E6156 – Topics in SW Engineering (F23)
Cloud Computing
Lecture 2: Containers, REST, BLOBs

- We will start in a minute or two.

Contents

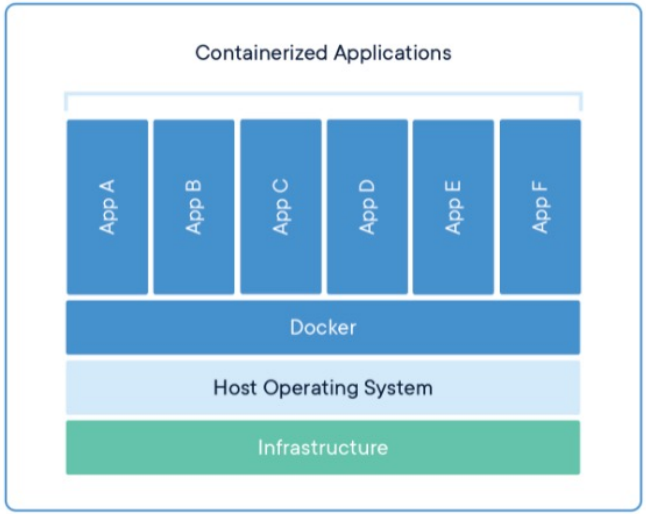
Containers

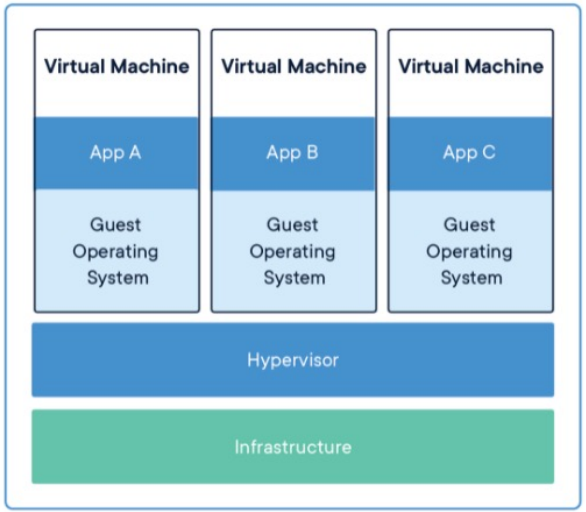
Concepts

Fundamental, Recurring Problem

- I have one big computer and I want to run multiple applications.
- This creates several challenges, e.g.
  - Resource sharing and allocation (CPU, memory, disk, ...)
  - Isolation: Application A should not be able to corrupt/mess with application B's files, memory, ...
  - Configuration: Applications require libraries, versions of libraries, prerequisites, compiler/interpreter levels, ...
- Basically, I want a way to someone package or fence all of this.
  We see some of the issues with Java Classpath, Python environments, ...
- There are a few ways to do this:
  - OS process and paths.
  - VMs
  - Containers

Containers and VMs





CONTAINERS

Containers are an abstraction at the app layer that packages code and dependencies together. Multiple containers can run on the same machine and share the OS kernel with other containers, each running as isolated processes in user space. Containers take up less space than VMs (container images are typically tens of MBs in size), can handle more applications and require fewer VMs and Operating systems.

VIRTUAL MACHINES

Virtual machines (VMs) are an abstraction of physical hardware turning one server into many servers. The hypervisor allows multiple VMs to run on a single machine. Each VM includes a full copy of an operating system, the application, necessary binaries and libraries - taking up tens of GBs. VMs can also be slow to boot.

Concept (from Wikipedia)

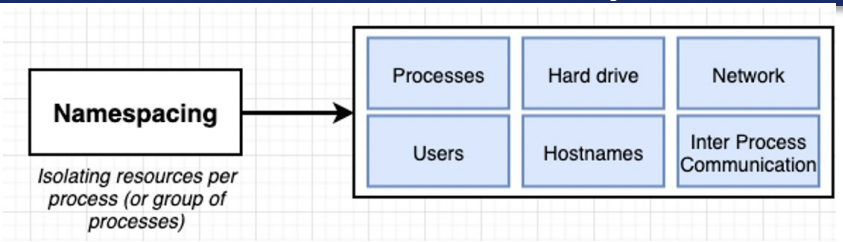
- “cgroups (abbreviated from control groups) is a Linux kernel feature that limits, accounts for, and isolates the resource usage (CPU, memory, disk I/O, network, etc.) of a collection of processes.”

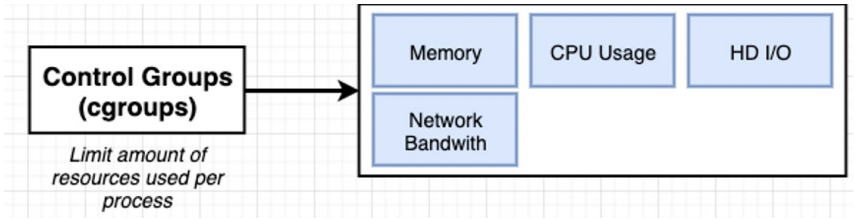
- “Namespaces are a feature of the Linux kernel that partitions kernel resources such that one set of processes sees one set of resources while another set of processes sees a different set of resources.
  … …
  those namespaces refer to distinct resources. Resources may exist in multiple spaces. Examples of such resources are process IDs, hostnames, user IDs, file names, and some names associated with network access, ...”

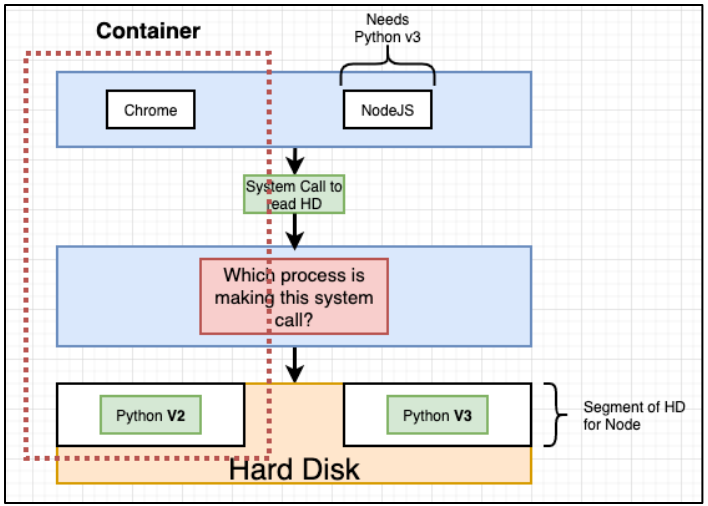
Containers vs VMs

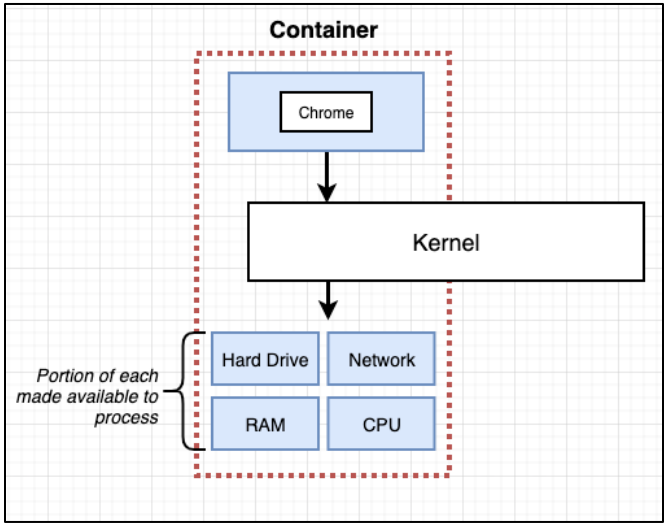
	Process	Container	VM
Definition	A representation of a running program.	Isolated group of processes managed by a shared kernel.	A full OS that shares host hardware via a hypervisor.
Use case	Abstraction to store state about a running process.	Creates isolated environments to run many apps.	Creates isolated environments to run many apps.
Type of OS	Same OS and distro as host,	Same kernel, but different distribution.	Multiple independent operating systems.
OS isolation	Memory space and user privilieges.	Namespaces and cgroups.	Full OS isolation.
Size	Whatever user's application uses.	Images measured in MB + user's application.	Images measured in GB + user's application.
Lifecycle	Created by forking, can be long or short lived, more often short.	Runs directly on kernel with no boot process, often is short lived.	Has a boot process and is typically long lived.

Some Container/Docker Implementation Concepts





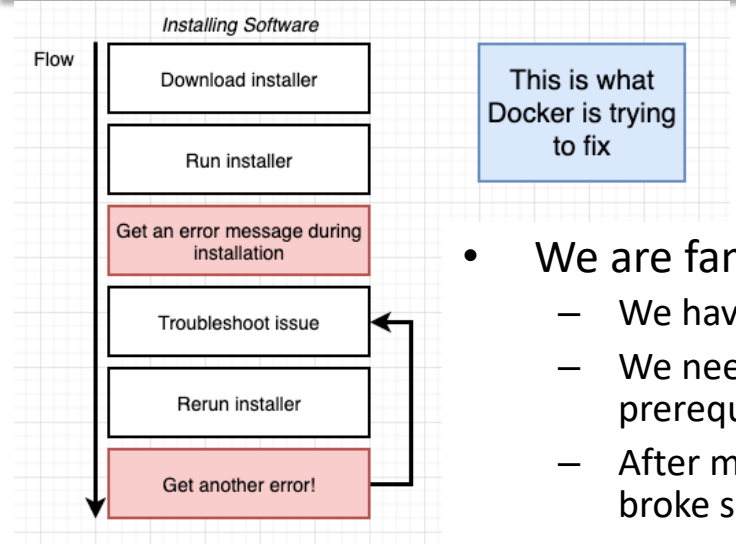




Isolates libraries, paths, packages, PIDs, ...

Partitions and caps resource consumption.

Containers and Some Docker Overview



This is what Docker is trying to fix

Why use Docker? → Docker makes it really easy to install and run software without worrying about setup or dependencies

- We are familiar with the problem
  - We have a system with an OS and installed SW.
  - We need to install something new, and that requires installing prerequisites, changing versions, etc.
  - After many tries, we get the application installed only to find out we broke some other application.
- Docker and containers allow you to:
  - Develop an application or SW system.
  - Package up the entire environment (paths, versions, libs, ...) into an image that works and is self-contained.
  - Someone installing/starting your application simply gets the image from a repository and starts the image to create a running container.

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Demo 1 – Simple Flask Application

Simple Tutorial

- We will follow two tutorials
  - https://docs.docker.com/language/python/
  - https://www.docker.com/blog/containerized-python-development-part-2/
    (/Users/donaldferguson/Dropbox/000-NewProjects/nginx-flask-mysql)

  But, the in the future, basic idea is the same as we have previously followed.
- The steps:
  - Find an example of something cool.
  - Download it, set it up and run it.
  - Modify it and add my application code and logic.
  - Push it somewhere, in this case Docker Hub. (I had to use GitHub)
  - Deploy on the cloud. AWS gives you two or three options:
    - Docker on EC2
    - Elastic Container Service

  We will start with EC2.

Simple Flask Example

- Walk through project:
  - /Users/donaldferguson/Dropbox/000-NewProjects/E6156F23/python-docker
  - https://github.com/donald-f-ferguson/python-docker.git
- Install Docker on AWS
  - https://medium.com/@mehmetodabashi/how-to-install-docker-on-ec2-and-create-a-container-75ca88e342d2

Deploying to EC2

- The simplest thing to do is to:
  - Tag and push your instance to Docker Hub.
  - Create an EC2, then install and start Docker
  - Pull the image, run it, remembering to expose the ports.
  - Test it locally with curl
  - Update security group to expose port.
- In my case:
  - I have an ARM Mac.
  - The Amazon instances is x86
  - So, I clone the project and rebuild locally.
- There is a way to specify the architecture in an environment variable when building. This allows build on ARM for x86 and vice-versa.

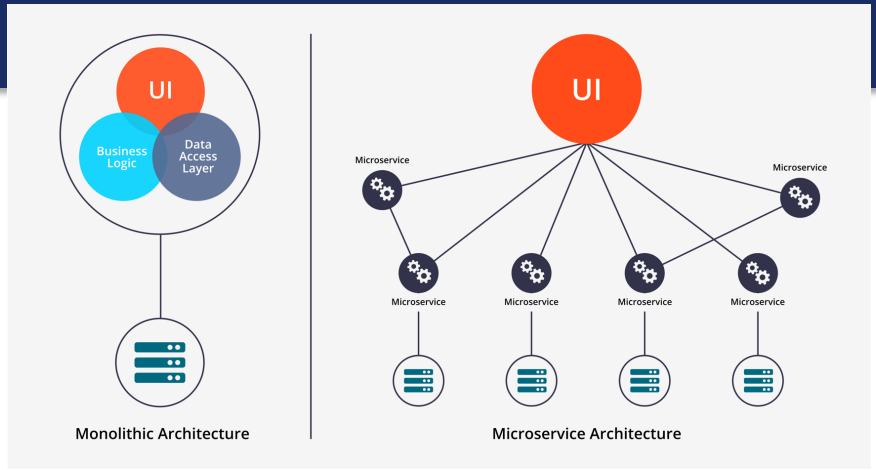
Microservices Continued

Microservices

Historically, complex applications were implemented and deployed as “one big application.”

- **Monolith Architecture** is built in one large system and usually one code-base. A monolith is often deployed all at once, both front-end and back-end code together, regardless of what was changed.
- **Microservices Architecture** is built as a suite of small services, each with their own code-base. These services are built around specific capabilities and are usually independently deployable.

https://medium.com/hengky-sanjaya-blog/monolith-vs-microservices-b3953650dfd



Components of Microservices architecture:

- The services are independent, small, and loosely coupled
- Encapsulates a business or customer scenario
- Every service is a different codebase
- Services can be independently deployed
- Services interact with each other using APIs

Microservices

	Monolithic	Microservice
Architecture	Built as a single logical executable (typically the server-side part of a three tier client-server-database architecture)	Built as a suite of small services, each running separately and communicating with lightweight mechanisms
Modularity	Based on language features	Based on business capabilities
Agility	Changes to the system involve building and deploying a new version of the entire application	Changes can be applied to each service independently
Scaling	Entire application scaled horizontally behind a load-balancer	Each service scaled independently when needed
Implementation	Typically written in one language	Each service implemented in the language that best fits the need
Maintainability	Large code base intimidating to new developers	Smaller code base easier to manage
Transaction	ACID	BASE

- You can drive yourself crazy trying to:
  - Compare microservice architectures to other architecture patterns.
  - Define the characteristics of microservices. What makes something a microservice?
- Why do I cover microservices?
  - It does have benefits in large scale SW development projects.
  - It looks “cool” on your resume.

SOLID Principles

- "In software engineering, SOLID is a mnemonic acronym for five design principles intended to make software designs more understandable, flexible, and maintainable. " (https://en.wikipedia.org/wiki/SOLID)
- The concept started with OO but applies to microservices.
- We will focus on the "S" for now.
- For my project purposes, a thing can be:
  - A user profile service
  - Or
  - A commerce catalog service
  - Or
  - …

  But not both.

12 Factor Applications

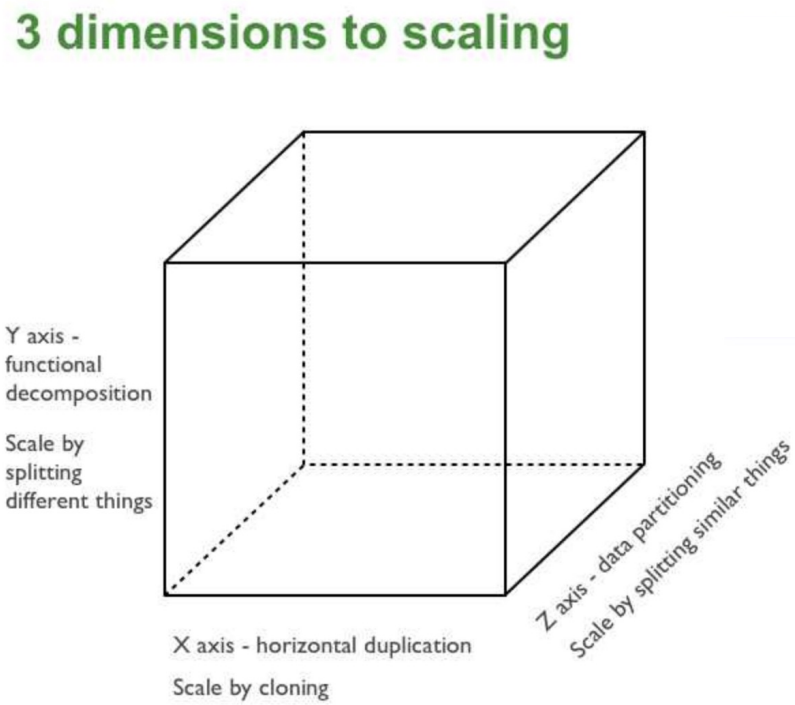
https://dzone.com/articles/12-factor-app-principles-and-cloud-native-microser

Microservices Scalability Cube

The Scale Cube

https://microservices.io/articles/scalecube.html

The book, The Art of Scalability, describes a really useful, three dimension scalability model: the scale cube.



- X-axis scaling consists of running multiple copies of an application behind a load balancer. If there are N copies then each copy handles 1/N of the load. This is a simple, commonly used approach of scaling an application.
- Y-axis axis scaling splits the application into multiple, different services. Each service is responsible for one or more closely related functions.
- When using Z-axis scaling each server runs an identical copy of the code. In this respect, it's similar to X-axis scaling. The big difference is that each server is responsible for only a subset of the data. Some component of the system is responsible for routing each request to the appropriate server

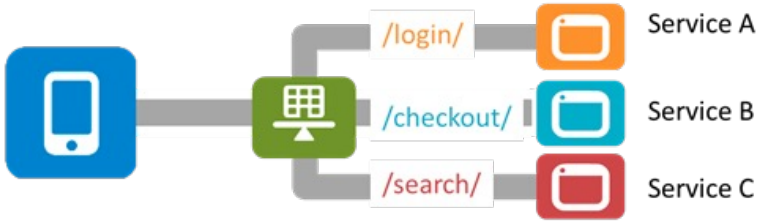
XYZ – Scaling

X-AXIS SCALING

Network name: Horizontal scaling, scale out

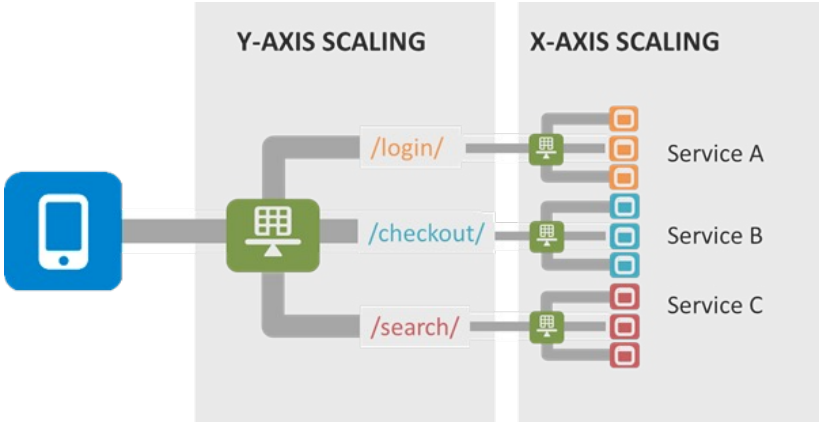
Y-AXIS SCALING

Network name: Layer 7 Load Balancing, Content switching, HTTP Message Steering



Z-AXIS SCALING

Network name: Layer 7 Load Balancing, Content switching, HTTP Message Steering

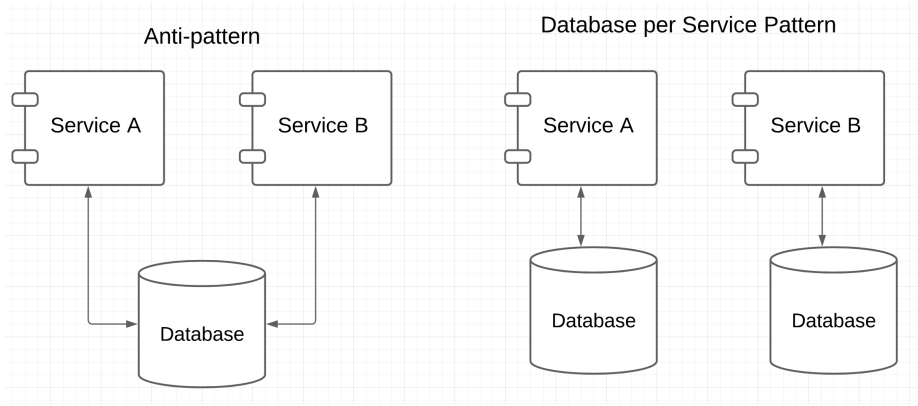


- There are three dimensions.
- A complete solution/environment typical is a mix and composition of patterns.
- Application design and data access determines opitions.

Patterns and Anti-patterns

- “software design pattern is a general, reusable solution to a commonly occurring problem within a given context in software design. It is not a finished design that can be transformed directly into source or machine code. Rather, it is a description or template for how to solve a problem that can be used in many different situations.” (https://en.wikipedia.org/wiki/Software_design_pattern)
- “An anti-pattern is a common response to a recurring problem that is usually ineffective and risks being highly counterproductive.” (https://en.wikipedia.org/wiki/Anti-pattern)

https://microservices.io/patterns/data/database-per-service.html



Prevents independent evolution by creating dependency.

REST, Part I

Concepts

REST (https://restfulapi.net/)

What is REST

- REST is acronym for **RE**presentational **S**tate **T**ransfer. It is architectural style for **distributed hypermedia systems** and was first presented by Roy Fielding in 2000 in his famous dissertation.
- Like any other architectural style, REST also does have it's own 6 guiding constraints which must be satisfied if an interface needs to be referred as **RESTful**. These principles are listed below.

Guiding Principles of REST

- **Client–server** – By separating the user interface concerns from the data storage concerns, we improve the portability of the user interface across multiple platforms and improve scalability by simplifying the server components.
- **Stateless** – Each request from client to server must contain all of the information necessary to understand the request, and cannot take advantage of any stored context on the server. Session state is therefore kept entirely on the client.
- **Cacheable** – Cache constraints require that the data within a response to a request be implicitly or explicitly labeled as cacheable or non-cacheable. If a response is cacheable, then a client cache is given the right to reuse that response data for later, equivalent requests.
- **Uniform interface** – By applying the software engineering principle of generality to the component interface, the overall system architecture is simplified and the visibility of interactions is improved. In order to obtain a uniform interface, multiple architectural constraints are needed to guide the behavior of components. REST is defined by four interface constraints: identification of resources; manipulation of resources through representations; self-descriptive messages; and, hypermedia as the engine of application state.
- **Layered system** – The layered system style allows an architecture to be composed of hierarchical layers by constraining component behavior such that each component cannot "see" beyond the immediate layer with which they are interacting.
- **Code on demand (optional)** – REST allows client functionality to be extended by downloading and executing code in the form of applets or scripts. This simplifies clients by reducing the number of features required to be pre-implemented.

Resources

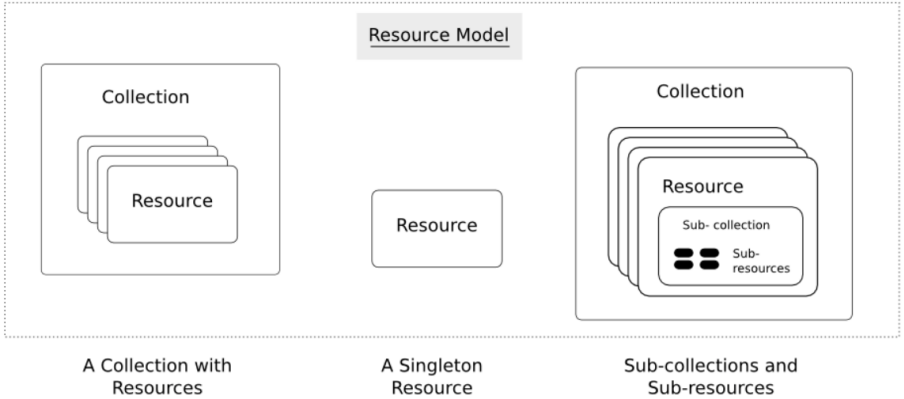
Resources are an abstraction. The application maps to create things and actions.

"A resource-oriented API is generally modeled as a resource hierarchy, where each node is either a *simple resource* or a *collection resource*. For convenience, they are often called a resource and a collection, respectively.

- A collection contains a list of resources of **the same type**. For example, a user has a collection of contacts.
- A resource has some state and zero or more sub-resources. Each sub-resource can be either a simple resource or a collection resource.

For example, Gmail API has a collection of users, each user has a collection of messages, a collection of threads, a collection of labels, a profile resource, and several setting resources.

While there is some conceptual alignment between storage systems and REST APIs, a service with a resource-oriented API is not necessarily a database, and has enormous flexibility in how it interprets resources and methods. For example, creating a calendar event (resource) may create additional events for attendees, send email invitations to attendees, reserve conference rooms, and update video conference schedules. (Emphasis added) (https://cloud.google.com/apis/design/resources#resources)



https://restful-api-design.readthedocs.io/en/latest/resources.html

REST – Resource Oriented

- When writing applications, we are used to writing functions or methods:
  - openAccount(last_name, first_name, tax_payer_id)
  - account.deposit(deposit_amount)
  - account.close()

  We can create and implement whatever functions we need.
- REST only allows four methods:
  - POST: Create a resource
  - GET: Retrieve a resource
  - PUT: Update a resource
  - DELETE: Delete a resource

  That's it. That's all you get.

"The key characteristic of a resource-oriented API is that it emphasizes resources (data model) over the methods performed on the resources (functionality). A typical resource-oriented API exposes a large number of resources with a small number of methods." (https://cloud.google.com/apis/design/resources)

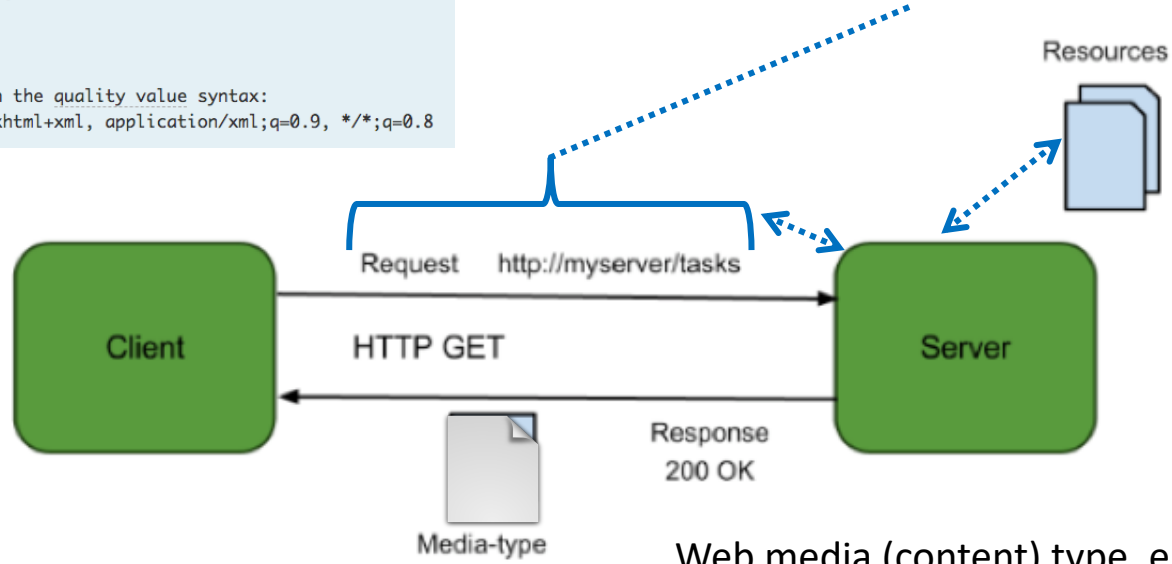
- A REST client needs no prior knowledge about how to interact with any particular application or server beyond a generic understanding of hypermedia.

Resources, URLs, Content Types

Accept type in headers.

```
Accept: <MIME_type>/<MIME_subtype>
Accept: <MIME_type>/*
Accept: */*

// Multiple types, weighted with the quality value syntax:
Accept: text/html, application/xhtml+xml, application/xml;q=0.9, */*;q=0.8
```

- Relative URL identifies “resource” on the server.
- Server implementation maps abstract resource to tangible “thing,” file, DB row, … and any application logic.



Client may be

Browser

Mobile device

Other REST Service

… …

Web media (content) type, e.g.

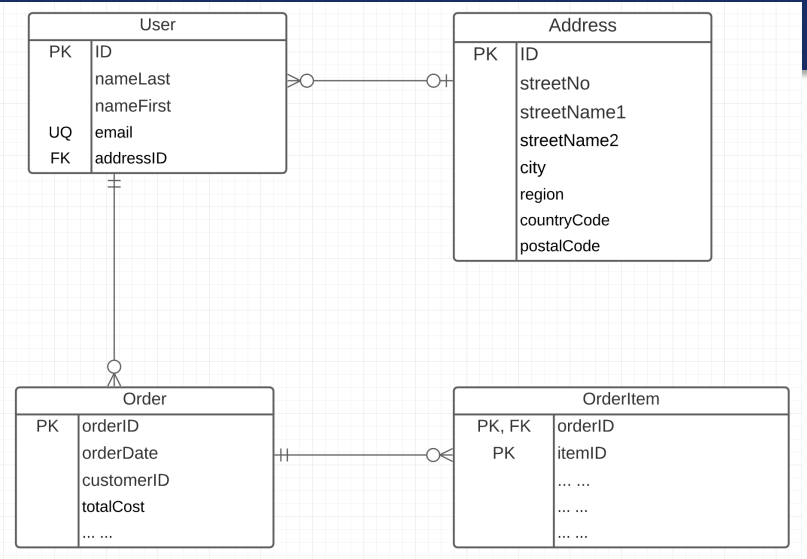
- text/html
- application/json

REST Principles

- What about all of those principles?
  - Client/Server
  - Stateless
  - Cacheable
  - Uniform Interface
  - Layered System
  - Code on demand
- Some of these principles
  - Are simple and obvious.
  - Are subtle and have major implications.
  - Stateless can be baffling, but we will cover later.
- We will go into the principles in later lectures, ... but first linked resources ... ...

Linked Data

Linked Data



- Consider two microservices:
  - UserService handles two resources:
    - User
    - Address
  - OrderService handles two resources:
    - Order
    - OrderItem
- Associations/Link/Relationships can be surprisingly complicated. There are many considerations. (See https://www.uml-diagrams.org/association.html)
- In this example, we have
  - Association (User-Address, User-Order)
  - Composition (Order-OrderItem)

Resource Paths

The simple object model might/could/would/should have the following:

- /users
- /users/<userID>
- /users/<userID>/address
- /users/<userID>/orders
- /addresses
- /addresses/<addressID>/users
- /orders/<orderID>
- /orders/<orderID>/orderitems
- /orders<orderID>/orderitems/<itemID>
- … …

Composition

```
{
    "orderID": 2101,
    "orderDate": "2021-09-17",
    "totalCost": 10346.10,
    "orderItems": [
        {
            "itemID": 1,
            "someOtherFields": "... .."
        },
        {
            "itemID": 2,
            "someOtherFields": "... .."
        }
    ],
    "links": [
        {
            "href": "/users/gtg201",
            "rel": "user"
        }
    ]
}
```

Association

```
{
    "userID": "gtg101",
    "nameLast": "Ferguson",
    "nameFirst": "Donald",
    "email": "gtg@orthanc.gov",
    "links": [
        {
            "href": "/addresses/201",
            "rel": "address"
        },
        {
            "href": "/users/gtg101",
            "rel": "self"
        }
    ]
}
```

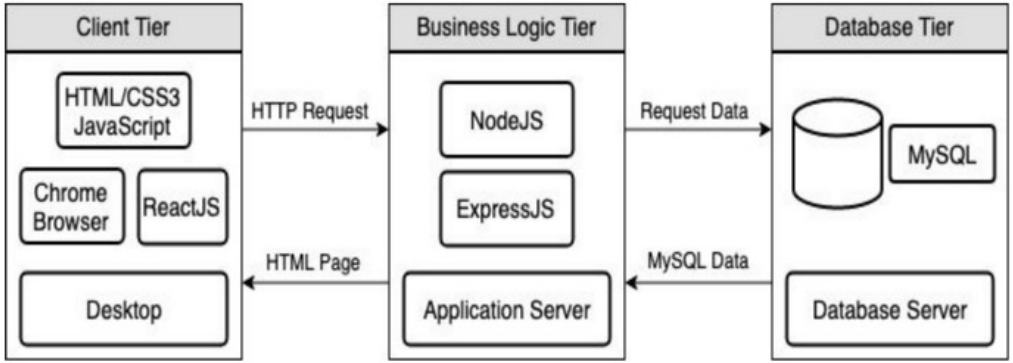
- How do you “point backwards” in a “foreign key relationship,” e.g. Address → User
  - “href” : “/users?addressID=201”
  - This means you store the addressID in the DB but return a link om REST.

Example

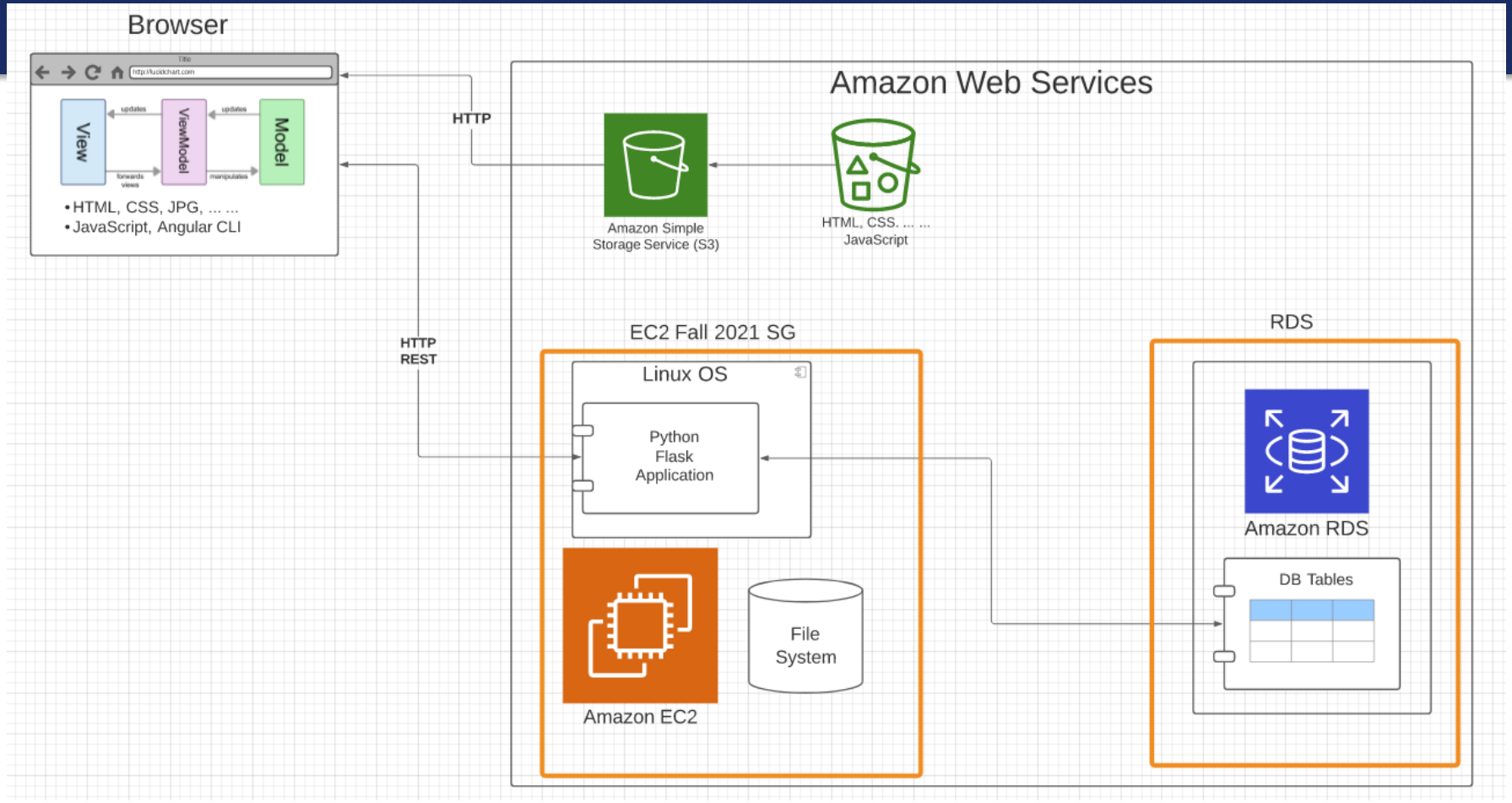
BLOBs, AWS S3, Web Server

Full Stack Web Application – Reminder

https://levelup.gitconnected.com/a-complete-guide-build-a-scalable-3-tier-architecture-with-mern-stack-es6-ca129d7df805



- We have seen how to use Flask (or FastAPI) to implement an endpoint (a set of paths):
  - Some of the paths can run application logic and return the result data.
  - Some can return pages that a browser can render. Basically, these paths are returning the "client application" to the browser to execute, and may have API calls in JavaScript/Typescript.
  - Do not worry about this now.
- But, running application logic and simply delivering files are two different "concerns."
  - Having one runtime implement both would violate the SOLID principle.
  - The design points are different: "You can be a floor wax or a mouth wash, but not both."
- So, we need a separate "web server."



BLOB: Binary Large Object

- Definitions:
  - "A binary large object (BLOB or blob) is a collection of binary data stored as a single entity. Blobs are typically images, audio or other multimedia objects, though sometimes binary executable code is stored as a blob. They can exist as persistent values inside some databases or version control system, or exist at runtime as program variables in some programming languages." (https://en.wikipedia.org/wiki/Binary_large_object)
  - "Blob is the data type in MySQL that helps us store the object in the binary format. It is most typically used to store the files, images, etc media files for security reasons or some other purpose in MySQL." (https://www.educba.com/mysql-blob/)
- Intent:
  - File systems are not good for many application scenarios, which is why database management systems emerged.
  - Database management systems implement structured (or semi-structured) data, e.g. tables.
  - Database BLOBs were a way to have some "big things" as table or document properties.

Simple Example

```
CREATE TABLE `products` (
  `productCode` varchar(15) NOT NULL,
  `productName` varchar(70) NOT NULL,
  `productLine` varchar(50) NOT NULL,
  `productScale` varchar(10) NOT NULL,
  `productVendor` varchar(50) NOT NULL,
  `productDescription` text NOT NULL,
  `quantityInStock` smallint NOT NULL,
  `buyPrice` decimal(10,2) NOT NULL,
  `MSRP` decimal(10,2) NOT NULL,
  `productImage` blob,
  `productManual` blob
)
```

- Structured or semi-structured information about an entity.
  - Queryable
  - Editable on forms
  - etc.
- Unstructured: A file-like, opaque property associated with the entity. This is a BLOB.

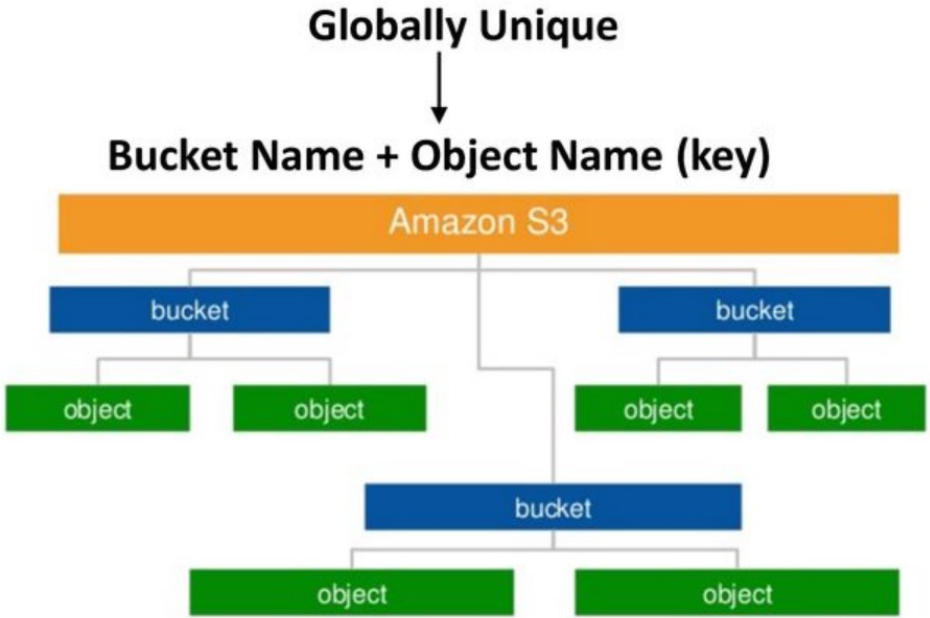
URLs have primarily replaced BLOBs.

Amazon S3

We used the equivalent capability on Azure for uploading CAD files, storing processed files and results, etc.

AWS S3

Concepts of S3 – Namespace



Can support a logical hierarchy with a convention on keys.

- x/y
- x/z
- x/y/z
- … …

Acts kind of file system like, but is really just key strings.

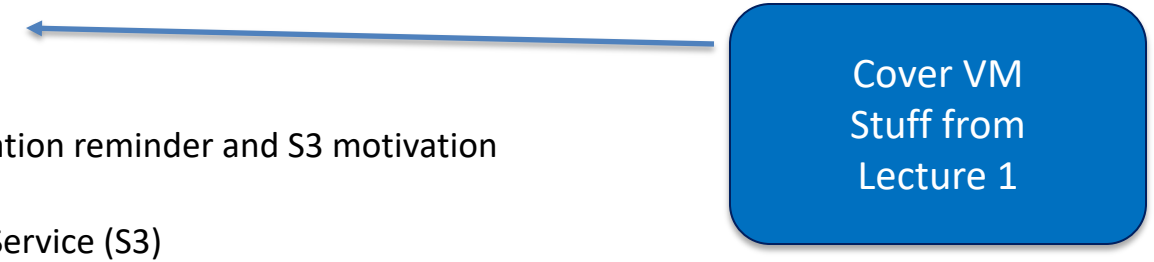
Simple S3 Example

```python
import boto3
import json

s3_client = boto3.client('s3')

s3_resource = boto3.resource('s3')


def list_buckets():
    response = s3_client.list_buckets()

    # Output the bucket names
    print('\n\nexisting buckets:')
    for bucket in response['Buckets']:
        print(f'  {bucket["Name"]}')
```

```python
def get_object():

    res = s3_client.get_object(
        Bucket='e6156f20site',
        Key='assets/snuffle.png')

    print("\n\n The object is ...\n", json.dumps(res, indent=2, default=str))

    dd = res['Body'].read()
    print("\n\nThe first 1000 bytes of the body are:\n", dd[0:1000])

    with open("./snuffle.png", "wb") as outfile:
        outfile.write(dd)
        outfile.close()

    print("Wrote the file.")


if __name__ == "__main__":

    # list_buckets()
    get_object()
```

/Users/donaldferguson/Dropbox/00NewProjects/e6156examples/s3/s3_examples.py

Contents



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