# Software Architecture & Design of Large Scale Systems

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# Introduction to System Requirements & Architectural Drivers

## Introduction to System Design & Architectural Drivers

- **Requirements** - Formal description of what we need to build
- **Types of Requirements** - Architectural Drivers
    - Features of the System
        - Functional requirements


    - Quality Attributes
        - Non-Functional requirements
            - Examples:
                - Scalability
                - Availability
                - Reliability
                - Security
                - Performance
        - Dictate the software architecture of our system

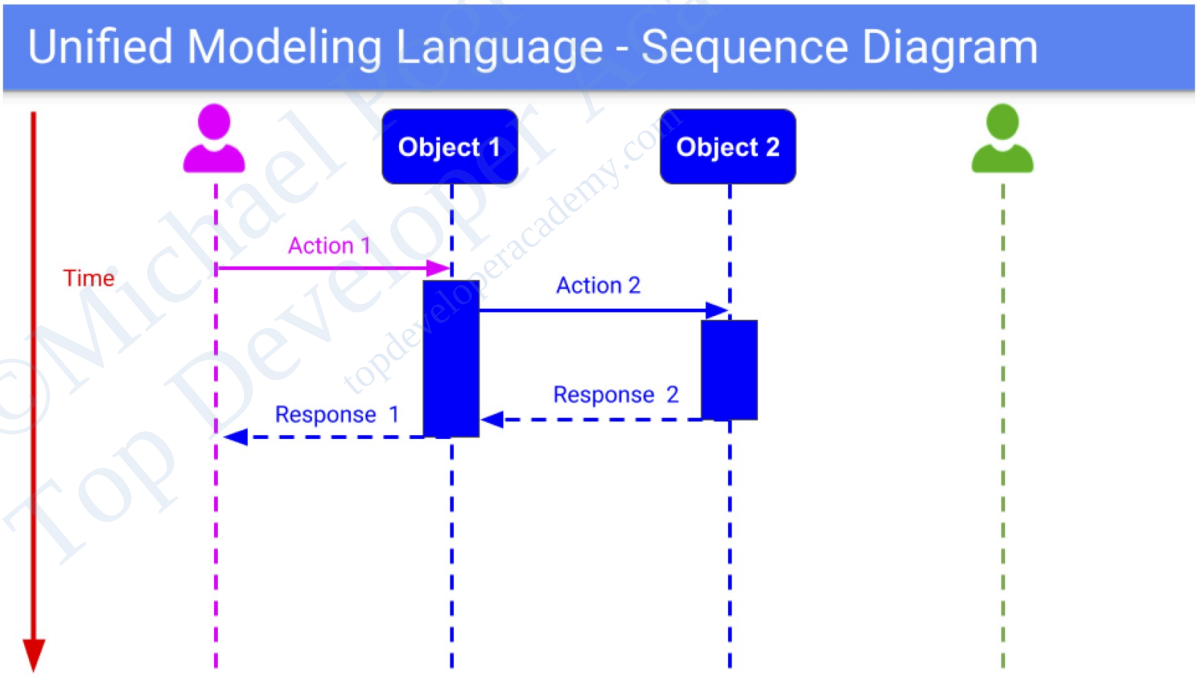

    - System Constraints
        - Limitations and boundaries



**Notes:**

# Feature Requirements - Step-by-Step Process

- Methods of Gathering Requirements
  - Use Cases
    - Situation / Scenario in which our system is used
  - User Flows
    - A Step-By-Step / Graphical representation of each use case
- Requirement Gathering Steps
  - Identify all the actors/users in our system
  - Capture and describe all the possible use cases/ scenarios
  - User Flow - Expand each use case through the flow of events.
    - Each event contains
      - Action
      - Data
- Sequence Diagram
  - The diagram that represents interactions between actors and objects.






**Notes:**

# System Quality Attributes Requirements

- System Quality Attributes
  - Provide a quality measure of how well our system performs on a particular dimension
  - Have a direct correlation with the architecture of our system
- Important Considerations
  - Testability and Measurability
  - Trade-Offs
    - No single software architecture can provide all the quality attributes.
    - Certain quality attributes contradict one another
    - Some combinations of quality attributes are very hard/impossible to achieve
  - Feasibility
    - We need to make sure that the system is capable of delivering with the client asking for

## Notes:

# System Constraints in Software Architecture

- Definition:
    - “A system constraint is essentially a decision that was already either fully or partially made for us, restricting our degrees of freedom.”
- Types of Constraints:
    - Technical constraints
    - Business constraints
        - Forces us to make sacrifices in:
            - Architecture
            - Implementation
    - Regulatory/legal constraints
        - Global
        - Specific to a region
- Considerations:
- We shouldn't take any given constraint lightly
- Use loosely coupled architecture

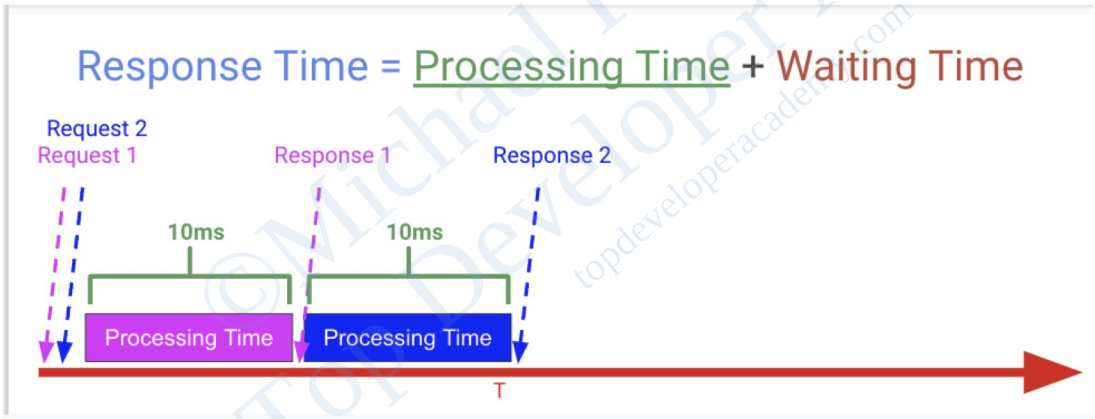
## Notes:

# Most Important Quality Attributes in Large-Scale Systems

## Performance

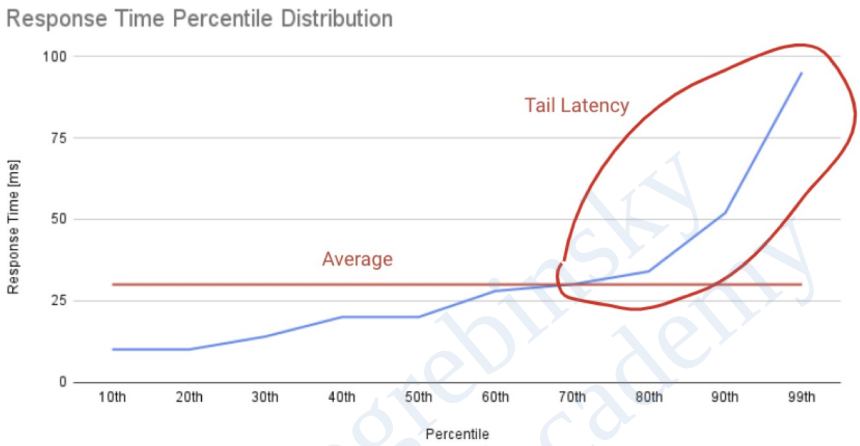
- Definitions
  - **Response Time**:
    - The time between a client sending a request and receiving a response
    - Response Time = Processing Time + Waiting Time
    - Waiting Time - Duration of time request/response spends inactively in our system


  - **Throughput**
    - Amount of work performed by our system time
      - Measured in tasks/second
    - Amount of data processed by our system per unit of time
      - Measured in bits/second, Bytes/second, MBytes/second
- Important Considerations:
  - Measuring Response Time Correctly



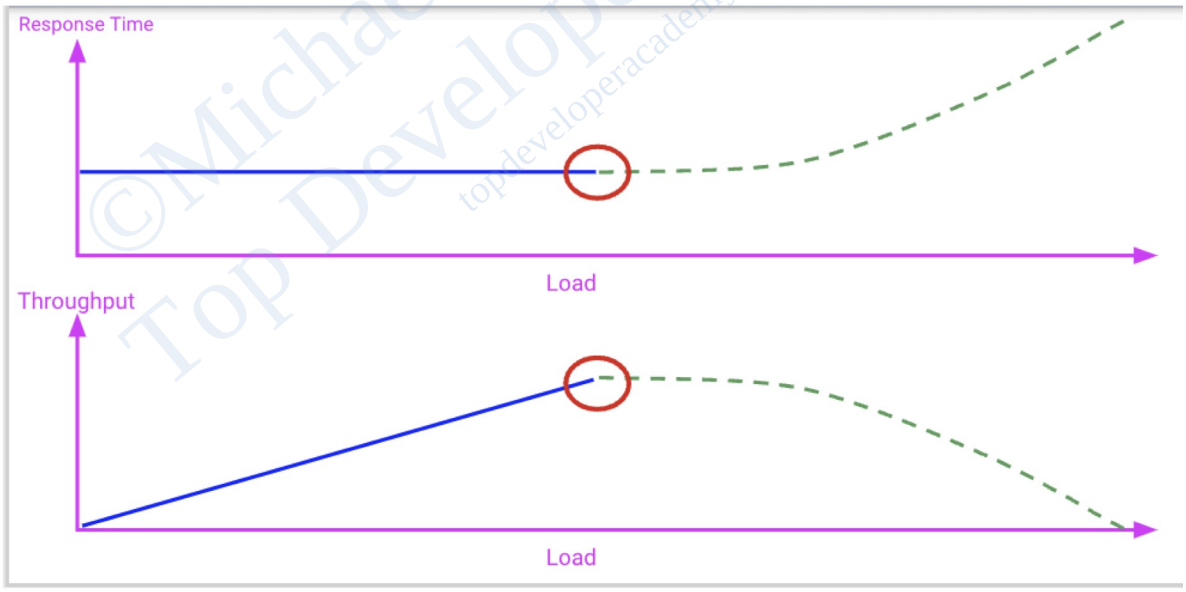

  - Response Time Distribution

- **Percentile**: The “xth percentile” is the value below which x% of the values can be found




- **Tail Latency**: The small percentage of response times from a system that take the longest in comparison to the rest of the values

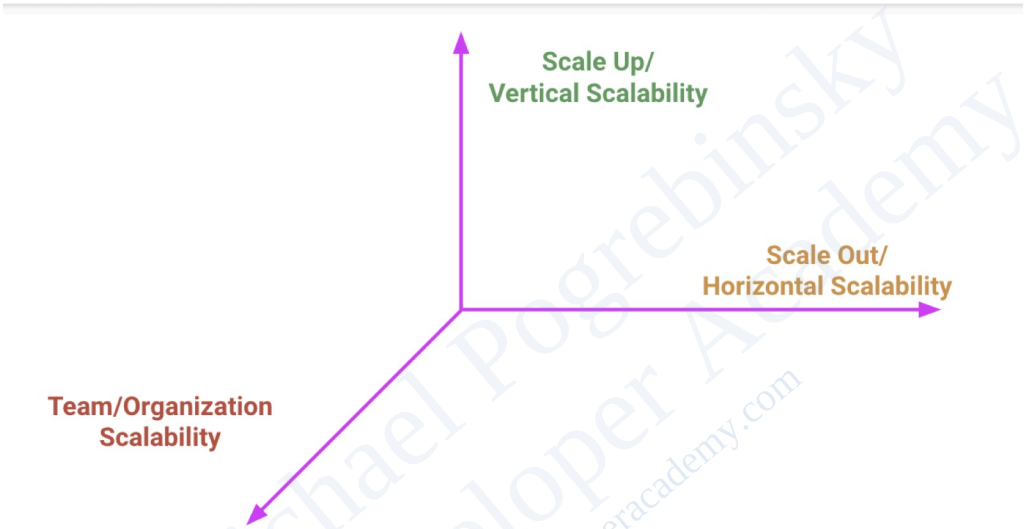
- Performance Degradation




## Notes:

# Scalability

- **Scalability Definition:**
  - “The measure of a system's ability to handle a growing amount of work, in an easy and cost-effective way, by adding resources to the system”
- **Types of Scalability**






  - Vertical Scalability
    - Adding resources or upgrading the existing resources on a single computer
  - Horizontal Scalability
    - Adding more resources in the form of new instances running on different machines
  - Team/Organizational Scalability
    - Software Architecture impacts engineering velocity (team productivity)

## Notes:

# Availability - Introduction & Measurement

- **Availability**:
  - *"The fraction of time/probability that our service is operationally functional and accessible to the user."*

***Availability = Uptime / (Uptime + Downtime)***

- **Uptime**:
  - The time that our system is operationally functional and accessible to the user
- **Downtime:**
  - The time that our system is unavailable to the user
- **MTTR**
  - Mean Time to Recovery

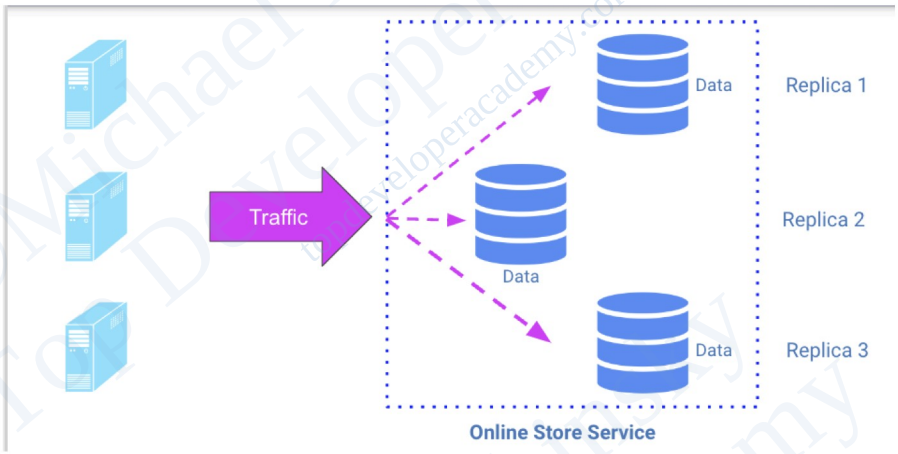
***Availability = MTBF / (MTBF + MTTR)***



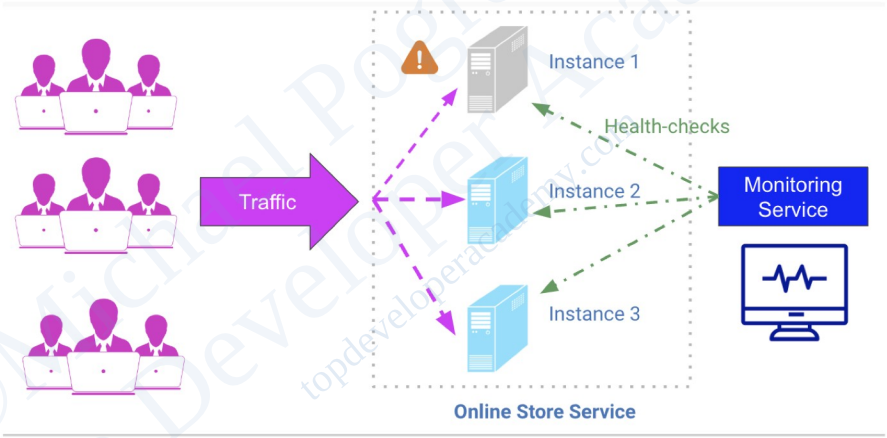
## Notes:

# Fault Tolerance & High Availability

- **Sources of Failure:**
  - Human Error
  - Software Errors
  - Hardware Failures
- **Fault Tolerance:**
  - *"Enables our system to remain operational and available to the users despite failures within one or multiple of its components."*
- **Tactics for achieving Fault Tolerance**
  - Failure Prevention
    - Redundancy and Replication




  - Failure Detection and Isolation:
    - Monitoring




  - Recovery
    - Stop sending traffic
    - Restart the host
    - Rollback

## Notes:

# SLA, SLO, SLI

- **SLA - Service Level Agreement**
  - It is a legal contract that represents our quality service
- **SLOs - Service Level Objectives**
  - Each SLO represents a target value/range that our service needs to meet
- **SLIs - Service Level Indicators**
  - A quantitative measure of our compliance with a service-level objective
- **Important Considerations:**
  - We shouldn't take every SLI that we can measure in our system and define an objective associated with it
  - Promising fewer SLOs is better
  - Set realistic goals with a budget for error
  - Create a recovery plan for when the SLIs show that we are not meeting our SLOs

## Notes:

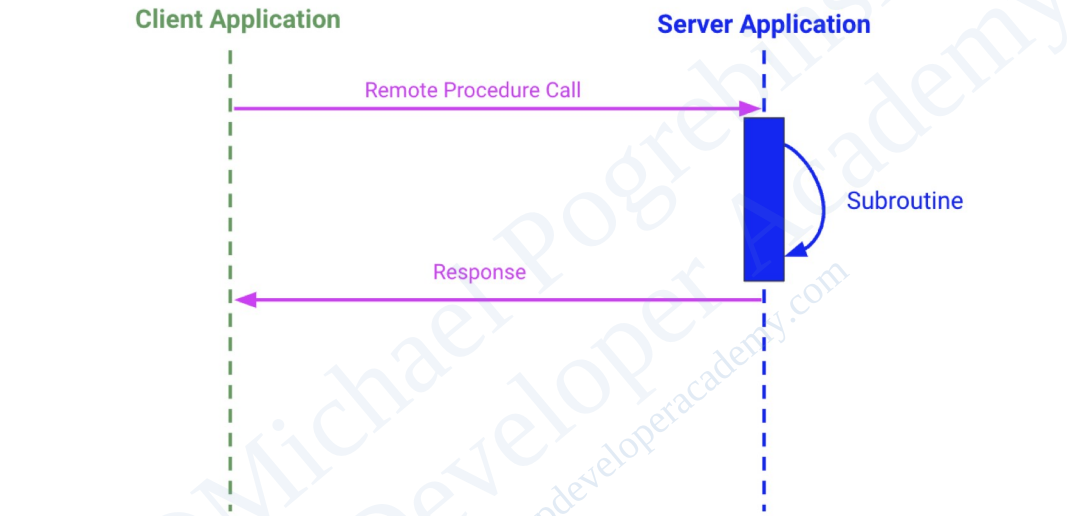
# API Design

## Introduction to API Design for Software Architects

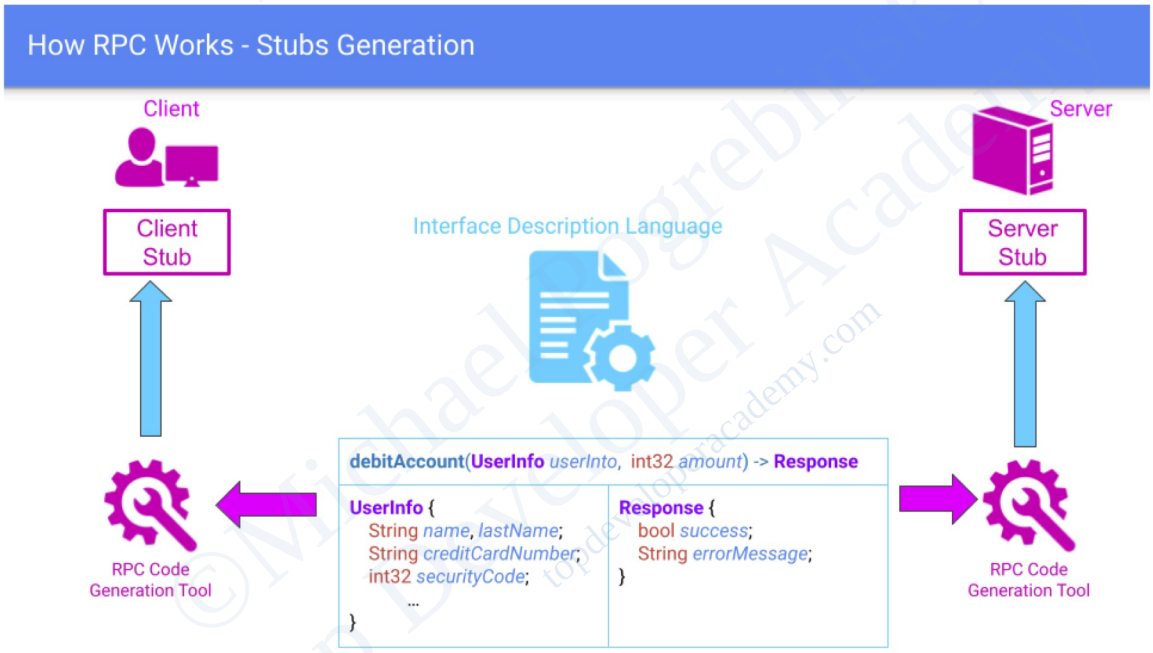
- **An API is a contract between:**
  - Engineers who implement the system
  - Client applications that use the system
- **Categories of API**
  - Public APIs
  - Private/Internal APIs
  - Partner APIs
- **API best practices and patterns:**
  - Complete Encapsulation of the internal design and implementation
  - Easy to Use
  - Keeping the Operations Idempotent
    - *"An operation doesn't have any additional effect on the result if it is performed more than once."*
  - API Pagination
  - Asynchronous Operations
  - Versioning our API

## Notes:

# RPC




- **Features of RPC:**
  - Looks like calling a normal local method
  - RPC frameworks support multiple programming languages




- **Benefits of RPC:**
  - Convenience to the developers
  - The details of communication establishment/data transfer between client to server are abstracted
  - Failures in communication with the server result in an error or exception depending on the programming language

- **Drawbacks of RPC over local method invocation:**
  - Slower
  - Less reliable

## Notes:

# REST API

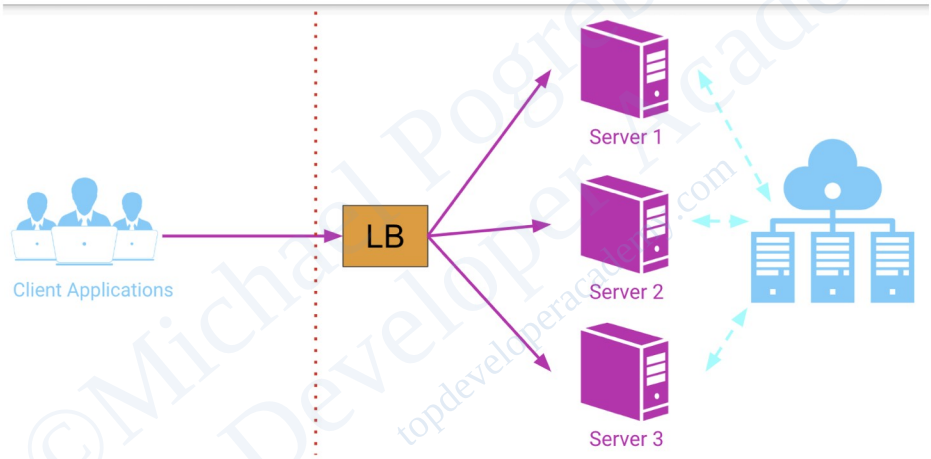
- **REST - Representational State Transfer**
  - Set of architectural constraints and best practices for defining APIs for the web
- **Important Concepts:**
  - HATEOAS -
    - The interface is dynamic through Hypermedia as the Engine of the Application State (HATEOAS)
  - Statelessness
  - Cacheability
  - Named Resources - Each resource is either:
    - Simple resource
    - Collection resource
- **Resources - Best Practices:**
  - Naming our resources using nouns
  - Making a distinction between collection resources and simple resources
  - Giving the resources clear and meaningful names
  - The resource identifiers should be unique and URL friendly
- **REST API Operations Mapping to HTTP Methods**
  - REST operations are mapped to HTTP methods as follows:
    - ***Create*** *a new resource* -> **POST**
    - ***Update*** *an existing resource* -> **PUT**
    - ***Delete*** *an existing resource* -> **DELETE**
    - ***Get*** *the state of a resource* } **GET**
    - ***List*** *the sub-resources of a collection* } **GET**
  - In some situations, we define additional custom methods
- **REST API - Step-by-Step Process**
  - Identifying Entities
  - Mapping Entities to URIs
  - Defining Resources' Representations
  - Assigning HTTP Methods To Operations on Resources

## Notes:

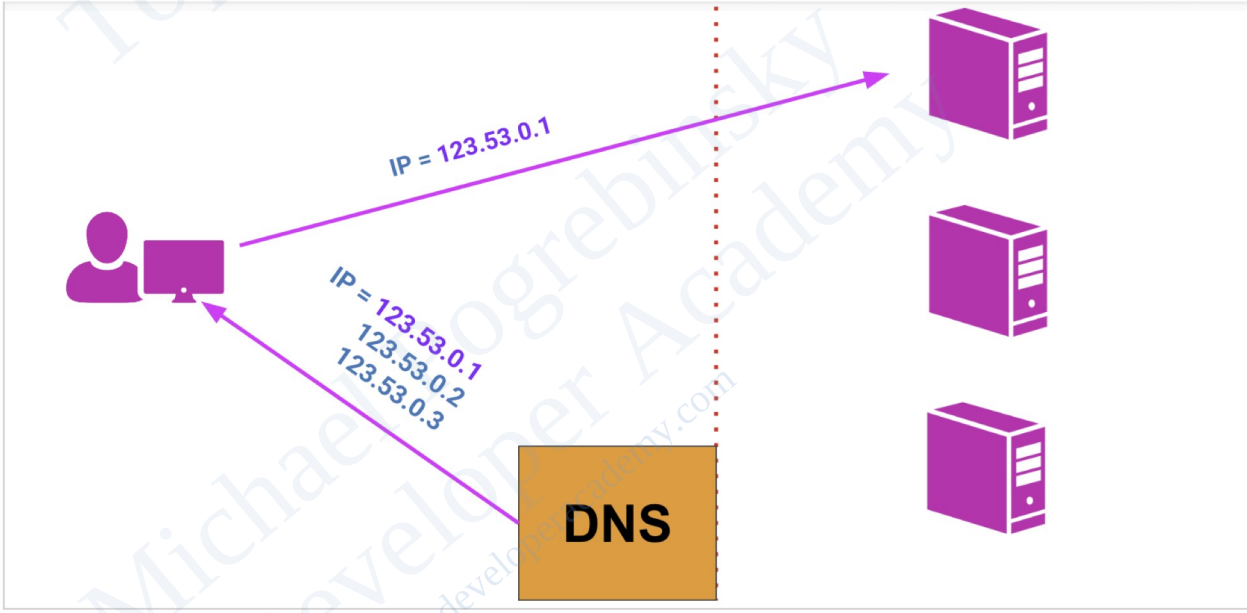
# Large Scale Systems Architectural Building Blocks

## DNS, Load Balancing & GSLB

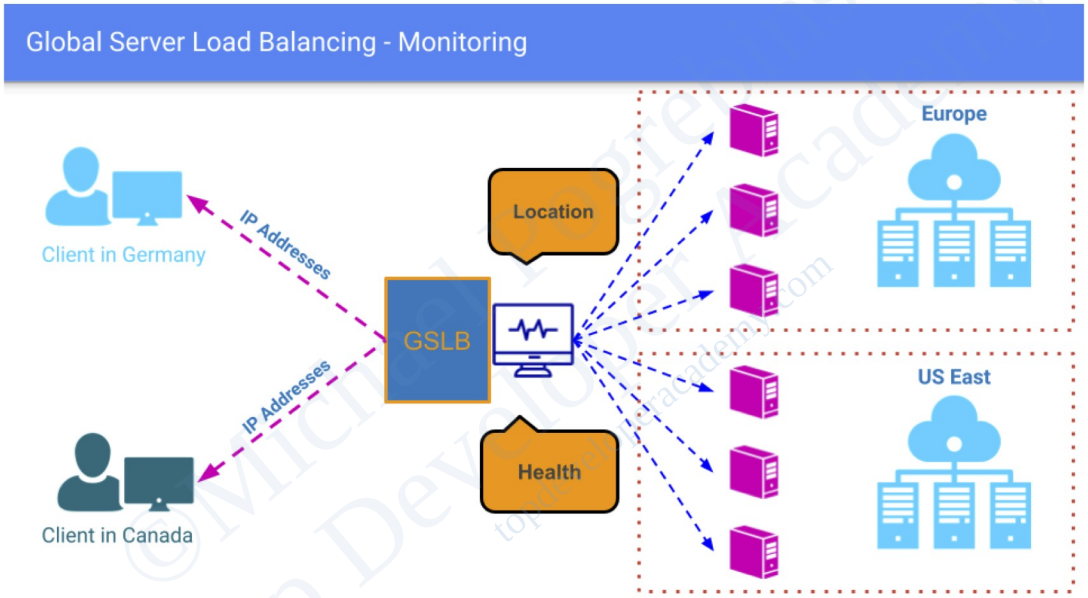
- **Role of Load Balancer:**
  - Balance load among a group of servers




- **Types of load balancers**
  - DNS load balancing



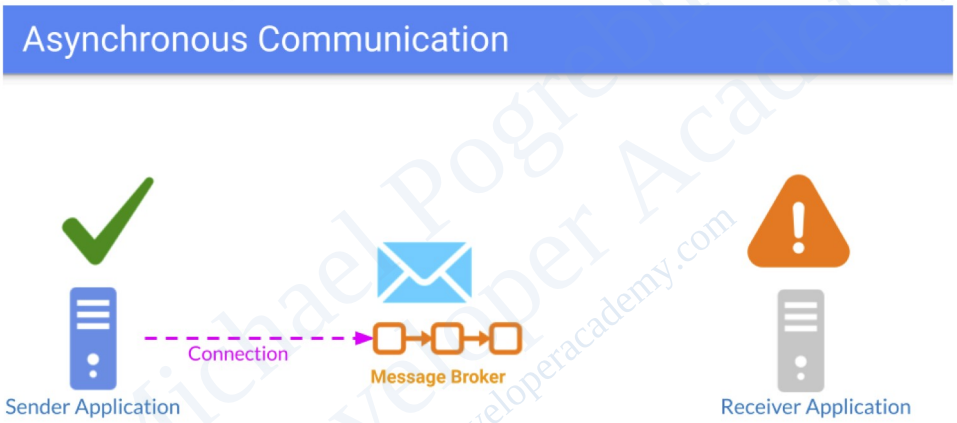

  - Hardware load balancing
    - Run on dedicated devices designed and optimized specifically for load balancing
  - Software load balancing
    - Programs that can run on a general-purpose computer and perform a load-balancing function
  - Global Server Load Balancing




## Notes:

# Message Brokers

- **Definition:**
  - A software architectural building block that uses the queue data structure to store messages between senders and receivers
  - Used inside our system and not exposed externally

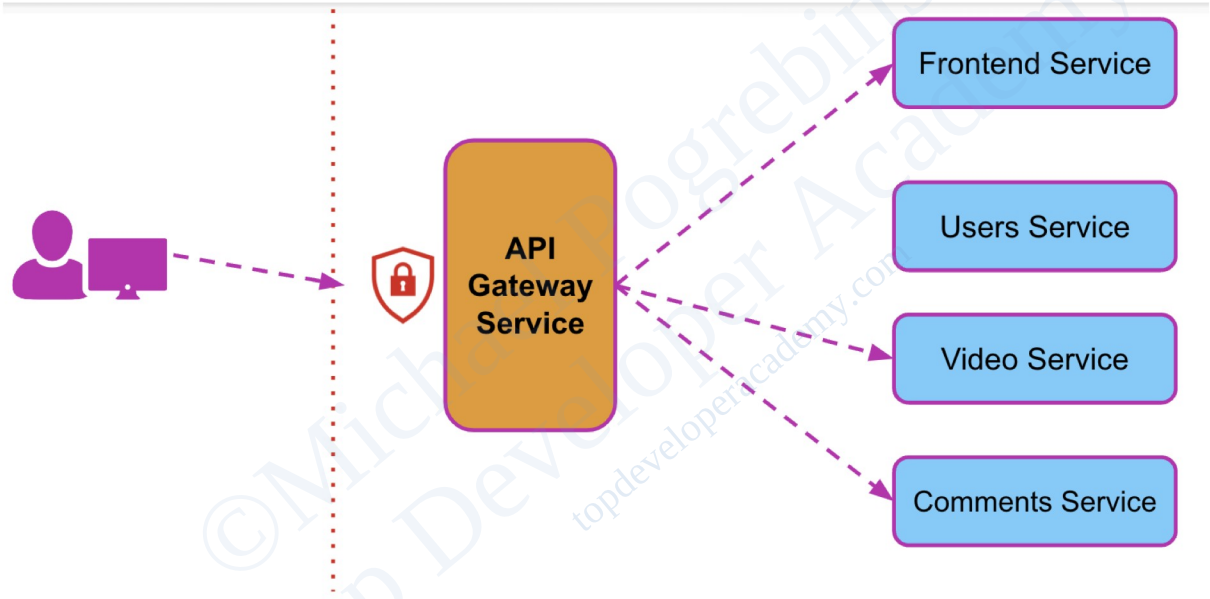



- **Benefits:**
  - Services can
    - Publish messages to a particular channel
    - Subscribe to that channel
    - Get notified when a new event is published

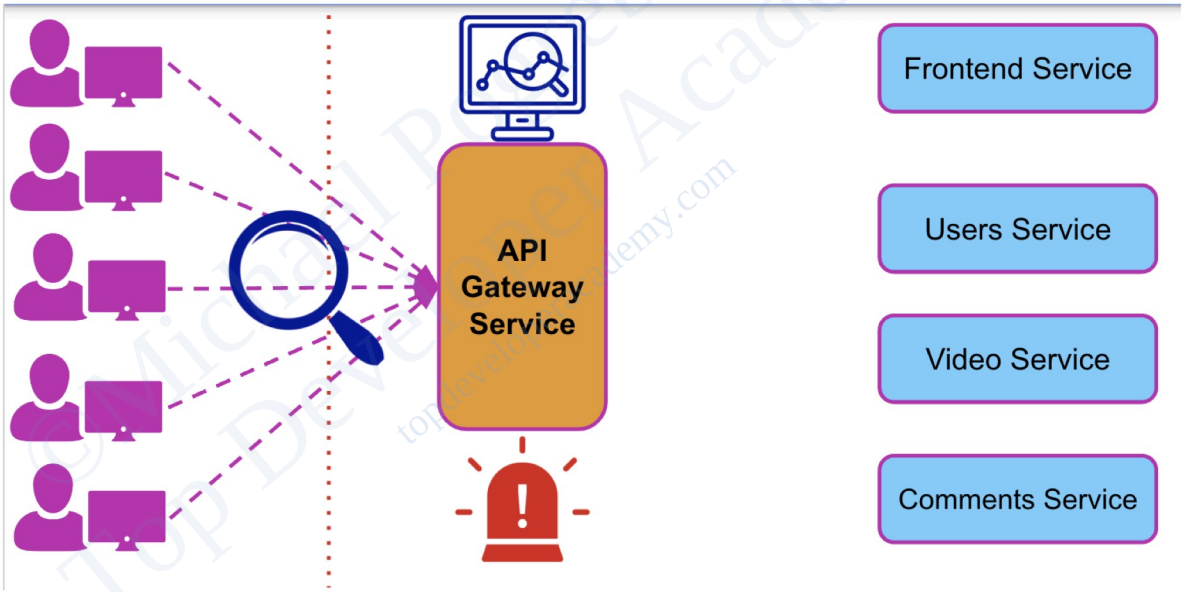
## Notes:

# API Gateway

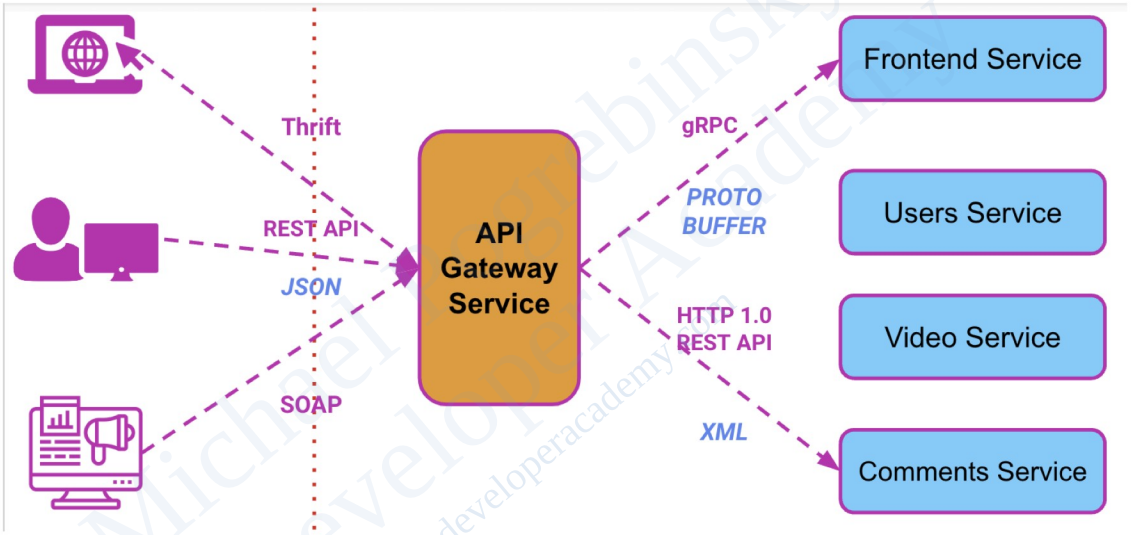
- **Definition**:
  - Follows a software architecture pattern called “API composition.”
  - The client applications can call one single service




- **Benefits**
  - Seamless internal modifications/Refactoring
  - Consolidating all security, authorization, and authentication in a single place
    Request Routing
  - Static content and response caching
  - Monitoring and alerting




  - Protocol Translation

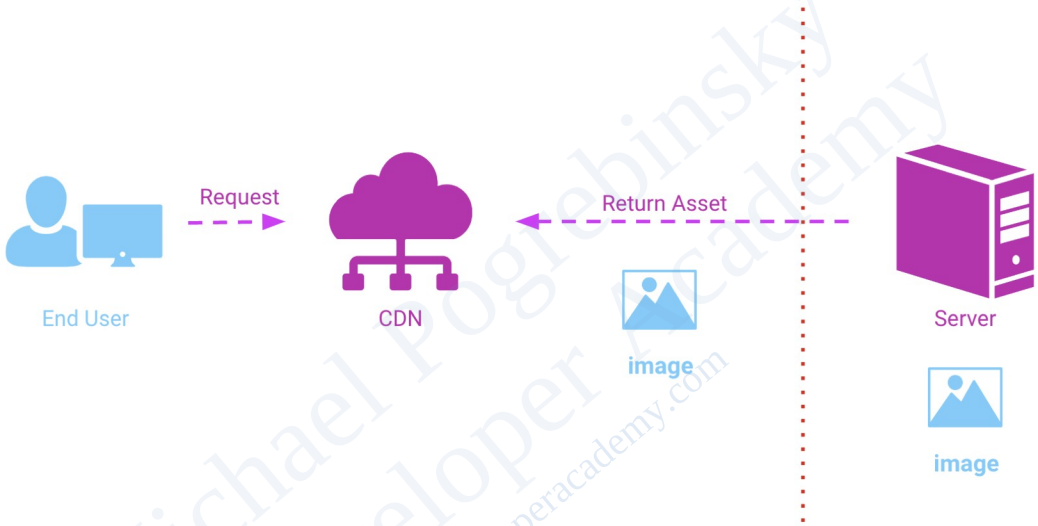



- **Considerations**:
  - API Gateway shouldn't contain any business logic
  - API Gateway may become a Single Point of Failure
  - Avoid bypassing API Gateway from external services

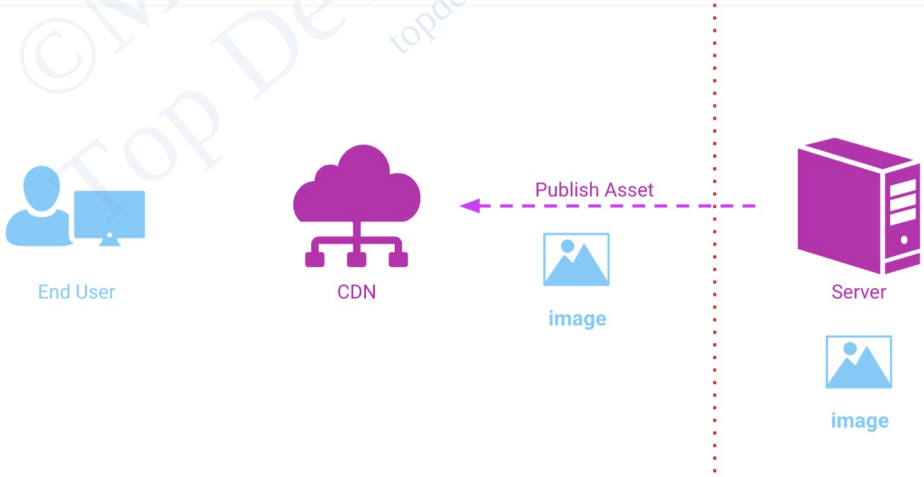
## Notes:

# Content Delivery Network - CDN

- **Definition:**
  - A globally distributed network of servers located in strategic places
- **Main purpose:**
  - Speeding up the delivery of content to end-users
- **Content Publishing Strategies**
  - *Pull Strategy*




  - *Push Strategy*






## Notes:

# Data Storage at Global Scale

## Relational Databases & ACID Transactions

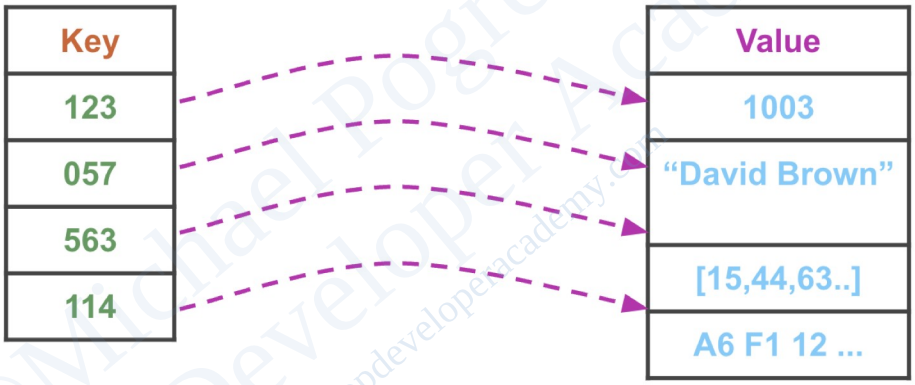
- **Properties:**
  - The structure (schema) of each table is defined ahead of time
  - Gives us the knowledge of each what each record must have
- **Advantages:**
  - Ability to form complex and flexible queries
  - Efficient storage
  - Natural structure of data for humans
  - ACID transactions
    - *Atomicity* - Each set of operations that are part of one transaction either:
      - Appear all at once
      - Don't appear at all
    - *Consistency* -
      - A transaction that was already committed is seen by all future queries/transactions
      - A transaction doesn't violate any constraints that we set for our data
    - *Isolation*
      - Related to Atomicity in the context of concurrent operations performed on our database
    - *Durability*
      - Once a transaction is complete, its final state will persist and remain permanently inside the database



## Notes:

# Non-Relational Databases

- Categories:
  - **Key/Value Store**




  - **Document Store**
    - We can store collections of documents with more structure inside each document
    - Each document is an object with different attributes
  - **Graph Database**
    - Optimized for navigating and analyzing relationships between different records

## Notes:

# Techniques to Improve Performance, Availability & Scalability Of Databases

- **Database Indexing**

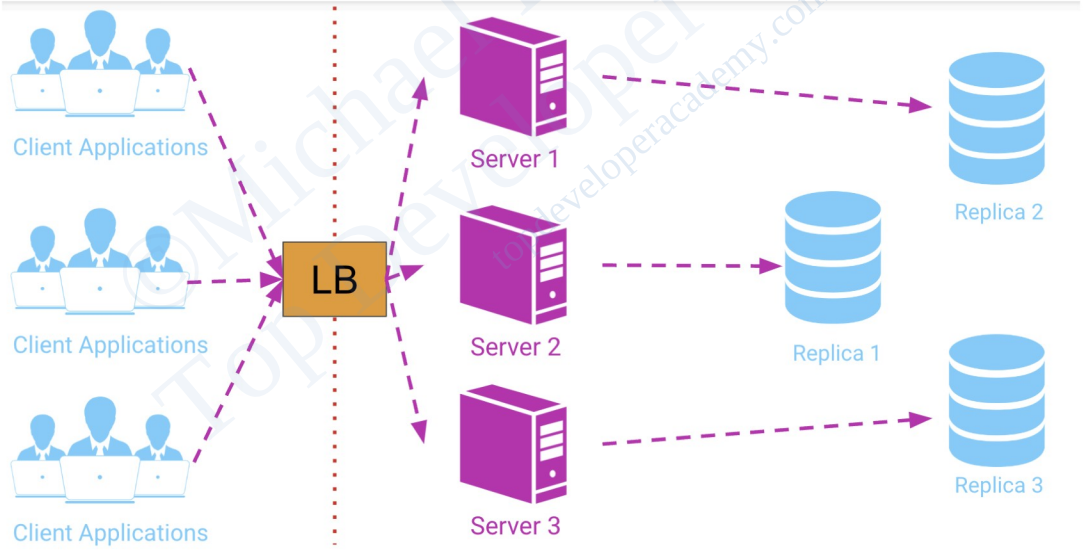
Index Table

| City | Row |
|---|---|
| Los Angeles | 1 |
| Boston | 2 |
| Los Angeles | 3 |
| New York | 4 |
| Amsterdam | 5 |
| ... | ... |

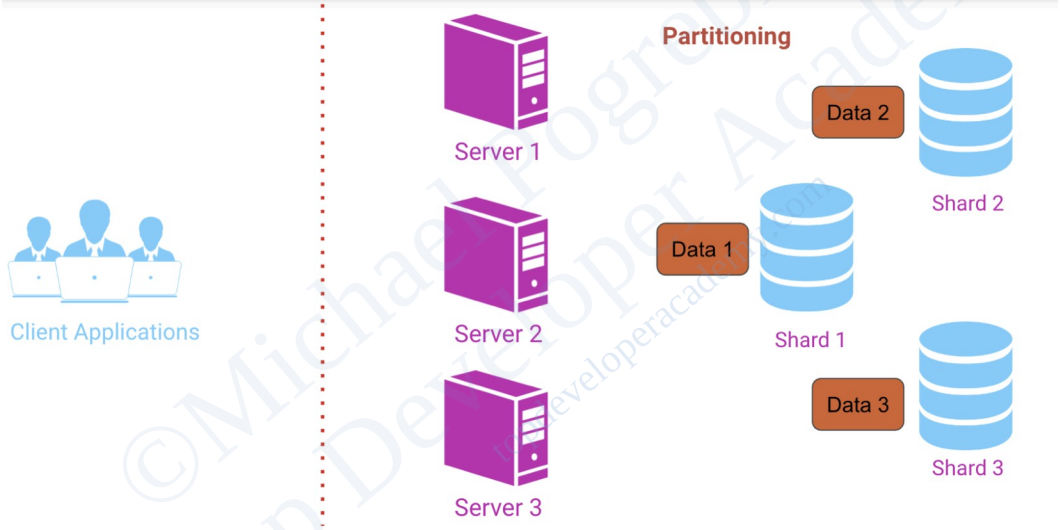
Users Table

| Id | City | FirstName | LastName | Age |
|---|---|---|---|---|
| 1 | Los Angeles | Alexander | Ivanov | 35 |
| 2 | Boston | John | Smith | 44 |
| 3 | Los Angeles | Mary | Johnson | 15 |
| 4 | New York | Michael | Bird | 86 |
| 5 | Amsterdam | Joseph | Young | 51 |
| ... | ... | ... | ... | ... |

- **Database Replication**



- **Database Partitioning/Sharding**

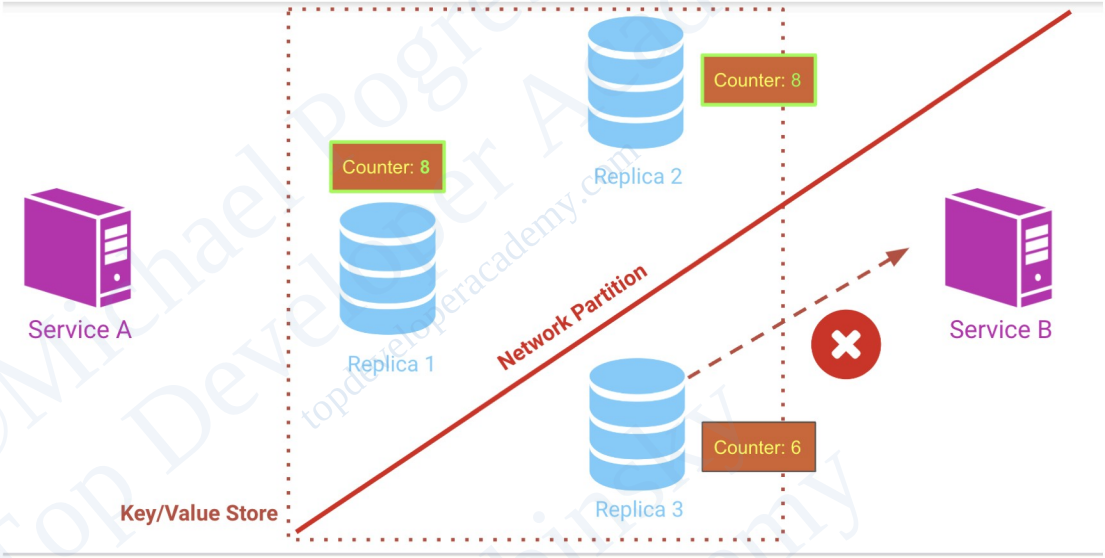




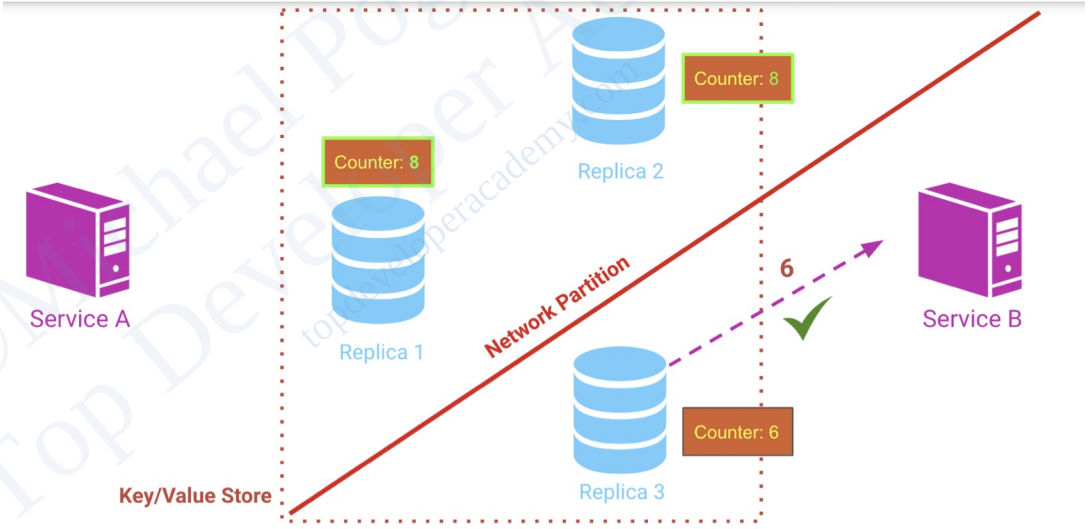

## Notes:

# Brewer's (CAP) Theorem

- Definition:
  - *"In the presence of a Network Partition, a distributed database cannot guarantee both Consistency and Availability and has to choose only one of them."*
- CAP
  - **Consistency**
    - "Every read request receives either the most recent write or an error"




  - **Availability**
    - "Every request receives a non-error response, without the guarantee that it contains the most recent write."




## Notes:

# Unstructured Data Storage

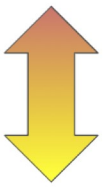
- **Definitions:**
  - Unstructured Data: “Data that doesn’t follow a particular structure, schema, or model.”
  - Blob: *Binary Large Object*
- **Solutions:**
  - DFS - Distributed File System
  - Object Store
    - Object fields:
      - Unique name / Identifier
      - Value - Content
      - Metadata
      - ACL - Access Control List
    - Objects are stored in Containers/Buckets
    - Cloud Solutions are broken into tiers/storage classes:

High Availability/ Performance

Limited Access/ Low Performance

| Amazon S3 | GCP Storage | Azure Blob | Alibaba OSS |
|---|---|---|---|
| S3 Standard | Standard | Hot tier | Standard |
| Standard - Infrequent Access | Nearline | | IA |
| Glacier Instant Retrieval | Coldline | Cool tier | Archive |
| Glacier Deep Archive | Archive | Archive Tier | Cold Archive |

Expensive

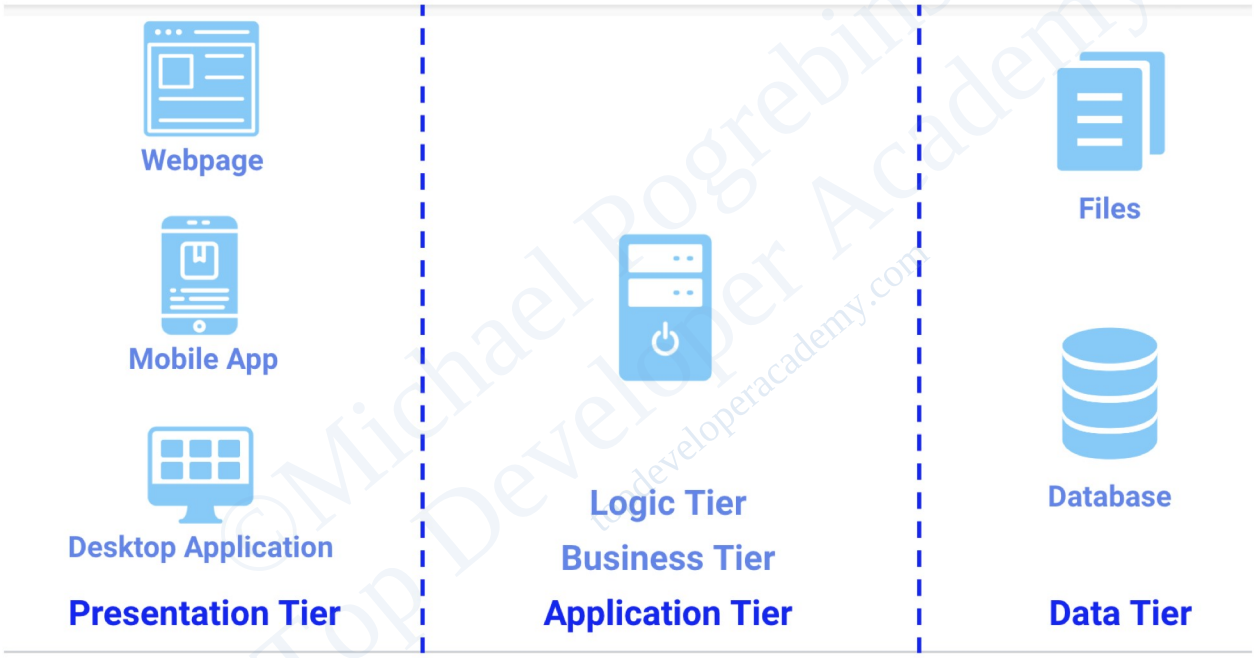


Cheap

## Notes:

# Software Architecture Patterns

## Multi-Tier Architecture



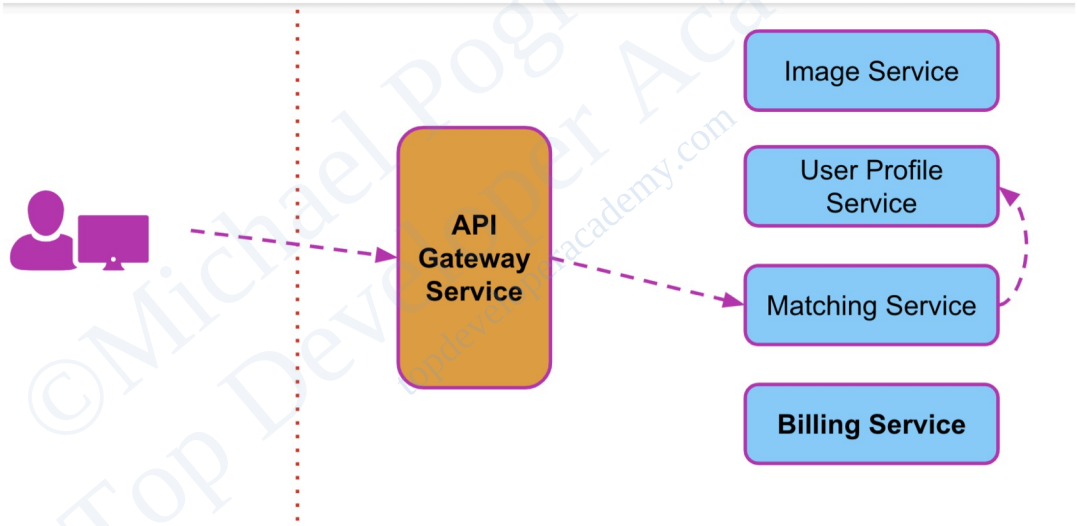



- **Advantages:**
  - Fits a large variety of use cases
  - Easy to scale horizontally
- **Drawbacks:**
  - Monolithic structure of our logic tier

**Notes:**

# Microservices Architecture

- Definition:
  - *"Microservices Architecture organizes our business logic as a collection of loosely coupled and independently deployed services."*
- Best Practices:
  - Single Responsibility Principle
  - Separate Database Per Service

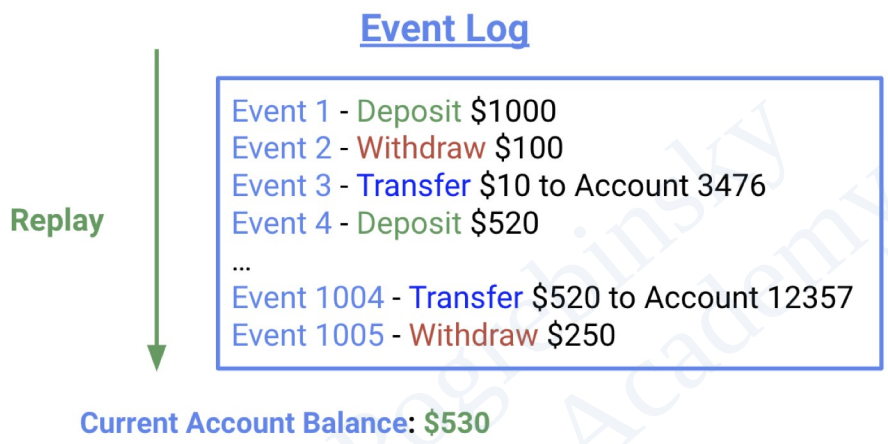


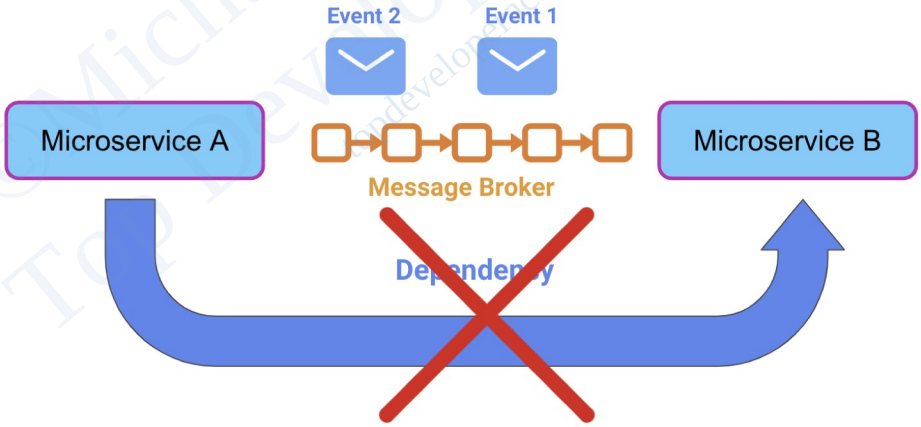



## Notes:

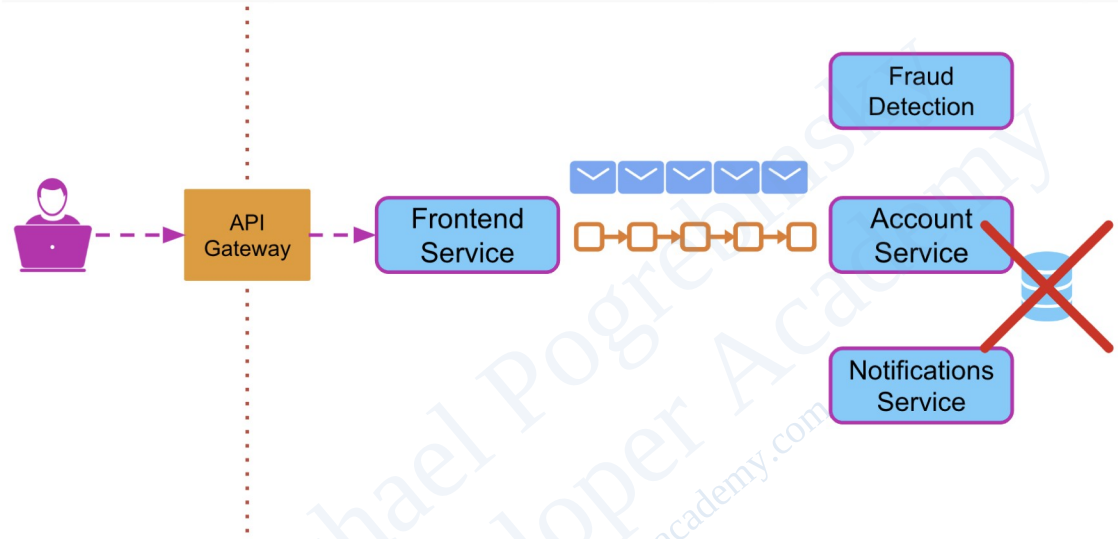
# Event-Driven Architecture

- Definition:
  - An event is an immutable statement of a fact or a change

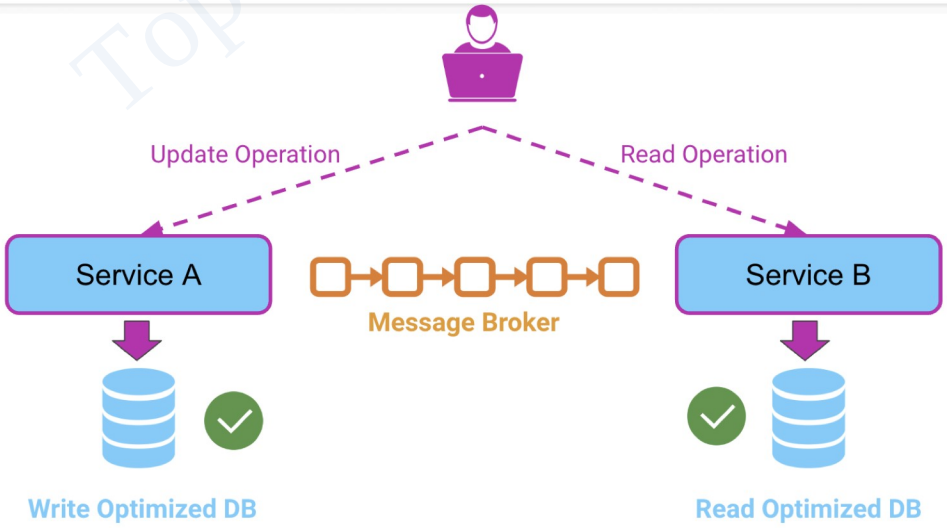


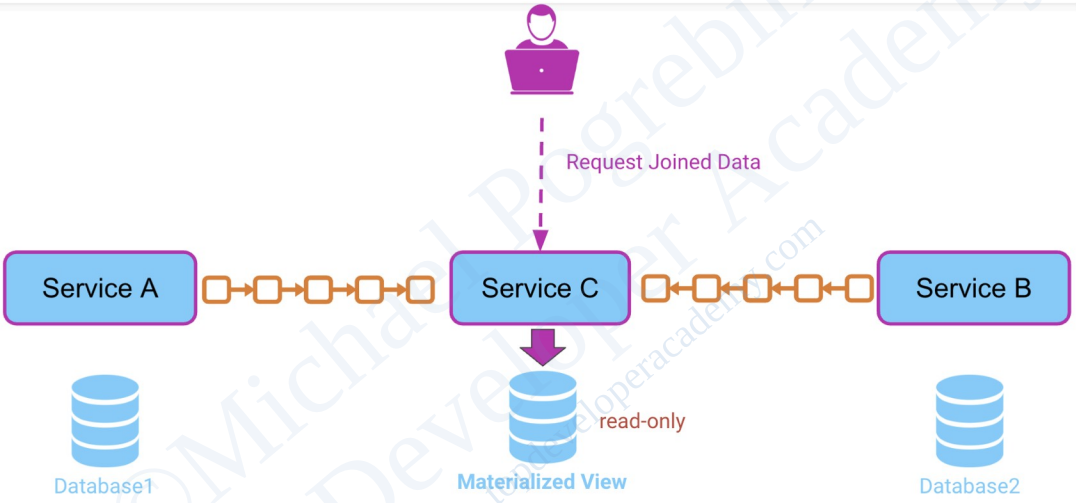



- Event Sourcing Pattern




- CQRS
  - C = Command
  - Q = Query
  - R = Responsibility
  - S = Segregation





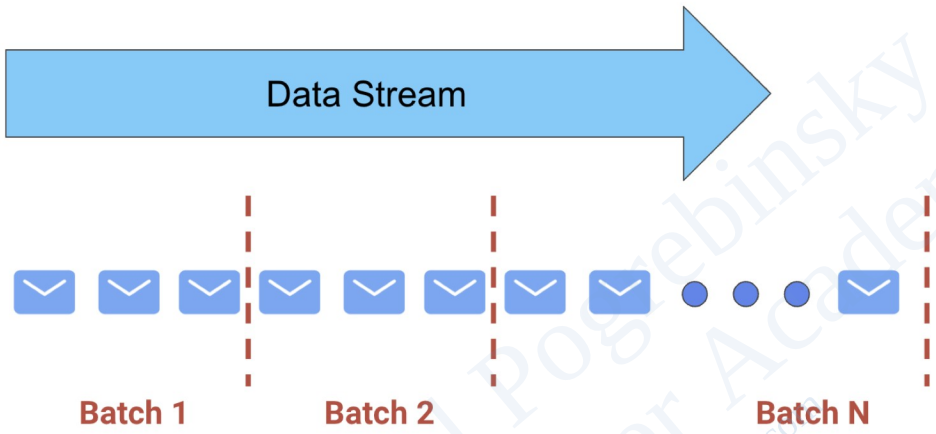



## Notes:

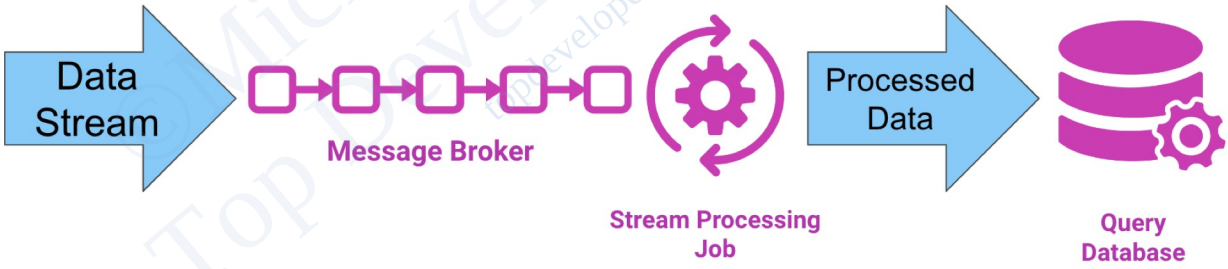
# Big Data Architecture Patterns

## Big Data Processing Strategies

- **Batch Processing**




- **Real-Time Processing**

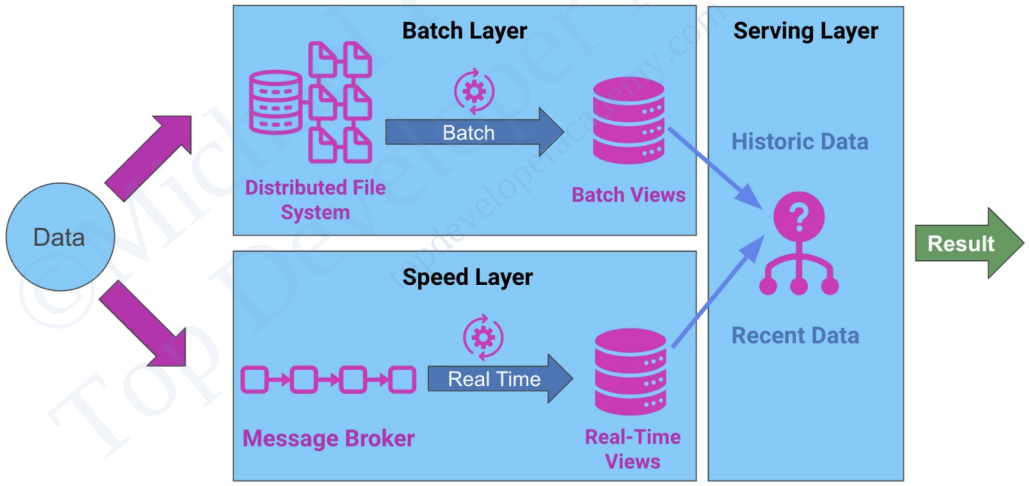





**Notes:**

# Lambda Architecture

- Layers:
  - Batch Layer
  - Speed Layer
  - Serving Layer

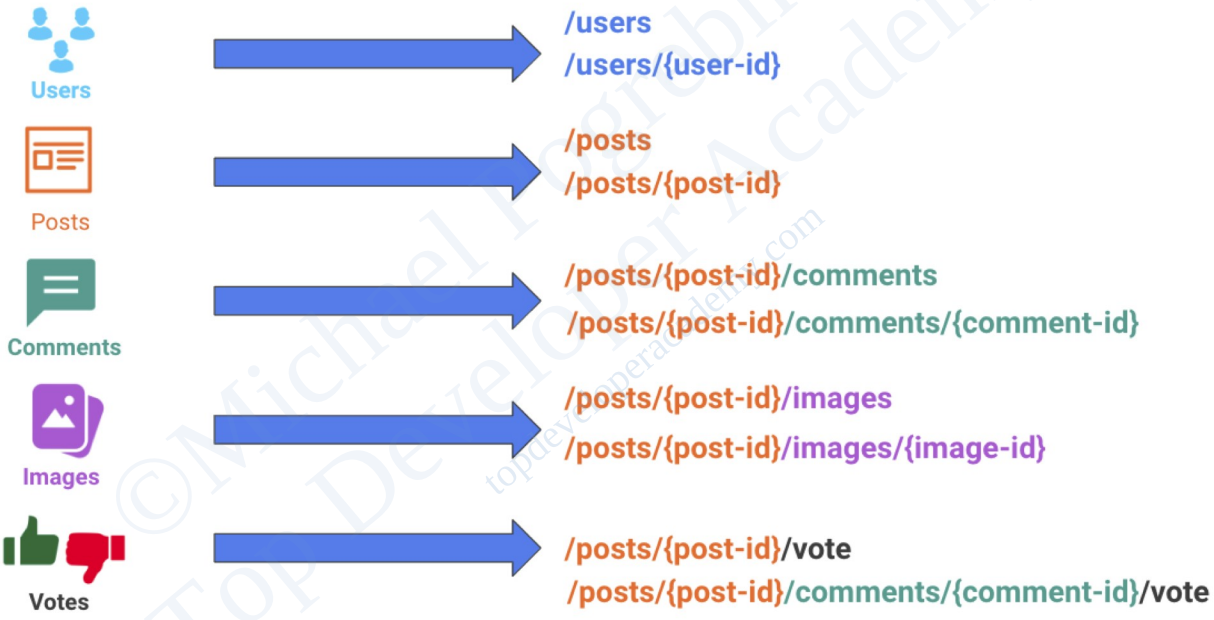



## Notes:

# Software Architecture & System Design Practice

## Design a Highly Scalable Discussion Forum 1 - Requirements & API

- **API Definition:**
  - Entity URLs:

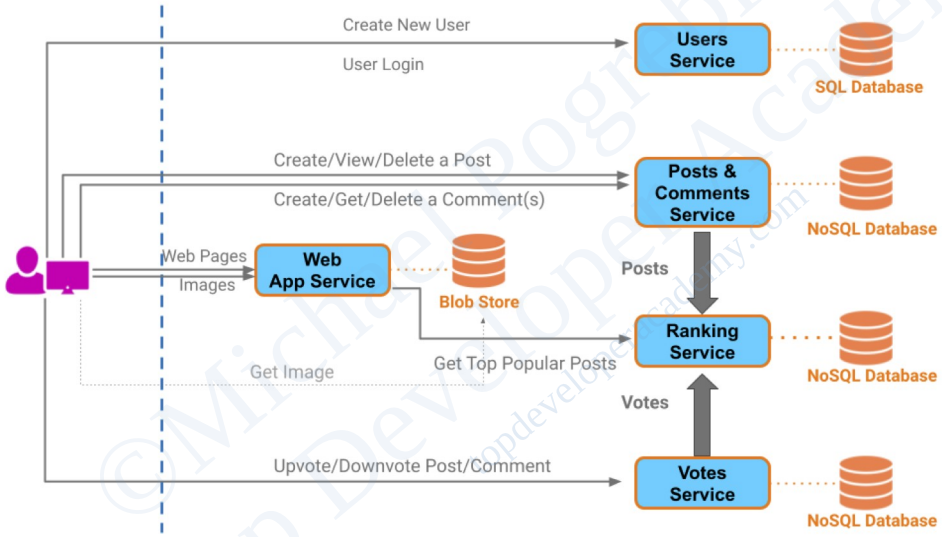





### Notes:

# Design a Highly Scalable Discussion Forum 2 - Functional Architecture Diagram

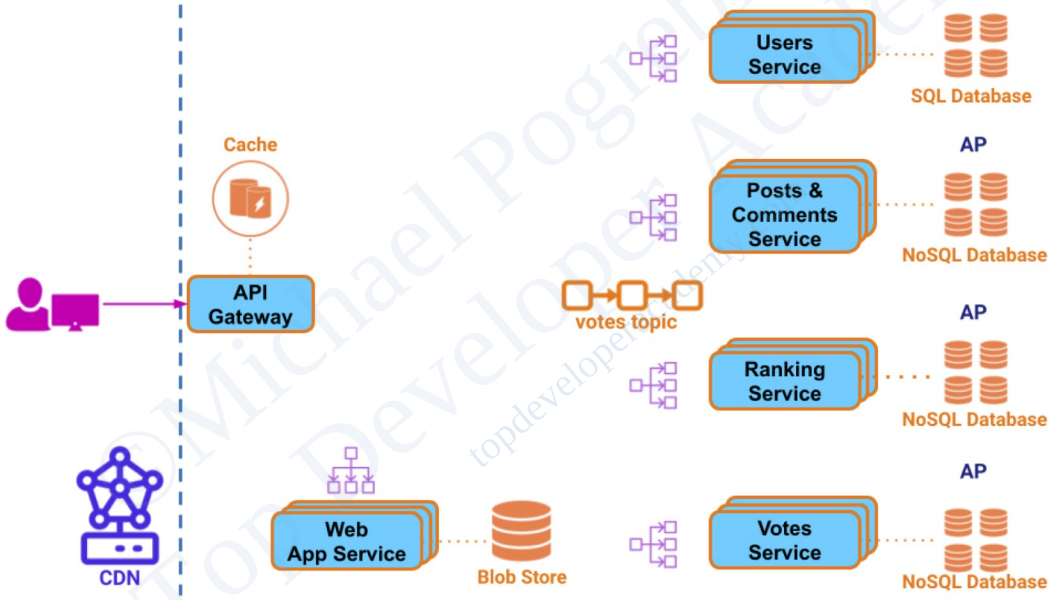
- **Functional Software Architecture Diagram:**




## Notes:

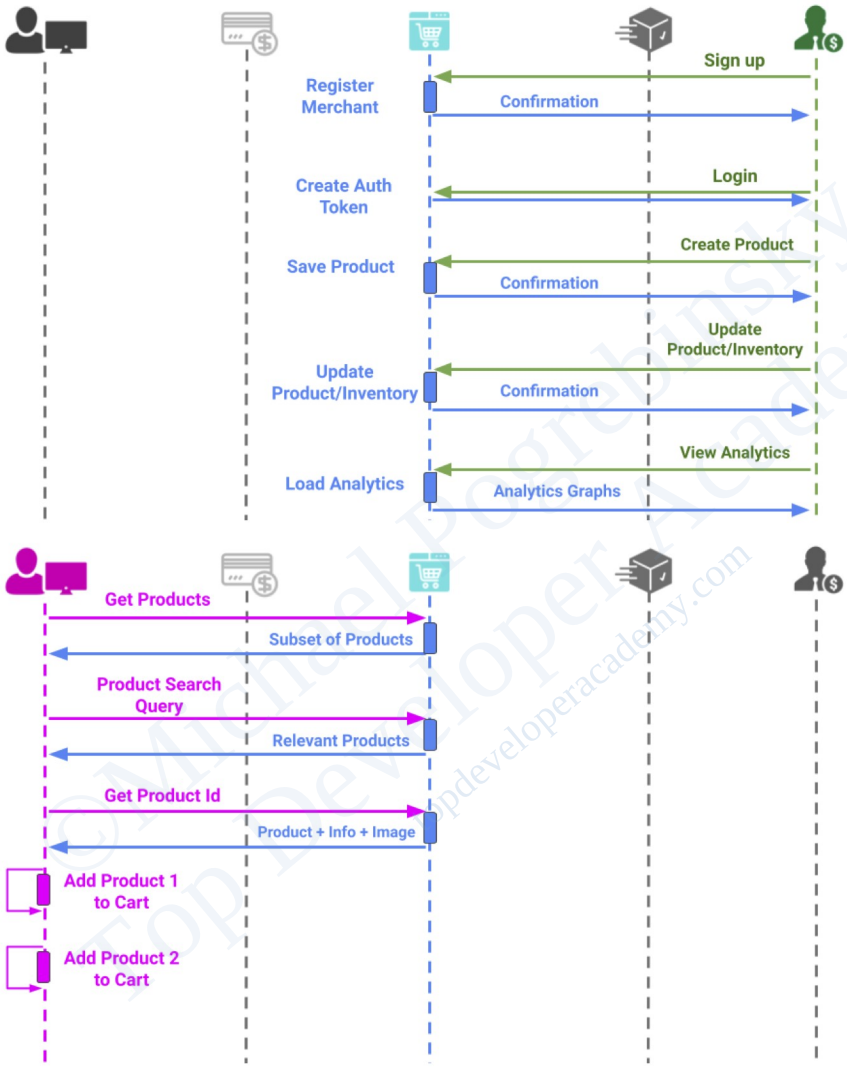
# Design a Highly Scalable Discussion Forum 3 - Final Software Architecture

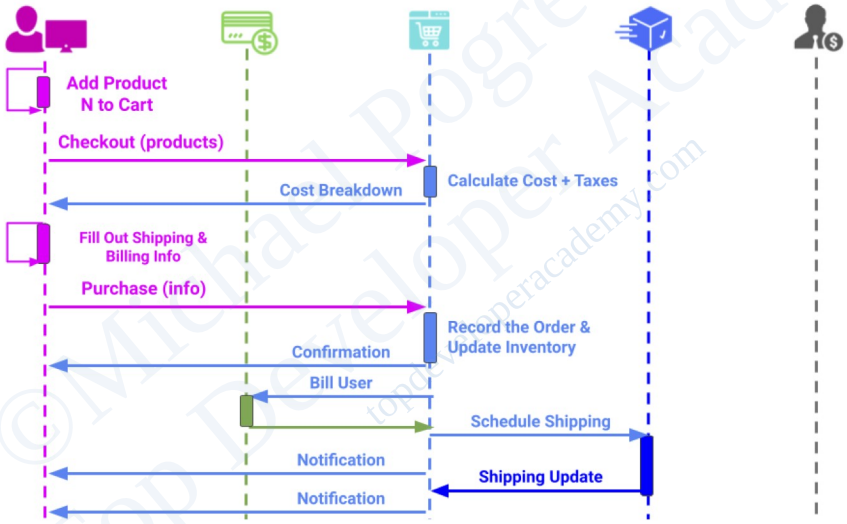
- **Final Software Architecture Diagram:**



# Design an E-Commerce Marketplace Platform 1 - Requirements & Sequence Diagram

- **Sequence Diagram:**

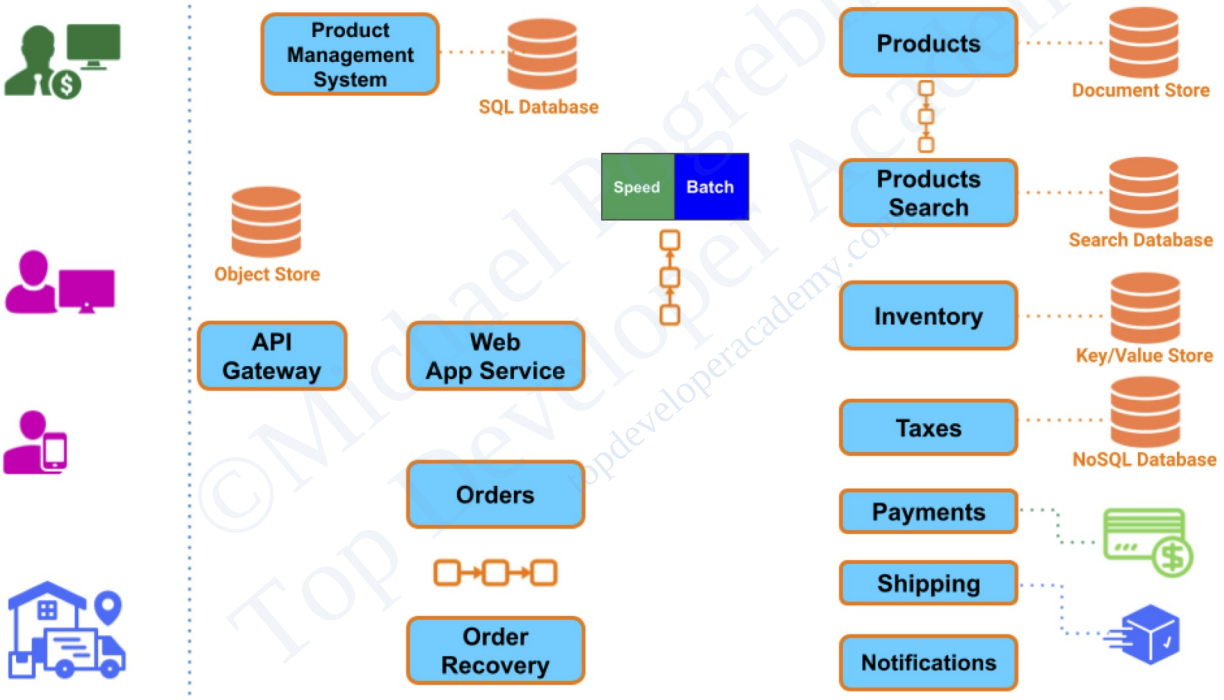





**Notes:**

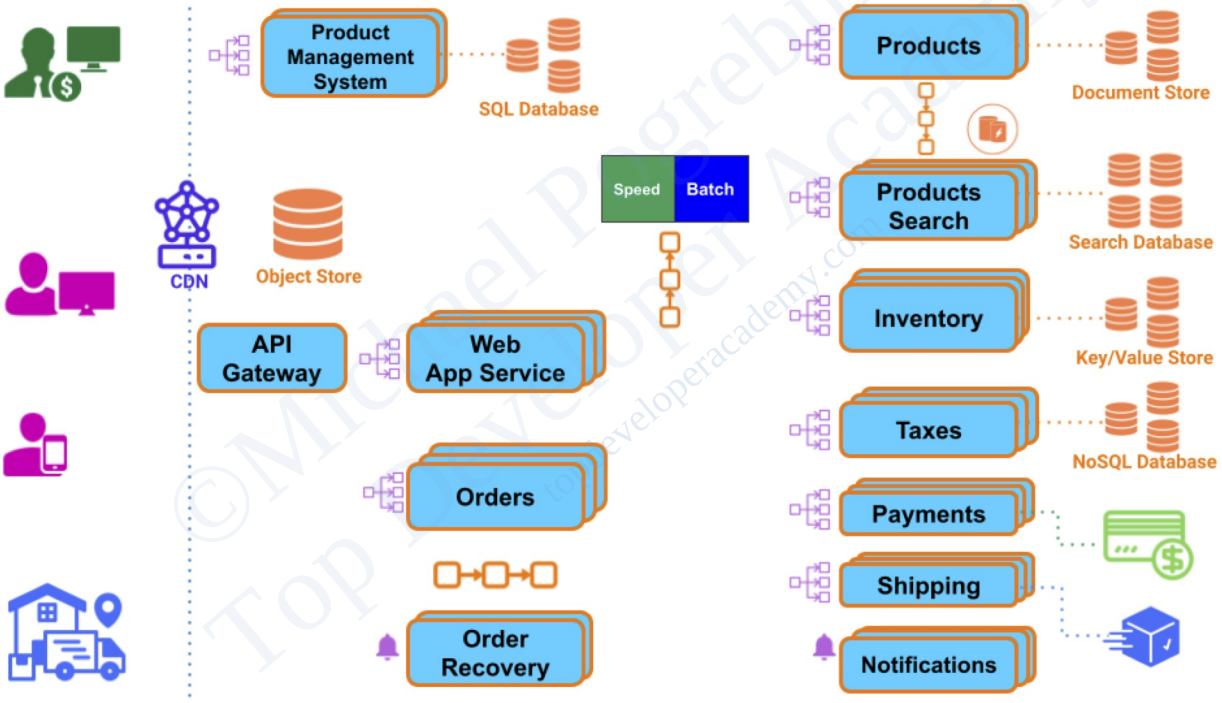
# Design an E-Commerce Marketplace Platform 2 - Functional Diagram

- **Functional Software Architecture Diagram:**




## Notes:

# Design an E-Commerce Marketplace Platform 3 - Final Software Architecture




## Notes: