows multiple operating systems to execution simultaneously on a physical machine.

- Virtualization achieved through a virtual machine monitor (VMM).

- VMM is also known as hypervisor.

- VMMs are responsible for keeping track of all activities performed by virtual machines.



Key Definitions

- Host Operating System:
  - The operating system actually running on the hardware
  - Together with *virtualization layer*, it simulates environment for …

- Guest Operating System:
  - The operating system running in the simulated environment i.e., the one we are trying to isolate

X86 Privilege Ring

- On the X86 architecture, four privilege levels are available and known as Ring 0, 1, 2, and 3.
- Privilege levels are used to manage hardware resources to the applications and OS.
- Ring 0 is the most privilege level and Ring 3 is the least privilege level.
- Usually, OS instructions execute in Ring 0 and user application instructions execute in Ring 3.

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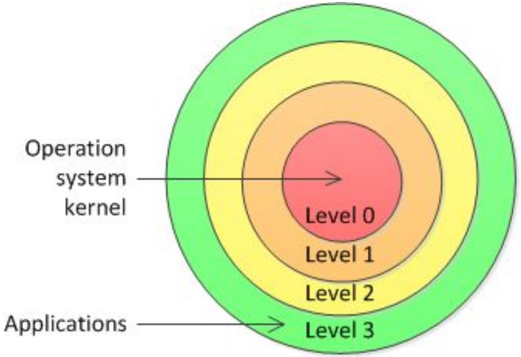
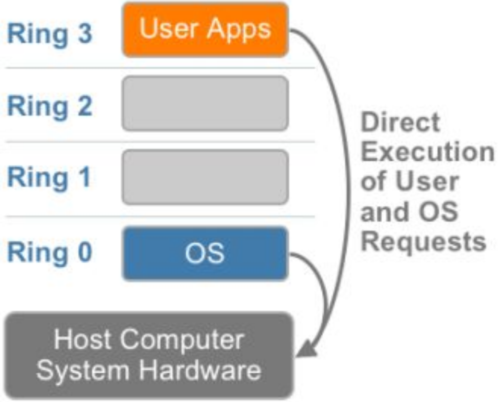



Ring 3
User Apps
Ring 2
Ring 1
Ring 0
OS
Direct Execution of User and OS Requests
Host Computer System Hardware

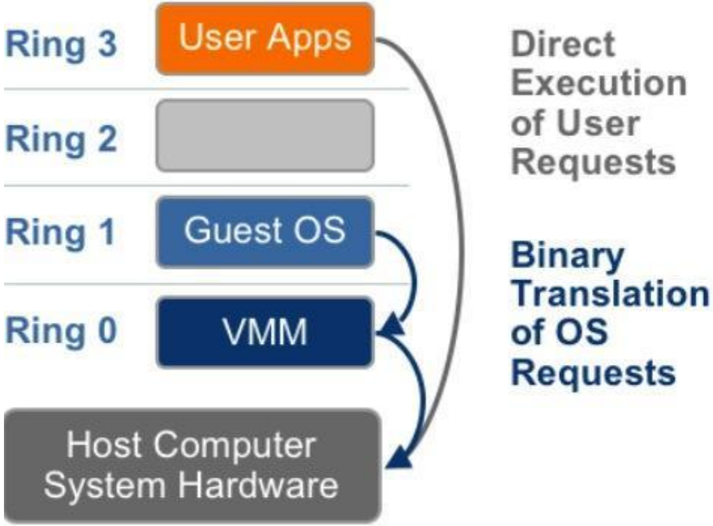
Virtualization Types

- Full Virtualization

- Paravirtualization

Full Virtualization

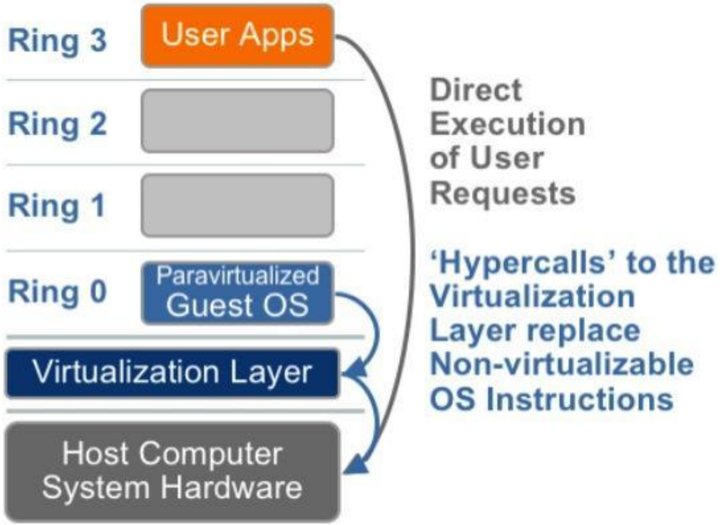
- Full virtualization is achieved using direct execution of user application code and binary translation of OS requests.



Ring 3
User Apps
Ring 2
Ring 1
Guest OS
Ring 0
VMM
Host Computer System Hardware
Direct Execution of User Requests
Binary Translation of OS Requests

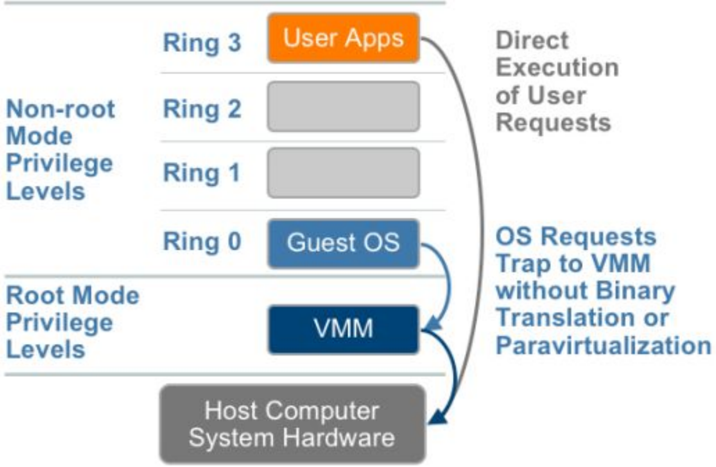
OS Assisted Virtualization or Paravirtualization

- Paravirtualization is achieved through the modification of a guest OS.
- Paravirtualization involves modifying the OS kernel to replace nonvirtualizable instructions with hypercalls that communicate directly with the virtualization layer hypervisor.


Ring 3
User Apps
Ring 2
Ring 1
Ring 0
Paravirtualized Guest OS
Virtualization Layer
Host Computer System Hardware
Direct Execution of User Requests
'Hypercalls' to the Virtualization Layer replace Non-virtualizable OS Instructions

Hardware Assisted Virtualization

- Hardware vendors are rapidly embracing virtualization and developing new features to simplify virtualization techniques.
- Intel Virtualization Technology (VT-x) and AMD's AMD-V which both target privileged instructions with a new CPU execution mode feature that allows the VMM to run in a new root mode below ring 0
- It helps to reduce binary translation overhead in full virtualization


Ring 3
User Apps
Direct Execution of User Requests
Non-root Mode Privilege Levels
Ring 2
Ring 1
Ring 0
Guest OS
OS Requests Trap to VMM without Binary Translation or Paravirtualization
Root Mode Privilege Levels
VMM
Host Computer System Hardware

Full virtualization vs Paravirtulization

- Paravirtualization is different from full virtualization, where the unmodified OS does not know it is virtualized and sensitive OS calls are trapped using binary translation at run time. In paravirtualization, these instructions are handled at compile time when the non-virtualizable OS instructions are replaced with hypercalls.

- The advantage of paravirtualization is lower virtualization overhead, but the performance advantage of paravirtualization over full virtualization can vary greatly depending on the workload. Most user space workloads gain very little, and near native performance is not achieved for all workloads.

- As paravirtualization cannot support unmodified operating systems (e.g. Windows 2000/XP), its compatibility and portability is poor.

Virtualization Platforms

- Xen
- VMWare
- KVM
- Virtual Box

Xen

- Open-source
- Paravirtualization
- It allows several guest operating systems to execute on one physical machine simultaneously.
- The first guest OS is known as Domain-0 in Xen terminology.
- Domain-0 automatically boots whenever Xen software boots.
- Users need to login on Domain-0 to execute other guest operating systems

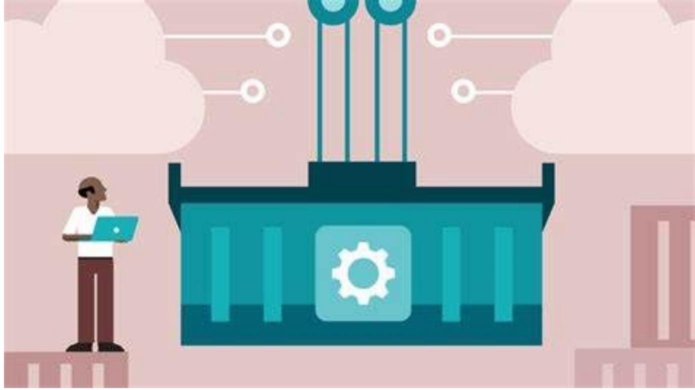
VMWare

- Commercial

- VMWare Workstation, VMWare Server, VMWare ESX

- Highly portable

- Any OS can be install



Containers

The Challenge

Multiplicity of Stacks

Static website
nginx 1.5 + modsecurity + openssl + bootstrap 2

User DB
postgresql + pgv8 + v8

Queue
Redis + redis-sentinel

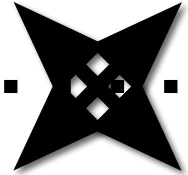
Analytics DB
hadoop + hive + thrift +

Background workers
Python 3.0 + celery + pyredis + libcurl + ffmpeg + libopencv + nodejs + phantomjs

Web frontend
Ruby + Rails + sass + Unicorn

API endpoint
Python 2.7 + Flask + pyredis + celery + psycopg + postgresql-client

Do services and apps interact appropriately?

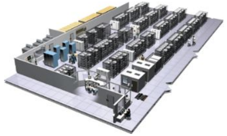


Multiplicity of hardware environments

Development VM

QA server

Public Cloud



Production Cluster

Disaster recovery

Customer Data Center

Contributor's laptop

Production Servers

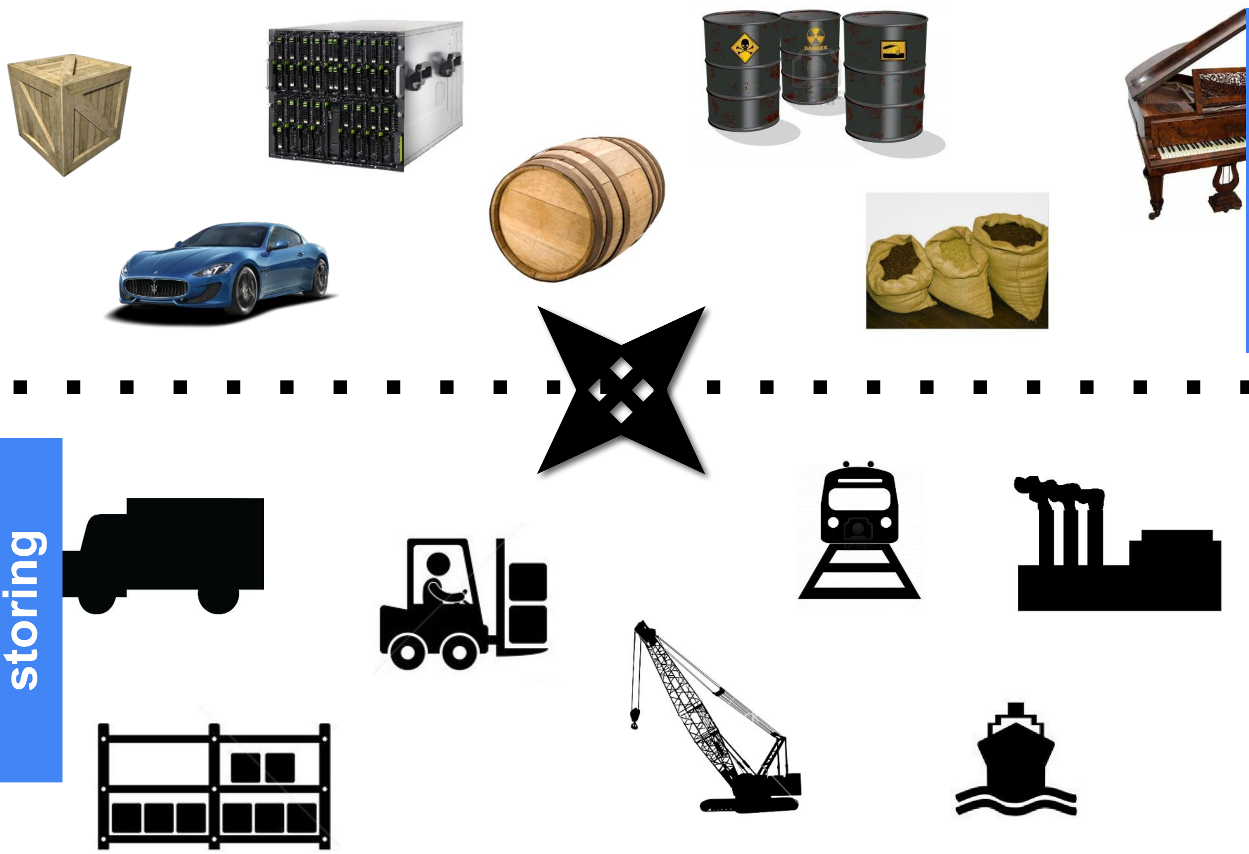
Can I migrate smoothly and quickly?

Results in N X N compatibility nightmare

Static website	?	?	?	?	?	?	?
Web frontend	?	?	?	?	?	?	?
Background workers	?	?	?	?	?	?	?
User DB	?	?	?	?	?	?	?
Analytics DB	?	?	?	?	?	?	?
Queue	?	?	?	?	?	?	?
	Development VM	QA Server	Single Prod Server	Onsite Cluster	Public Cloud	Contributor's laptop	Customer Servers

Cargo Transport Pre-1960

Multiplicity of Goods

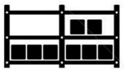


Do I worry about how goods interact (e.g. coffee beans next to spices)

Multipilicity of methods for transporting/ storing

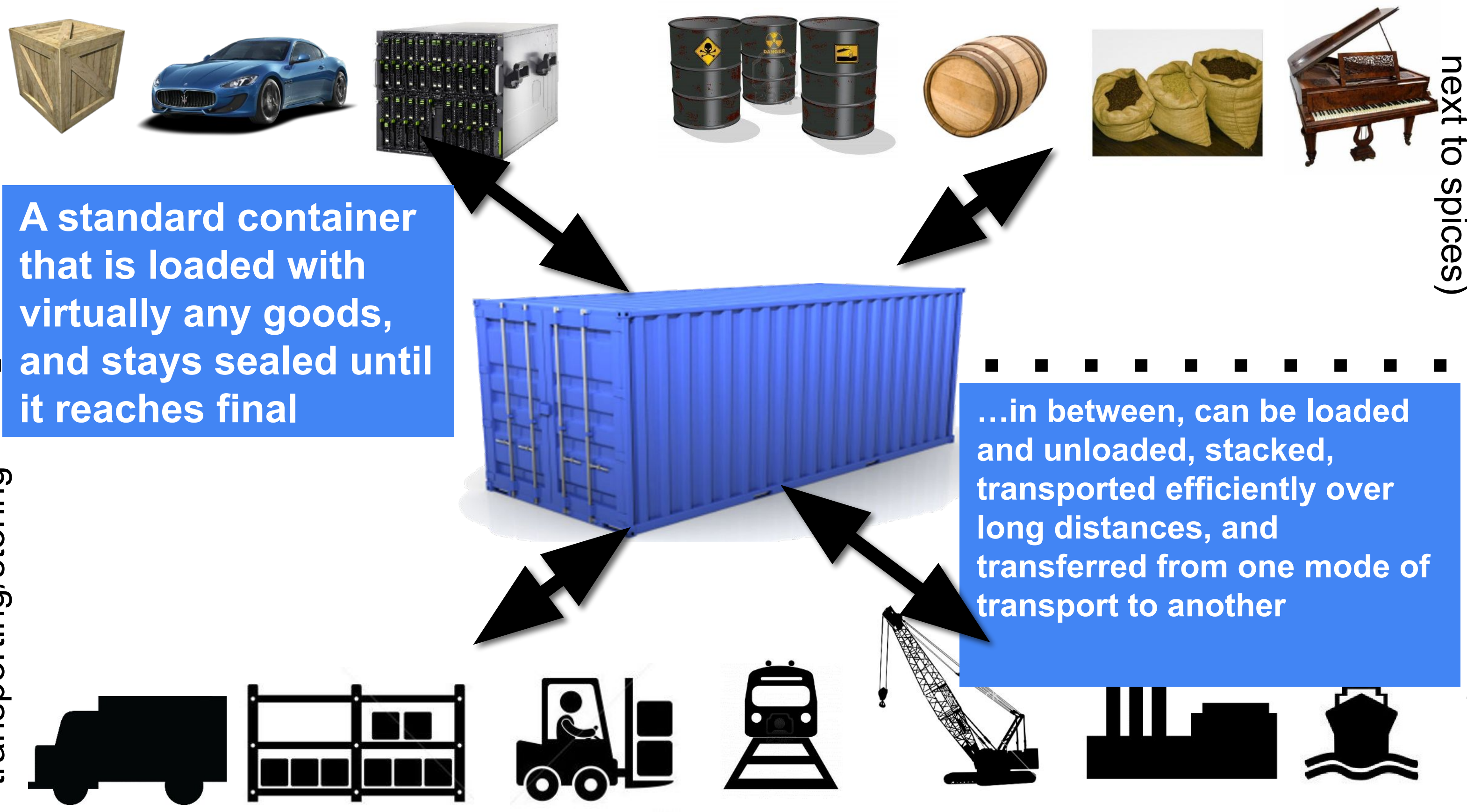
Can I transport quickly and smoothly (e.g. from boat to train to truck)

NxN Matrix?

	?	?	?	?	?	?	?
	?	?	?	?	?	?	?
	?	?	?	?	?	?	?
	?	?	?	?	?	?	?
	?	?	?	?	?	?	?
	?	?	?	?	?	?	?
							

Solution: Shipping Container

Multiplicity of Goods



A standard container that is loaded with virtually any goods, and stays sealed until it reaches final

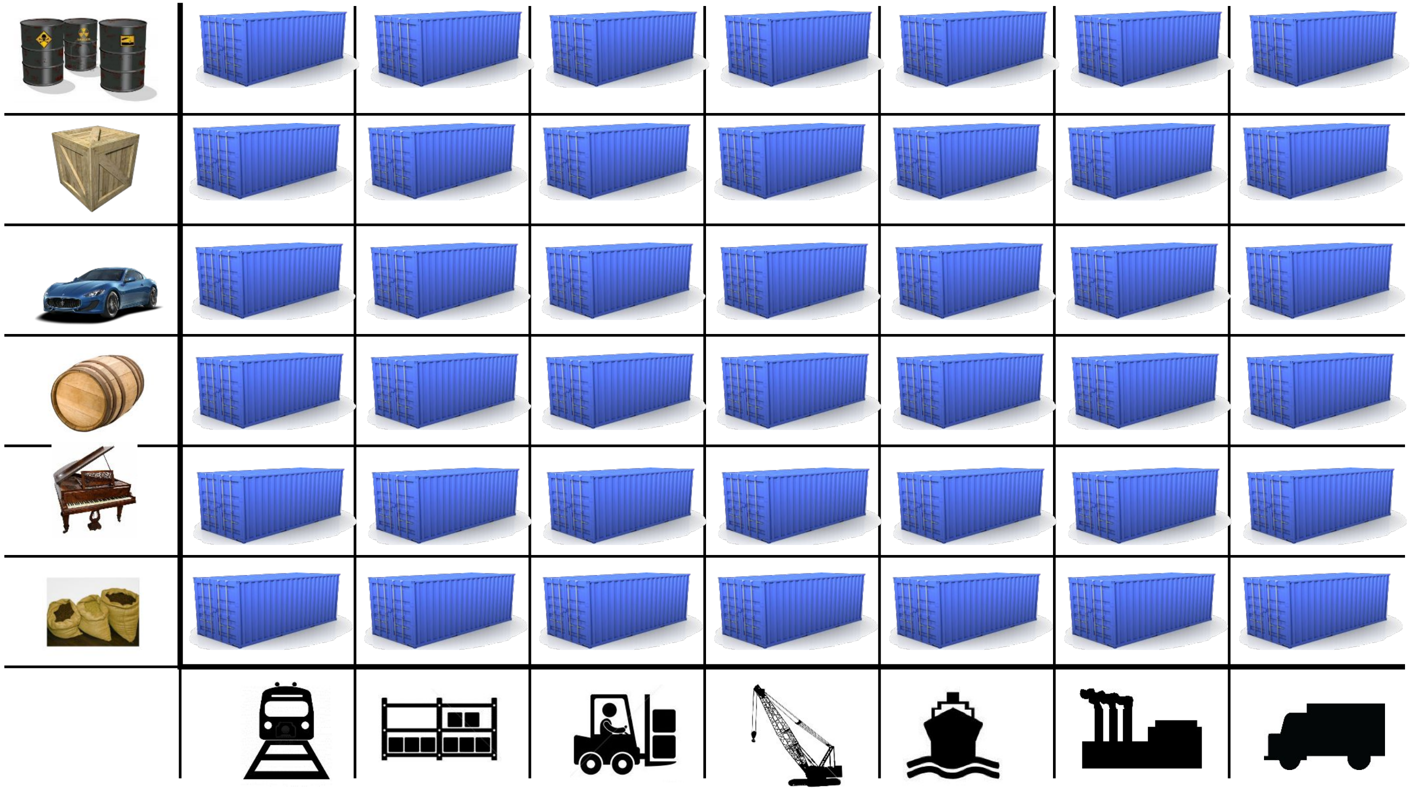
…in between, can be loaded and unloaded, stacked, transported efficiently over long distances, and transferred from one mode of transport to another

Do I worry about how goods interact (e.g. coffee beans next to spices)

Multiplicity of methods for transporting/storing

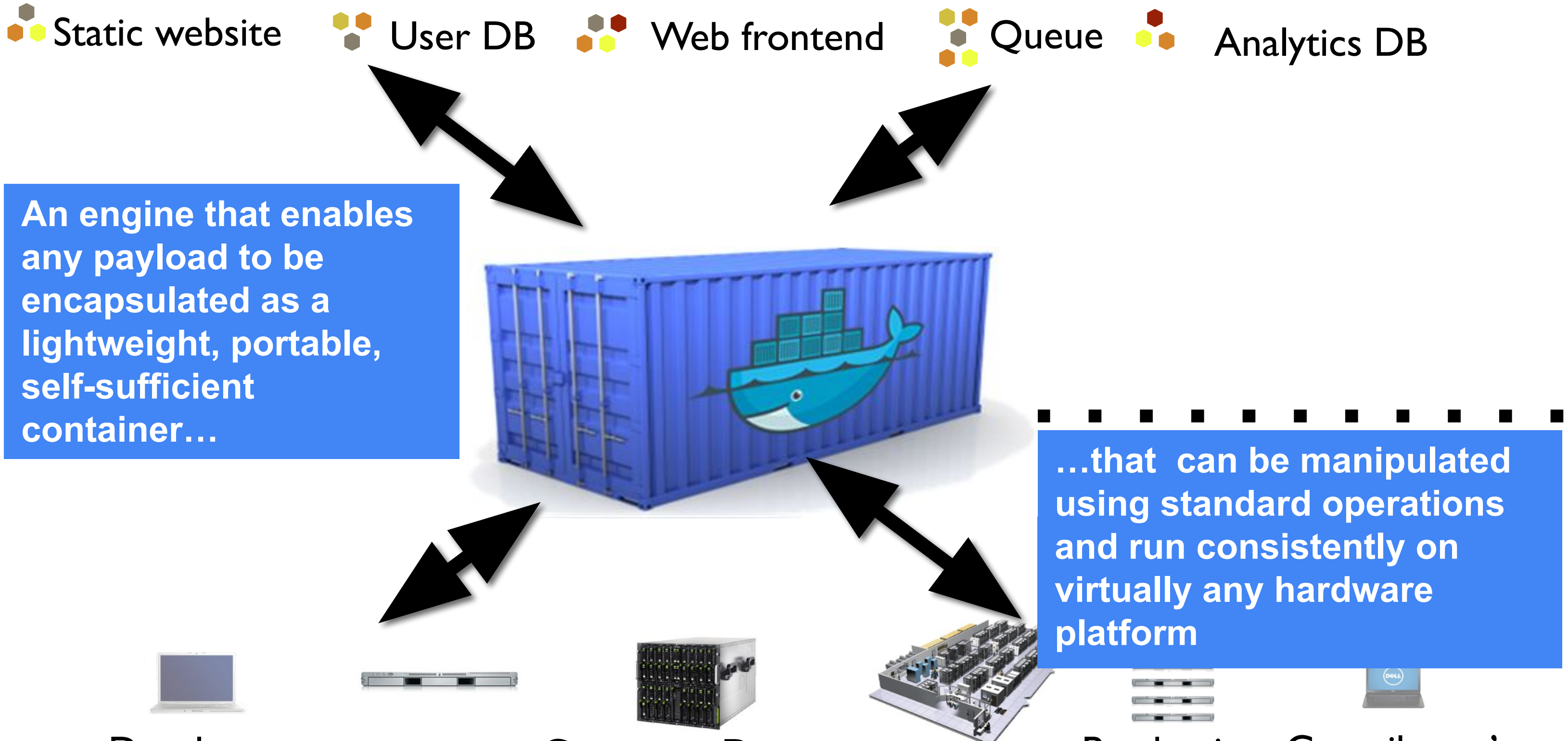
Can I transport quickly and smoothly (e.g. from boat to train to truck)

This eliminated the NXN problem…



- 90% of all cargo now shipped in a standard container
- Order of magnitude reduction in cost and time to load and unload ships
- Massive reduction in losses due to theft or damage
- Huge reduction in freight cost as percent of final goods (from >25% to <3%)
  massive globalizations
- 5000 ships deliver 200M containers per year

Docker is a shipping container system for code



Static website

User DB

Web frontend

Queue

Analytics DB

Multiplicity of Stacks

Do services and apps interact appropriately?

An engine that enables any payload to be encapsulated as a lightweight, portable, self-sufficient container…

…that can be manipulated using standard operations and run consistently on virtually any hardware platform

Multiplicity of hardware environments

Can I migrate smoothly and quickly

Development VM

QA server

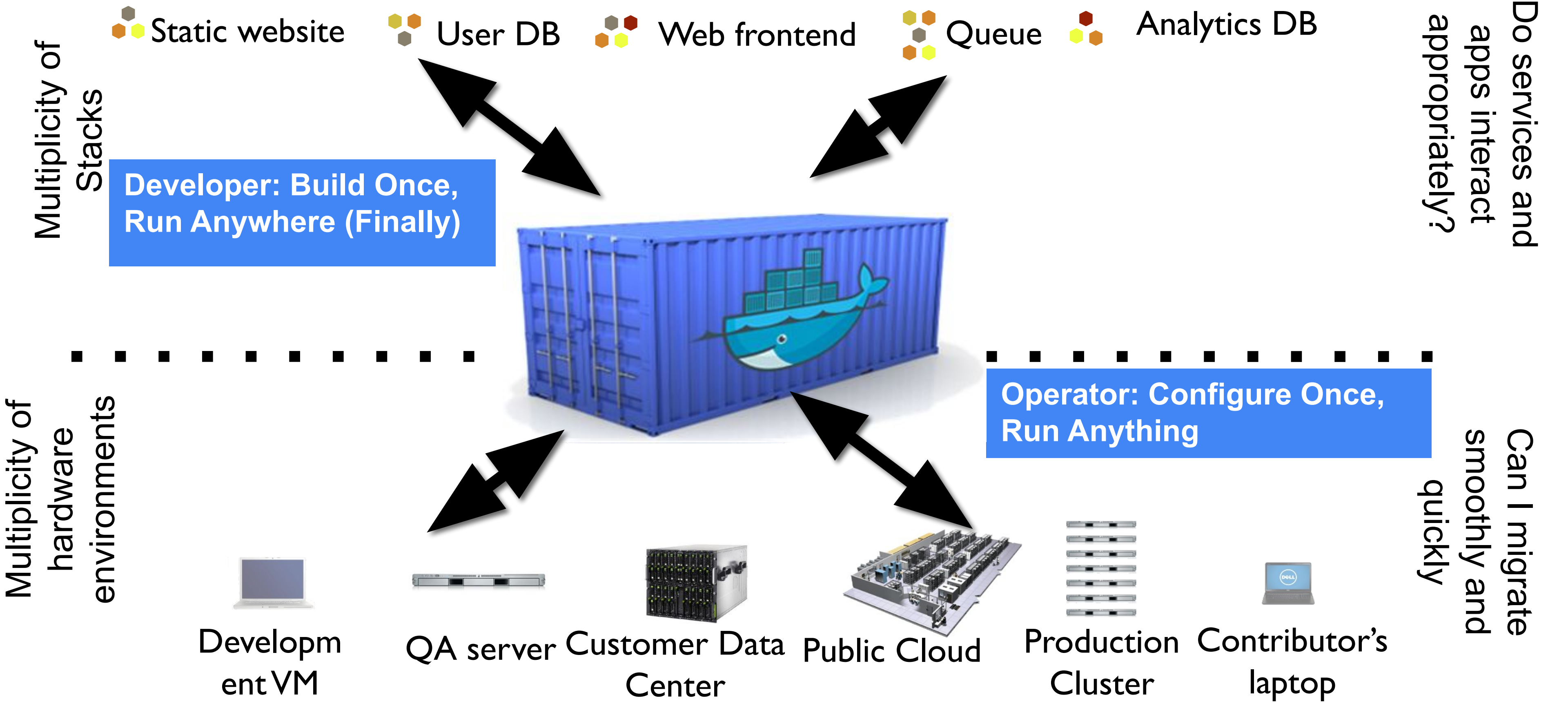
Customer Data Center

Public Cloud

Production Cluster

Contributor's laptop

Or…put more simply



Multiplicity of Stacks

Static website

User DB

Web frontend

Queue

Analytics DB

Do services and apps interact appropriately?

Developer: Build Once, Run Anywhere (Finally)

Operator: Configure Once, Run Anything

Multiplicity of hardware environments

Developm ent VM

QA server

Customer Data Center

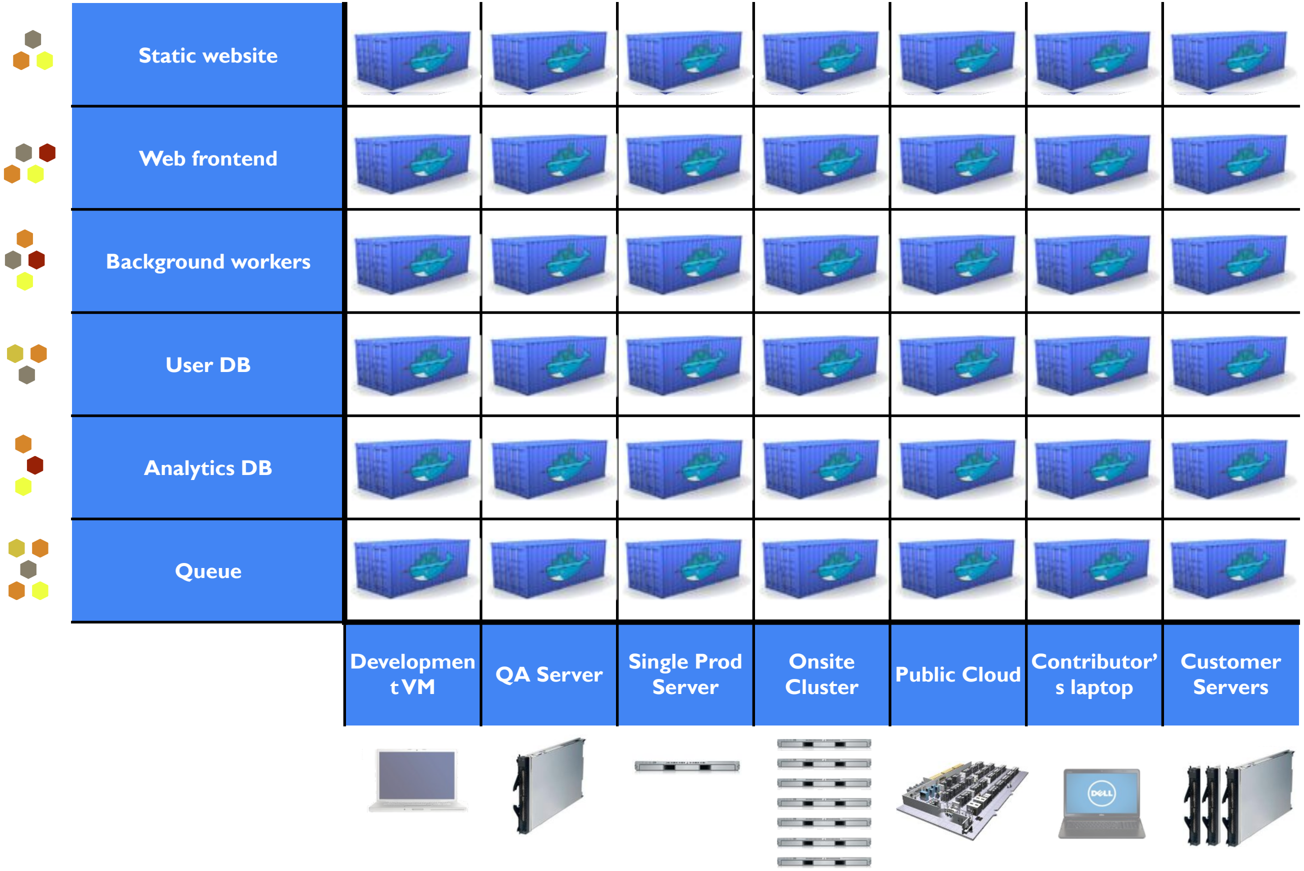
Public Cloud

Production Cluster

Contributor's laptop

Can I migrate smoothly and quickly

Docker solves the NXN problem



Static website

Web frontend

Background workers

User DB

Analytics DB

Queue

Developmen tVM

QA Server

Single Prod Server

Onsite Cluster

Public Cloud

Contributor’s laptop

Customer Servers

Container

- Container is a type of virtualization that allows multiple isolated applications to run on a single host operating system.
- Containers are lightweight and portable, and they provide a way to package an application and its dependencies together, so it can run consistently across different environments.
- Containers are different from virtual machines (VMs) as they do not require a separate operating system to be installed for each container. This avoids the overhead of running multiple separate operating system.

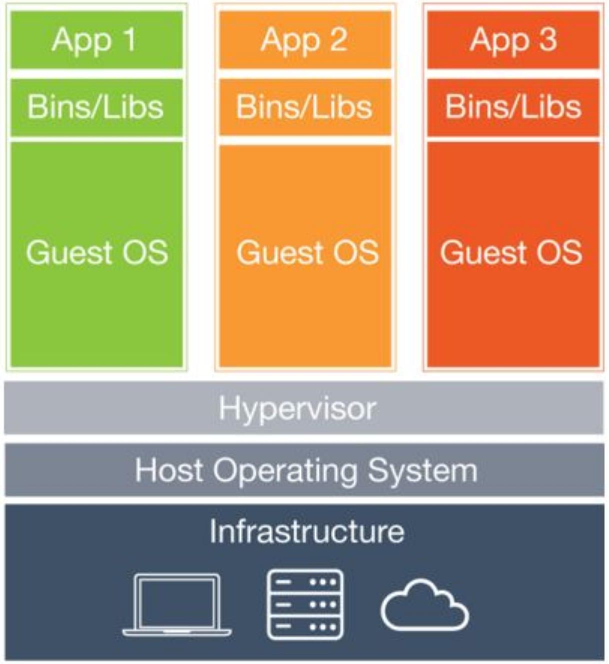
Container (Cont.)

- The core component of container virtualization is the container engine, which is a software that manages the creation and execution of containers.
- The container engine uses the host operating system's kernel to create isolated environments for each container.
- These isolated environments, called containers which share the host operating system's kernel and libraries, but have their own file system, network stack, and process space.
- Containers are created from container images, which are pre-configured and bundled with all the necessary dependencies for the application to run.
- Container images can be stored in a container registry, and can be easily pulled and run on any host that supports the container engine.

LXC

- In Linux, the most common container technology is LXC (Linux Containers).
- LXC uses Linux kernel features such as control groups and namespaces to create isolated environments for containers.
- Control groups, also known as cgroups, are used to limit, prioritize and account system resources such as CPU, memory, and I/O.
- Namespaces, on the other hand, are used to provide isolated environments for container's process, network and file system.

VMs vs Containers



App 1
Bins/Libs
Guest OS

App 2
Bins/Libs
Guest OS

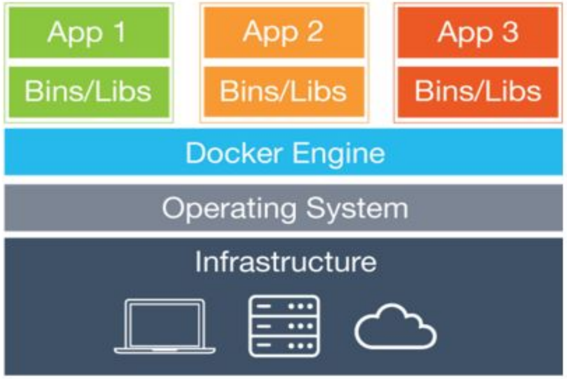
App 3
Bins/Libs
Guest OS

Hypervisor

Host Operating System

Infrastructure

Virtual Machines



App 1
Bins/Libs

App 2
Bins/Libs

App 3
Bins/Libs

Docker Engine

Operating System

Infrastructure

Containers

Virtual Machines vs Containers (Cont.)

- Containers share resources with the host OS, which makes them an order of magnitude more efficient
- Applications running in containers incur little to no overhead compared to applications running natively on the host OS.
- The fundamental goals of VMs and containers are different
  - the purpose of a VM is to fully emulate a foreign environment
  - the purpose of a container is to make applications portable and self-contained

Containers over VMs

1. Cloud-native applications: Containerized applications are designed to run in distributed environments and can be easily deployed to different cloud platforms, making them well suited for cloud-native applications.

2. Microservices: Containers are well suited for microservices architecture, as they provide isolation and are lightweight, making it easy to deploy and scale individual services.

3. Resource efficiency: Containers are more lightweight and efficient than VMs, as they share the host operating system's kernel and libraries, which reduces the resources required to run the application.

4. Rapid Development and Testing: Containers allow developers to quickly create and test new applications, as they can be easily created and destroyed, which can help to speed up the development process.

VMs over Containers

1. Legacy Applications: If an application is not designed to run in a containerized environment, it may be more efficient to run it in a virtual machine, as it will not require any modification.

2. High Security Requirements: In some cases, such as for sensitive data or applications with strict regulatory compliance requirements, virtual machines may be a better option as they provide a higher level of isolation and security than containers.

3. Hardware-intensive Workloads: Applications that require direct access to physical hardware resources such as GPUs, high-speed networking, or specialized devices may be better suited for virtual machines as they can provide direct access to these resources.

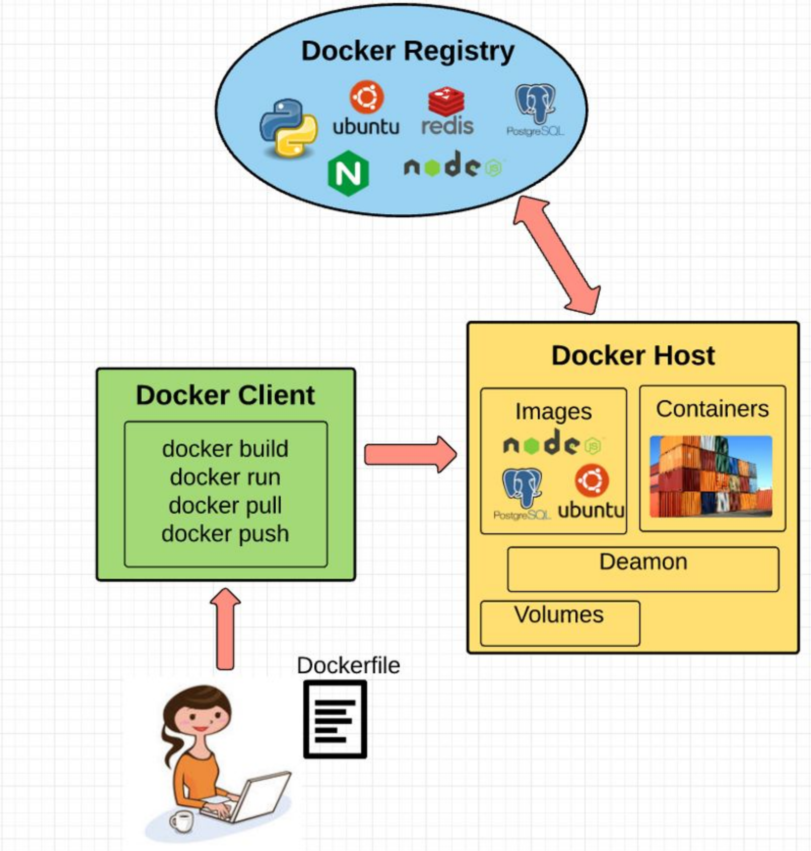
4. Different Operating Systems: If your application requires different operating systems for different components, it may be more efficient to use VMs, as each VM can run a different operating system.

5. High Performance Computing: Applications that need high-performance computing resources like large memory, high-speed storage, or complex network configurations are better suited for virtual machines.

Docker

- Docker is an open-source platform that is widely used container engine on Linux.
- Docker provides a simple and efficient way to create, deploy, and run containerized applications.
- It also provides an easy-to-use command-line interface and an API that allows you to automate the management of your containers.

Docket (Cont.)


Docker Registry
ubuntu
redis
PostgreSQL
node JS
Docker Client
docker build
docker run
docker pull
docker push
Docker Host
Images
node JS
PostgreSQL
ubuntu
Containers
Deamon
Volumes
Dockerfile

Container Orchestration

- Container orchestration is the process of automating the deployment, scaling, and management of containerized applications.
- It involves the use of software tools that can manage and coordinate the scheduling, scaling, and deployment of containers across a cluster of machines.
- With container orchestration, administrators can define the desired state of their applications, such as the number of replicas of a container, and the orchestration tool will automatically ensure that the desired state is met by creating, updating, or deleting containers as needed.
- Some of the key features of container orchestration include:
    - Automatic scaling: The ability to automatically scale the number of containers in response to changes in demand.
    - Self-healing: The ability to automatically recover from failures, such as if a container crashes, by restarting it or rescheduling it on another node.
    - Load balancing: The ability to automatically distribute incoming traffic across multiple containers.
    - Service discovery: The ability to automatically discover and connect to other services in the system.

Docker Swarm

- Docker Swarm is a native clustering and orchestration solution for Docker.
- It allows you to create and manage a cluster of Docker nodes as a single virtual system.
- It provides features such as service discovery, load balancing, and scaling, which makes it easy to build, ship and run distributed applications.
- It also allows you to schedule the placement of containers across the nodes in the cluster, and to ensure that the desired number of replicas of a container are running at all times.

Kubernetes

- Kubernetes (often shortened to "K8s") is an open-source container orchestration system that automates the deployment, scaling, and management of containerized applications.
- It was originally developed by Google and is now maintained by the Cloud Native Computing Foundation (CNCF).
- Kubernetes manage containerized applications in a clustered environment. It abstracts away the underlying infrastructure and provides a consistent set of APIs for deploying, scaling, and managing containerized applications.
- Kubernetes uses a declarative configuration model, where the desired state of the system is defined in configuration files.
- The declarative configuration model is a way of describing the desired state of a system, rather than the steps needed to achieve that state.
- This approach allows administrators to specify the desired state of their applications and infrastructure, and then rely on Kubernetes to automatically make the necessary changes to achieve that state.

Kubernetes (Cont.)

Kubernetes provides several key features:

- Automatic scaling of application replicas based on resource usage
- Self-healing capabilities to automatically replace and reschedule failed containers
- Automated rollouts and rollbacks of application updates
- Service discovery and load balancing for application components
- Automated storage provisioning and management
- Automatic binpacking of containers onto nodes in the cluster

Docker Swarm Vs Kubernetes

Kubernetes and Docker Swarm are both popular container orchestration systems. However, they have some key differences:

1. Kubernetes is an open-source platform that was originally developed by Google and is now maintained by the Cloud Native Computing Foundation (CNCF). Docker Swarm, on the other hand, is a native clustering and orchestration solution for Docker.

2. Kubernetes provides a more powerful and flexible orchestration engine, with more advanced features such as automatic scaling, self-healing, and rollouts, and rollbacks. Docker Swarm is more limited in terms of its orchestration capabilities, but it is simpler to set up and use.

3. Kubernetes provides a declarative configuration model where the desired state of the system is defined in configuration files, while Docker Swarm uses a more imperative model where the desired state is defined through commands.

4. Kubernetes supports a wide range of deployment options including on-premise, in the public cloud, and hybrid deployments. Docker Swarm is typically used for deployments on a single cluster or a single cloud provider.

5. Kubernetes has a large and active community, with many contributors and a wide range of third-party tools and plugins available. Docker Swarm has a smaller community and fewer third-party tools and plugins.

6. Kubernetes is more complex to set up and manage, it is typically used for large-scale production deployments, while Docker Swarm is simpler and more suited for small-scale and development deployments.

Coming up next!

- Working with Docker and Kubernetes