# Module - Overview

# Overview

As data sets grow larger, in-memory processing on a single machine does not work well

Distributed frameworks such as Hadoop/MapReduce help

Configuring a cluster of distributed machines is complicated and expensive

Cloud services such as GCP, AWS and Azure help

# The Test

# The Test

"Google Certified Data Engineer"

2 hours, 50 questions, multiple-choice

Not easy to "game"

# Major Topics

- Big Data

    BigQuery, DataFlow, Pub/Sub

- Storage Technologies

    Cloud storage, Cloud SQL, BigTable, Datastore

- Machine Learning

    Concepts, TensorFlow, Cloud ML

# Minor Topics

- Compute choices

  AppEngine, Compute Engine, Containers

- Logging and monitoring

  Stackdriver

- Security, networking

  API keys, load balancing...

## Required Context

- Hadoop, Spark, MapReduce...
- Hive, HBase, Pig
- RDBMS, indexing, hashing

## Drills and Labs

- Syntax is tested too

- Implementation knowledge essential

Don’t try to “prep for the test” (famous last words)

# Why Cloud Computing

# Why Cloud Computing

Data is getting bigger

World is getting smaller

Nothing fits in-memory on a single machine

# Big Data, Small World

Super-computer

Cluster of generic computers

# Big Data, Small World

Monolithic

Distributed


Distributed

Lots of cheap hardware

Replication & fault tolerance

Distributed computing


Distributed

Lots of cheap hardware

HDFS

Replication & fault tolerance

YARN

Distributed computing

MapReduce

# Distributed

"Clusters"

"Nodes"

"Server Farms"

# "Server Farms"


All of these servers need to be co-ordinated by a single piece of software

# Single Co-ordinating Software


Partition data

Co-ordinate computing tasks

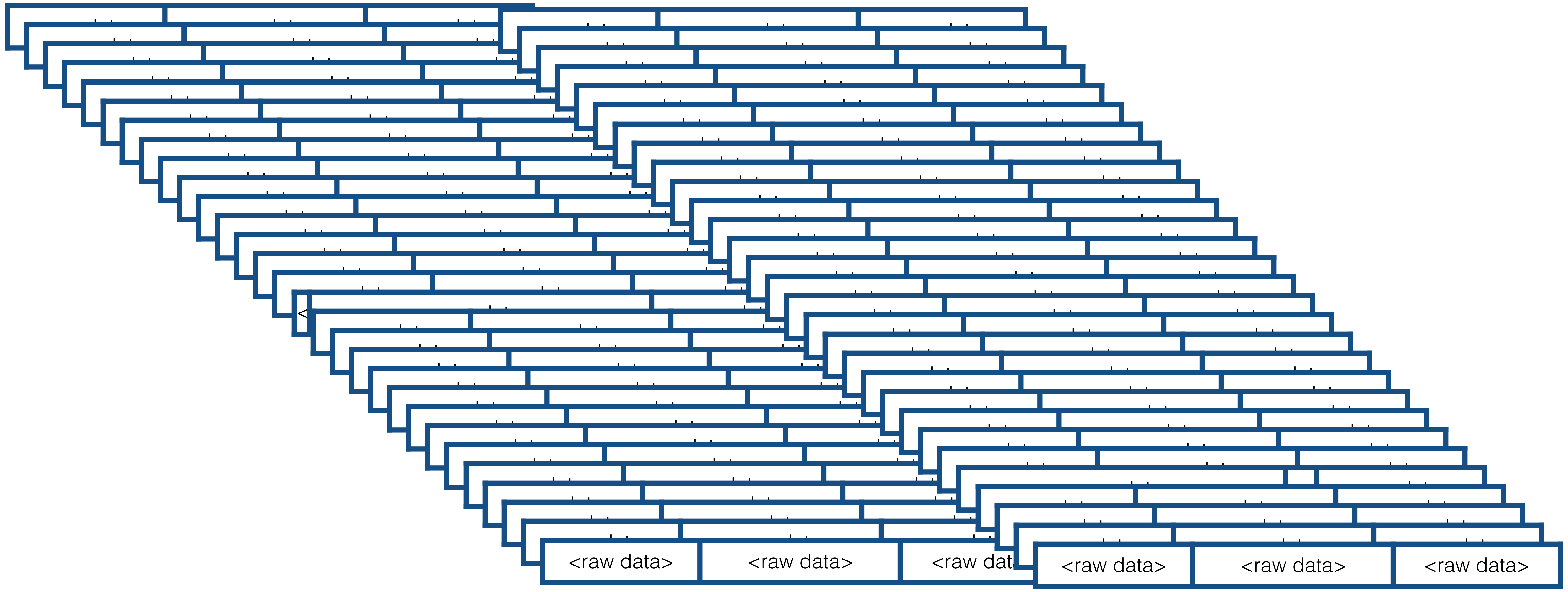
Handle fault tolerance and recovery

Allocate capacity to processes

# Single Co-ordinating Software


Google developed proprietary software to run on these distributed systems

# Single Co-ordinating Software




First: store millions of records on multiple machines

# Single Co-ordinating Software


Second: run processes on all these machines to crunch data

# Single Co-ordinating Software

| | |
|---|---|
| Google File System | To solve distributed storage |
| MapReduce | To solve distributed computing |

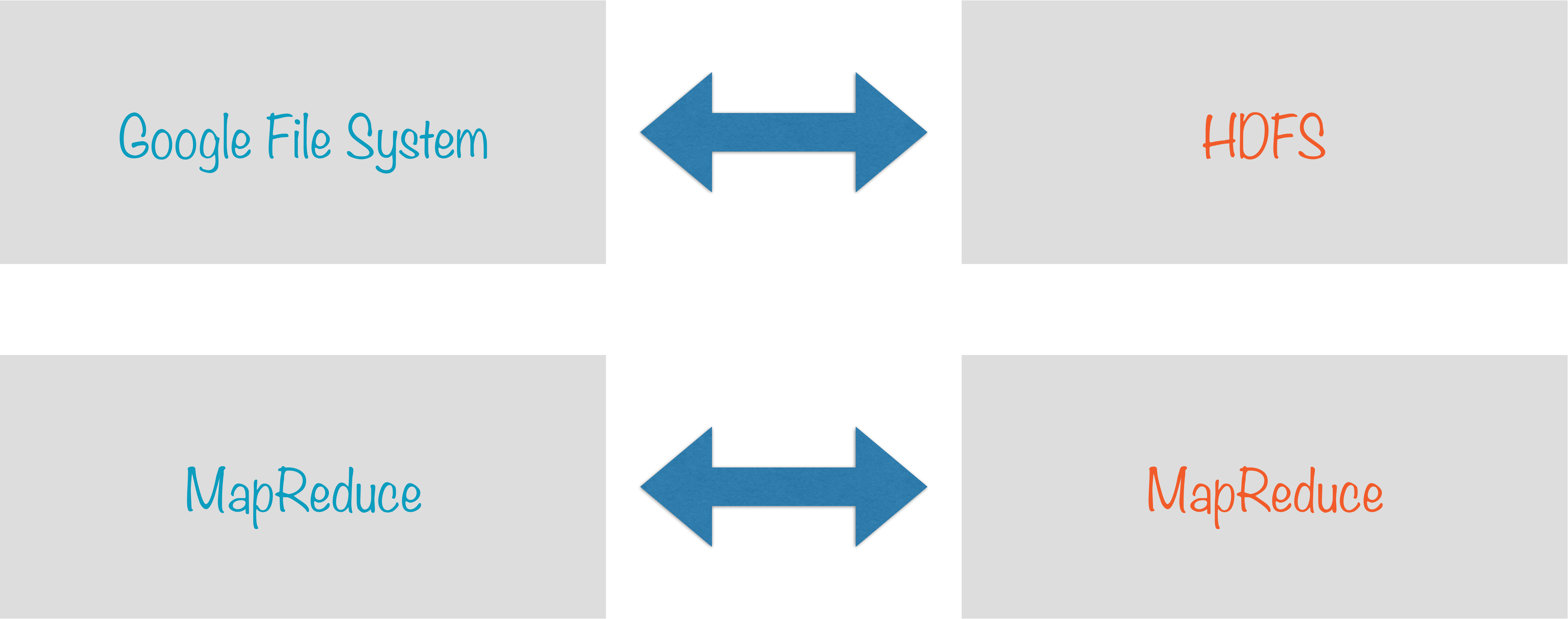
# Single Co-ordinating Software

Google File System

MapReduce

Apache developed open source versions of these technologies

# Single Co-ordinating Software



# Hadoop

HDFS

MapReduce

A file system to manage the storage of data

A framework to process data across multiple servers

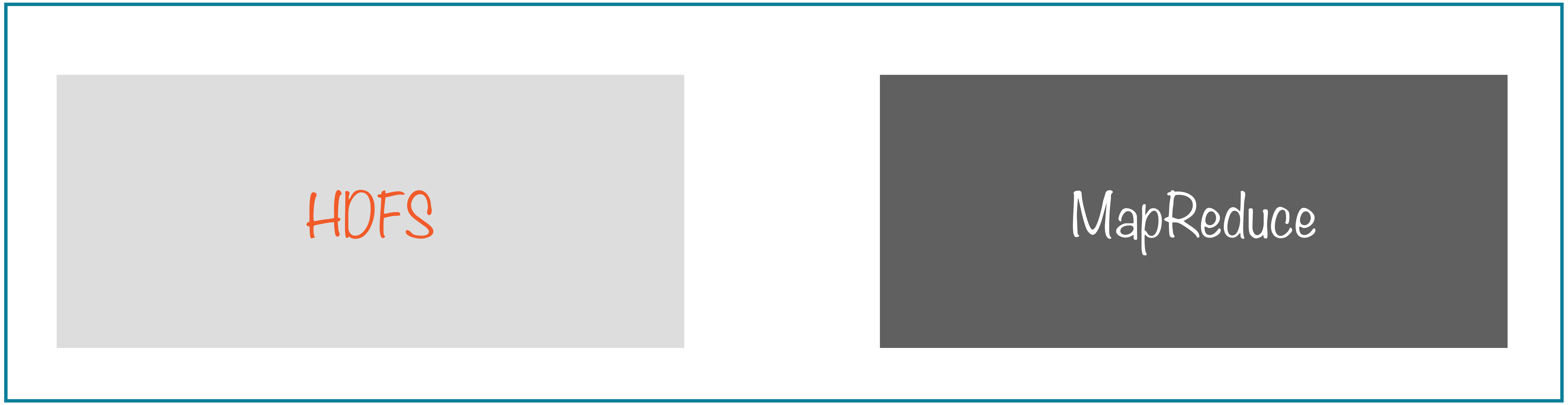
# Hadoop

HDFS

MapReduce

In 2013, Apache released Hadoop 2.0

# Hadoop




MapReduce was broken into two separate parts

# Hadoop

| HDFS | MapReduce | YARN |
|---|---|---|
| | A framework to define a data processing task | A framework to run the data processing task |

# Hadoop

| HDFS | MapReduce | YARN |
|---|---|---|

Each of these components have corresponding configuration files

# Co-ordination Between Hadoop Blocks

MapReduce

YARN

HDFS

User defines map and reduce tasks using the MapReduce API

# Co-ordination Between Hadoop Blocks

MapReduce

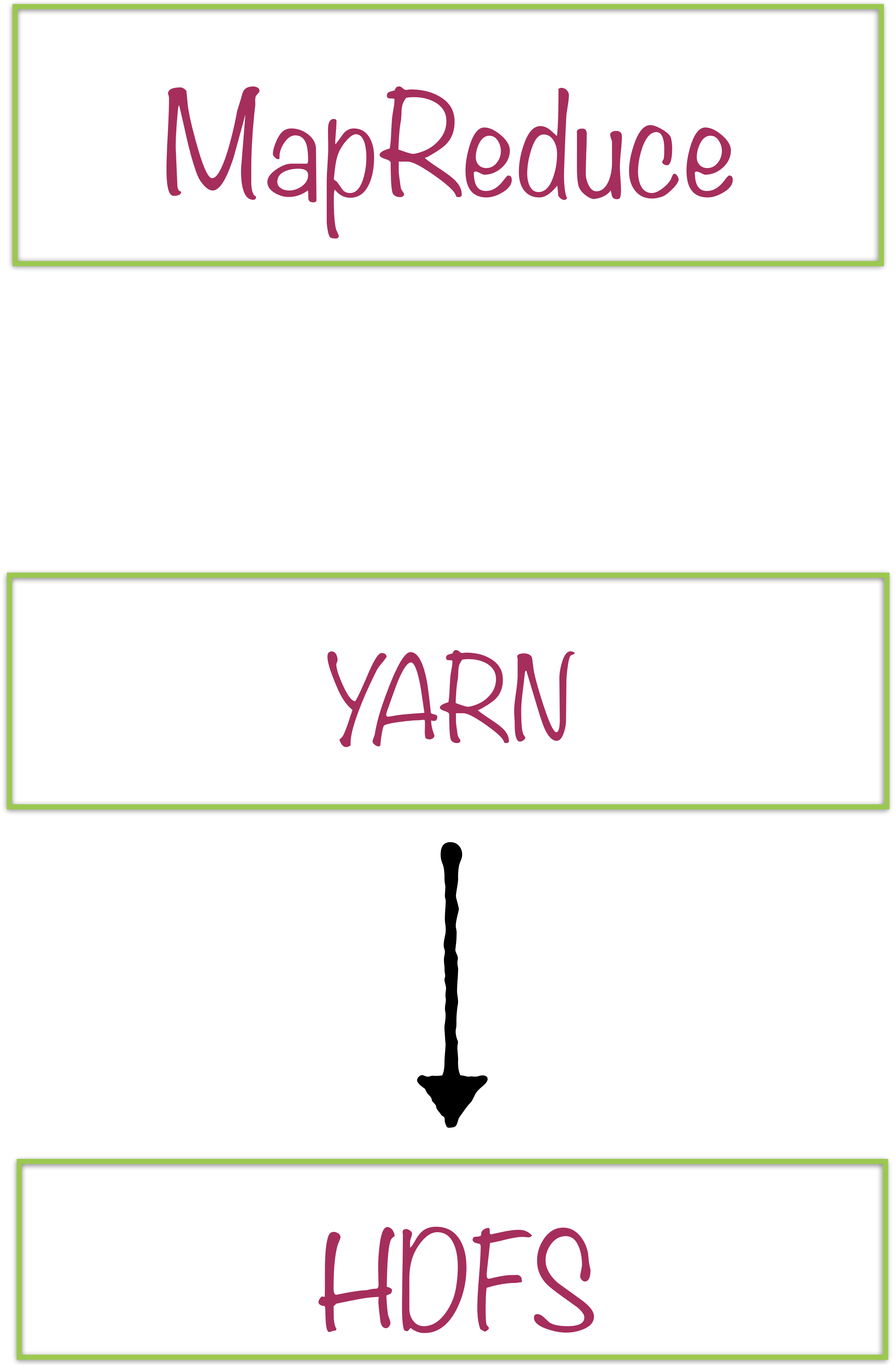
↓

YARN

HDFS

A job is triggered on the cluster

# Co-ordination Between Hadoop Blocks




YARN figures out where and how to run the job, and stores the result in HDFS

# Hadoop Ecosystem

Hadoop

An ecosystem of tools have sprung up around this core piece of software

# Hadoop Ecosystem

Hive

HBase

Pig

Hadoop

Kafka

Spark

Oozie

# Hadoop Ecosystem

| | | |
|---|---|---|
| Hive | HBase | Pig |
| Kafka | Spark | Oozie |

# Hive

Provides an SQL interface to Hadoop

The bridge to Hadoop for folks who don't have exposure to OOP in Java

## HBase

A database management system on top of Hadoop

Integrates with your application just like a traditional database

## Pig

A data manipulation language

Transforms unstructured data into a structured format

Query this structured data using interfaces like Hive

## Spark

A distributed computing engine used along with Hadoop

Interactive shell to quickly process datasets

Has a bunch of built in libraries for machine learning, stream processing, graph processing etc.

## Oozie

A tool to schedule workflows on all the Hadoop ecosystem technologies

Kafka

Stream processing for unbounded datasets

# Hadoop Ecosystem

Hive

HBase

Pig

Hadoop

Kafka

Spark

Oozie

# Hadoop Ecosystem

Hive

HBase

Pig

Hadoop

Setting up and running distributed software is an expensive, complicated exercise

Kafka

Spark

Oozie

# Distributed Computing Infrastructure

Who owns the machines?

Who deploys the software?

How does scaling happen?

# Distributed Computing Infrastructure


On-premise


Colocation Services


Cloud Services


**On-premise**

Who owns the machines?

You do.

Who deploys the software?

You do.

How does scaling happen?

You **buy** machines and scale them in.


# Colocation Services

Who owns the machines?

You (usually and mostly) do

Who deploys the software?

You do.

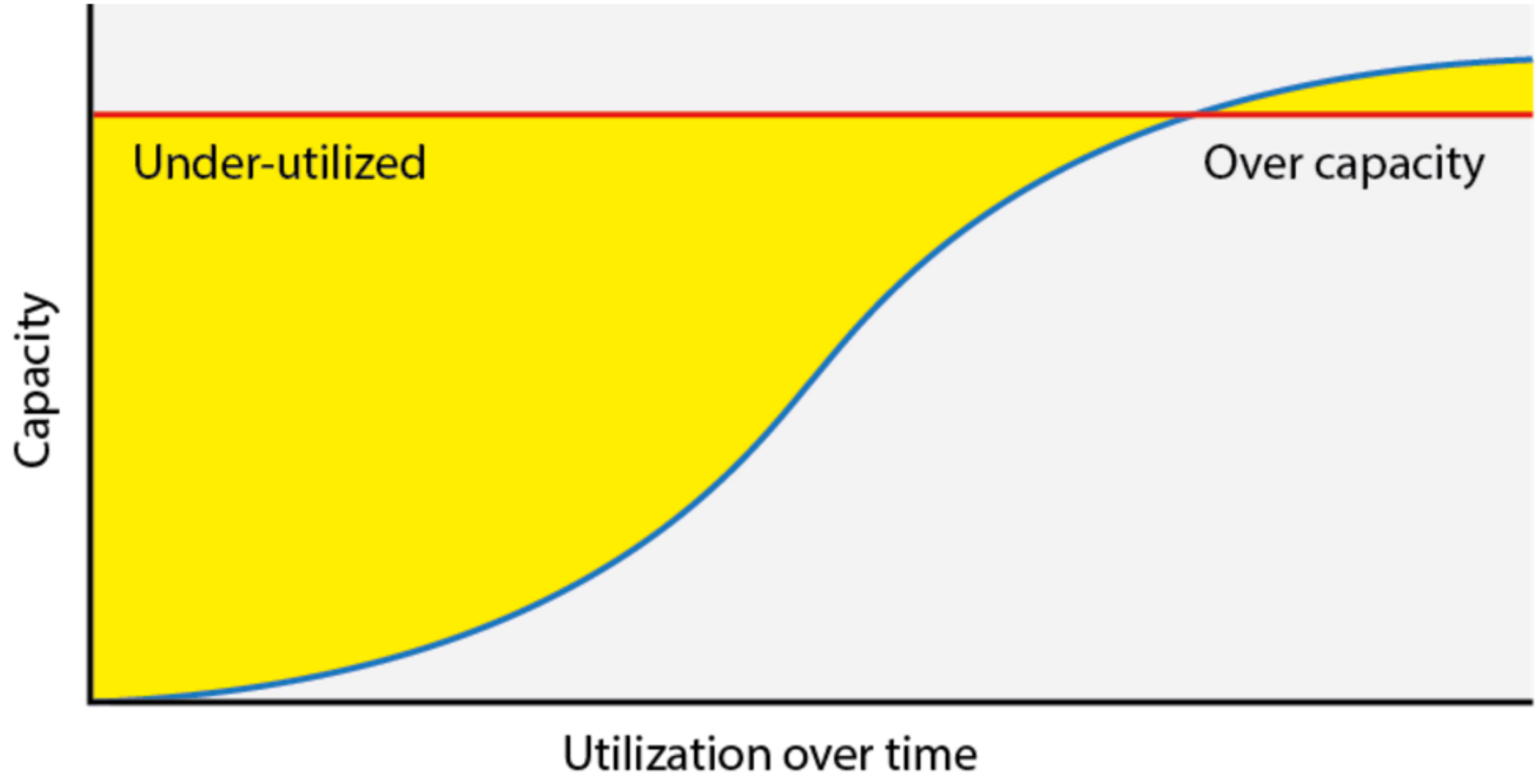
How does scaling happen?

You **buy or lease** machines.


On-premise


Colocation Services

Utilisation planning is super-important




Else, end up with a white elephant data centre


# Cloud Services

Who owns the machines?

Google, Amazon or Microsoft does

Who deploys the software?

GCP, AWS or Azure does it for you

How does scaling happen?

You **dynamically** add machines


# Cloud Services: Financial Implications

OpEx rather than CapEx

Conserve cash

Watch for nickel-and-diming


# Cloud Services: Operational Implications

Utilisation planning very simple indeed

Little chance of a white elephant data center

# GCP Overview

# Google Cloud Platform

"Use Resources"

Hardware (VMs, disks) and
Software (BigQuery, BigTable...)

"Pay for resources"

Billed for usage per-project

# Google Cloud Platform

Resources

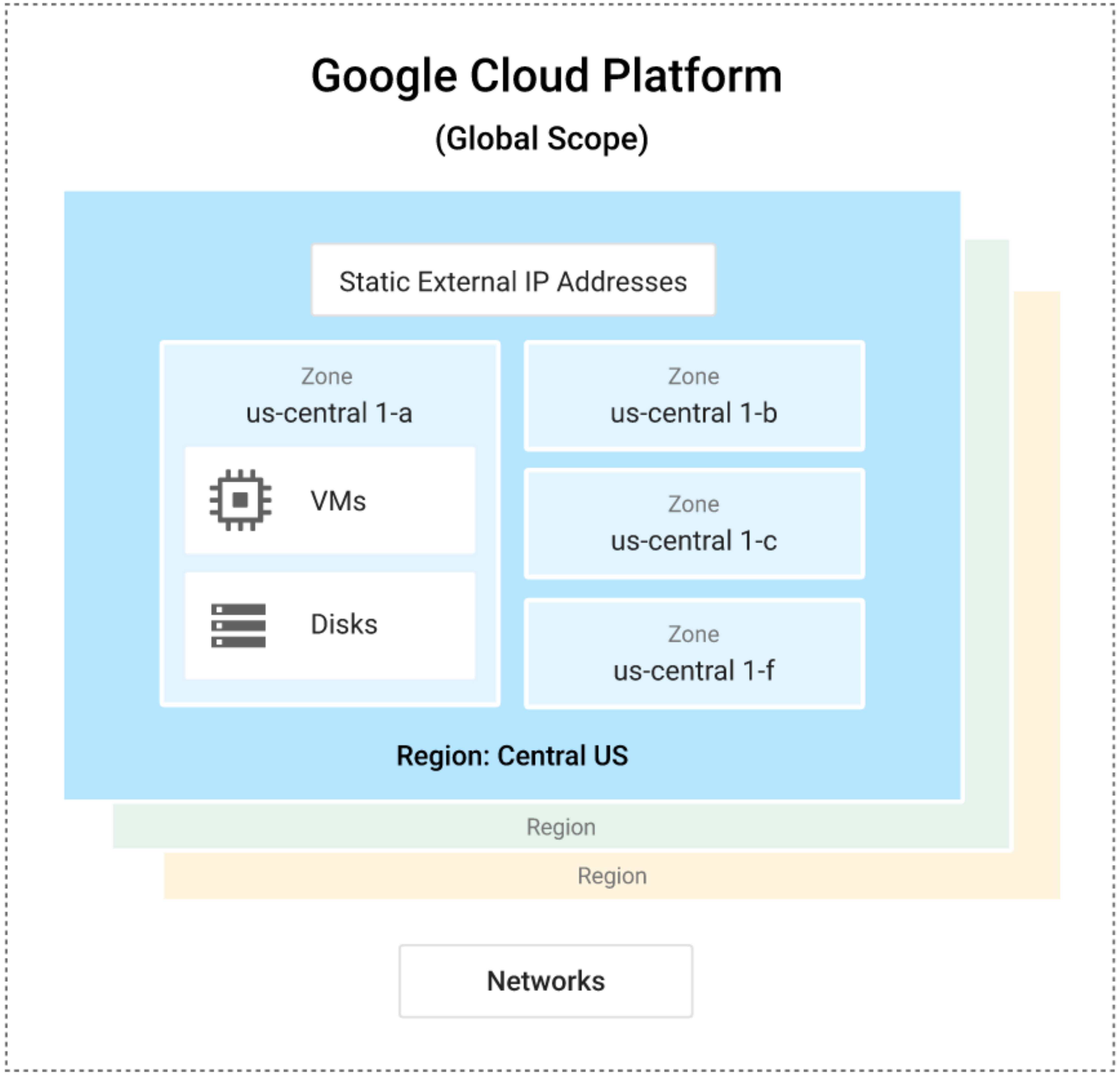
Billing

# Google Cloud Platform

Resources

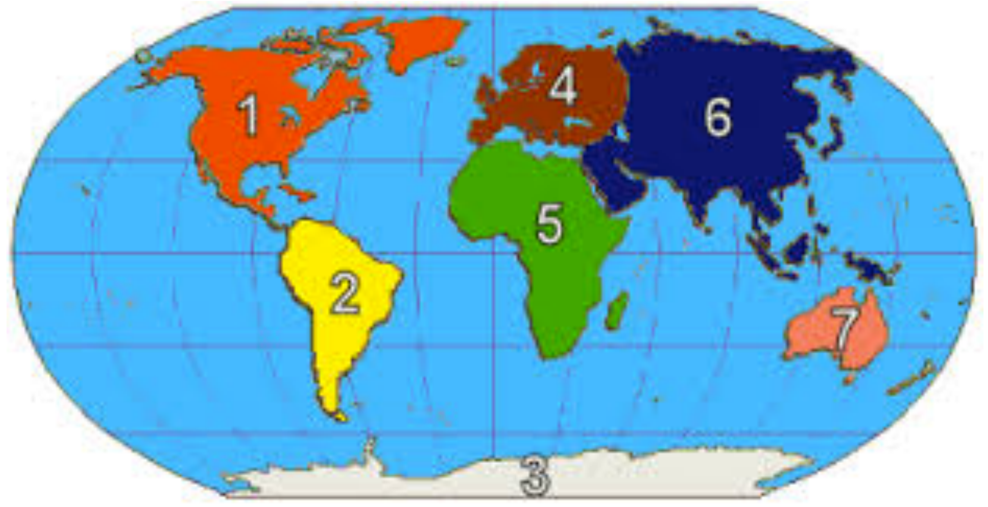
Billing

# Resources



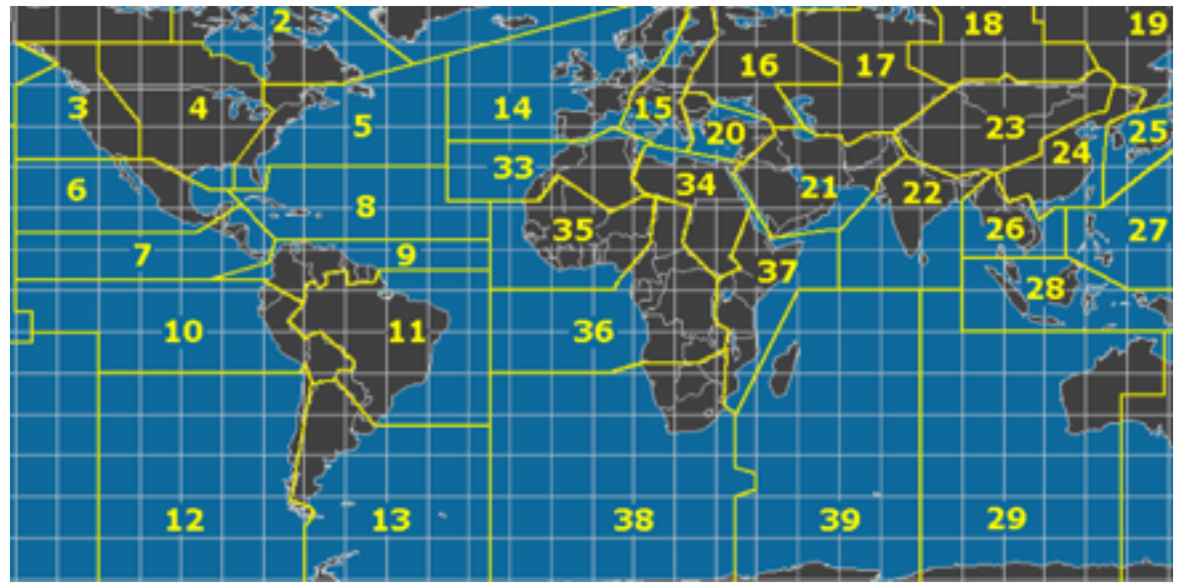
Google Cloud Platform
(Global Scope)
Static External IP Addresses
Zone
us-central 1-a
VMs
Disks
Zone
us-central 1-b
Zone
us-central 1-c
Zone
us-central 1-f
Region: Central US
Region
Region
Networks

# Location Hierarchy




“Regions”

e.g. Central US, Western Europe, and East Asia



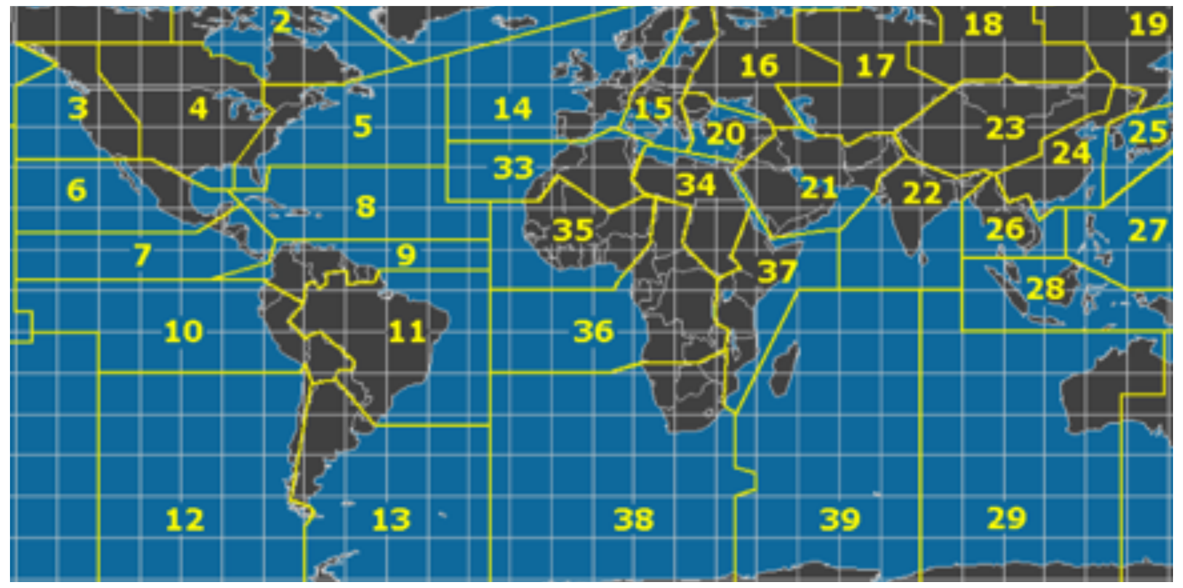

“Zones”

Basically, data centres within regions


# “Regions”

e.g. Central US, Western Europe, and East Asia

Within region, locations usually have network latencies of less than 5ms




# “Zones”

**Basically, data centres within regions**

“Single failure domain” within a region

Identified as region-name + letter

asia-east1-a

**Zones**

↓

**Resources**

Hardware

computers, hard disks

Software

Virtual machines (VMs)

Zones

Resources

Global aka multi-regional

Cloud Storage, DataStore, BigQuery

Regional

AppEngine instances

Zonal

VM (Compute Engine) instances, disks

# Resources

## Hardware

computers, hard disks

## Software

Virtual machines (VMs),
Software services

# Resources

## Hardware

Compute choices,
Storage technologies...

## Software

Big data,
machine learning ...

Recall

# Major Topics

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  BigQuery, DataFlow, Pub/Sub

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- Security, networking

  API keys, load balancing...

# Resources

## Hardware

Compute choices,
Storage technologies...

## Software

Big data,
machine learning ...

# Consumption Mechanisms

## GCP Console

web front-end

## Command-line Interface

gcloud utility (needs SDK), or gcloud shell

## Client Libraries

Python, Java, Go...

# Google Cloud Platform

Resources

Billing

# Google Cloud Platform

Resources

Billing

# Billing

All resources consumed associated with a **project**

Projects are associated with accounts

Billing happens per-project

# Projects

Resources + Settings + Metadata

Resources within a project can easily interact

Project ~ Namespace

# Project

Name, ID, number

ID is unique, forever

Project ~ Namespace

# Summary

Cloud services have important advantages over on-premise or colocated data centers

GCP, Google's Cloud Platform, offers a suite of storage and compute solutions

TensorFlow and Cloud ML give GCP an edge in machine learning applications

The Google Cloud Data Engineer test is a fairly rigorous one

# Module - Compute

# Overview

GCP offers three Compute Options for running cloud apps

Google AppEngine is the PaaS option - serverless and ops-free

Google ComputeEngine is the IaaS option - fully controllable down to OS

Google Container Engine lies in between - clusters of machines running Kubernetes and hosting containers

# Hosting Web Content:
# A Case Study of Compute Options

# Cloud Use-Cases

Hosting a website

Running a Hadoop cluster

Serving a TensorFlow model

Relatively basic

"Big data"

"Machine Learning"

# Cloud Use-Cases

Hosting a website

Running a Hadoop cluster

Serving a TensorFlow model

Relatively basic

“Big data”

“Machine Learning”

# Hosting a Website

**Static, No SSL**

Plain HTML files

Just buy storage

**SSL, CDN, Bells & whistles**

Still quite static, but rich content

Need HTTPS serving, release management etc

**Load balancing, scaling**

Currently on VMs or servers

Get VMs, manage yourself

**Lots of dependencies**

Deployment is becoming painful

Create containers, manage clusters

**Heroku, Engine Yard**

Lots of code, languages

Just focus on code, forget the rest

# Hosting a Website

**Static, No SSL**

Plain HTML files

Just buy storage

Buy disk space

Automatic scaling

No HTTPS, no deployment help, nothing

"Google Cloud Storage"

## Hosting on Cloud Storage

To host a static site, create a Cloud Storage Bucket and upload content

Can use “storage.googleapis.com” URL, or own domain

## Hosting on Cloud Storage

Could write own HTML CSS

Or use static generators

- Jekyll
- Ghost
- Hugo

## Hosting on Cloud Storage

Can copy over content to bucket directly

- Web Console
- Cloud Shell

Or

- store on GitHub
- then use WebHook to run update script

Or

- use CI/CD tool like Jenkins
- Cloud Storage plug-in for post-build step

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# Hosting a Website

SSL so that HTTPS serving is possible

CDN edges world-over

Atomic deployment, one-click rollback

**SSL, CDN, Bells & whistles**

Still quite static, but rich content

Need HTTPS serving, release management etc

"Firebase Hosting + Google Cloud Storage"

# Hosting a Website

"Google Cloud Storage"

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# Hosting a Website

**Load balancing, scaling**

Currently on VMs or servers

Get VMs, manage yourself

You'd like to control load balancing, scaling etc yourself

IAAS ("Infra-as-a-service")

"Google Compute Engine"

Configuration, administration, management - all on you

No need to buy machines or install OS, dev stack, languages etc

## Hosting with Compute Engine

Google Cloud Launcher

LAMP stack or WordPress in a few minutes

Cost estimates before deployment

# Hosting with Compute Engine

You choose machine types, disk sizes before deployment

Can customise configuration, rename instances etc

After deployment, have full control of machine instances

## Hosting with Compute Engine

Loads of **storage options**

- Cloud Storage Buckets
- Standard persistent disks
- SSD (solid state disks)
- Local SSD

After deployment, have full control of machine instances

## Hosting with Compute Engine

Loads of **storage technologies** if you prefer

- Cloud SQL (MySQL, PostgreSQL
- NoSQL
- GCP NoSQL tools - BigTable, Datastore

**Hosting with Compute Engine**

**Load Balancing** options

- Network load balancing: forwarding rules based on address, port, protocol

- HTTP load balancing: look into content, examine cookies, certain clients to one server...

- Internal: On private network not on internet

- Auto-scaled

## Hosting with Compute Engine

# DevOps - laundry list

Compute Engine Management with Puppet, Chef, Salt, and Ansible

Automated Image Builds with Jenkins, Packer, and Kubernetes

Distributed Load Testing with Kubernetes

Continuous Delivery with Travis CI

Managing Deployments with Spinnaker

## Hosting with Compute Engine

StackDriver for logging and monitoring

# Hosting a Website

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Just focus on code, forget the rest

"Firebase Hosting + Google Cloud Storage"

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Deployment is becoming painful

Create containers, manage clusters

# Hosting a Website

You run separate web server, database

Separate containers to isolate from each other

Service-oriented architecture

Microservices

"Google Container Engine"

**Lots of dependencies**

Deployment is becoming painful

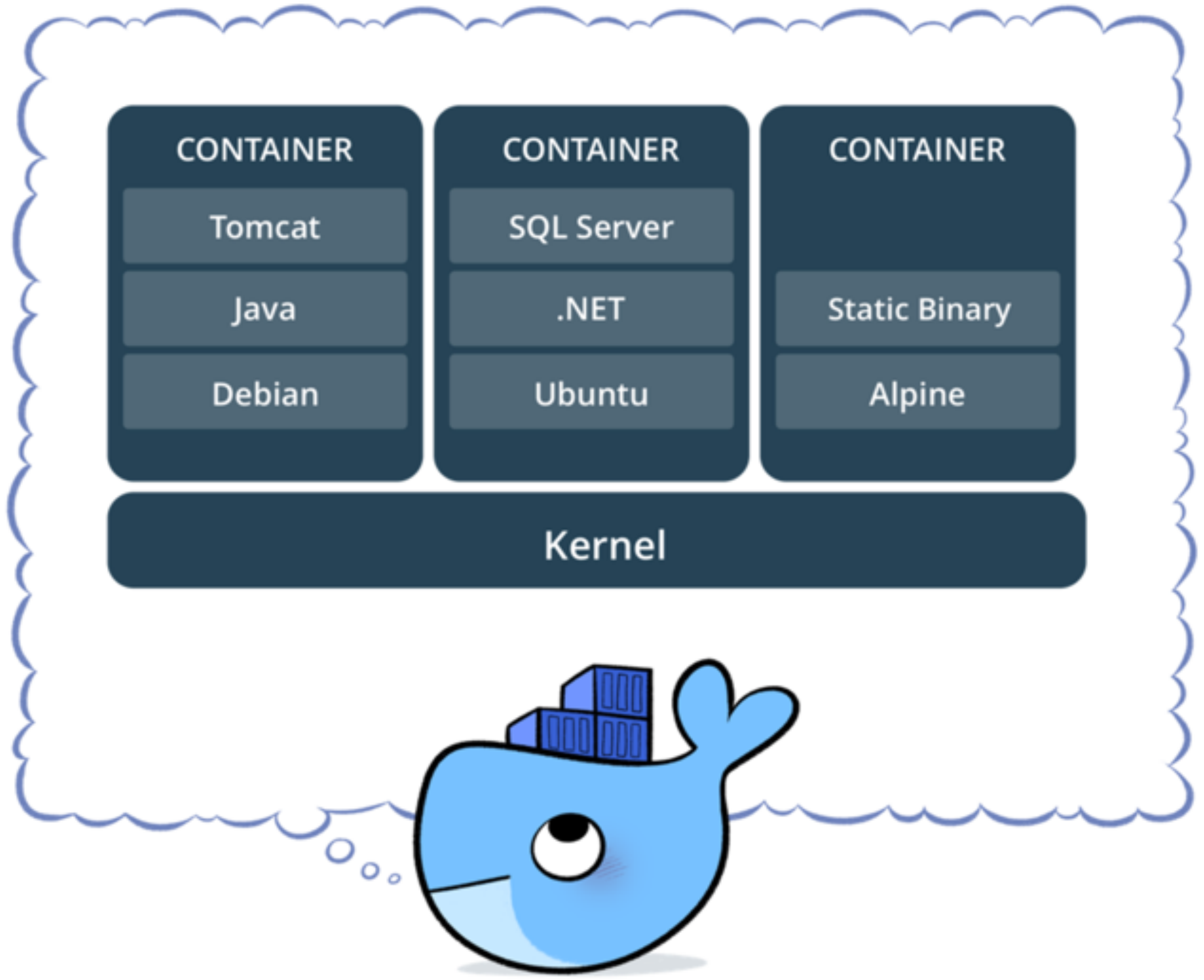
Create containers, manage clusters

# Container

A container image is a lightweight, stand-alone, executable package of a piece of software that includes everything needed to run it: code, runtime, system tools, system libraries, settings

(www.docker.com)

# Container

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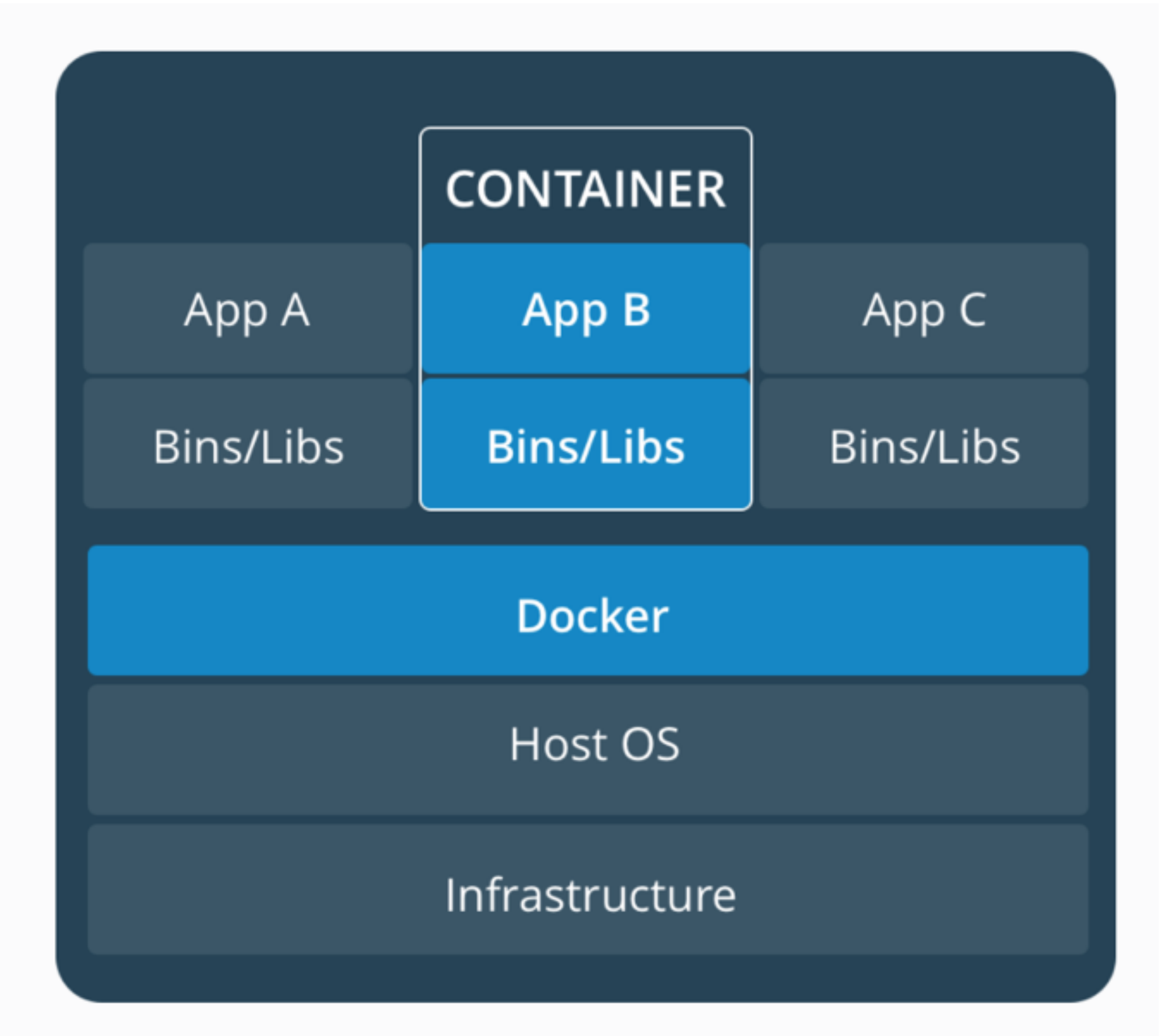
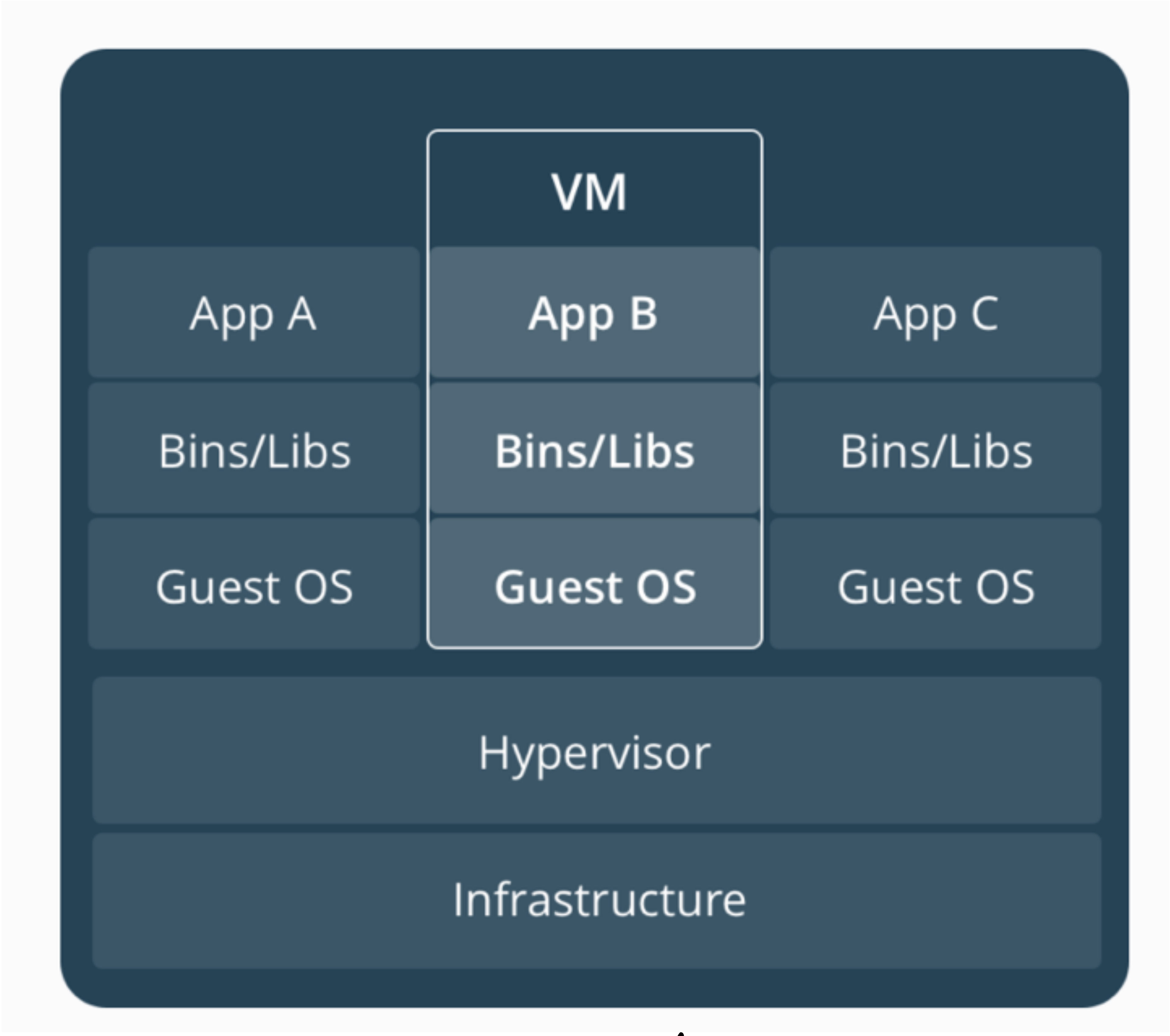
# Containers and VMs

## Containers

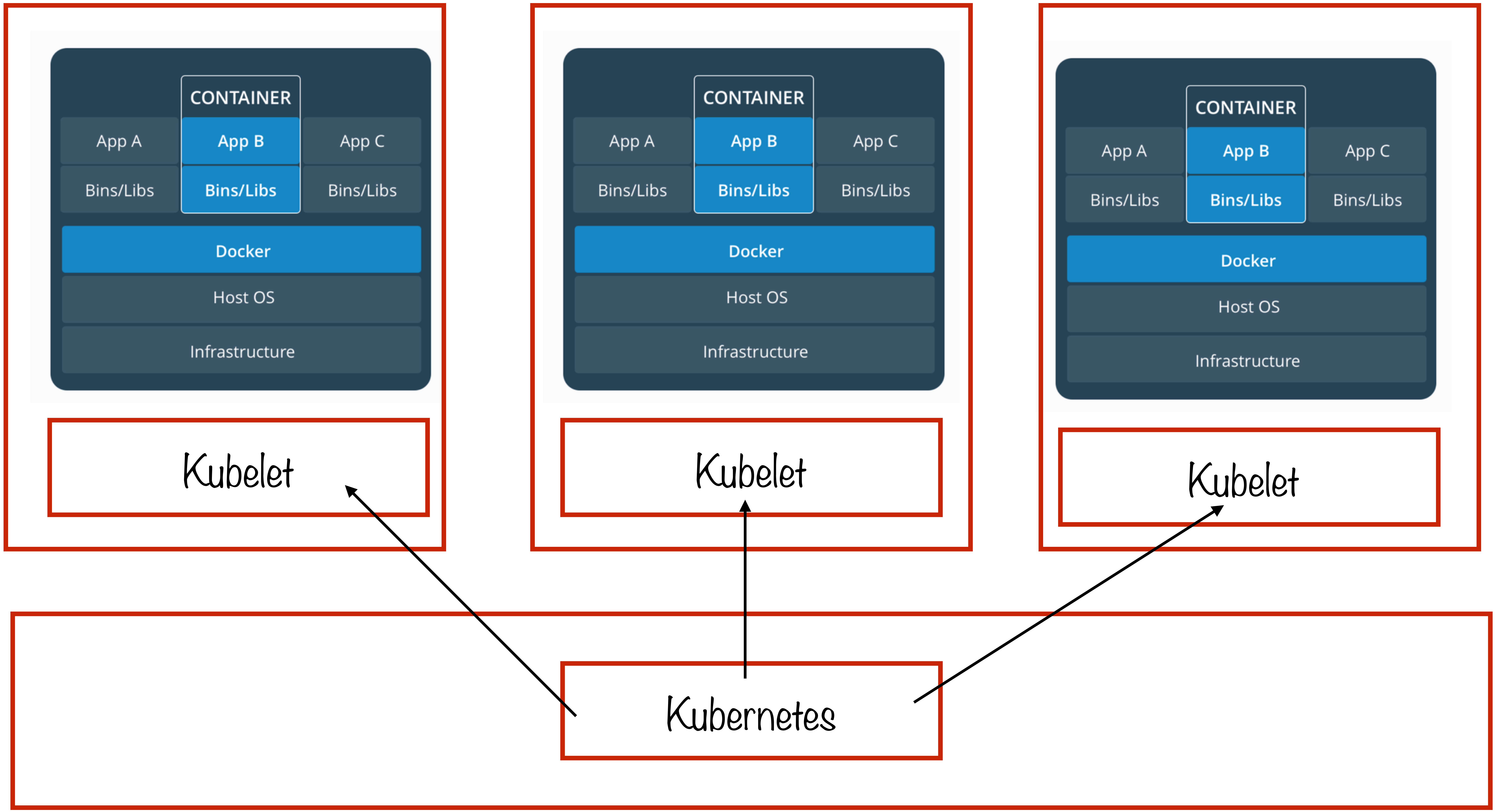



## Virtual Machines




(www.docker.com)

# Container Cluster



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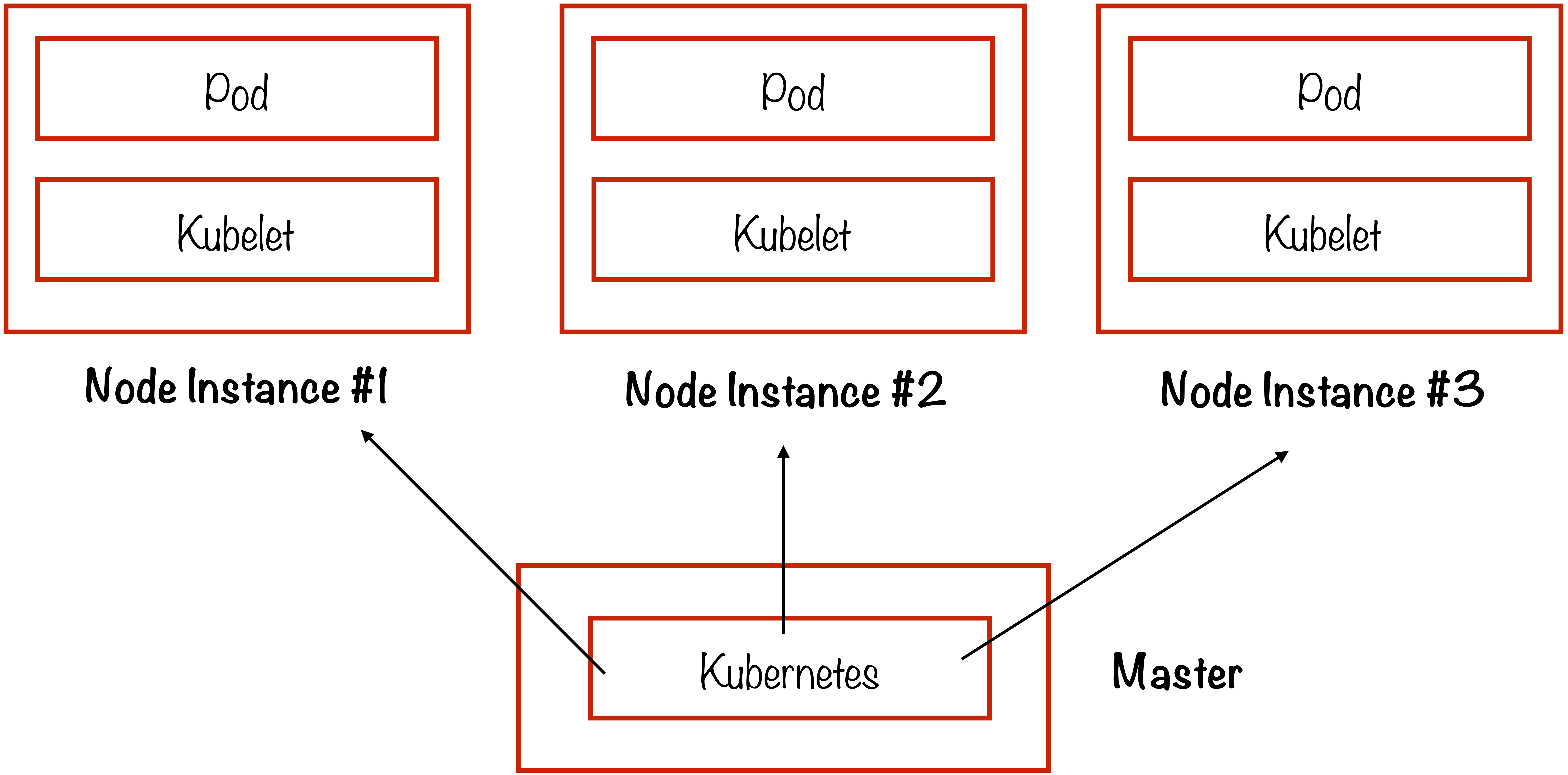

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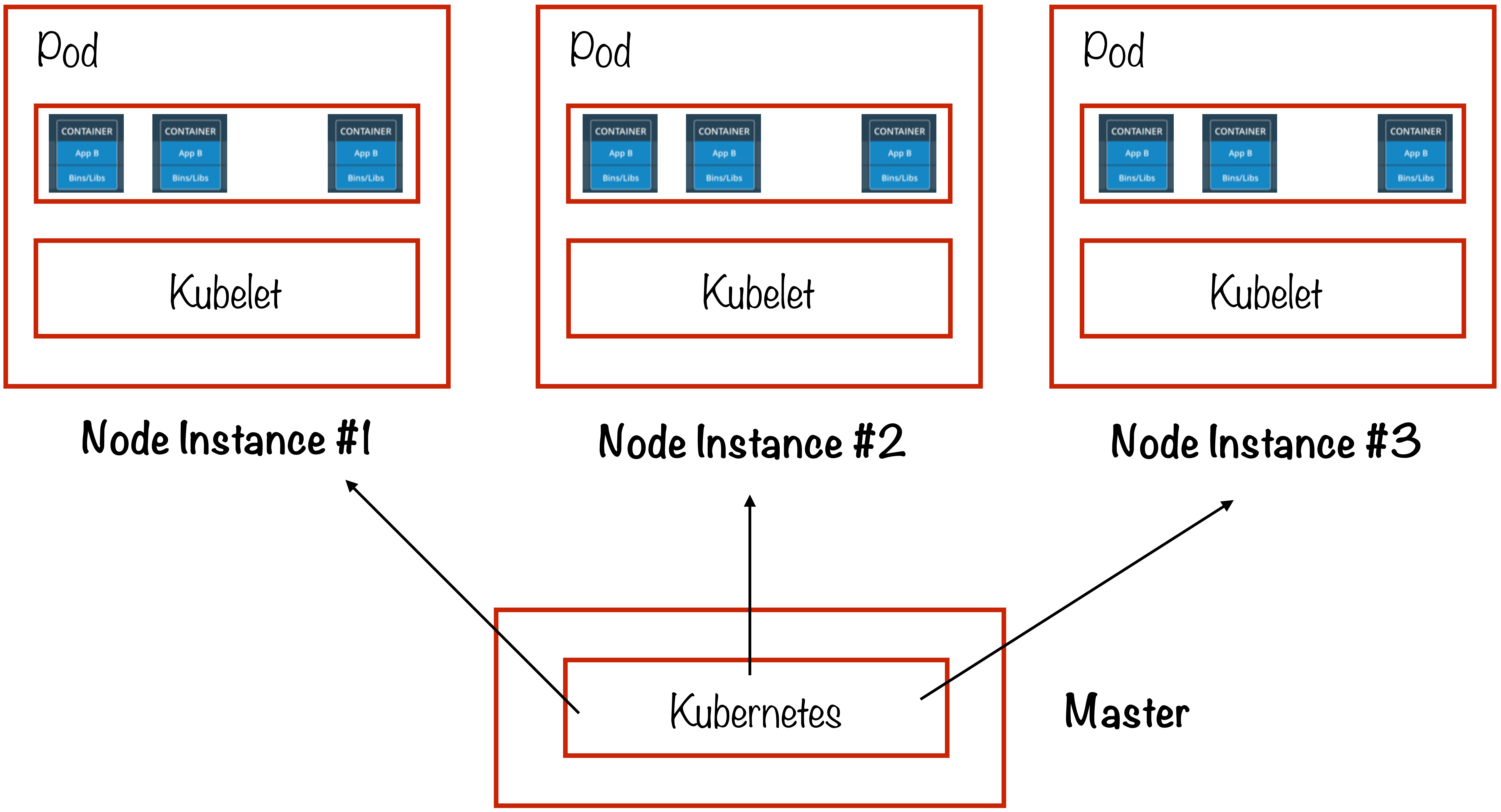


# Containers and VMs

| Containers | Virtual Machines |
|---|---|
| Virtualise the Operating System | Virtualise hardware |
| More portable | Less portable |
| Quick to boot | Slow to boot |
| Size - tens of MBs | Size - tens of GBs |

(www.docker.com)

## Hosting with Container Engine

DevOps - need largely mitigated

Can use Jenkins for CI/CD

# Hosting with Container Engine

StackDriver for logging and monitoring

# Hosting a Website

You run separate web server, database

Separate containers to isolate from each other

Service-oriented architecture

Microservices

"Google Container Engine"

**Lots of dependencies**

Deployment is becoming painful

Create containers, manage clusters

# Hosting a Website

"Google Cloud Storage"

"Firebase Hosting + Google Cloud Storage"

"Google Compute Engine"

"Google Container Engine"

Heroku, Engine Yard

Lots of code, languages

Just focus on code, forget the rest

# Hosting a Website

**Heroku, Engine Yard**

Lots of code, languages

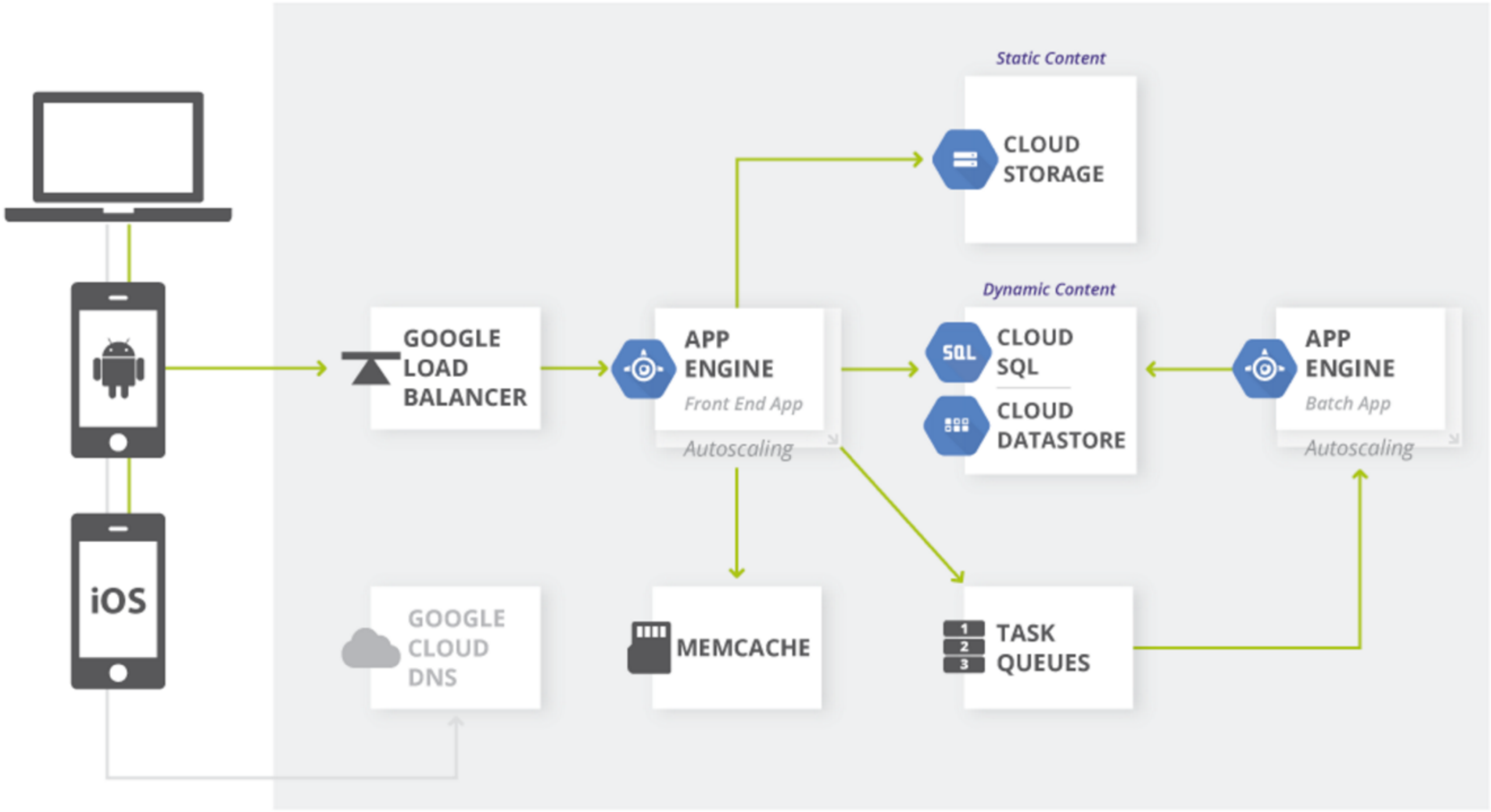
Just focus on code, forget the rest

Just write the code - leave the rest to platform

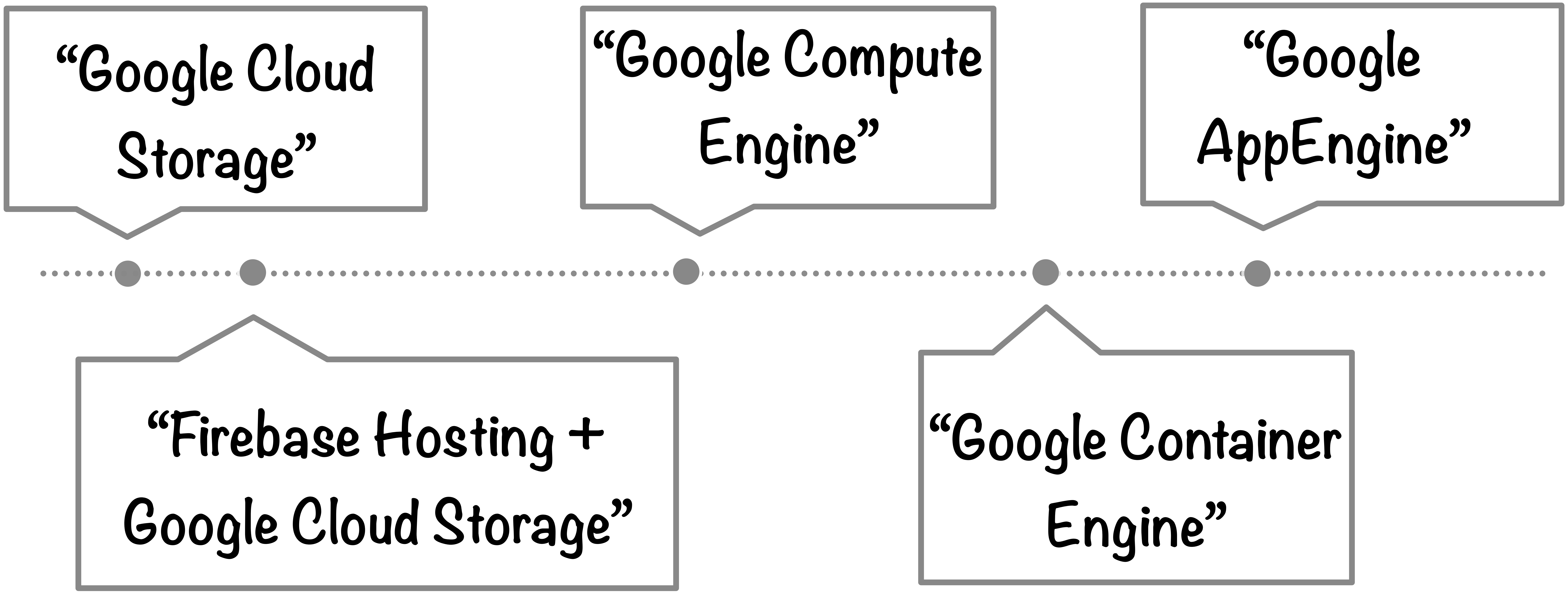
PaaS ("Platform-as-a-Service")

"Google AppEngine"

# Hosting on AppEngine



# Hosting a Website



# Compute Choices

## App Engine

A flexible, zero ops (serverless!) platform for building highly available apps

## Container Engine

Logical infrastructure powered by Kubernetes, the open source container orchestration system.

## Compute Engine

Virtual machines running in Google's global data center network

## App Engine

You want to focus on writing code, and never want to touch a server, cluster, or infrastructure.

## Container Engine

You want to increase velocity and improve operability dramatically by separating the app from the OS.

## Compute Engine

You need complete control over your infrastructure and direct access to high-performance hardware such as GPUs and local SSDs.

## App Engine

You neither know nor care about the OS running your code

## Container Engine

You don't have dependencies on a specific operating system.

## Compute Engine

You need to make OS-level changes, such as providing your own network or graphic drivers, to squeeze out the last drop of performance.

## App Engine

Support for Java, Python, PHP, Go, Ruby (beta) and Node.js (beta) ... or bring your own app runtime.

## Container Engine

Run the same application on your laptop, on premise and in the cloud.

## Compute Engine

Direct access to GPUs that you can use to accelerate specific workloads.

# App Engine

Web sites; Mobile app and gaming backends

RESTful APIs

Internet of things (IoT) apps.

# Container Engine

Containerized workloads

Cloud-native distributed systems.

Hybrid applications.

# Compute Engine

Any workload requiring a specific OS or OS configuration

Currently deployed, on-premises software that you want to run in the cloud.

Can't be containerised easily; or need existing VM images

# Mix-and-Match

- Use App Engine for the front end serving layer, while running Redis in Compute Engine.

- Use Container Engine for a rendering microservice that uses Compute Engine VMs running Windows to do the actual frame rendering.

- Use App Engine for your web front end, Cloud SQL as your database, and Container Engine for your big data processing.

# App Engine

# Environments

## Standard

Pre-configured with: Java 7, Python 2.7, Go, PHP

## Flexible

More choices: Java 8, Python 3.x, .NET

- **Serverless!**
- **Instance classes determine price, billing**
- **Laundry list of services - pay for what you use**

# Environments

## Standard

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## AppEngine Standard Environment

- Based on container instances running on Google's infrastructure

- Preconfigured with one of several available runtimes (Java 7, Python 2.7, Go and PHP)

- Each runtime also includes libraries that support App Engine Standard APIs

- Maybe all you need

## AppEngine Standard Environment

- Applications run in a secure, sandboxed environment
- App Engine standard environment distributes requests across multiple servers, and scaling servers to meet traffic demands
- Your application runs within its own secure, reliable environment that is independent of the hardware, operating system, or physical location of the server.

# Environments

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## AppEngine Flexible Environment

- Allows you to customize your runtime and even the operating system of your virtual machine using Dockerfiles
- Under the hood, merely instances of Google Compute Engine VMs

# Environments

## Standard

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# Cloud Functions

- Serverless execution environment for building and connecting cloud services
- Write simple, single-purpose functions
- Attached to events emitted from your cloud infrastructure and services
- Cloud Function is triggered when an event being watched is fired

# Cloud Functions

- Your code executes in a fully managed environment
- No need to provision any infrastructure or worry about managing any servers
- Cloud Functions are written in Javascript
- Run it in any standard Node.js runtime

# Compute Engine

Recall

# Hosting a Website

**Load balancing, scaling**

Currently on VMs or servers

Get VMs, manage yourself

You'd like to control load balancing, scaling etc yourself

IAAS ("Infra-as-a-service")

"Google Compute Engine"

Configuration, administration, management - all on you

No need to buy machines or install OS, dev stack, languages etc

# Image Types

- Public images for Linux and Windows Server that Google provides
- Private images that you create or import to Compute Engine
- Images of other OSes OK too

# Creation

- Creator has full root privileges, SSH capability
  - Can share with other users

- While creating instance specify
  - zone
  - OS
  - machine type

# Projects and Instances

- Each instance belongs to a project
- Projects can have any number of instances
- Projects can have upto 5 VPC (Virtual Private Networks)
- Each instance belongs in one VPC
  - instances within VPC communicate on LAN
  - instances across VPC communicate on internet

# Machine Types

- Standard
- High-memory
- High-CPU
- Shared-core (small, non-resource intensive)

- Can attach GPU dies to most machine types

# Preemptible Instances

- Much much cheaper than regular Compute Engine instances
- But, might be terminated (preempted) at any time if Compute Engine needs the resources
- Use for fault-tolerant applications

# Preemptible Instances

- Will definitely be terminated after running for 24 hours

- Probability of termination varies by day/zone etc

- Cannot live migrate (stay alive during updates) or auto-restart on maintenance

# Preemptible Instances

- Step 1 in Preemption: Compute Engine sends a Soft Off signal
- Step 2: Hopefully, you have a shutdown script to clean up and give up control within 30 seconds
- Step 3: If not, Compute Engine sends a Mechanical Off signal
- Compute Engine transitions to Terminated state

# Storage Options

- Each instance comes with a small root persistent disk containing the OS

- Add additional storage options
  - Persistent disks
    - Standard
    - SSD
  - Local SSDs
  - Cloud Storage

# Storage Options

| | Standard persistent disks | SSD persistent disks | Local SSDs | Cloud Storage buckets |
|---|---|---|---|---|
| **Storage type** | Efficient and reliable block storage | Fast and reliable block storage | High-performance local block storage | Affordable object storage |
| **Price per GB/month** | $0.040 - $0.052 | $0.170 - $0.221 | $0.218 - $0.283 | $0.007 - $0.026 |
| **Maximum space per instance** | 64 TB | 64 TB | 3 TB | Almost infinite |
| **Scope of access** | Zone | Zone | Instance | Global |
| **Data redundancy** | Yes | Yes | No | Yes |
| **Encryption at rest** | Yes | Yes | Yes | Yes |
| **Custom encryption keys** | Yes | Yes | No | Yes |
| **Machine type support** | All machine types | All machine types | Most machine types | All machine types |

# Persistent Disks

- Durable network storage devices that instances can access like physical disks in a desktop or a server
- Compute Engine manages physical disks and data distribution to ensure redundancy and optimize performance
- Encrypted (custom encryption possible)
- Built-in redundancy
- Restricted to the zone where instance is located

# Persistent Disks

- Two types - Standard and SSD
- Standard Persistent - regular hard disks - cheap - OK for sequential access
- SSD Persistent - expensive - fast for random access

# Local SSD

- Physically attached to the server that hosts your virtual machine instance
- Local SSDs have higher throughput and lower latency
- **The data that you store on a local SSD persists only until you stop or delete the instance**
- Small - each local SSD is 375 GB in size, but you can attach up to eight local SSD devices for 3 TB of total local SSD storage space per instance.

# Local SSD

- Very high IOPS and low latency
- Unlike persistent disks, you must manage the striping on local SSDs yourself
- Encrypted, custom encryption not possible

# Cloud Storage Buckets

- use when latency and throughput are not a priority
- and
- when you must share data easily between multiple instances or zones.

# Cloud Storage Buckets

- Flexible, scalable, durable
- ~Infinite size possible
- Performance depends on storage class
  - Multi-regional
  - Regional
  - Nearline
  - Coldline

# Containers

Recall

# Hosting a Website

"Google Cloud Storage"

"Google Compute Engine"

Heroku, Engine Yard

Lots of code, languages

Just focus on code, forget the rest

"Firebase Hosting + Google Cloud Storage"

Lots of dependencies

Deployment is becoming painful

Create containers, manage clusters

Recall

# Hosting a Website

You run separate web server, database

Separate containers to isolate from each other

"Google Container Engine"

Service-oriented architecture

Microservices

**Lots of dependencies**

Deployment is becoming painful

Create containers, manage clusters

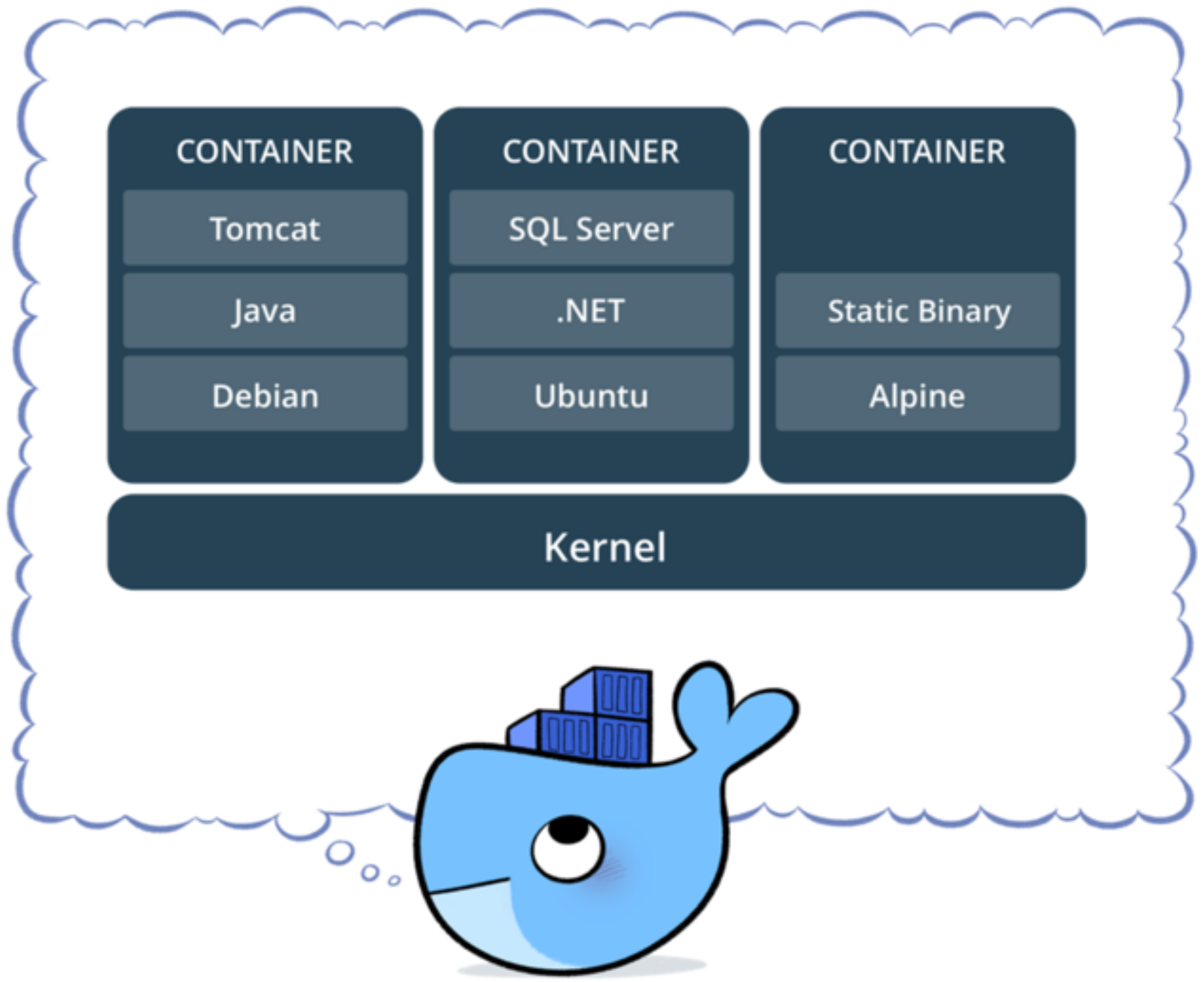
Recall

# Container

A container image is a lightweight, stand-alone, executable package of a piece of software that includes everything needed to run it: code, runtime, system tools, system libraries, settings

(www.docker.com)

# Container

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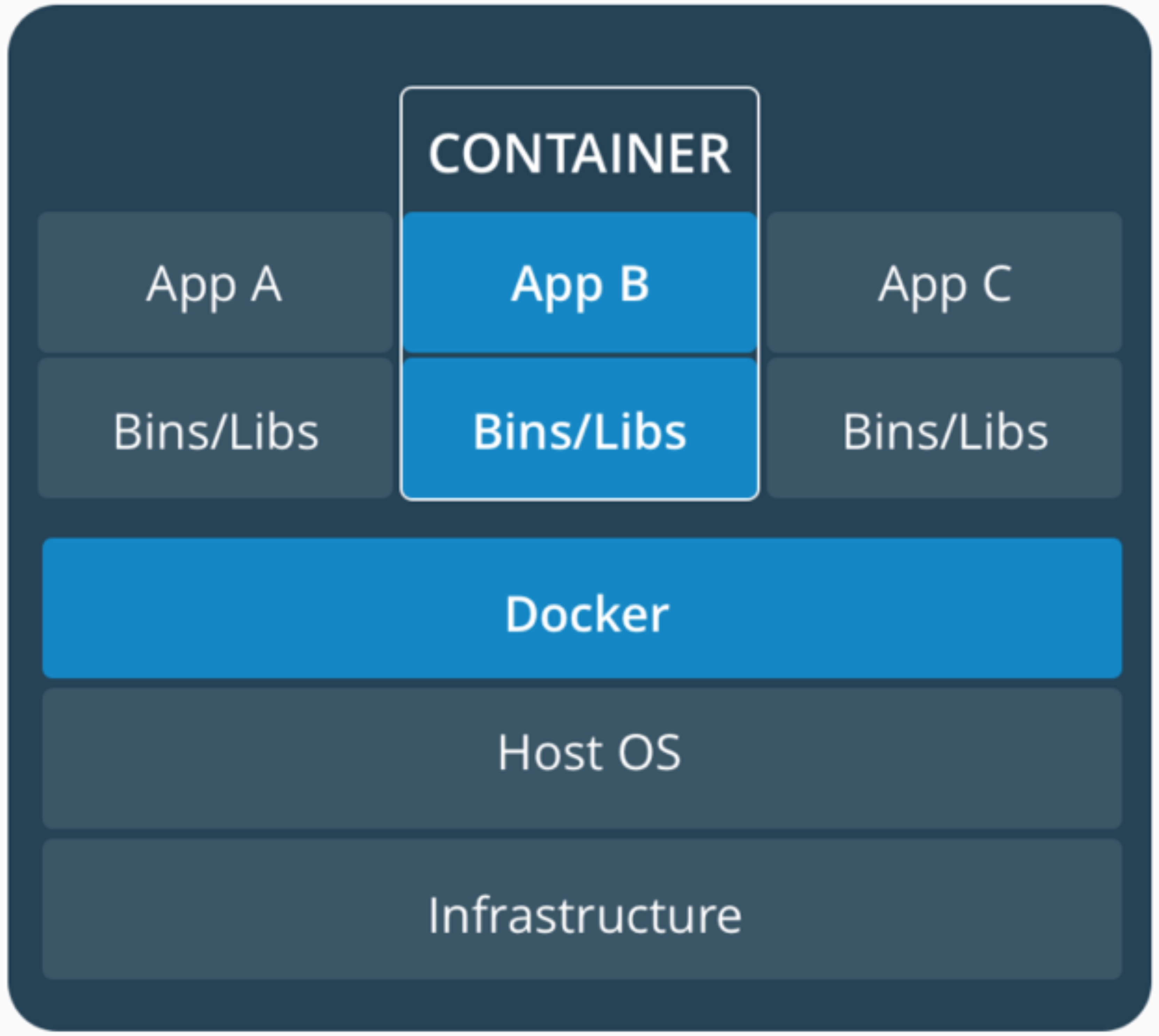
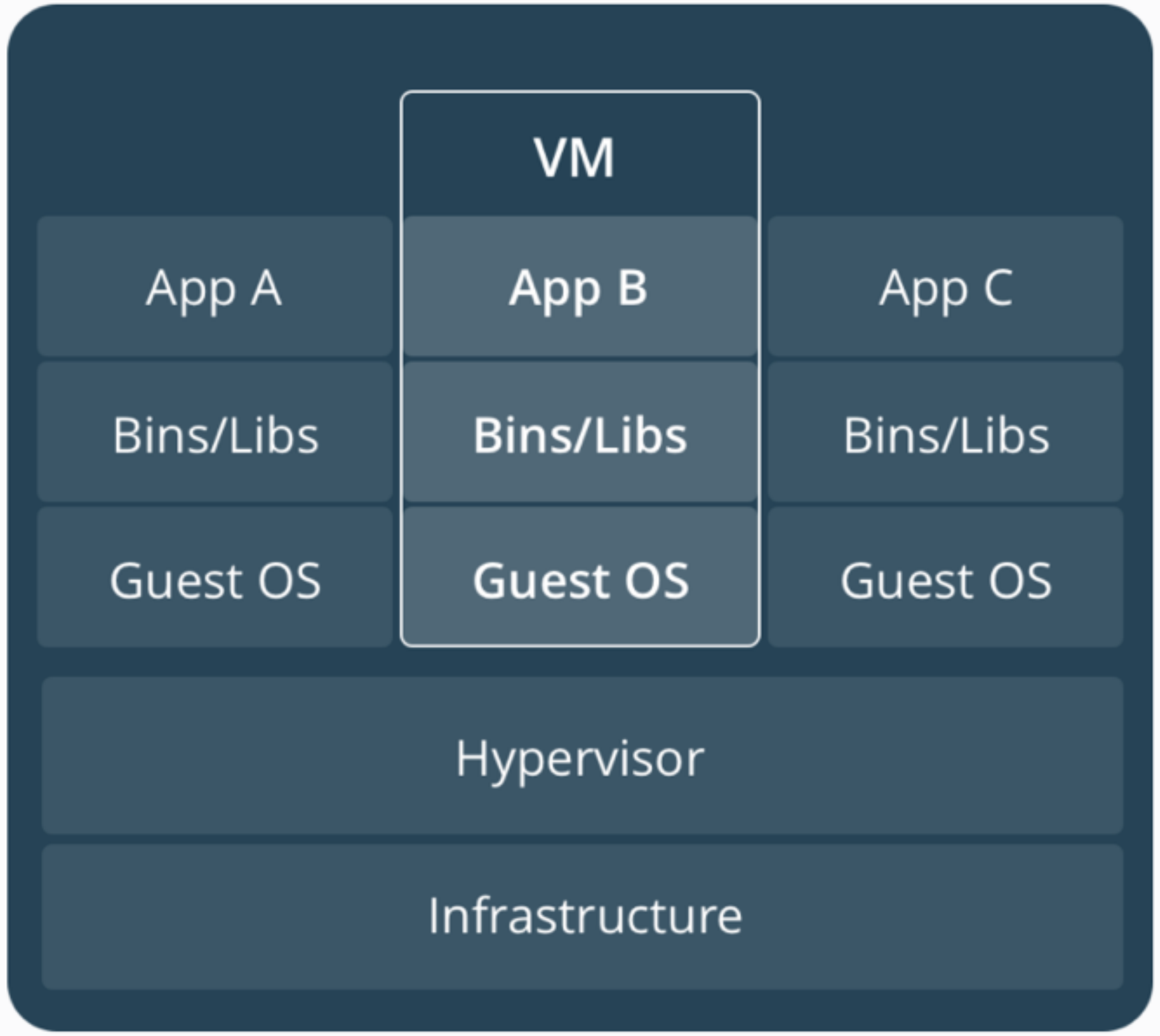
# Containers and VMs

Containers




Virtual Machines




(www.docker.com)

# Containers and VMs

| Containers | Virtual Machines |
| --- | --- |
| Virtualise the Operating System | Virtualise hardware |
| More portable | Less portable |
| Quick to boot | Slow to boot |
| Size - tens of MBs | Size - tens of GBs |

(www.docker.com)

# Hosting a Website

You run separate web server, database

Separate containers to isolate from each other

Service-oriented architecture

Microservices

"Google Container Engine"

**Lots of dependencies**

Deployment is becoming painful

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"Google Compute Engine"

"Google Container Engine"

Heroku, Engine Yard

Lots of code, languages

Just focus on code, forget the rest

# Advantages

Componentization - microservices

Portability

Rapid deployment

# Advantages

Orchestration - Kubernetes clusters

Image registration - Pull images from container registry

Flexibility - mix-and-match with other cloud providers, on-premise

# Storage options

Storage options as with Compute Engine

However, remember that container disks are ephemeral

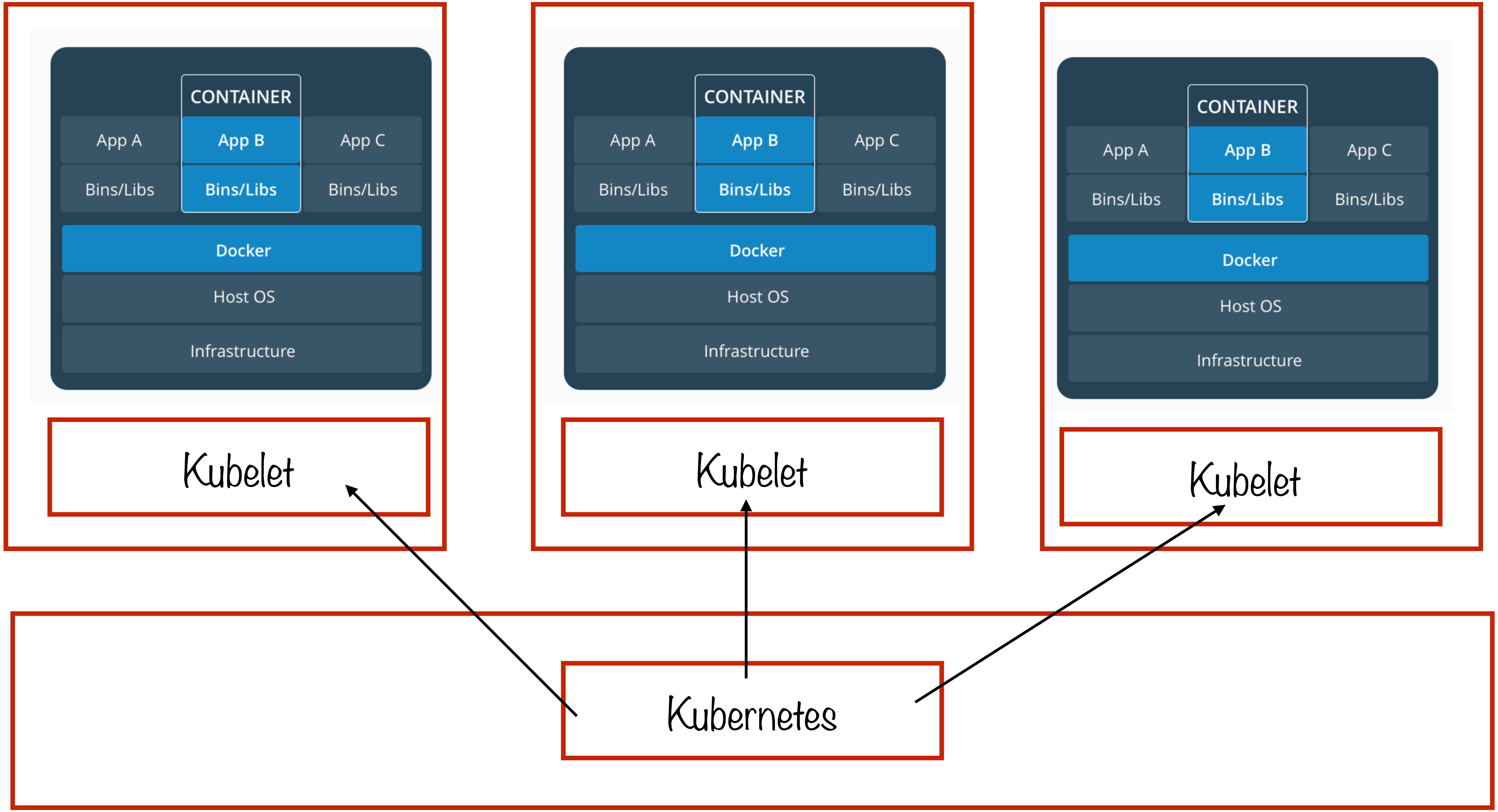
Need to use gcePersistentDisk abstraction for persistent disk

# Load Balancing

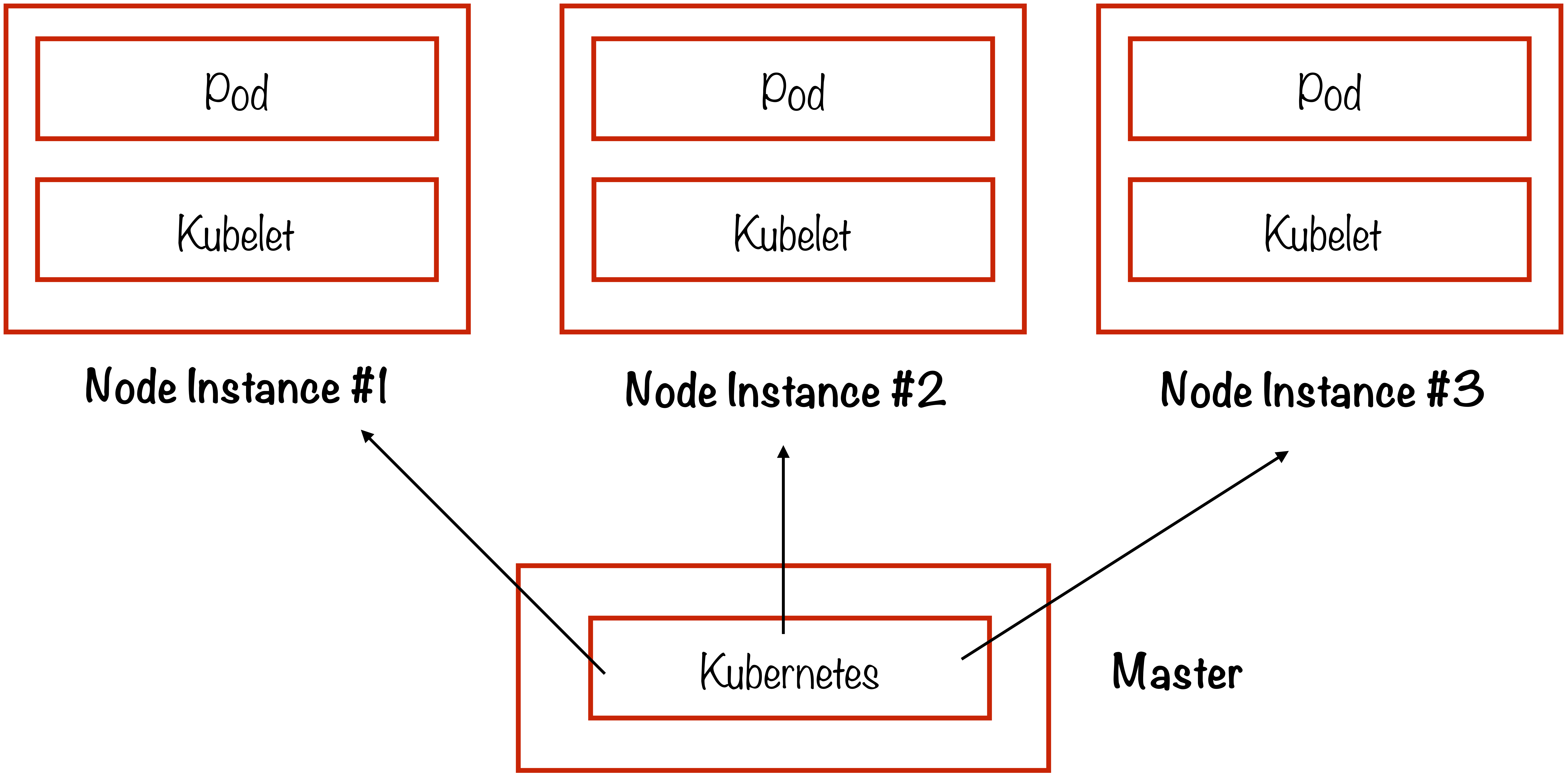
Network load balancing works out-of-box with Container Engine

For HTTP load balancing, need to integrate with Compute Engine load balancing

# Container Cluster



# Container Cluster



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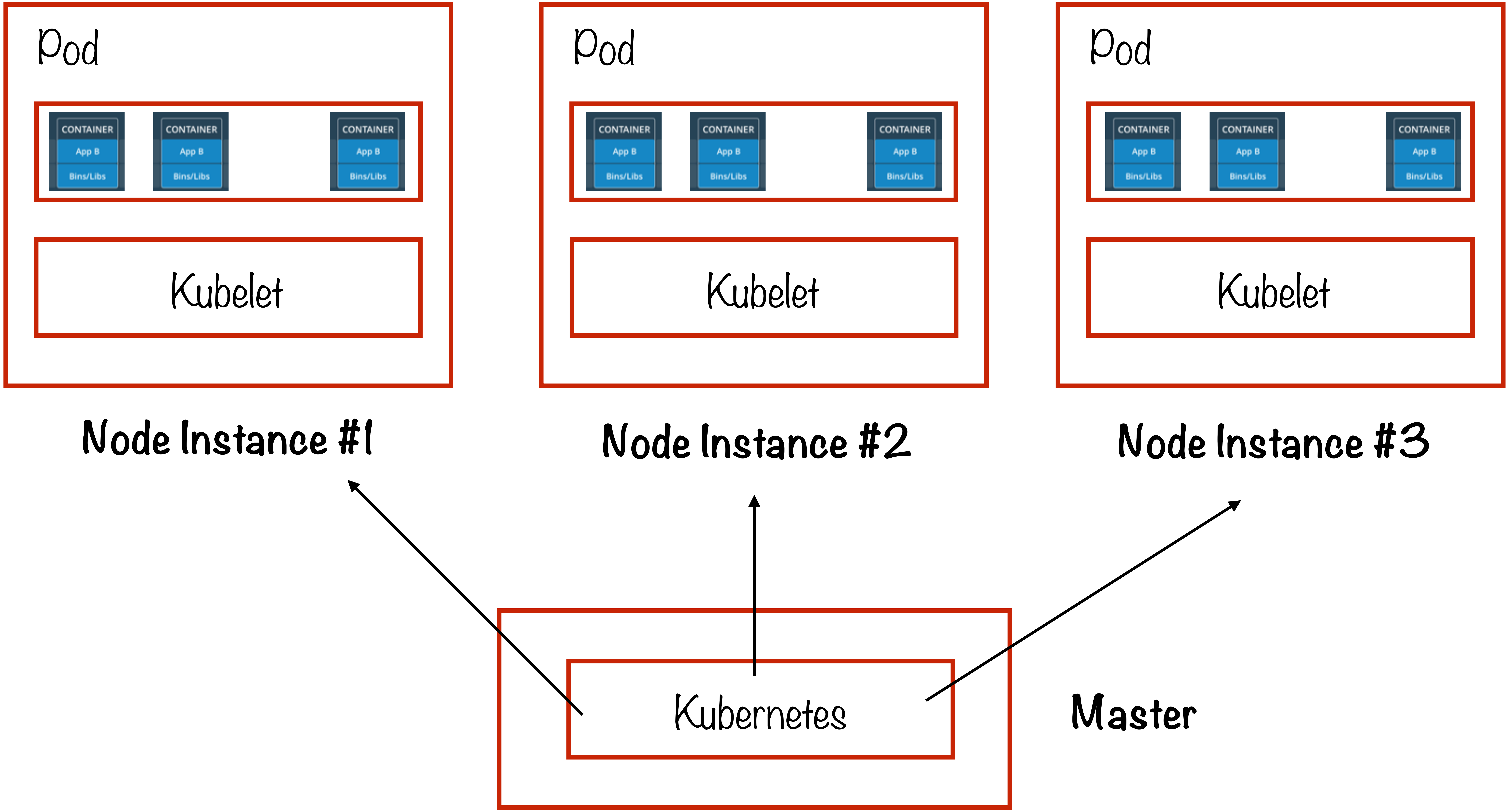


# Container Cluster

- Group of Compute Engine instances running Kubernetes.
- It consists of
  - one or more node instances, and
  - a managed Kubernetes master endpoint.

# Node Instances

- Managed from the master
- Run the services necessary to support Docker containers
- Each node runs the Docker runtime and hosts a Kubelet agent, which manages the Docker containers scheduled on the host

# Master Endpoint

- Managed master also runs the Kubernetes API server, which
  - services REST requests
  - schedules pod creation and deletion on worker nodes
  - synchronizes pod information (such as open ports and location)

# Node Pool

- Subset of machines within a cluster that all have the same configuration.

- Useful for customizing instance profiles in your cluster

- You can also run multiple Kubernetes node versions on each node pool in your cluster, update each node pool independently, and target different node pools for specific deployments.

# Container Builder

- Tool that executes your container image builds on Google Cloud Platform's infrastructure

- Working:
  - import source code from a variety of repositories or cloud storage spaces
  - execute a build to your specifications
  - produce artifacts such as Docker containers or Java archives.

# Container Registry

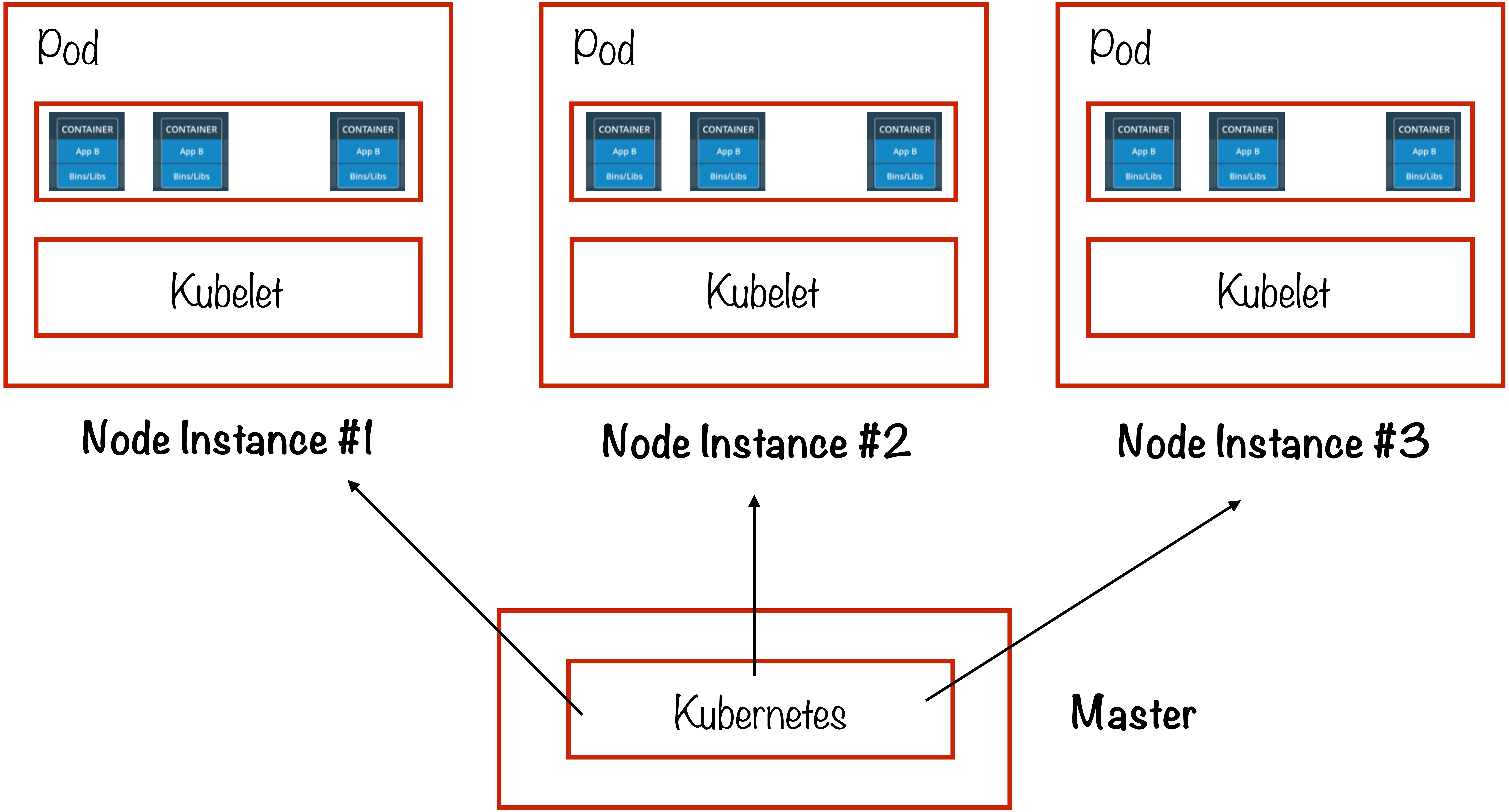
- Private registry for Docker images

- Can access Container Registry through secure HTTPS endpoints, which lets you push, pull, and manage images from any system, whether it's a Compute Engine instance or your own hardware

- Can use the Docker credential helper command-line tool to configure Docker to authenticate directly with Container Registry

- Can use third-party cluster management, continuous integration, or other solutions outside of Google Cloud Platform

# Autoscaling



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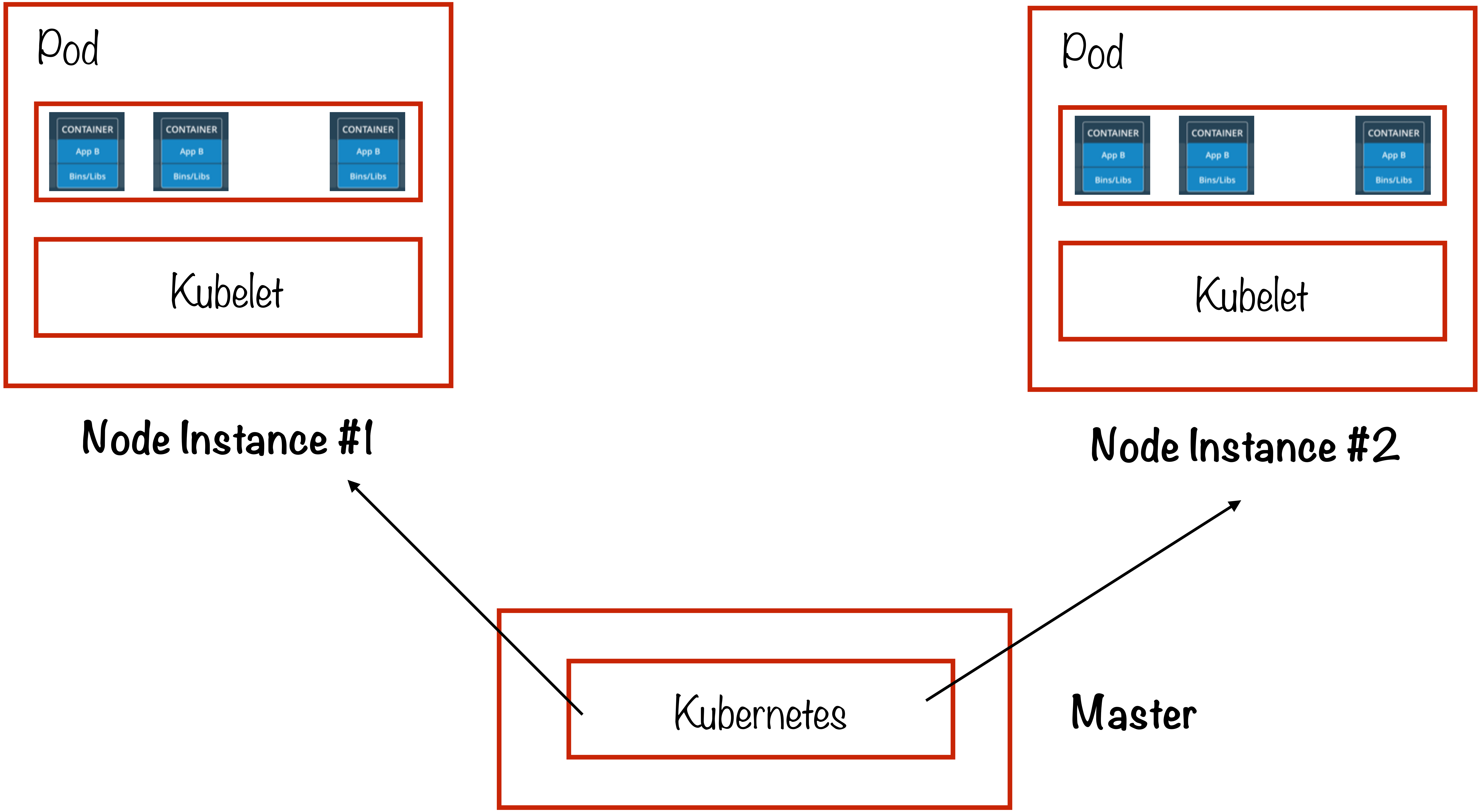

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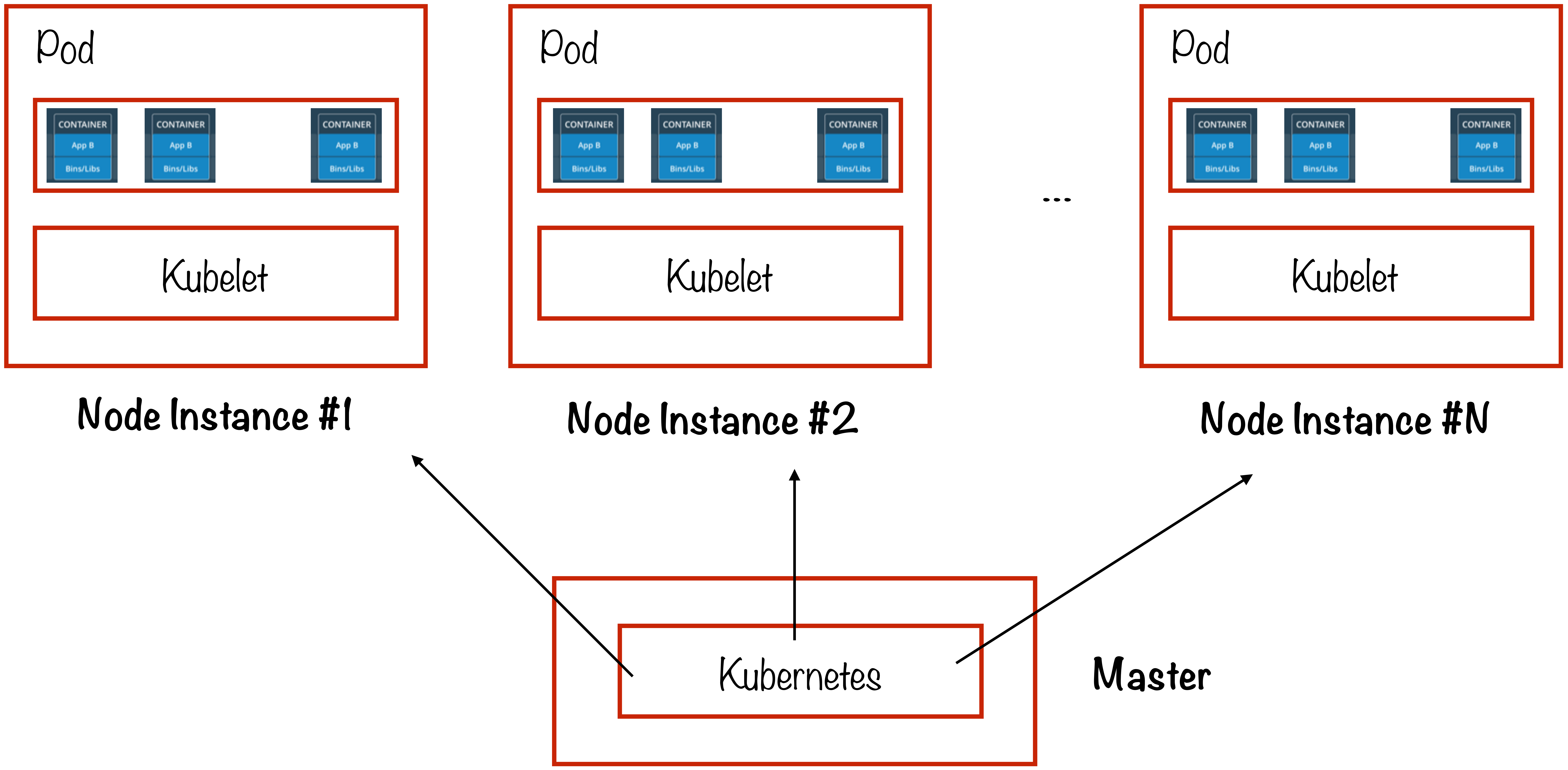

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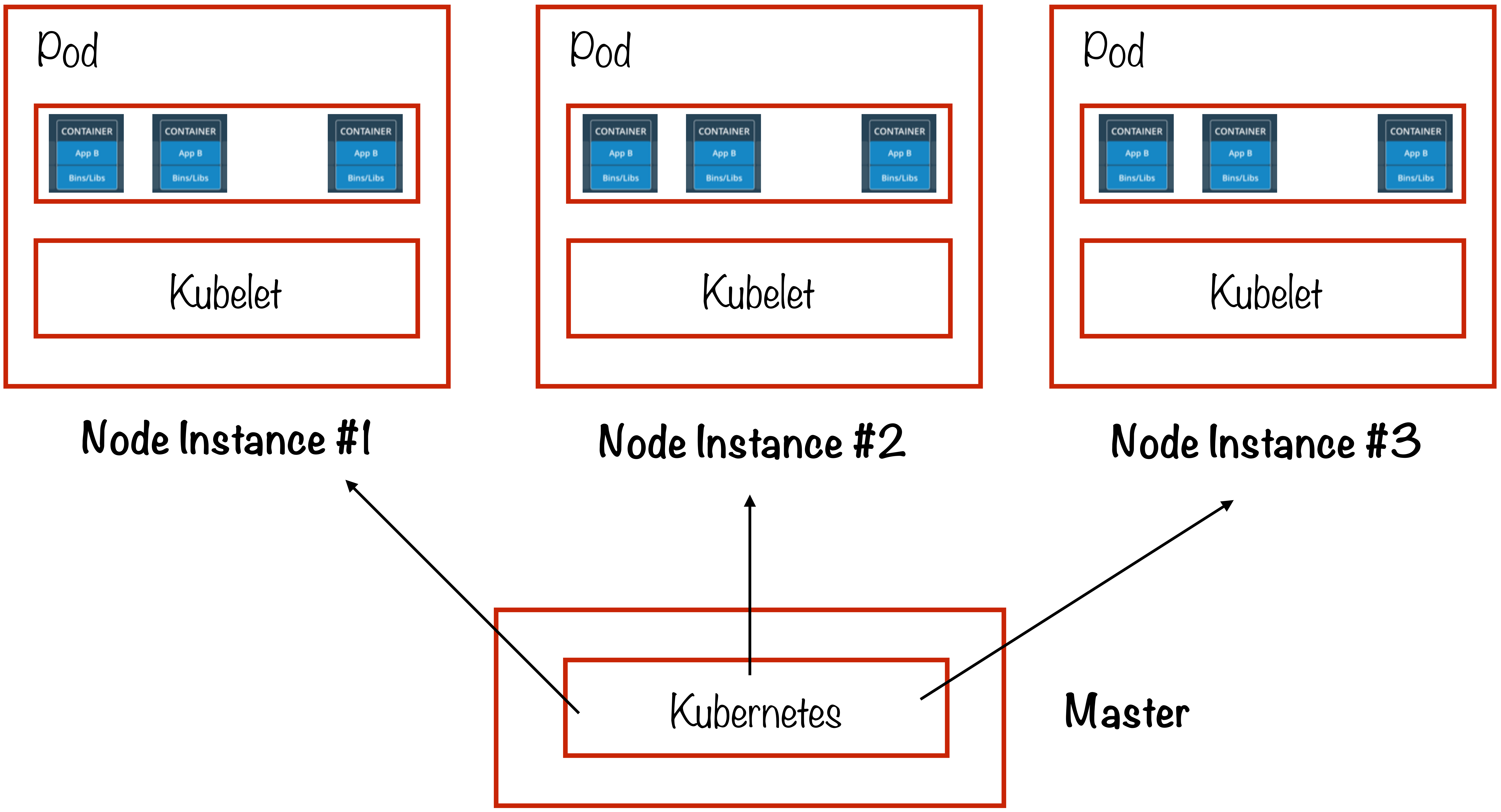

# Autoscaling

- Automatic resizing of clusters with **Cluster Autoscaler**
- Periodically checks whether there are any pods waiting, resizes cluster if needed
- Also monitors usage of nodes and deletes nodes if all its pods can be scheduled elsewhere

# Summary

AppEngine, Compute Engine and Container Engine are GCP's 3 compute options

Google AppEngine is the PaaS option - serverless and ops-free

Google ComputeEngine is the IaaS option - fully controllable down to OS

Google Container Engine lies in between - clusters of machines running Kubernetes and hosting containers

# Module - Storage

# Overview

Block storage for compute VMs - persistent disks or SSDs

Immutable blobs like video/images - Cloud Storage

OLTP - Cloud SQL or Cloud Spanner

NoSQL Documents like HTML/XML - Datastore

NoSQL Key-values - BigTable (~HBase)

Getting data into Cloud Storage - Transfer service

# Storage Options

# Use-Cases

| When you need | Use |
| --- | --- |
| Storage for Compute, Block Storage | Persistent (hard disks), SSD |
| Storing media, Blob Storage | File system - maybe HDFS |
| SQL Interface atop file data | Hive (SQL-like, but MapReduce on HDFS) |
| Document database, NoSQL | CouchDB, MongoDB (key-value/indexed database) |
| Fast scanning, NoSQL | HBase (columnar database) |
| Transaction Processing (OLTP) | RDBMS |
| Analytics/Data Warehouse (OLAP) | Hive  (SQL-like, but MapReduce on HDFS) |

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# Mobile-Specific Use-Cases

| When you need | Use |
| --- | --- |
| Storage for Compute, Block Storage along with mobile SDKs | Cloud Storage for Firebase |
| Fast random access with mobile SDKs | Firebase Realtime DB |

# Use-Cases

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# Block Storage

Data is not structured

Lowest level of storage - no abstraction at all

Meant for use from VMs

Location tied to VM location

# Block Storage

Data stored in volumes (called blocks)

Remember the options available on Compute Engine VMs

- Persistent disks
  - Standard
  - SSD
- Local SSDs
- (Also Cloud Storage - more in a bit)

# Use-Cases

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# Cloud Storage

- Create buckets to store data
- Buckets are globally unique
  - Name (globally unique)
  - Location
  - Storage Class

# Bucket Storage Classes

- Multi-regional - frequent access from anywhere in the world
- Regional - frequent access from specific region
- Nearline - accessed once a month at max
- Coldline - accessed once a year at max

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# BigQuery

- Latency bit higher than BigTable, DataStore - prefer those for low latency
- No ACID properties - can't use for transaction processing (OLTP)
- Great for analytics/business intelligence/data warehouse (OLAP)
- Recall that OLTP needs strict write consistency, OLAP does not

# BigQuery

- Superficially similar in use-case to Hive
- SQL-like abstraction for non-relational data
- Underlying implementation actually quite different from Hive though

# Use-Cases

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# Cloud SQL, Cloud Spanner

- Relational databases - super-structured data, constraints etc
- ACID properties - use for transaction processing (OLTP)
- Too slow and too many checks for analytics/BI/warehousing (OLAP)
- Recall that OLTP needs strict write consistency, OLAP does not

# Cloud SQL, Cloud Spanner

- Cloud Spanner is Google proprietary, more advanced than Cloud SQL
- Cloud Spanner offers "horizontal scaling" - i.e. bigger data, more instances, replication etc
- Under the hood, Cloud Spanner has a surprising design - more later

# Use-Cases

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# DataStore

- Document data - eg XML or HTML - has a characteristic pattern
- Key-value structure, i.e. structured data
- Typically not used either for OLTP or OLAP
- Fast lookup on keys is the most common use-case

# DataStore

- Speciality of DataStore is that query execution time depends on size of returned result (not size of data set)
- So, a returning 10 rows will take the same length of time whether dataset is 10 rows, or 10 billion rows
- Ideal for "needle-in-a-haystack" type applications, i.e. lookups of non-sequential keys

# DataStore

- Indices are always fast to read, slow to write
- So, don't use for write-intensive data

# Use-Cases

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# BigTable

- Fast scanning of sequential key values - use BigTable
- Columnar database, good for sparse data
- Sensitive to hot spotting - need to design key structure carefully
- Similar to HBase

# Cloud Storage

# Use-Cases

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- Coldline - accessed once a year at max

# Bucket Storage Classes

| Storage Class | Characteristics | Use Cases | Price (per GB per month)** |
|---|---|---|---|
| Multi-Regional Storage | • 99.95% availability SLA*<br>• Geo-redundant | Storing data that is frequently accessed ("hot" objects) around the world, such as serving website content, streaming videos, or gaming and mobile applications. | $0.026 |

- Frequently accessed ("hot" objects), such as serving website content, interactive workloads, or mobile and gaming applications.

- Highest availability of the storage classes

- Geo-redundant - Cloud Storage stores your data redundantly in at least two regions separated by at least 100 miles within the multi-regional location of the bucket.

# Bucket Storage Classes

| Storage Class | Characteristics | Use Cases | Price (per GB per month)** |
|---|---|---|---|
| Regional Storage | • 99.9% availability SLA*<br>• Lower cost per GB stored<br>• Data stored in a narrow geographic region | Storing frequently accessed in the same region as your Google Cloud DataProc or Google Compute Engine instances that use it, such as for data analytics. | $0.02 |

- Appropriate for storing data that is used by Compute Engine instances.
- Better performance for data-intensive computations, as opposed to storing your data in a multi-regional location

# Bucket Storage Classes

| Storage Class | Characteristics | Use Cases | Price (per GB per month)** |
|---|---|---|---|
| Nearline Storage | • 99.0% availability SLA* <br> • Very low cost per GB stored <br> • Data retrieval costs <br> • Higher per-operation costs <br> • 30-day minimum storage duration | Data you do not expect to access frequently (i.e., no more than once per month). Ideal for back-up and serving long-tail multimedia content. | $0.01 |

- Slightly lower availability
- 30-day minimum storage duration
- Data you plan to read or modify on average once a month or less
- Data backup, disaster recovery, and archival storage.

# Bucket Storage Classes

| Storage Class | Characteristics | Use Cases | Price (per GB per month)** |
|---|---|---|---|
| Coldline Storage | • 99.0% availability SLA*<br>• Lowest cost per GB stored<br>• Data retrieval costs<br>• Higher per-operation costs<br>• 90-day minimum storage duration | Data you expect to access infrequently (i.e., no more than once per year). Typically this is for disaster recovery, or data that is archived and may or may not be needed at some future time. | $0.007 |

- Unlike other "cold" storage services, same throughput and latency (i.e. not slower to access)
- 90-day minimum storage duration, costs for data access, and higher per-operation costs
- Infrequently accessed data, such as data stored for legal or regulatory reasons

# Working with Cloud Storage

- XML and JSON APIs
- Command line (gsutil)
- GCP Console (web)
- Client SDK

# Domain-Named Buckets

- Cloud Storage considers bucket names that contain dots to be domain names
- Must be syntactically valid DNS names
  - E.g bucket...example.com is not valid because it contains three dots in a row
- End with a currently-recognized top-level domain, such as .com
- Pass domain ownership verification
  - E.g. Team member creating bucket must be domain owner or manager

# Domain Verification

- Number of ways to demonstrate ownership of a site or domain, including:
  - Adding a special Meta tag to the site's homepage.
  - Uploading a special HTML file to the site.
  - Verifying ownership directly from Search Console.
  - Adding a DNS TXT or CNAME record to the domain's DNS configuration.

# Mobile-Specific Use-Cases

| When you need | Use |
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# Cloud SQL

# Use-Cases

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- Recall that OLTP needs strict write consistency, OLAP does not

# Relational Data

| StudentID | Student Name |
|---|---|
| 1 | Jane Doe |
| 2 | John Walsh |
| 3 | Raymond Wu |

| CourseID | Course Name |
|---|---|
| CS101 | Introduction to Computer Science |
| EE275 | Logic Circuits |
| CS183 | Computer Architecture |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| 1 | Jane Doe | CS101 | Fall 2015 | A- |
| 2 | John Walsh | CS294 | Spring 2016 | B+ |
| 3 | Raymond Wu | ME101 | Winter 2015 | C+ |
| 1 | Jane Doe | CS183 | Summer 2012 | A+ |

# Cloud SQL, Cloud Spanner

- Cloud Spanner is Google proprietary, more advanced than Cloud SQL
- Cloud Spanner offers "horizontal scaling" - i.e. bigger data, more instances, replication etc
- Under the hood, Cloud Spanner has a surprising design - more later

# Cloud SQL

- MySQL - fast and the usual
- PostgreSQL - complex queries

# Instances

- Instances need to be created explicitly
    - Not serverless
    - Specify region while creating instance
- First vs. second generation instances
    - Second generation instances allow proxy support - no need to whitelist IP addresses or configure SSL
    - Higher availability  configuration
    - Maintenance won't take down the server

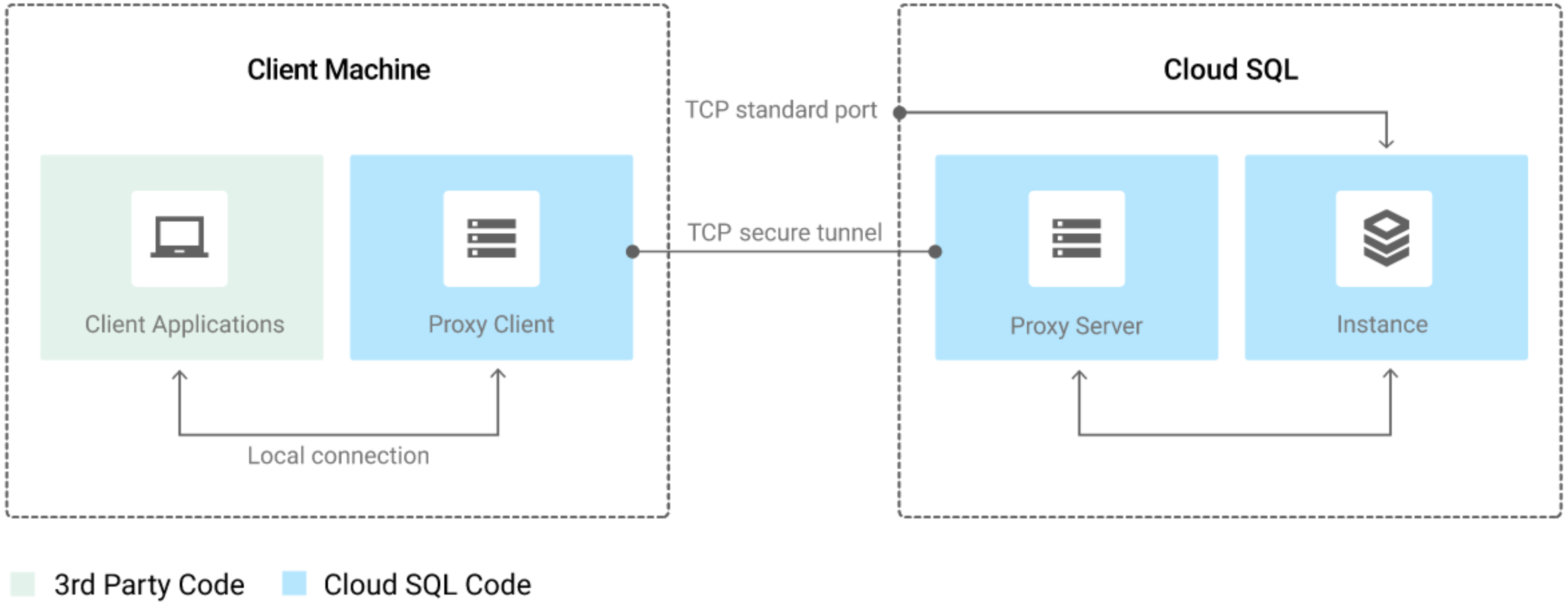
# High Availability Configuration

- A Second Generation instance is in an high availability configuration when it has a failover replica
- The failover replica must be in a different zone than the original instance, also called the master
- All changes made to the data on the master, including to user tables, are replicated to the failover replica using semisynchronous replication.

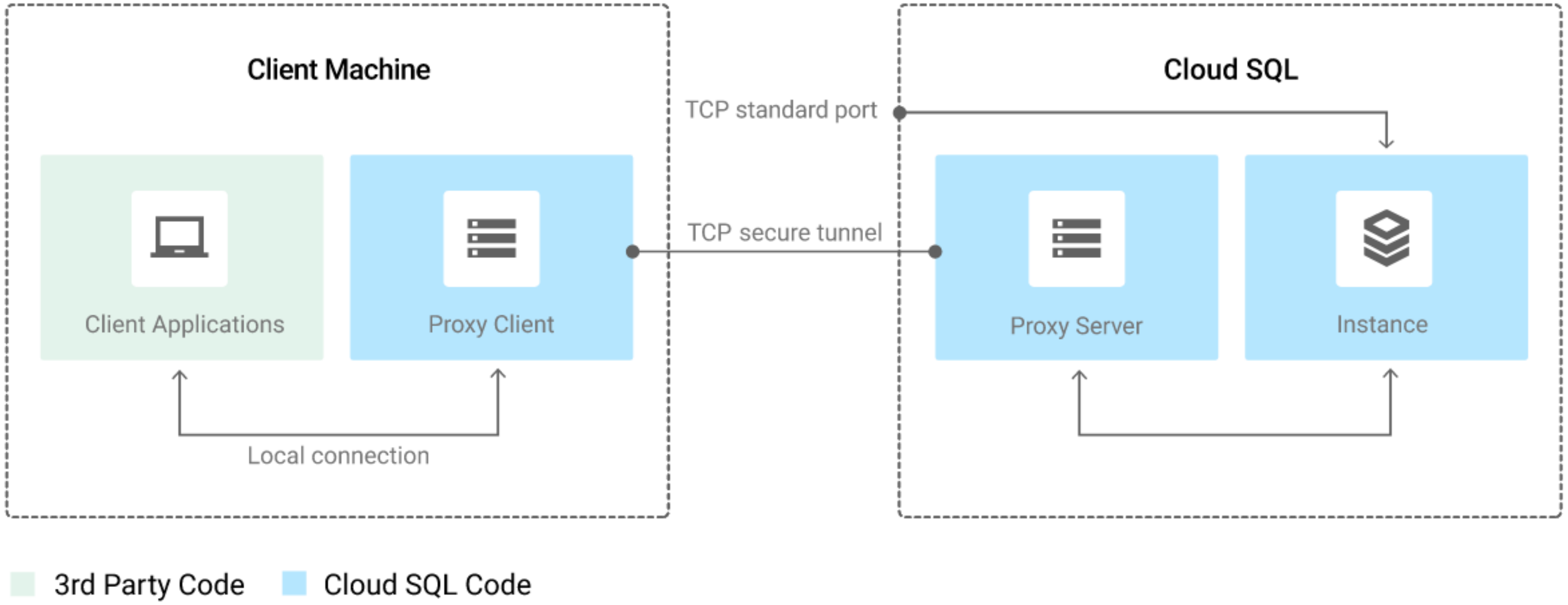
# Cloud Proxy

- Provides secure access to your Cloud SQL Second Generation instances without having to whitelist IP addresses or configure SSL.
- Secure connections: The proxy automatically encrypts traffic to and from the database; SSL certificates are used to verify client and server identities.
- Easier connection management: The proxy handles authentication with Google Cloud SQL, removing the need to provide static IP addresses.

# Cloud Proxy

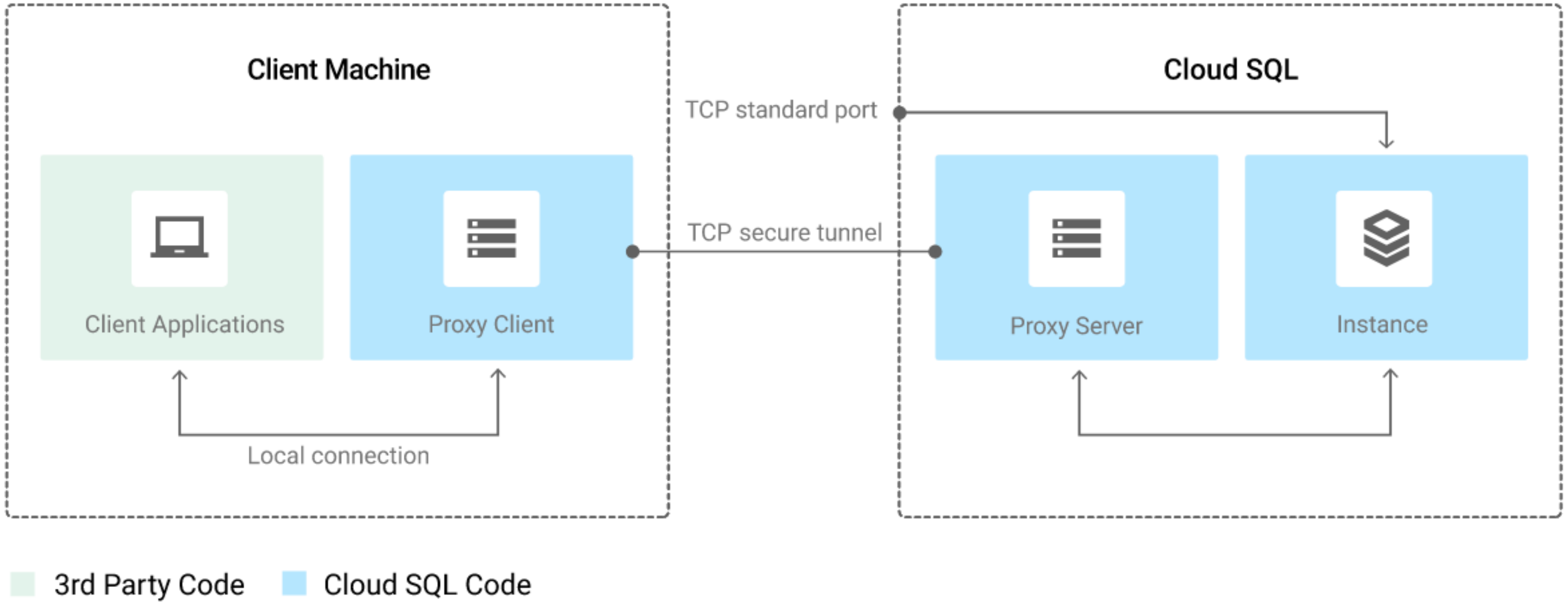

Client Machine
Cloud SQL
TCP standard port
TCP secure tunnel
Client Applications
Proxy Client
Proxy Server
Instance
Local connection
3rd Party Code
Cloud SQL Code

# Cloud Proxy



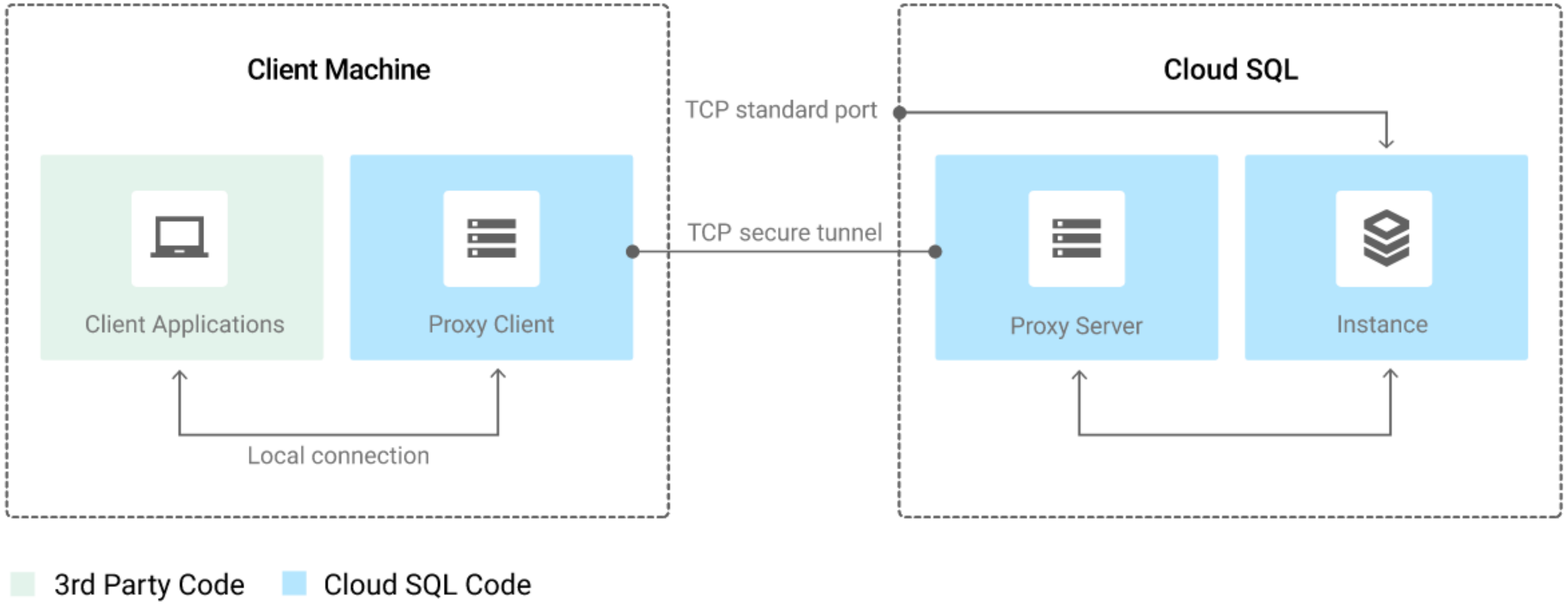

The Cloud SQL Proxy works by having a local client, called the proxy, running in the local environment

# Cloud Proxy



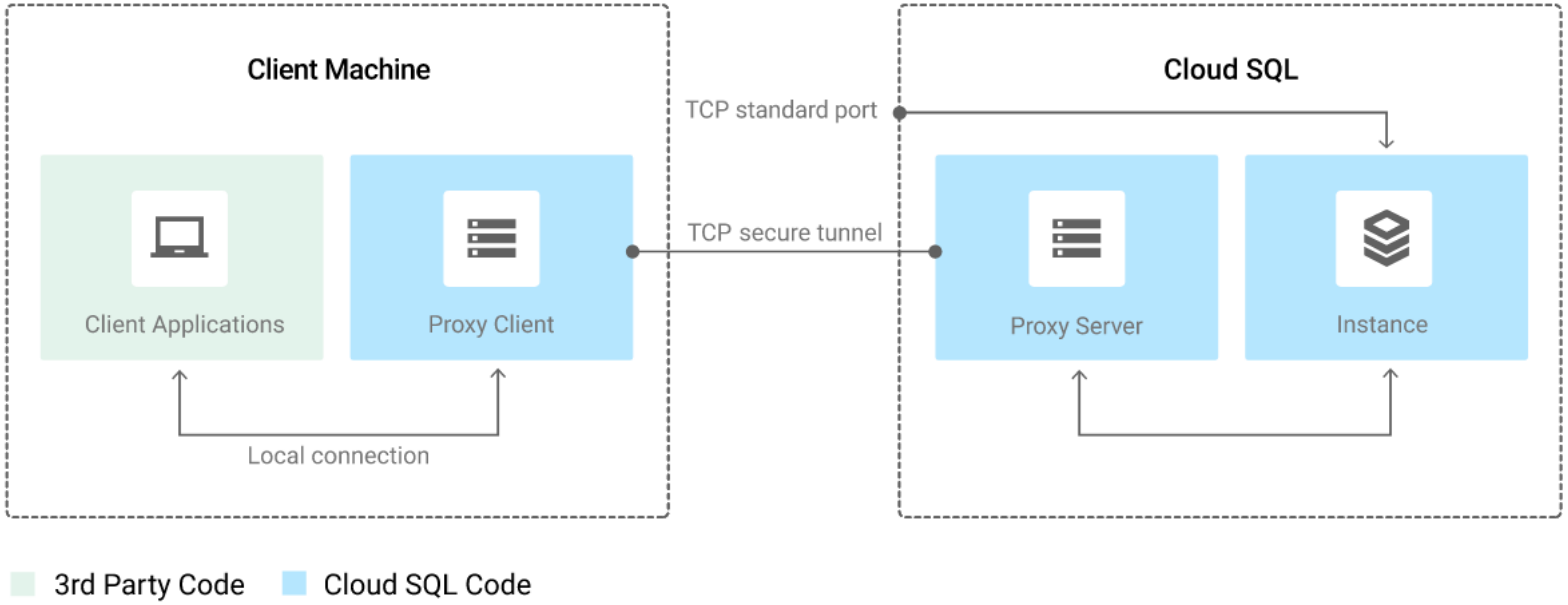

Your application communicates with the proxy with the standard database protocol used by your database

# Cloud Proxy




The proxy uses a secure tunnel to communicate with its companion process running on the server.

# Cloud Proxy

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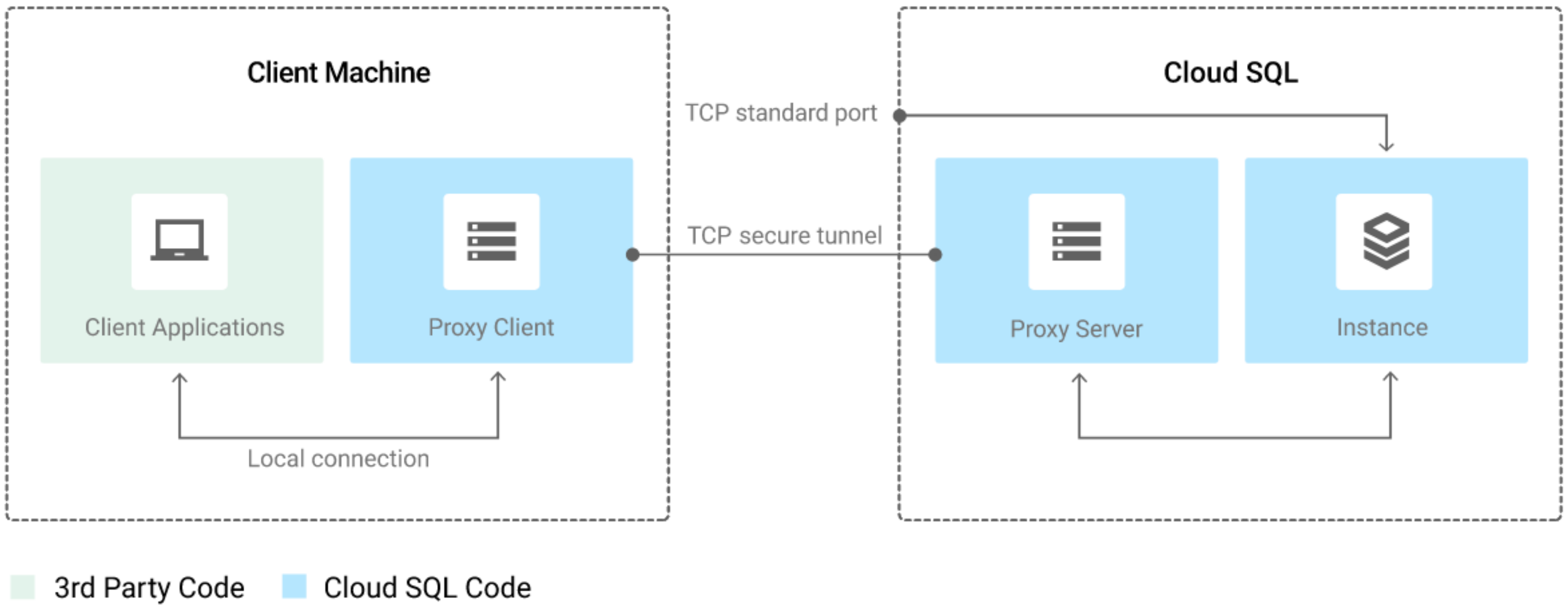
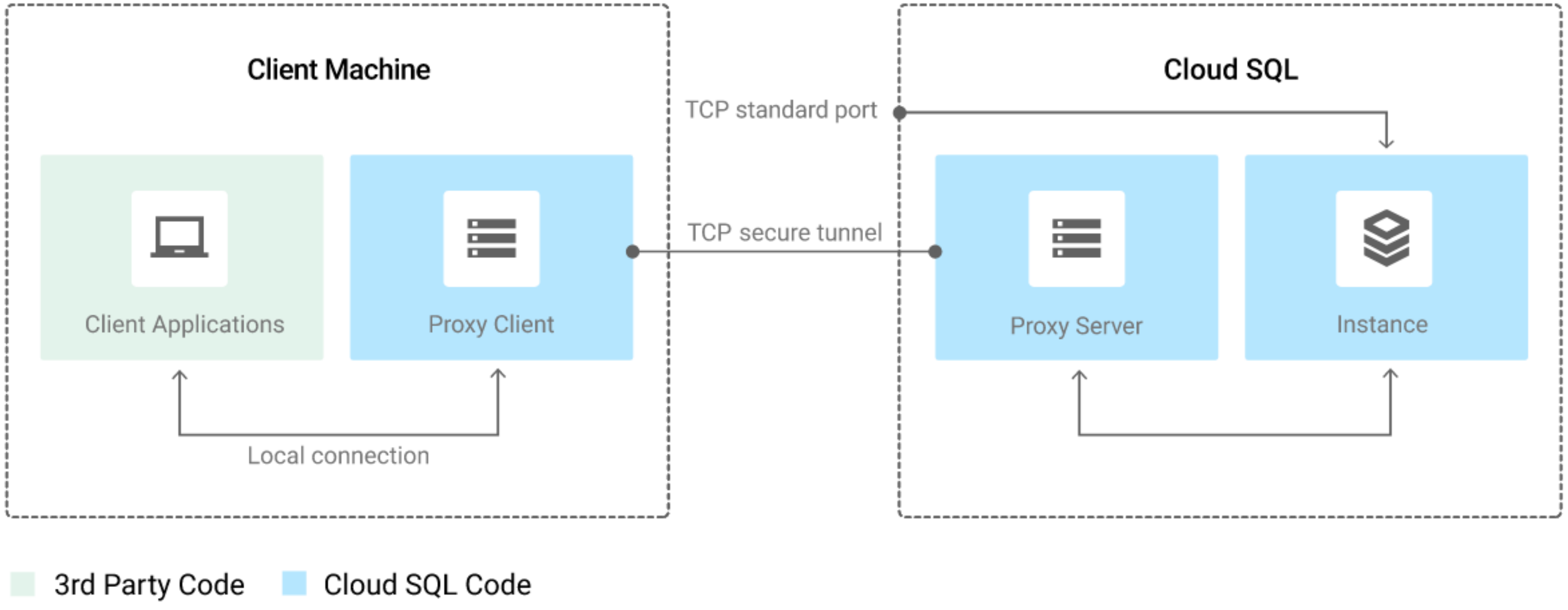



When you start the proxy, need to tell it

- What Cloud SQL instances it should establish connections to
- Where it will listen for data coming from your application to be sent to Cloud SQL
- Where it will find the credentials it will use to authenticate your application to Cloud SQL

# Cloud Proxy




You can install the proxy anywhere in your local environment. The location of the proxy binaries does not impact where it listens for data from your application.

# Cloud Spanner

# Use-Cases

| When you need | Use |
|---|---|
| Storage for Compute, Block Storage | Persistent (hard disks), SSD |
| Storing media, Blob Storage | Cloud Storage |
| SQL Interface atop file data | BigQuery |
| Document database, NoSQL | DataStore |
| Fast scanning, NoSQL | BigTable |
| Transaction Processing (OLTP) | Cloud SQL, Cloud Spanner |
| Analytics/Data Warehouse (OLAP) | BigQuery |

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# Cloud SQL, Cloud Spanner

- Relational databases - super-structured data, constraints etc
- ACID properties - use for transaction processing (OLTP)
- Too slow and too many checks for analytics/BI/warehousing (OLAP)
- Recall that OLTP needs strict write consistency, OLAP does not

# Cloud SQL, Cloud Spanner

- Cloud Spanner is Google proprietary, more advanced than Cloud SQL
- Cloud Spanner offers "horizontal scaling" - i.e. bigger data, more instances, replication etc
- Under the hood, Cloud Spanner has a surprising design - more later

# Cloud Spanner

- Use when
  - Need high availability
  - strong consistency
  - transactional reads and writes (especially writes!)
- Don't use if
  - Data is not relational, or not even structured
  - Want an open source RDBMS
  - Strong consistency and availability is overkill

# Data Model

- Databases contain tables (as usual)
- Tables 'look' relational - rows, columns, strongly typed schemas
- But...

# Relational Data

| StudentID | Student Name |
|---|---|
| 1 | Jane Doe |
| 2 | John Walsh |
| 3 | Raymond Wu |

| CourseID | Course Name |
|---|---|
| CS101 | Introduction to Computer Science |
| EE275 | Logic Circuits |
| CS183 | Computer Architecture |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| 1 | Jane Doe | CS101 | Fall 2015 | A- |
| 2 | John Walsh | CS294 | Spring 2016 | B+ |
| 3 | Raymond Wu | ME101 | Winter 2015 | C+ |
| 1 | Jane Doe | CS183 | Summer 2012 | A+ |

# Relational Data

| StudentID | Student Name |
|---|---|
| 1 | Jane Doe |
| 2 | John Walsh |
| 3 | Raymond Wu |

- **Usually query student and course grades together**
- Most common query = get transcript
- Specify a parent-child relationship for efficient storage

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| 1 | Jane Doe | CS101 | Fall 2015 | A- |
| 2 | John Walsh | CS294 | Spring 2016 | B+ |
| 3 | Raymond Wu | ME101 | Winter 2015 | C+ |
| 1 | Jane Doe | CS183 | Summer 2012 | A+ |

# Interleaved Representation

| StudentID | Student Name | | | |
|---|---|---|---|---|
| 1 | Jane Doe | | | |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| 1 | Jane Doe | CS101 | Fall 2015 | A- |
| 1 | Jane Doe | CS183 | Summer 2012 | A+ |

| StudentID | Student Name |
|---|---|
| 2 | John Walsh |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| 2 | John Walsh | CS294 | Spring 2016 | B+ |

| StudentID | Student Name |
|---|---|
| 3 | Raymond Wu |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| 3 | Raymond Wu | ME101 | Winter 2015 | C+ |

# Parent-Child

- Parent-child relationships between tables
- These cause physical location for fast access
- If you query Students and Grades together, make Grades child of Students
    - Data locality will be enforced between 2 independent tables!

# Parent-Child

- Every table **must** have primary keys
- To declare table is child of another…
- Prefix parent's primary key onto primary key of child
- (This storage model resembles HBase btw)

# Interleaving

- Rows are stored in sorted order of primary key values
- Child rows are inserted between parent rows with that key prefix
- "Interleaving"
- Fast sequential access - like HBase

# Hotspotting

- As in HBase - need to choose Primary key carefully
- Do not use monotonically increasing values, else writes will be on same locations - hot spotting
- Use hash of key value if you naturally monotonically ordered keys
- Under the hood, Cloud Scanner divides data among servers across key ranges

# Hotspotting

| StudentID | Student Name |
|---|---|
| 1 | Jane Doe |
| 2 | John Walsh |
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| 1 | Jane Doe | CS183 | Summer 2012 | A+ |

# Interleaved Representation

| StudentID | Student Name |
|---|---|
| 1 | Jane Doe |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| 1 | Jane Doe | CS101 | Fall 2015 | A- |
| 1 | Jane Doe | CS183 | Summer 2012 | A+ |

| StudentID | Student Name |
|---|---|
| 2 | John Walsh |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| 2 | John Walsh | CS294 | Spring 2016 | B+ |

| StudentID | Student Name |
|---|---|
| 3 | Raymond Wu |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| 3 | Raymond Wu | ME101 | Winter 2015 | C+ |

# Hotspotting

| StudentID | Student Name |
| --- | --- |
| X23 | Jane Doe |
| F23 | John Walsh |
| B99 | Raymond Wu |

- Change key so that it is not monotonically increasing
- Hash StudentID values

| StudentID | Student Name | CourseID | Term | Grade |
| --- | --- | --- | --- | --- |
| 1 | Jane Doe | CS101 | Fall 2015 | A- |
| 2 | John Walsh | CS294 | Spring 2016 | B+ |
| 3 | Raymond Wu | ME101 | Winter 2015 | C+ |
| 1 | Jane Doe | CS183 | Summer 2012 | A+ |

# Interleaved Representation

| StudentID | Student Name | | | |
|---|---|---|---|---|
| X23 | Jane Doe | | | |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| X23 | Jane Doe | CS101 | Fall 2015 | A- |
| X23 | Jane Doe | CS183 | Summer 2012 | A+ |

| StudentID | Student Name |
|---|---|
| F23 | John Walsh |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| F23 | John Walsh | CS294 | Spring 2016 | B+ |

| StudentID | Student Name |
|---|---|
| B99 | Raymond Wu |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| B99 | Raymond Wu | ME101 | Winter 2015 | C+ |

# Splits

- Parent-child relationships can get complicated - up to 7 layers deep!
- CloudScanner is distributed - uses "splits"
- A split is a range of rows that can be moved around independent of others
- Splits are added to distribute high read-write data (to break up hotspots)
- Splits are, of course, influenced by parent-child relationships

# Splits

| StudentID | Student Name |
|---|---|
| X23 | Jane Doe |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| X23 | Jane Doe | CS101 | Fall 2015 | A- |
| X23 | Jane Doe | CS183 | Summer 2012 | A+ |

| StudentID | Student Name |
|---|---|
| F23 | John Walsh |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| F23 | John Walsh | CS294 | Spring 2016 | B+ |

| StudentID | Student Name |
|---|---|
| B99 | Raymond Wu |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| B99 | Raymond Wu | ME101 | Winter 2015 | C+ |

# Secondary Indices

- Like in HBase, key-based storage ensures fast sequential scan of keys
  - Remember that tables must have primary keys
- Unlike in HBase, can also add secondary indices
  - Might cause same data to be stored twice
- Fine-grained control on use of indices
  - Force query to use a specific index (index directives)
  - Force column to be copied into a secondary index (STORING clause)

# Relational Data

| StudentID | Student Name |
|---|---|
| 1 | Jane Doe |
| 2 | John Walsh |
| 3 | Raymond Wu |

| CourseID | Course Name |
|---|---|
| CS101 | Introduction to Computer Science |
| EE275 | Logic Circuits |
| CS183 | Computer Architecture |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| 1 | Jane Doe | CS101 | Fall 2015 | A- |
| 2 | John Walsh | CS294 | Spring 2016 | B+ |
| 3 | Raymond Wu | ME101 | Winter 2015 | C+ |
| 1 | Jane Doe | CS183 | Summer 2012 | A+ |

# Primary Index - Interleaved Representation

| StudentID | Student Name |
|---|---|
| X23 | Jane Doe |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| X23 | Jane Doe | CS101 | Fall 2015 | A- |
| X23 | Jane Doe | CS183 | Summer 2012 | A+ |

| StudentID | Student Name |
|---|---|
| F23 | John Walsh |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| F23 | John Walsh | CS294 | Spring 2016 | B+ |

| StudentID | Student Name |
|---|---|
| B99 | Raymond Wu |

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| B99 | Raymond Wu | ME101 | Winter 2015 | C+ |

# Relational Data

| CourseID | Course Name |
|---|---|
| CS101 | Introduction to Computer Science |
| EE275 | Logic Circuits |
| CS183 | Computer Architecture |

- Usually query student and course grades together
- But also query courses and grades
- **So, create secondary index**

| StudentID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| 1 | Jane Doe | CS101 | Fall 2015 | A- |
| 2 | John Walsh | CS294 | Spring 2016 | B+ |
| 3 | Raymond Wu | ME101 | Winter 2015 | C+ |
| 1 | Jane Doe | CS183 | Summer 2012 | A+ |

# Secondary Index - Interleaved Representation

| CourseID | CourseName |
|---|---|
| CS101 | Introduction to Computer Science |

| CourseID | Student Name | StudentID | Term | Grade |
|---|---|---|---|---|
| CS101 | Jane Doe | X23 | Fall 2015 | A- |
| CS101 | John Walsh | F23 | Fall 2002 | B+ |

| CourseID | CourseName |
|---|---|
| EE275 | Logic Circuits |

| CourseID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| EE275 | John Walsh | EE275 | Spring 2016 | A- |

| CourseID | CourseName |
|---|---|
| CS183 | Computer Architecture |

| CourseID | Student Name | CourseID | Term | Grade |
|---|---|---|---|---|
| CS183 | Raymond Wu | CS183 | Winter 2015 | C+ |

# Data Types

- Remember that tables are strongly-typed (schemas must have types)
- Non-normalized types such as ARRAY and STRUCT available too
- STRUCTs are not OK in tables, but can be returned by queries (eg if query returns ARRAY of ARRAYs)
- ARRAYs are OK in tables, but ARRAYs of ARRAYs are not

# Transactions

- Supports serialisability
- Cloud Spanner transaction support is super-strong, even stronger than traditional ACID
    - Transactions commit in an order that is reflected in their commit timestamps
    - These commit timestamps are "real time" so you can compare them to your watch

# Transactions

- Two transaction modes
  - Locking read-write (slow)
  - Read-only (fast)
- If making a one-off read, use something known as a "Single Read Call"
  - Fastest, no transaction checks needed!

# Staleness

- Can set **timestamp bounds**
- Strong - “read latest data”
- Bounded Staleness - “read version no later than ...”
- Exact Staleness - “read at exactly ...”
  - (could be in past or future)
- Cloud Scanner has a version-gc that reclaims versions older than 1 hour old

# Bigtable

# Use-Cases

| When you need | Use |
|---|---|
| Storage for Compute, Block Storage | Persistent (hard disks), SSD |
| Storing media, Blob Storage | Cloud Storage |
| SQL Interface atop file data | BigQuery |
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# BigTable

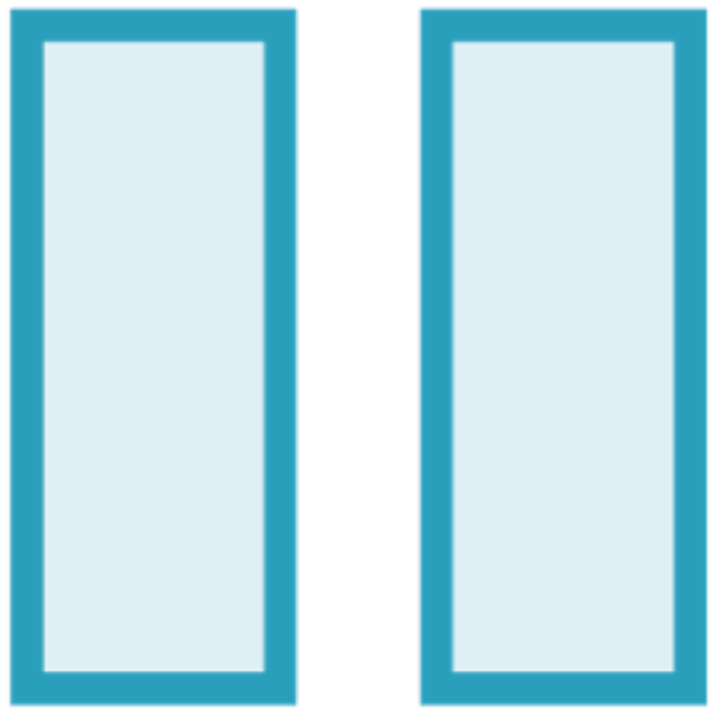
- Fast scanning of sequential key values - use BigTable
- Columnar database, good for sparse data
- Sensitive to hot spotting - need to design key structure carefully
- Similar to HBase

# BigTable and HBase

- BigTable is basically GCP's managed HBase
    - This is a much stronger link than between say Hive and BigQuery!
- Usual advantages of GCP -
    - scalability
    - low ops/admin burden
    - cluster resizing without downtime
    - many more column families before performance drops (~100 OK)

# HBase vs. Relational Databases

# Properties of HBase

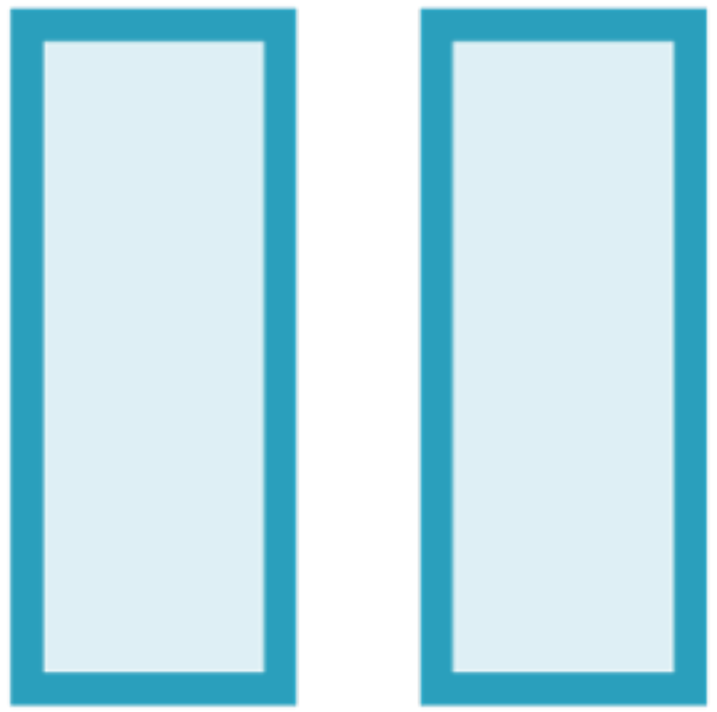


Columnar store

Denormalized storage

Only CRUD operations

ACID at the row level



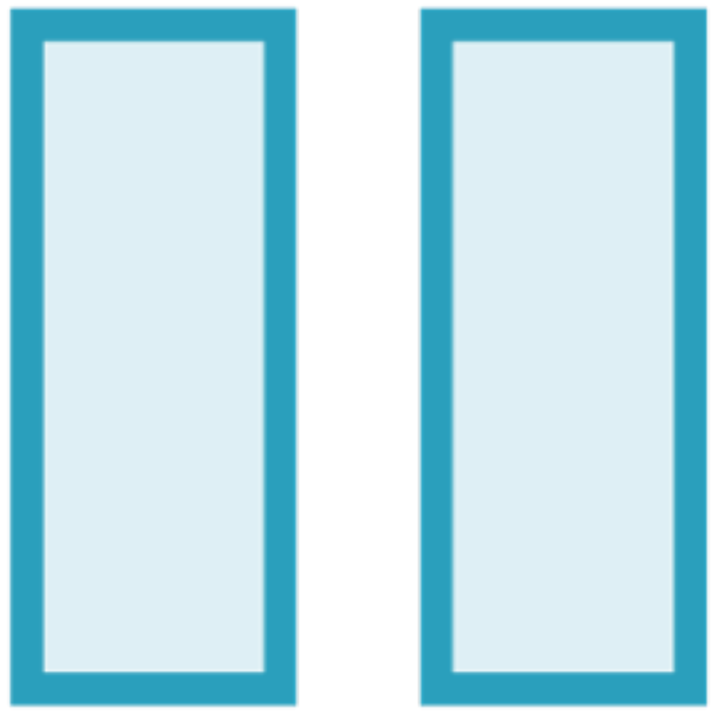
Columnar store

# A Notification Service

| Id | To | Type | Content |
|---|---|---|---|
| 1 | mike | offer | Offer on mobiles |
| 2 | john | sale | Redmi sale |
| 3 | jill | order | Order delivered |
| 4 | megan | sale | Clothes sale |

## Layout of a traditional relational database

# A Notification Service



Columnar store

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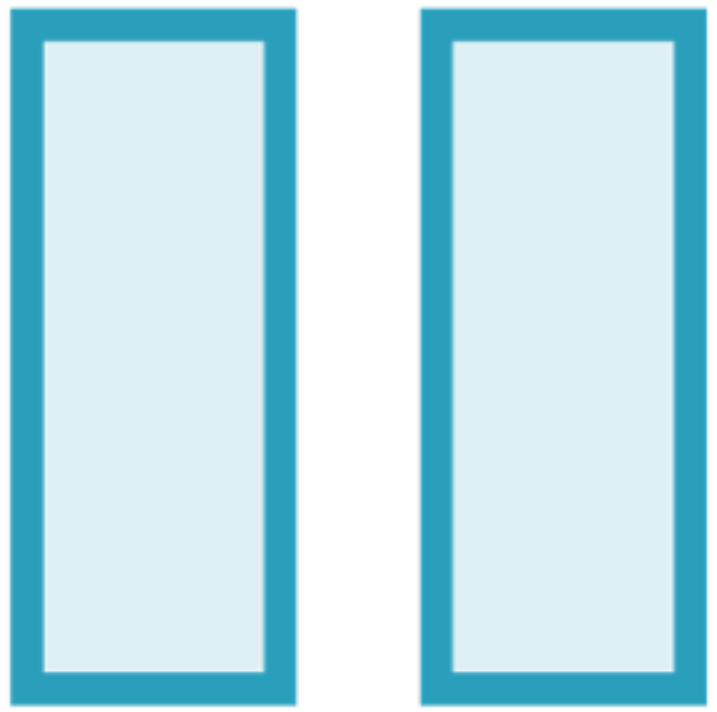
**Layout of a traditional relational database**



**Columnar store**

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|---|---|---|---|
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| 4 | megan | sale | Clothes sale |

**Row = 3**
**Column = To**

# Columnar Store

| Id | To | Type | Content |
|---|---|---|---|
| 1 | mike | offer | Offer on mobiles |
| 2 | john | sale | Redmi sale |
| 3 | jill | order | Order delivered |
| 4 | megan | sale | Clothes sale |

| Id | Column | Value |
|---|---|---|
| 1 | To | mike |
| 1 | Type | offer |
| 1 | Content | Offer on mobiles |
| 2 | To | john |
| 2 | Type | sale |
| 2 | Content | Redmi sale |
| 3 | To | jill |
| 3 | Type | order |
| 3 | Content | Order delivered |
| 4 | To | megan |
| 4 | Type | sale |
| 4 | Content | Clothes sale |

# Columnar Store

| Id | To | Type | Content |
|---|---|---|---|
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| Id | Column | Value |
|---|---|---|
| 1 | To | mike |
| 1 | Type | offer |
| 1 | Content | Offer on mobiles |
| 2 | To | john |
| 2 | Type | sale |
| 2 | Content | Redmi sale |
| 3 | To | jill |
| 3 | Type | order |
| 3 | Content | Order delivered |
| 4 | To | megan |
| 4 | Type | sale |
| 4 | Content | Clothes sale |

# Columnar Store

| Id | To | Type | Content |
|---|---|---|---|
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| Id | Column | Value |
|---|---|---|
| 1 | To | mike |
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| 1 | Content | Offer on mobiles |
| 2 | To | john |
| 2 | Type | sale |
| 2 | Content | Redmi sale |
| 3 | To | jill |
| 3 | Type | order |
| 3 | Content | Order delivered |
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| 4 | Type | sale |
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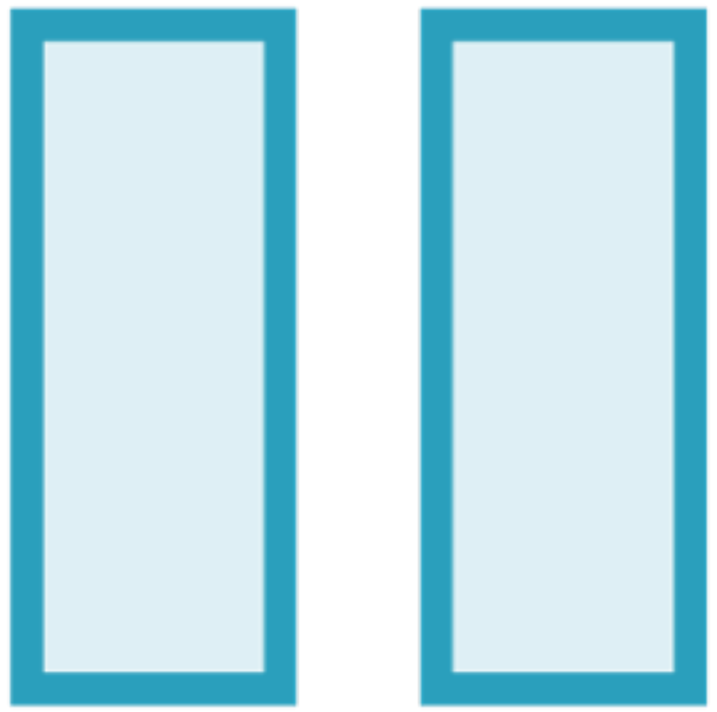


**Columnar store**

# Advantages of a Columnar Store

**Sparse tables**: No wastage of space when storing sparse data

**Dynamic attributes**: Update attributes dynamically without changing storage structure

# Sparse Tables

| Id | To | Type | Content | Expiry |
|---|---|---|---|---|
| 1 | mike | offer | Offer on mobiles | 2345689070 |
| 2 | john | sale | Redmi sale | |
| 3 | jill | order | Order delivered | |
| 4 | megan | sale | Clothes sale | 2456123989 |

**Sale and offer notifications may have an expiry time**

# Sparse Tables

| Id | To | Type | Content | Expiry | Order Status |
|---|---|---|---|---|---|
| 1 | mike | offer | Offer on mobiles | 2345689070 | |
| 2 | john | sale | Redmi sale | | |
| 3 | jill | order | Order delivered | | Delivered |
| 4 | megan | sale | Clothes sale | 2456123989 | |

**Order related notifications may have an order status**

# Sparse Tables

| Id | To | Type | Content | Expiry | Order Status |
|---|---|---|---|---|---|
| 1 | mike | offer | Offer on mobiles | 2345689070 | |
| 2 | john | sale | Redmi sale | | |
| 3 | jill | order | Order delivered | | Delivered |
| 4 | megan | sale | Clothes sale | 2456123989 | |

**In a traditional database this results in a change in database structure**

# Sparse Tables

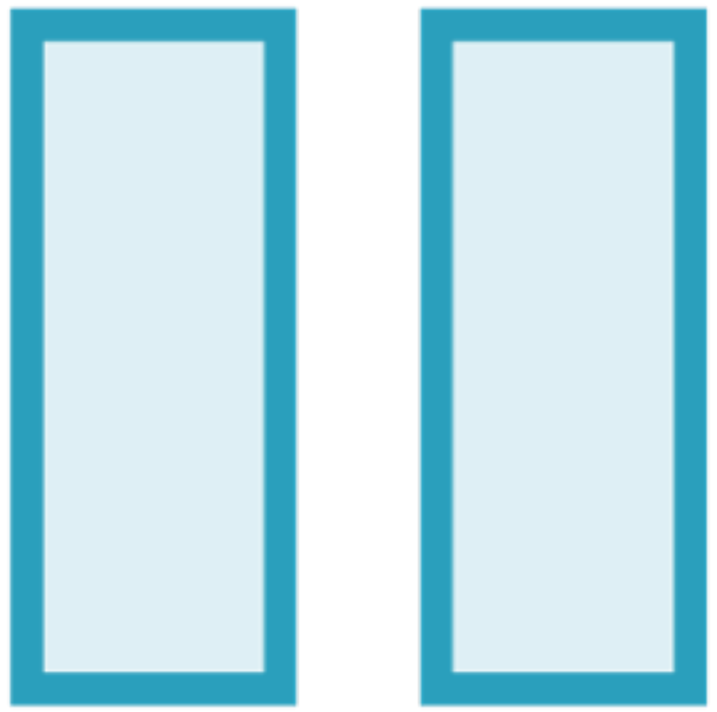
| Id | To | Type | Content | Expiry | Order Status |
|---|---|---|---|---|---|
| 1 | mike | offer | Offer on mobiles | 2345689070 | |
| 2 | john | sale | Redmi sale | | |
| 3 | jill | order | Order delivered | | Delivered |
| 4 | megan | sale | Clothes sale | 2456123989 | |

**And empty cells when data is not applicable to certain rows**

# Sparse Tables

| Id | To | Type | Content | Expiry | Order Status |
|---|---|---|---|---|---|
| 1 | mike | offer | Offer on mobiles | 2345689070 | |
| 2 | john | sale | Redmi sale | | |
| 3 | jill | order | Order delivered | | Delivered |
| 4 | megan | sale | Clothes sale | 2456123989 | |

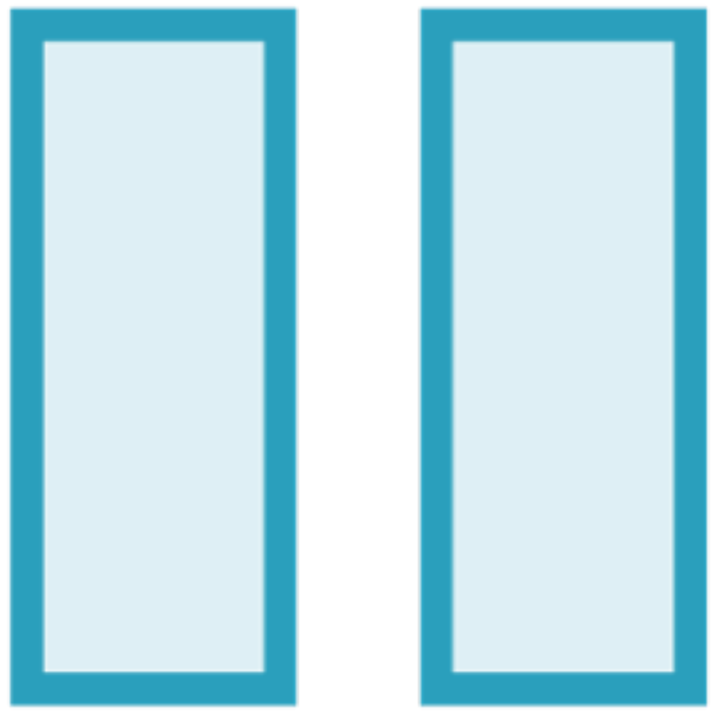
**These cells still occupy space!**



**Columnar store**

| Id | Column | Value |
|---|---|---|
| 1 | To | mike |
| 1 | Type | offer |
| 1 | Content | Offer on mobiles |
| 1 | Expiry | 2345689070 |
| 2 | To | john |
| 2 | Type | sale |
| 2 | Content | Redmi sale |
| 3 | To | jill |
| 3 | Type | order |
| 3 | Content | Order delivered |
| 4 | To | megan |
| 4 | Type | sale |
| 4 | Content | Clothes sale |
| 4 | Expiry | 2456123989 |

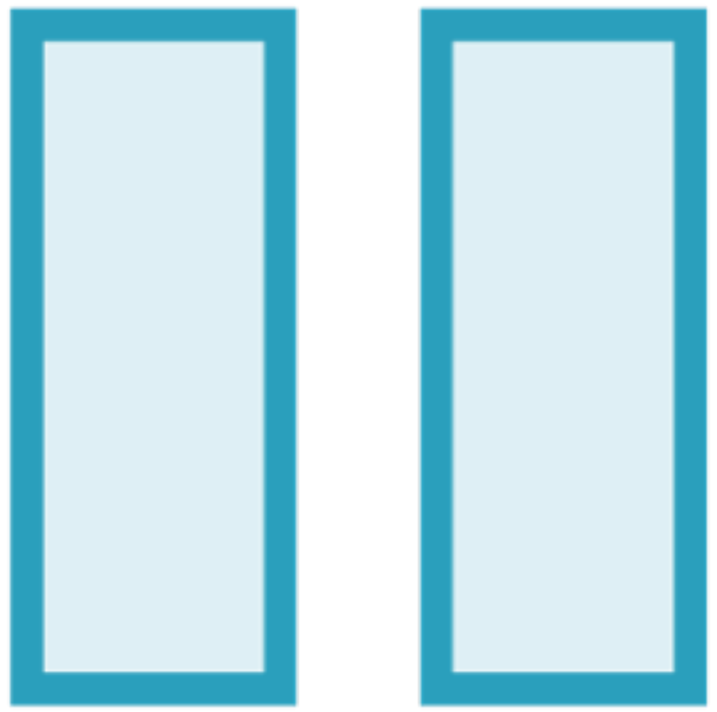
# Dynamically add new attributes as rows in this table



**Columnar store**

| Id | Column | Value |
|---|---|---|
| 1 | To | mike |
| 1 | Type | offer |
| 1 | Content | Offer on mobiles |
| 1 | Expiry | 2345689070 |
| 2 | To | john |
| 2 | Type | sale |
| 2 | Content | Redmi sale |
| 3 | To | jill |
| 3 | Type | order |
| 3 | Content | Order delivered |
| 4 | To | megan |
| 4 | Type | sale |
| 4 | Content | Clothes sale |
| 4 | Expiry | 2456123989 |

# No wastage of space with empty cells!

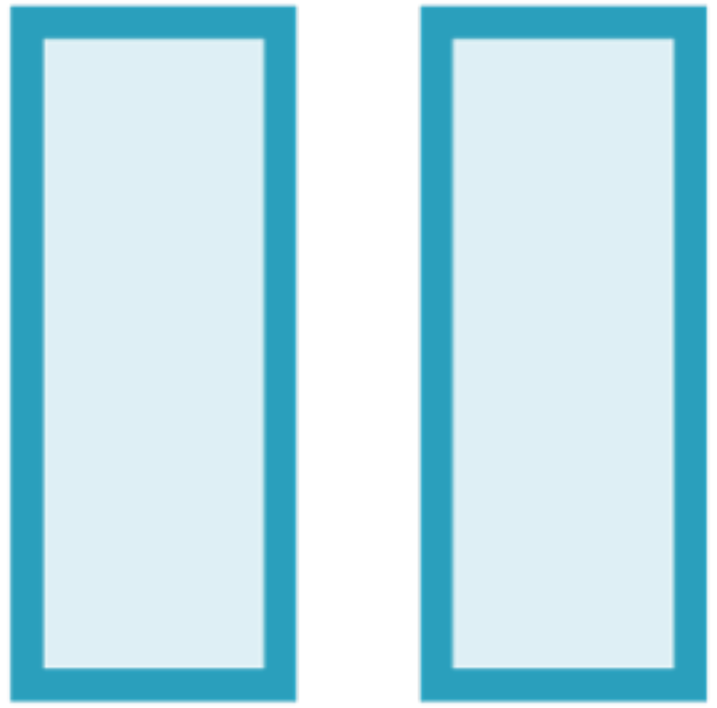


Columnar store

Note that this is not the exact layout of how data is stored in HBase

It is a general structure of how columnar stores are constructed

# Properties of HBase



**Columnar store**

**Denormalized storage**

**Only CRUD operations**

**ACID at the row level**

**Denormalized storage**

# Traditional databases use normalized forms of database design to minimize redundancy

**Denormalized storage**

# Minimize Redundancy

**Employee Details**

**Employee Subordinates**

**Employee Address**

**Denormalized storage**

## Employee Details

| Id | Name | Function | Grade |
|---|---|---|---|
| 1 | Emily | Finance | 6 |

## Employee Subordinates

| Id | Subordinate Id |
|---|---|
| 1 | 2 |
| 1 | 3 |

## Employee Address

| Id | City | Zip Code |
|---|---|---|
| 1 | Palo Alto | 94305 |
| 2 | Seattle | 98101 |

**Denormalized storage**

## Employee Details

| Id | Name | Function | Grade |
|---|---|---|---|
| 1 | Emily | Finance | 6 |
| 2 | John | Finance | 3 |
| 3 | Ben | Finance | 4 |

# All employee details in one table

**Denormalized storage**

## Employee Subordinates

| id | Subordinate id |
|---|---|
| 1 | 2 |
| 1 | 3 |

# Employees referenced only by ids everywhere else

**Denormalized storage**

### Employee Address

| Id | City | Zip Code |
|---|---|---|
| 1 | Palo Alto | 94305 |
| 2 | Seattle | 98101 |

## Data is made more granular by splitting it across multiple tables

**Denormalized storage**

| Id | Name | Function | Grade |
|---|---|---|---|
| 1 | Emily | Finance | 6 |

| Id | Subordinate Id |
|---|---|
| 1 | 2 |
| 1 | 3 |

| Id | City | Zip Code |
|---|---|---|
| 1 | Palo Alto | 94305 |
| 2 | Seattle | 98101 |

# Normalization

**Denormalized storage**

Normalization

## Optimizes storage

**But storage is cheap in a distributed system!**

Denormalized storage

But storage is cheap in a distributed system!

# Optimize number of disk seeks

# Denormalized Storage

| Id | Name | Function | Grade |
|---|---|---|---|
| 1 | Emily | Finance | 6 |
| 2 | John | Finance | 3 |
| 3 | Ben | Finance | 4 |

| Id | Subordinate Id |
|---|---|
| 1 | 2 |
| 1 | 3 |

| Id | Name | Function | Grade | Subordinates |
|---|---|---|---|---|
| 1 | Emily | Finance | 6 | **<ARRAY>** |
| 2 | John | Finance | 3 | |
| 3 | Ben | Finance | 4 | |

# Denormalized Storage

| Id | Name | Function | Grade |
|---|---|---|---|
| 1 | Emily | Finance | 6 |
| 2 | John | Finance | 3 |
| 3 | Ben | Finance | 4 |

| Id | City | Zip Code |
|---|---|---|
| 1 | Palo Alto | 94305 |
| 2 | Seattle | 98101 |

| Id | Name | Function | Grade | Subordinates | Address |
|---|---|---|---|---|---|
| 1 | Emily | Finance | 6 | **<ARRAY>** | **<STRUCT>** |
| 2 | John | Finance | 3 | | |
| 3 | Ben | Finance | 4 | | |

# Denormalized Storage

| Id | Name | Function | Grade | Subordinates | Address |
|---|---|---|---|---|---|
| 1 | Emily | Finance | 6 | **<ARRAY>** | **<STRUCT>** |
| 2 | John | Finance | 3 | | |
| 3 | Ben | Finance | 4 | | |

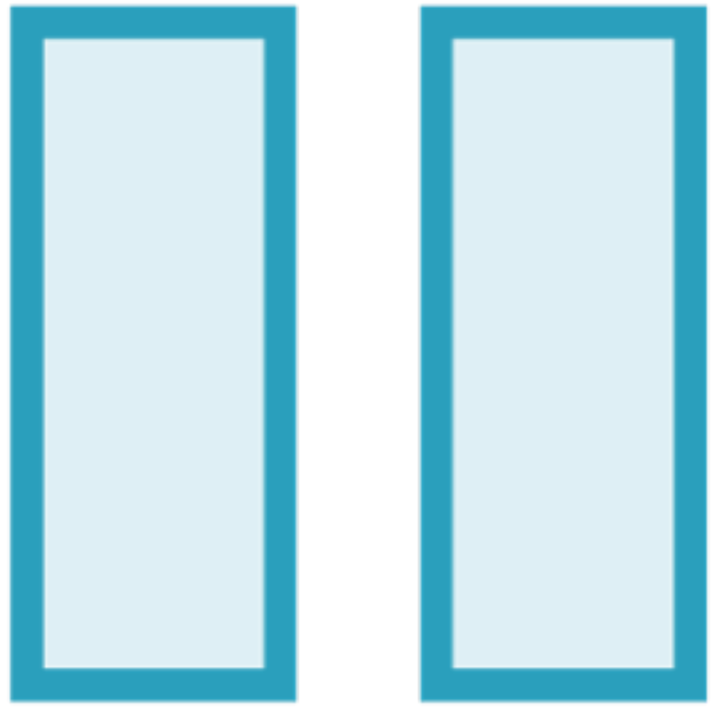
**Store everything related to an employee in the same table**

# Denormalized Storage

| Id | Name | Function | Grade | Subordinates | Address |
|---|---|---|---|---|---|
| 1 | Emily | Finance | 6 | **<ARRAY>** | **<STRUCT>** |
| 2 | John | Finance | 3 | | |
| 3 | Ben | Finance | 4 | | |

**Read a single record to get all details about an employee in one read operation**

# Properties of HBase



**Columnar store**

**Denormalized storage**

**Only CRUD operations**

**ACID at the row level**

**Only CRUD operations**

# Traditional Databases and SQL

**Joins: Combining information across tables using keys**

**Group By: Grouping and aggregating data for the groups**

**Order By: Sorting rows by a certain column**

Only CRUD operations

HBase does not support SQL

NoSQL

Only CRUD operations

Only a limited set of operations are allowed in HBase

Create

Read

Update

Delete

CRUD

Only CRUD operations

No operations involving multiple tables

No indexes on tables

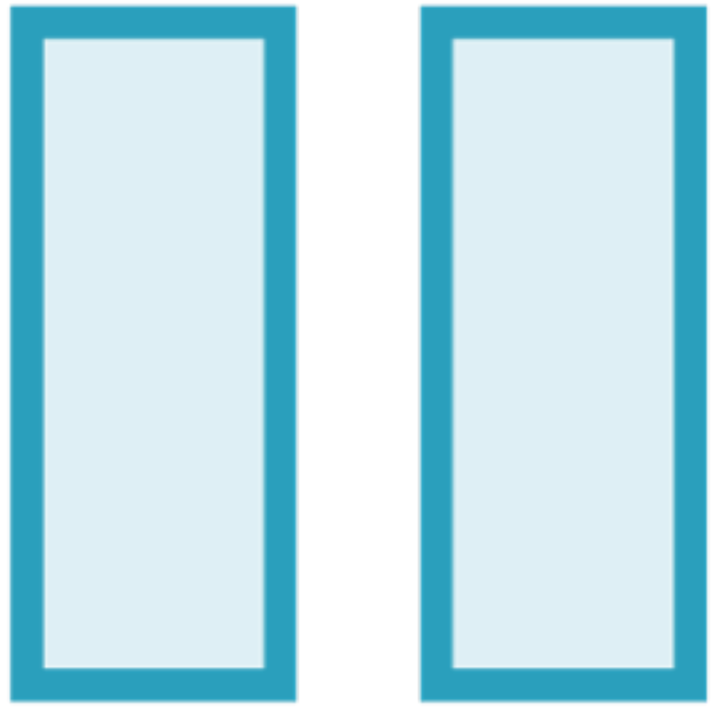
No constraints

Only CRUD operations

| Id | Name | Function | Grade | Subordinates | Address |
|---|---|---|---|---|---|
| | | | | | |

This is why all details need to be self contained in one row

# Properties of HBase



**Columnar store**

**Denormalized storage**

**Only CRUD operations**

**ACID at the row level**

**ACID at the row level**

## Updates to a single row are atomic

## All columns in a row are updated or none are

ACID at the row level

Updates to multiple rows are **not** atomic

Even if the update is on the same column in multiple rows

# Traditional RDBMS vs. HBase

| Traditional RDBMS | HBase |
| --- | --- |
| Data arranged in rows and columns | Data arranged in a column-wise manner |
| Supports SQL | NoSQL database |
| Complex queries such as grouping, aggregates, joins etc | Only basic operations such as create, read, update and delete |
| Normalized storage to minimize redundancy and optimize space | Denormalized storage to minimize disk seeks |
| ACID compliant | ACID compliant at the row level |

# How Is Data Laid out in HBase?

# Notification Data in a Traditional Database

| Id | To | Type | Content |
|---|---|---|---|
| 1 | mike | offer | Offer on mobiles |
| 2 | john | sale | Redmi sale |
| 3 | jill | order | Order delivered |
| 4 | megan | sale | Clothes sale |

**This is a 2-dimensional data model**

# Notification Data in a Traditional Database

| Id | To | Type | Content |
|---|---|---|---|
| 1 | mike | offer | Offer on mobiles |
| 2 | john | sale | Redmi sale |
| 3 | jill | order | Order delivered |
| 4 | megan | sale | Clothes sale |

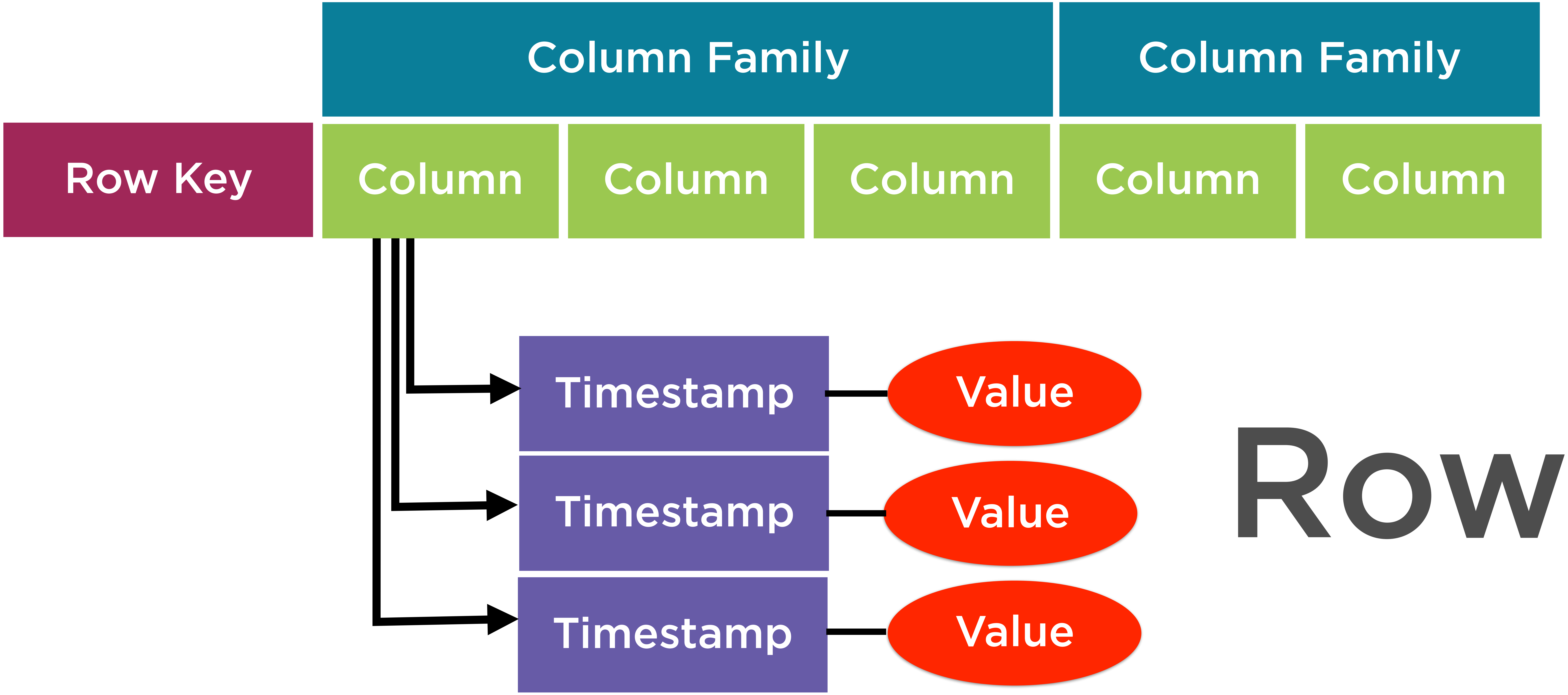
unique row id

column name

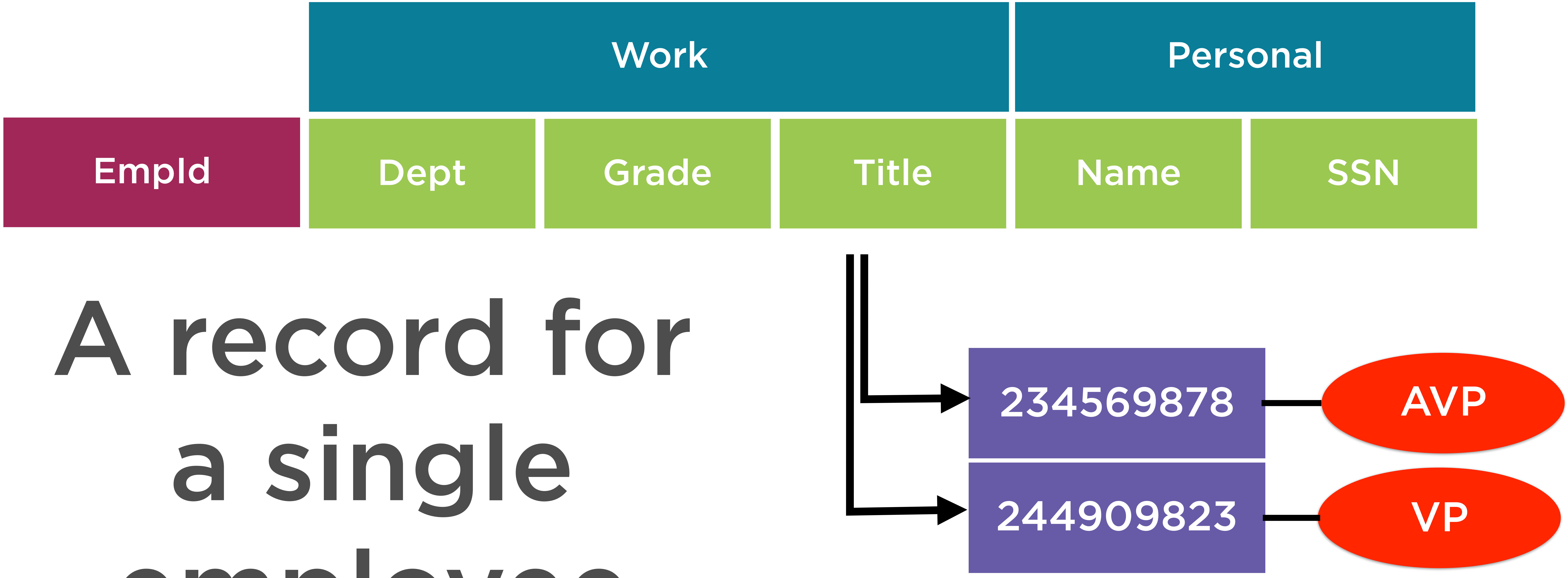
# 4-dimensional Data Model

| | |
|---|---|
| Row Key | Column Family |
| Column | Timestamp |

# 4-dimensional Data Model



# A Table for Employee Data




A record for a single employee

# Notification Data

| Id | To | Type | Content |
|---|---|---|---|
| 1 | mike | offer | Offer on mobiles |
| 2 | john | sale | Redmi sale |
| 3 | jill | order | Order delivered |
| 4 | megan | sale | Clothes sale |

| Id | Column | Value |
|---|---|---|
| 1 | To | mike |
| 1 | Type | offer |
| 1 | Content | Offer on mobiles |
| 2 | To | john |
| 2 | Type | sale |
| 2 | Content | Redmi sale |
| 3 | To | jill |
| 3 | Type | order |
| 3 | Content | Order delivered |
| 4 | To | megan |
| 4 | Type | sale |
| 4 | Content | Clothes sale |

# Notification Data

| Id | To | Type | Content |
|---|---|---|---|
| 1 | mike | offer | Offer on mobiles |
| 2 | john | sale | Redmi sale |
| 3 | jill | order | Order delivered |
| 4 | megan | sale | Clothes sale |

| Id | Column | Value |
|---|---|---|
| 1 | To | mike |
| 1 | Type | offer |
| 1 | Content | Offer on mobiles |
| 2 | To | john |
| 2 | Type | sale |
| 2 | Content | Redmi sale |
| 3 | To | jill |
| 3 | Type | order |
| 3 | Content | Order delivered |
| 4 | To | megan |
| 4 | Type | sale |
| 4 | Content | Clothes sale |

# Row Key

# Notification Data

| Id | To | Type | Content |
|---|---|---|---|
| 1 | mike | offer | Offer on mobiles |
| 2 | john | sale | Redmi sale |
| 3 | jill | order | Order delivered |
| 4 | megan | sale | Clothes sale |

| Id | Column | Value |
|---|---|---|
| 1 | To | mike |
| 1 | Type | offer |
| 1 | Content | Offer on mobiles |
| 2 | To | john |
| 2 | Type | sale |
| 2 | Content | Redmi sale |
| 3 | To | jill |
| 3 | Type | order |
| 3 | Content | Order delivered |
| 4 | To | megan |
| 4 | Type | sale |
| 4 | Content | Clothes sale |

# Column Family

# Notification Data

| Id | To | Type | Content |
|---|---|---|---|
| 1 | mike | offer | Offer on mobiles |
| 2 | john | sale | Redmi sale |
| 3 | jill | order | Order delivered |
| 4 | megan | sale | Clothes sale |

| Id | Column | Value |
|---|---|---|
| 1 | To | mike |
| 1 | Type | offer |
| 1 | Content | Offer on mobiles |
| 2 | To | john |
| 2 | Type | sale |
| 2 | Content | Redmi sale |
| 3 | To | jill |
| 3 | Type | order |
| 3 | Content | Order delivered |
| 4 | To | megan |
| 4 | Type | sale |
| 4 | Content | Clothes sale |

# Columns

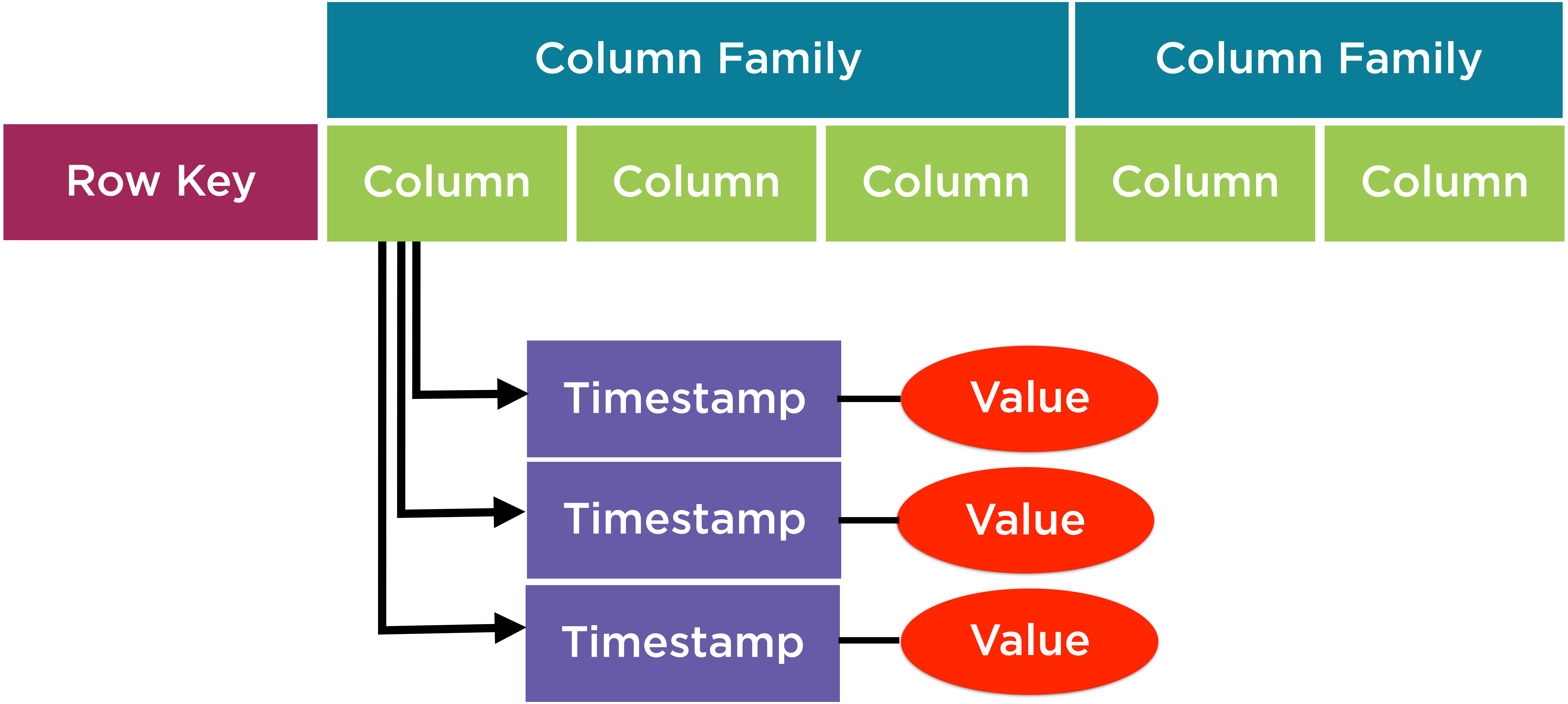
# Notification Data

| Id | To | Type | Content |
|---|---|---|---|
| 1 | mike | offer | Offer on mobiles |
| 2 | john | sale | Redmi sale |
| 3 | jill | order | Order delivered |
| 4 | megan | sale | Clothes sale |

| Id | Column | Value |
|---|---|---|
| 1 | To | mike |
| 1 | Type | offer |
| 1 | Content | Offer on mobiles |
| 2 | To | john |
| 2 | Type | sale |
| 2 | Content | Redmi sale |
| 3 | To | jill |
| 3 | Type | order |
| 3 | Content | Order delivered |
| 4 | To | megan |
| 4 | Type | sale |
| 4 | Content | Clothes sale |

**Value + Timestamp**

# Data Layout in HBase



Row Key

Uniquely identifies a row

Can be primitives, structures, arrays

Represented internally as a byte array

Sorted in ascending order

## Column Family

All rows have the same set of column families

Each column family is stored in a separate data file

Set up at schema definition time

Can have different columns for each row

Column

Columns are units within a column family

New columns can be added on the fly

ColumnFamily: ColumnName = Work:Department

Timestamp

Used as the version number for the values stored in a column

The value for any version can be accessed

# Census Data Layout in HBase

| | Personal | | | Professional | |
|---|---|---|---|---|---|
| Some ID | name | gender | marital_st<br>atus | employed | field |

# Filtering Rows Based on Conditions

# SQL vs. HBase Shell Commands

| SQL | HBase Shell |
| --- | --- |
| select * from census | scan ‘census’ |

# SQL vs. HBase Shell Commands

| SQL | HBase Shell |
| --- | --- |
| select name from census | scan 'census', {COLUMNS => ['personal:name']} |

# SQL vs. HBase Shell Commands

| SQL | HBase Shell |
| --- | --- |
| select * from census limit 1 | scan 'census', {LIMIT => 1} |

# SQL vs. HBase Shell Commands

| SQL | HBase Shell |
| --- | --- |
| select * from census where rowkey = 1 | get 'census', 1 |

Filters allow you to control what data is returned from a scan operation

# Built-in Filters

Conditions on row keys

Conditions on columns

Multiple conditions on columns

Timestamp range

# BigTable Performance

# Avoid BigTable When

- Don't use if you need transaction support (OLTP) - use Cloud SQL or Cloud Spanner
- Don't use for data less than 1 TB (can't parallelize)
- Don't use if analytics/business intelligence/data warehousing - use BigQuery instead
- Don't use for documents or highly structured hierarchies - use DataStore instead
- Don't use for immutable blobs like movies each > 10 MB - use Cloud Storage instead

# Use BigTable When

- Use for very fast scanning and high throughput
- Use for non-structured key/value data
- Where each data item < 10 MB and total data > 1 TB
- Use where writes infrequent/unimportant (no ACID) but fast scans crucial
- Use for Time Series data

# Use BigTable for Time Series

- BigTable is a natural fit for Timestamp data (range queries)
- Say IOT sensor network emitting data at intervals
    - Use **Device ID # Time** as row key if common query = "All data for a device over period of time"
    - Use **Time # Device ID** as row key if common query = "All data for a period for all devices"

# Hotspotting and Schema Design

- Like Cloud Spanner, data stored in sorted lex order of keys
- Data is distributed based on key values
- So, performance will be really poor if
    - Reads/writes are concentrated in some ranges
    - For instance if key values are sequential
- Use hashing of key values, or non-sequential keys

# Avoiding Hotspotting

- Field Promotion: Use in reverse URL order like Java package names
  - This way keys have similar prefixes, differing endings
- Salting
  - Hash the key value

# “Warming the Cache”

- BigTable will improve performance over time
- Will observe read and write patterns and redistribute data so that shards are evenly hit
- Will try to store roughly same amount of data in different nodes
- This is why testing over hours is important to get true sense of performance

# SSD or HDD Disks

- Use SSD unless skimping on cost
- SSD can be 20x faster on individual row reads
- More predictable throughput too (no disk seek variance)
- Don't even think about HDD unless storing > 10 TB and all batch queries
- The more random access, the stronger the case for SSD

# SSD or HDD Disks

| Storage Type | Reads | Writes | Scans |
|---|---|---|---|
| **SSD** | 10,000 QPS[1] @ 6 ms | 10,000 QPS @ 6 ms | 220 MB/s |
| **HDD** | 500 QPS @ 200 ms | 10,000 QPS @ 50 ms | 180 MB/s |

[1] Queries per second. A query is a read or write operation against a single row.

# Reasons for Poor Performance

- Poor schema design (eg sequential keys)
- Inappropriate workload
  - too small (<300 GB)
  - used in short bursts (needs hours to tune performance internally)
- Cluster too small
- Cluster just fired up or scaled up
- HDD used instead of SSD
- Development v Production instance

# Schema Design

- Each table has just one index - the row key. Choose it well
- Rows are sorted lexicographically by row key
- All operations are atomic at row level
- Related entities in adjacent rows

# Size Limits

- Row keys: 4KB per key
- Column Families: ~100 per table
- Column Values: ~ 10 MB each
- Total Row Size: ~100 MB

# Types of Row Keys

- Reverse domain names
- String identifiers
- Timestamps as suffix in key

# Row Keys to Avoid

- Domain names
- Sequential numeric values
- Timestamps alone
- Timestamps as prefix of row-key
- Mutable or repeatedly updated values

# Datastore

# Use-Cases

| When you need | Use |
|---|---|
| Storage for Compute, Block Storage | Persistent (hard disks), SSD |
| Storing media, Blob Storage | Cloud Storage |
| SQL Interface atop file data | BigQuery |
| Document database, NoSQL | DataStore |
| Fast scanning, NoSQL | BigTable |
| Transaction Processing (OLTP) | Cloud SQL, Cloud Spanner |
| Analytics/Data Warehouse (OLAP) | BigQuery |

# Use-Cases

| When you need | Use |
|---|---|
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| Transaction Processing (OLTP) | Cloud SQL, Cloud Spanner |
| Analytics/Data Warehouse (OLAP) | BigQuery |

# DataStore

- Document data - eg XML or HTML - has a characteristic pattern
- Key-value structure, i.e. structured data
- Typically not used either for OLTP or OLAP
- Fast lookup on keys is the most common use-case

# DataStore

- Speciality of DataStore is that query execution time depends on size of returned result (not size of data set)
- So, a returning 10 rows will take the same length of time whether dataset is 10 rows, or 10 billion rows
- Ideal for "needle-in-a-haystack" type applications, i.e. lookups of non-sequential keys

# Traditional RDBMS vs. DataStore

| Traditional RDBMS | DataStore |
| --- | --- |
| Atomic transactions | Atomic transactions |
| Indices for fast lookup | Indices for fast lookup |
| Some queries use indices - not all | All queries use indices! |
| Query time depend on both size of data set and size of result set | Query time independent of data set, depends on result set alone |

# Traditional RDBMS vs. DataStore

| Traditional RDBMS | DataStore |
| --- | --- |
| Structured relational data | Structured hierarchical data (XML, HTML) |
| Rows stored in Tables | Entities of different in Kinds (think HTML tags) |
| Rows consist of fields | Entities consist of Properties |
| Primary Keys for unique ID | Keys for unique ID |

# Traditional RDBMS vs. DataStore

## Traditional RDBMS

Rows of table have same properties (Schema is strongly enforced)

Types of all values in a column are the same

## DataStore

Entities of a kind can have different properties (think optional tags in HTML)

Types of different properties with same name in an entity can be different

# Avoid DataStore When

- Don't use if you need **very strong transaction support** (OLTP) - OK for basic ACID support though
- Don't use for non-hierarchical or unstructured data - BigTable is better
- Don't use if analytics/business intelligence/data warehousing - use BigQuery instead
- Don't use for immutable blobs like movies each > 10 MB - use Cloud Storage instead
- Don't use if application has lots of writes and updates on key columns

# Use DataStore When

- Use for crazy scaling of read performance - to virtually any size
- Use for hierarchical documents with key/value data

# Full Indexing

- “Built-in” Indices on each property (~field) of each entity kind (~table row)
- “Composite” Indices on multiple property values
- If you are certain a property will never be queried, can explicitly exclude it from indexing
- Each query is evaluated using its “perfect index”

# Perfect Index

- Given a query, which is the index that most optimally returns query results?
- Depends on following (in order)
  - equality filter
  - inequality filter (only 1 allowed)
  - sort conditions if any specified

# Implications of Full Indexing

- Updates are really slow
- No joins possible
- Can't filter results based on subquery results
- Can't include more than one inequality filter (one is OK)

# Multi-tenancy

- Separate data partitions for each client organization
- Can use the same schema for all clients, but vary the values
- Specified via a namespace (inside which kinds and entities can exist)

# Transaction Support

- Can optionally use transactions - not required
- Not as strong as Cloud Spanner (which is ACID++), but stronger than BigQuery or BigTable

# Consistency

- Two consistency levels possible for query results
  - Strongly consistent: return up-to-date result, however long it takes
  - Eventually consistent: faster, but might return stale

# Transfer Service

# Importing Data

- The transfer service helps get data **into Cloud Storage**
- From where?
  - From AWS, i.e. an S3 bucket
  - From HTTP/HTTPS location
  - From local files
  - From another Cloud Storage Bucket

# gsutil or Transfer Service?

- Recall that gsutil can be used to get data into cloud storage buckets
- Prefer the transfer service when transferring from AWS etc
- If copying files over from on-premise, use gsutil

# Transfer Service Bells & Whistles

- One-time v recurring transfers
- Delete from destination if they don't exist in source
- Delete from source after copying over
- Periodic synchronisation of source and destination based on file filters

# Summary

Block storage for compute VMs - persistent disks or SSDs

Immutable blobs like video/images - Cloud Storage

OLTP - Cloud SQL or Cloud Spanner

NoSQL Documents like HTML/XML - Datastore

NoSQL Key-values - BigTable (~HBase)

Getting data into Cloud Storage - Transfer service