

Software Architecture & Design of Large Scale Systems

By Michael Pogrebinsky



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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



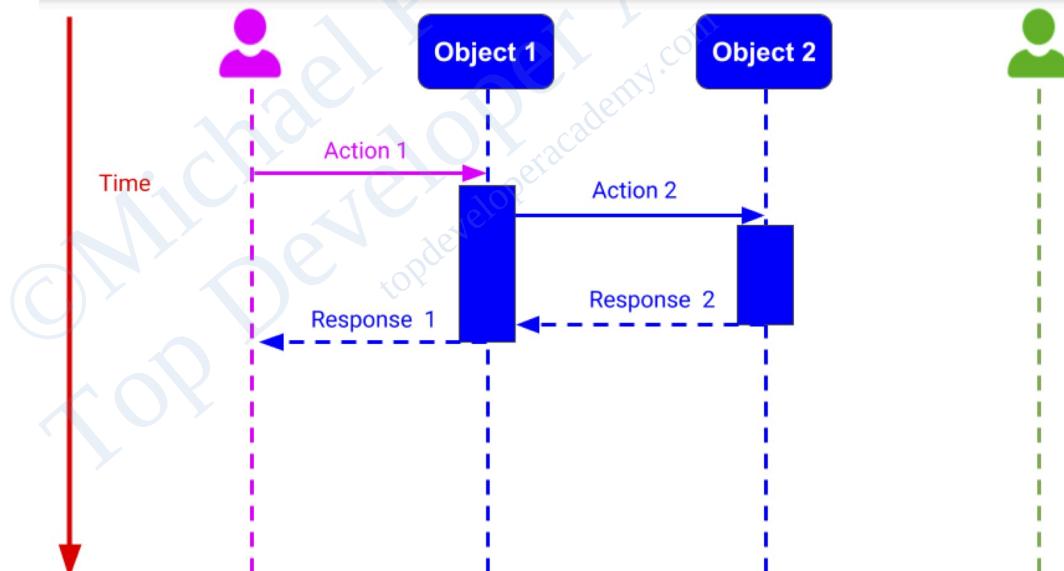
- System Constraints
 - Limitations and boundaries

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.

Unified Modeling Language - Sequence Diagram



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



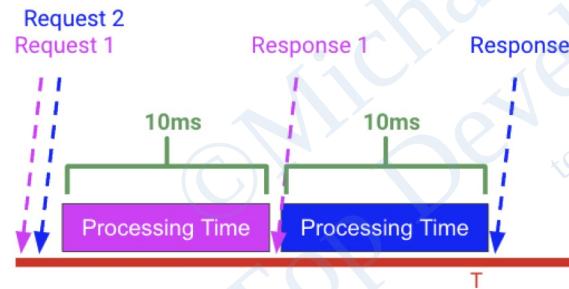
- Throughput**

- 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:

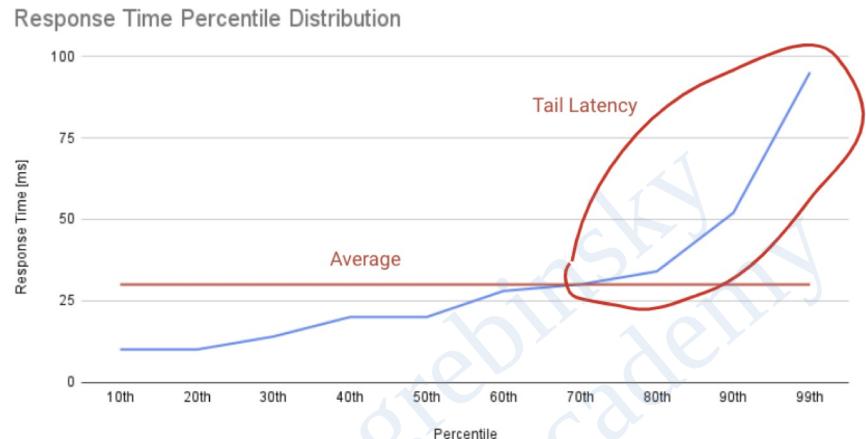
- Measuring Response Time Correctly

$$\text{Response Time} = \text{Processing Time} + \text{Waiting Time}$$



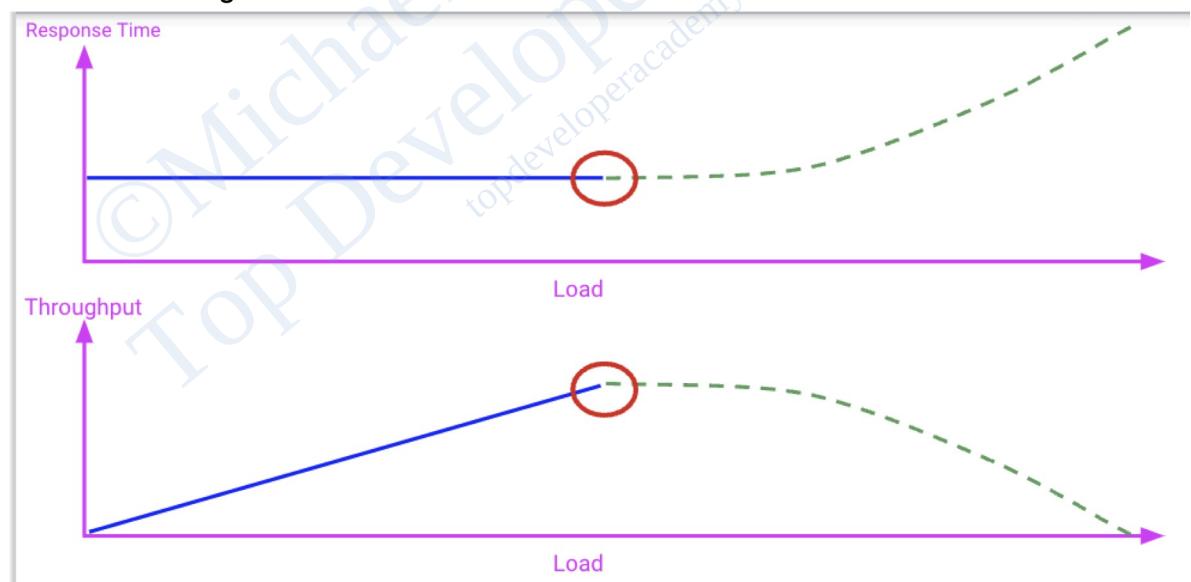
- Response Time Distribution

- **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



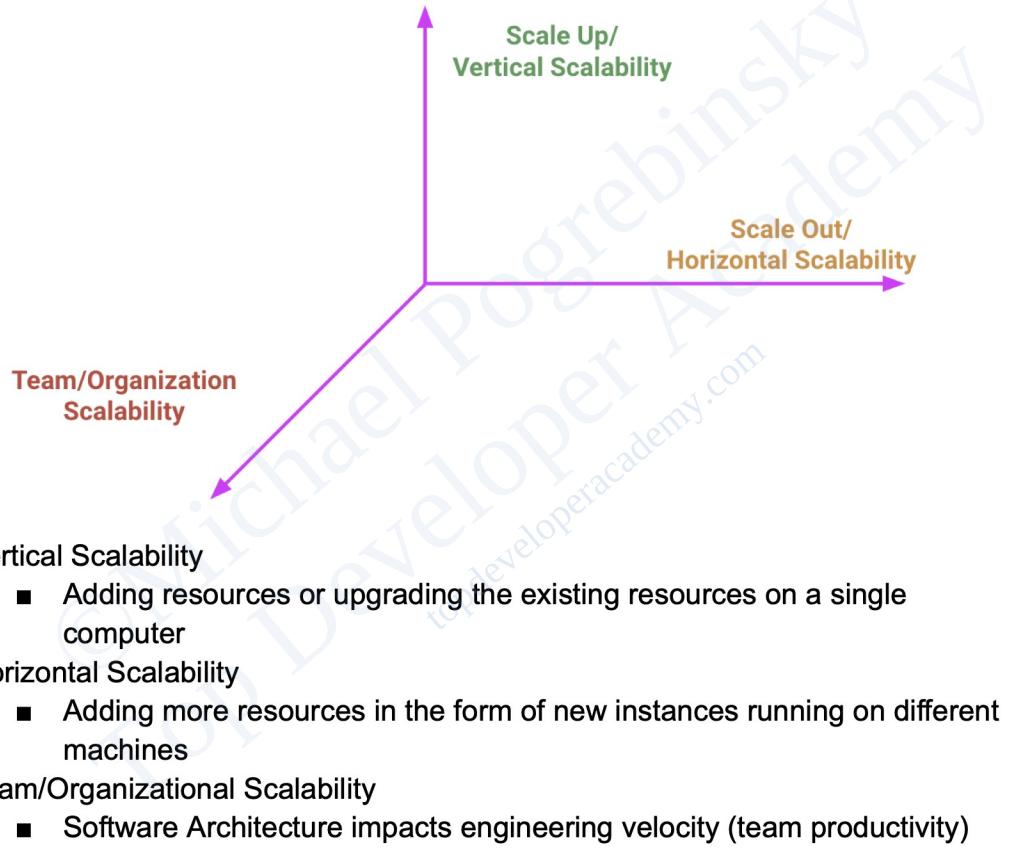
Notes:

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**



Notes:

Availability - Introduction & Measurement

- **Availability:**

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

$$\text{Availability} = \text{Uptime} / (\text{Uptime} + \text{Downtime})$$

- **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**

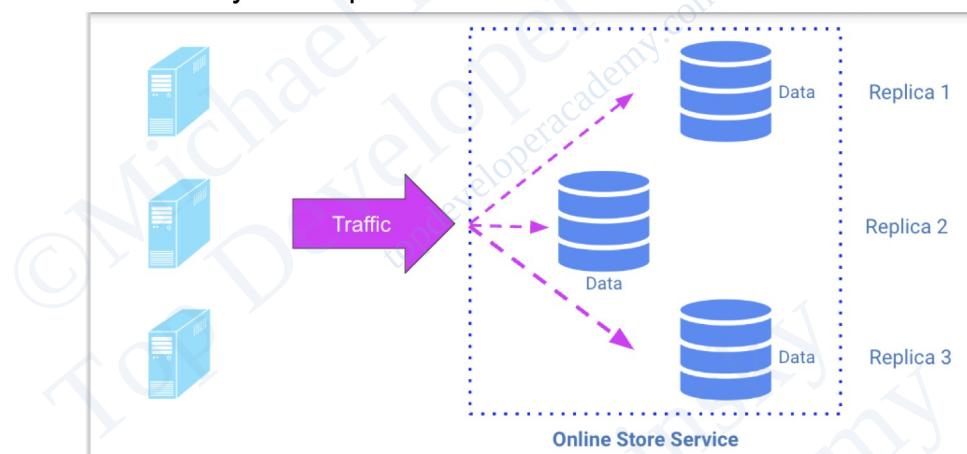
- Mean Time to Recovery

$$\text{Availability} = \text{MTBF} / (\text{MTBF} + \text{MTTR})$$

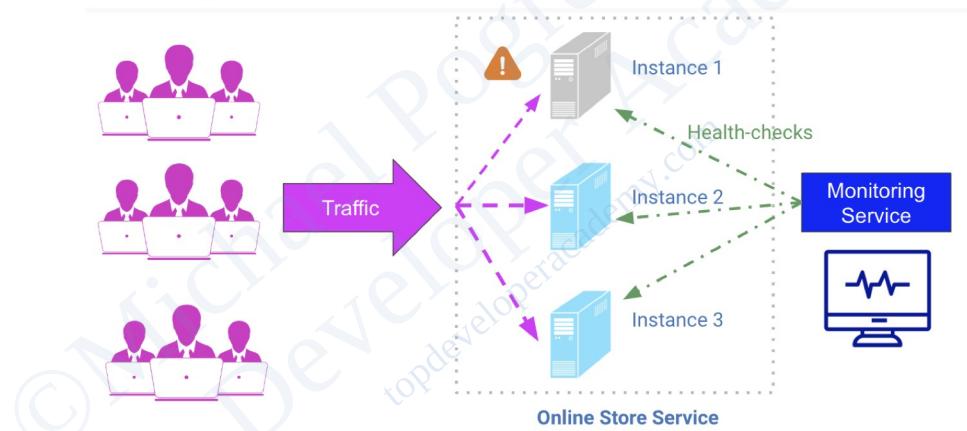
Notes:

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:

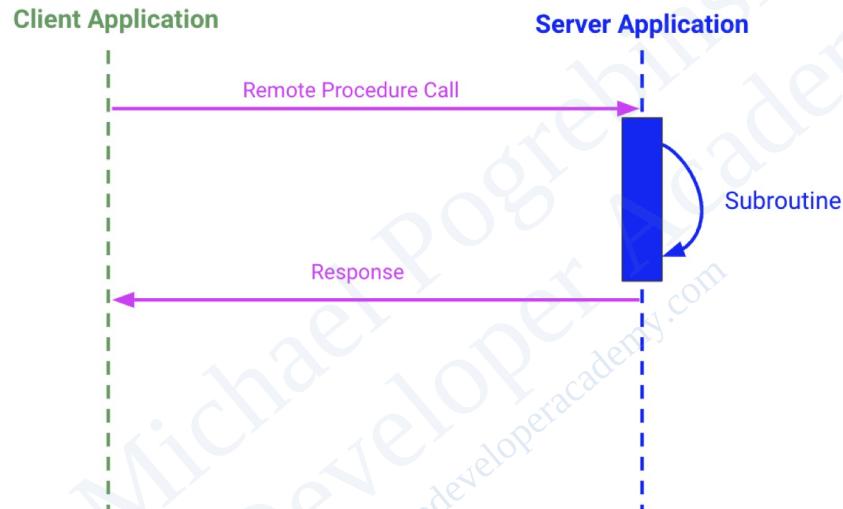
API Design

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

How RPC Works - Stubs Generation



- **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
○ **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

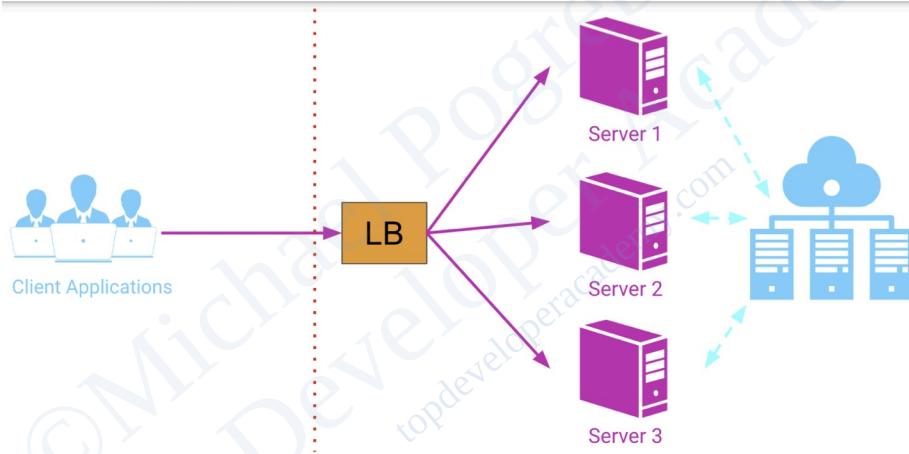
Notes:

Large Scale Systems Architectural Building Blocks

DNS, Load Balancing & GSLB

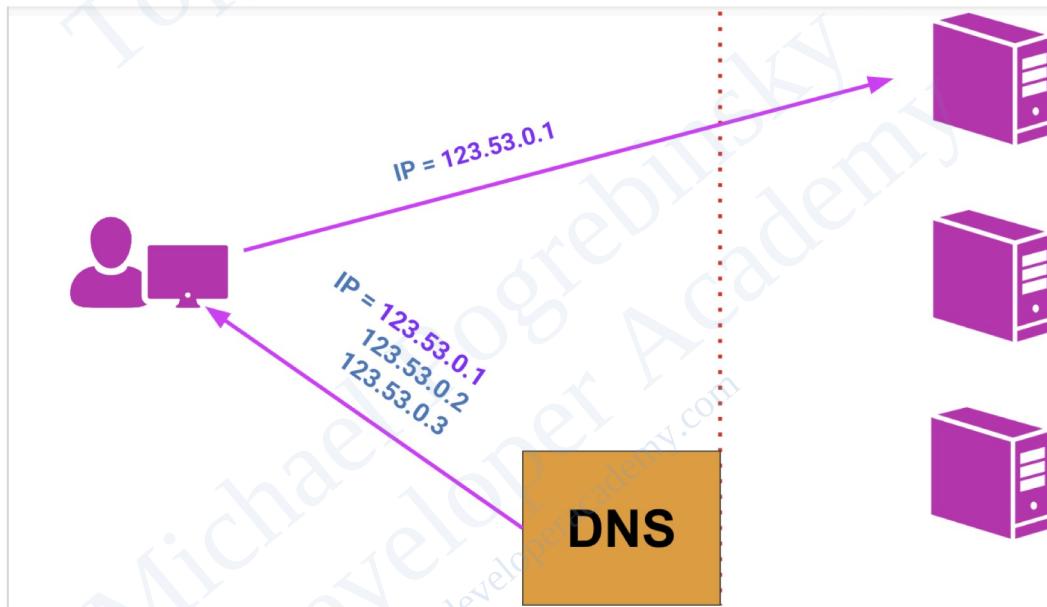
- **Role of Load Balancer:**

- Balance load among a group of servers



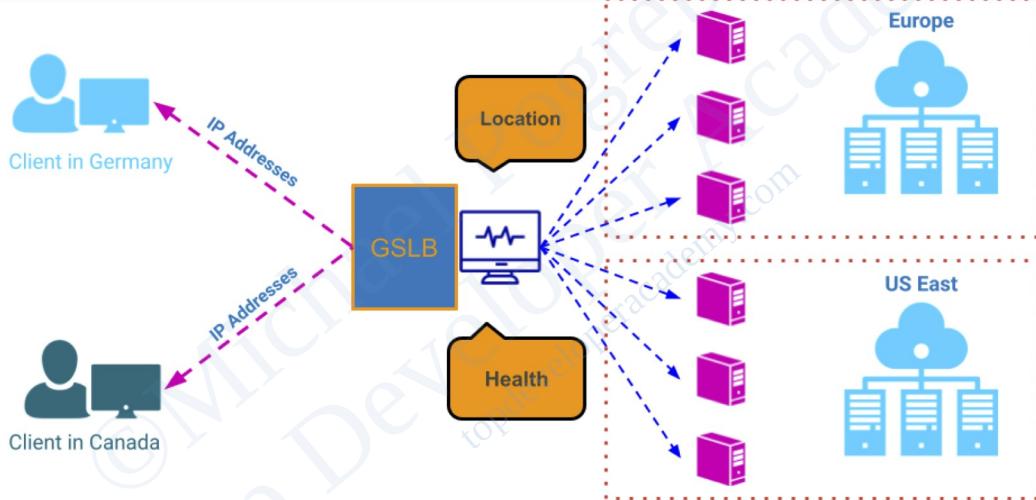
- **Types of load balancers**

- 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

Global Server Load Balancing - Monitoring



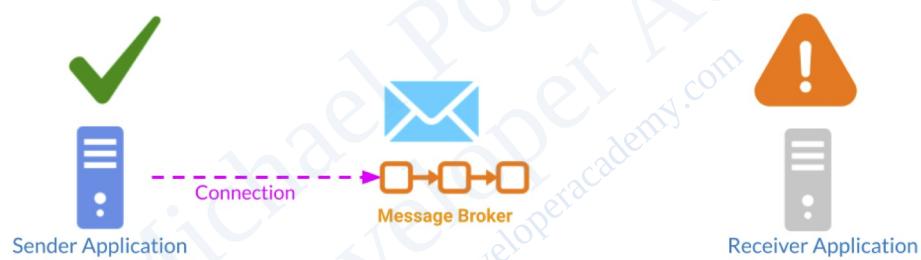
Notes:

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

Asynchronous Communication



- **Benefits:**

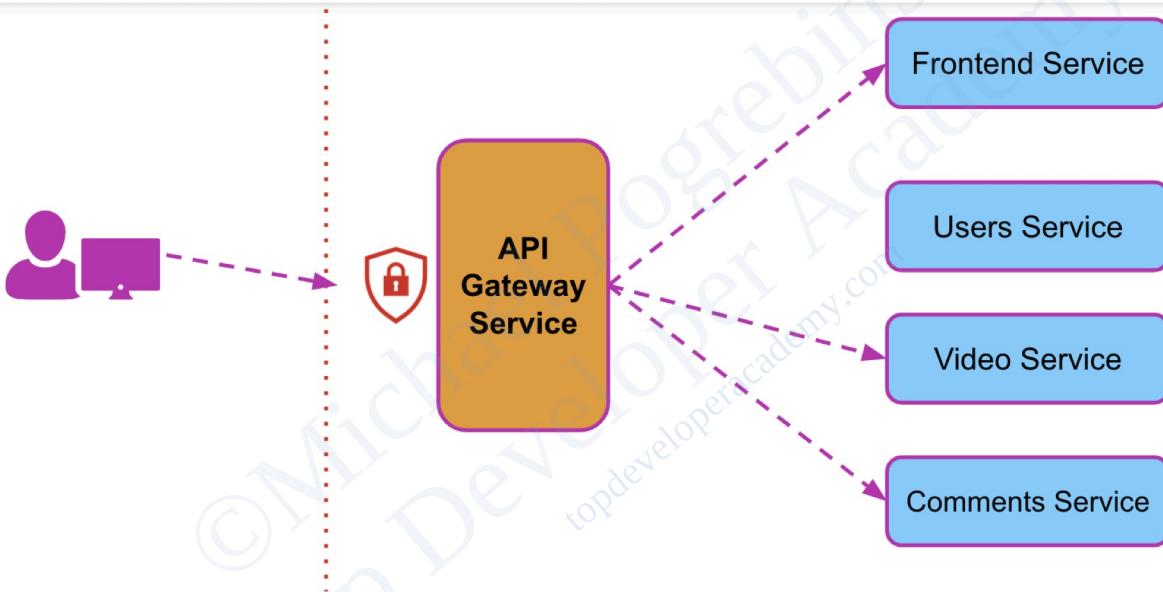
- Services can
 - Publish messages to a particular channel
 - Subscribe to that channel
 - Get notified when a new event is published

Notes:

API Gateway

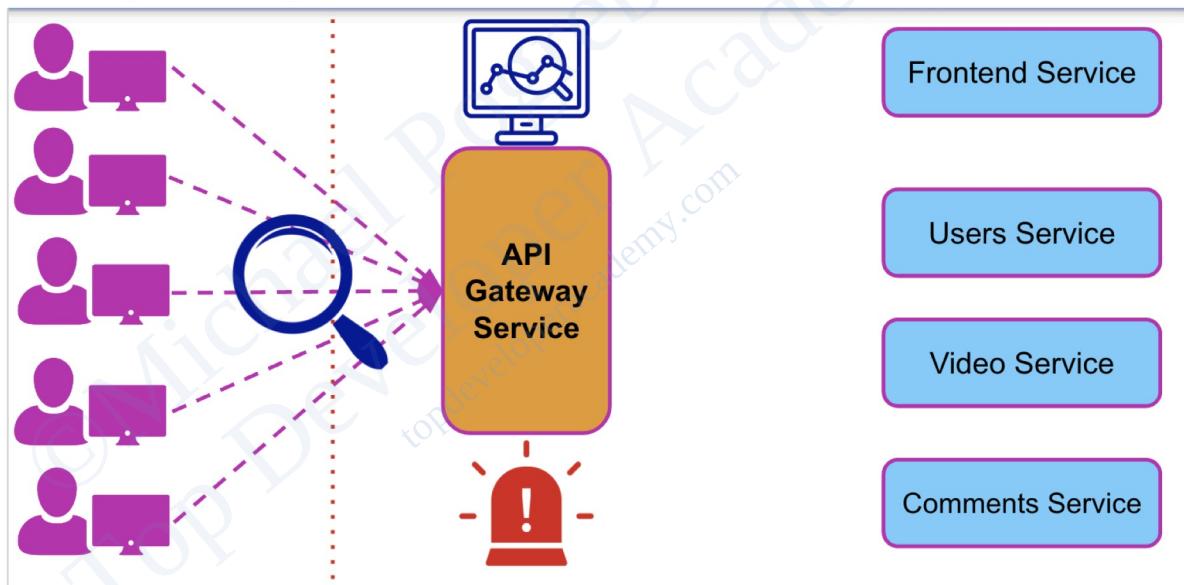
- **Definition:**

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

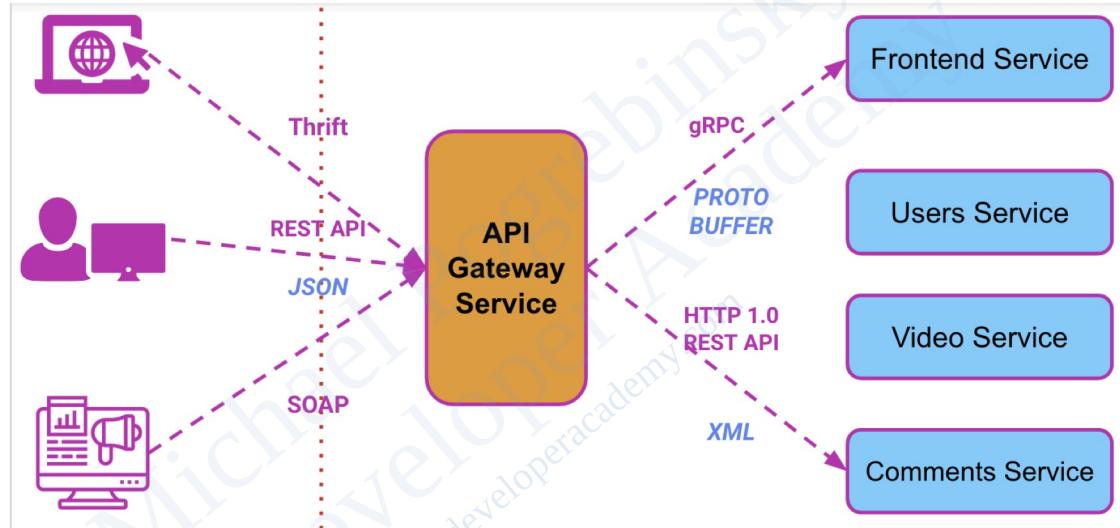


- **Benefits**

- 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



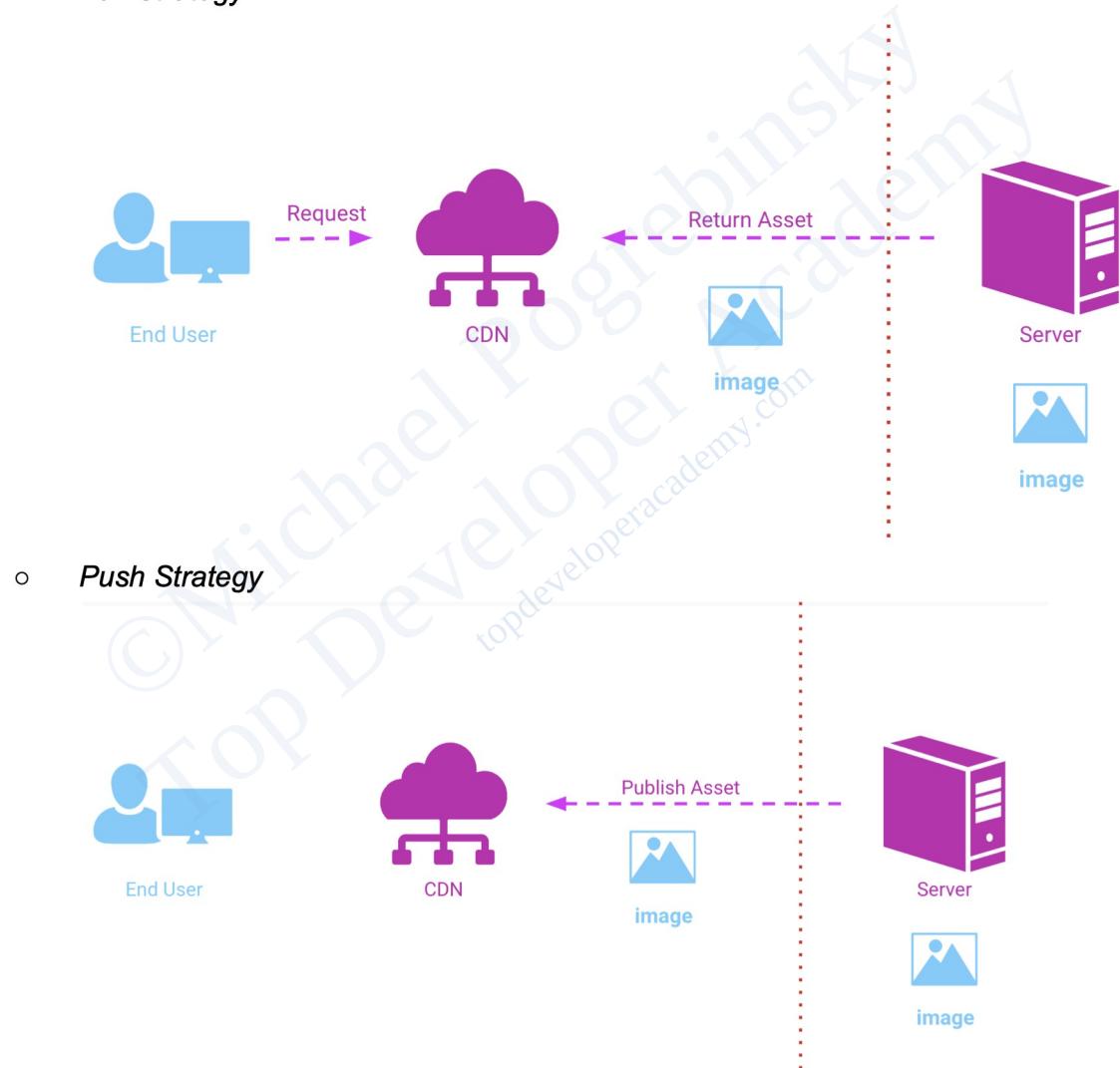
- **Considerations:**

- 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*



Notes:

Data Storage at Global Scale

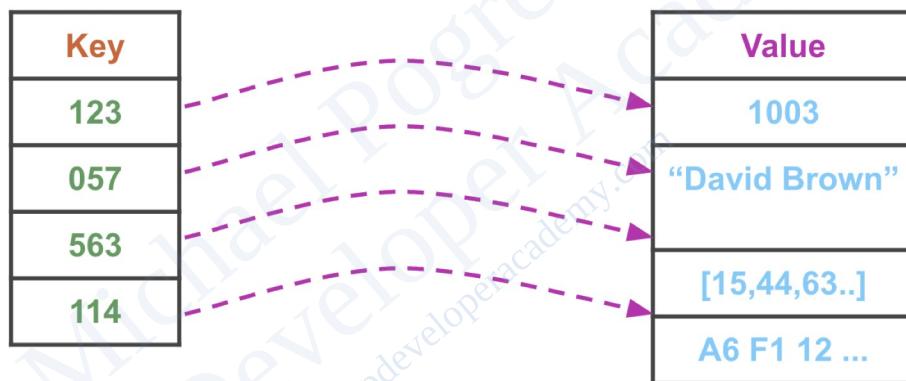
Relational Databases & ACID Transactions

- **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

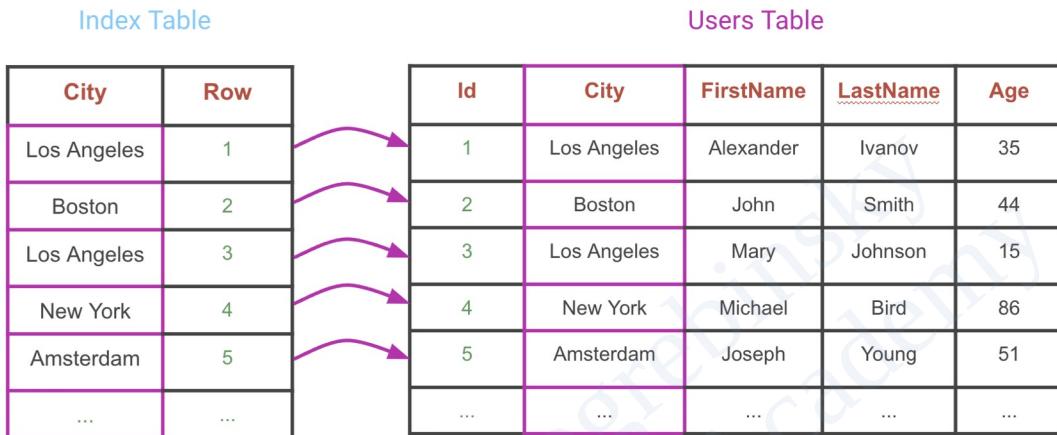


- Document Store
 - We can store collections of documents with more structure inside each document
 - Each document is an object with different attributes
- Graph Database
 - Optimized for navigating and analyzing relationships between different records

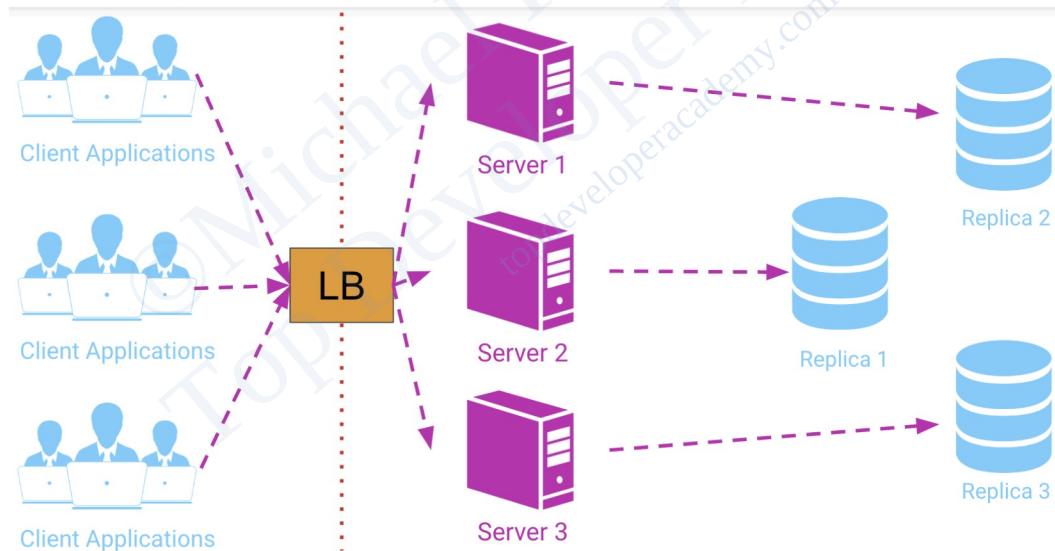
Notes:

Techniques to Improve Performance, Availability & Scalability Of Databases

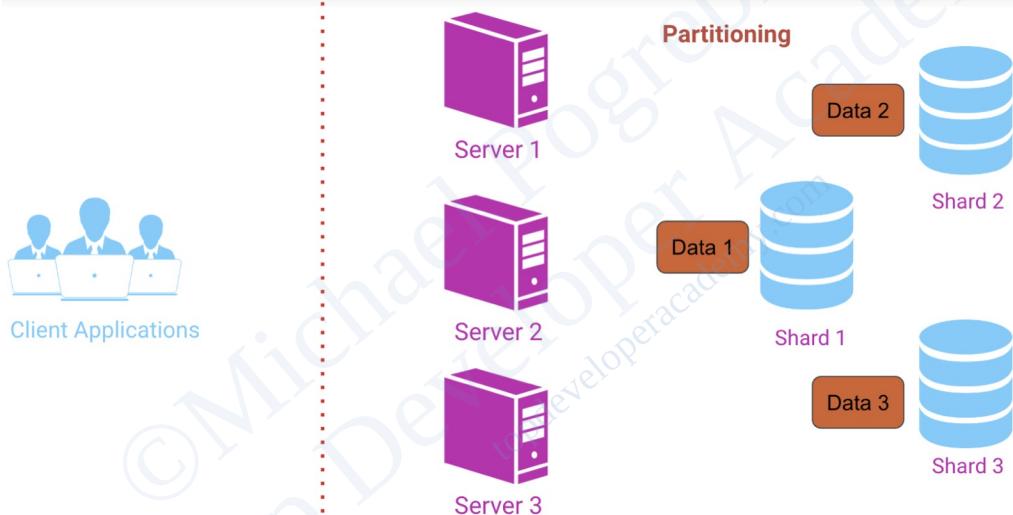
- **Database Indexing**



- **Database Replication**



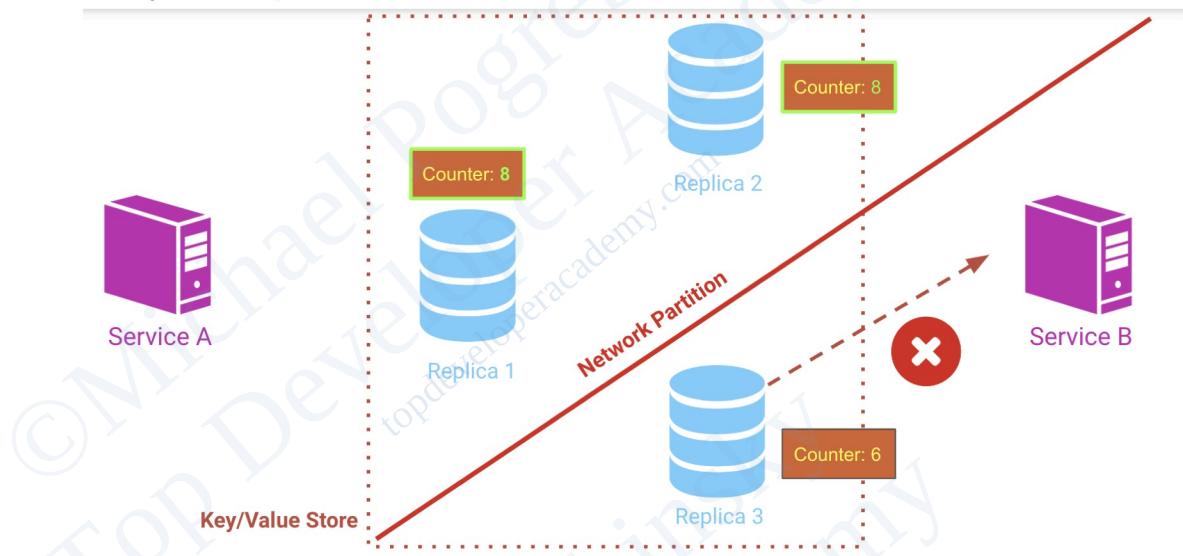
- **Database Partitioning/Sharding**



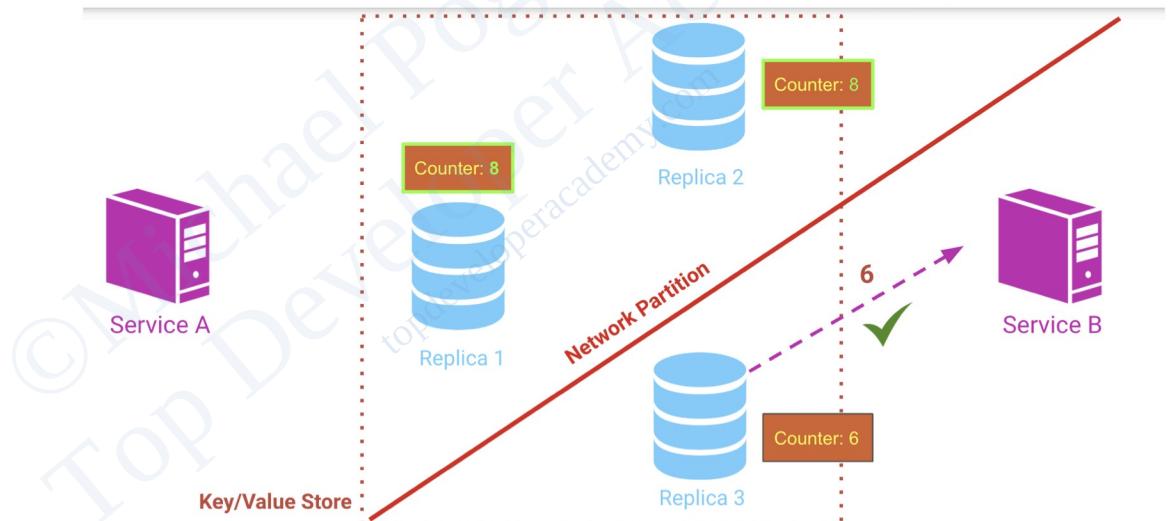
Notes:

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"



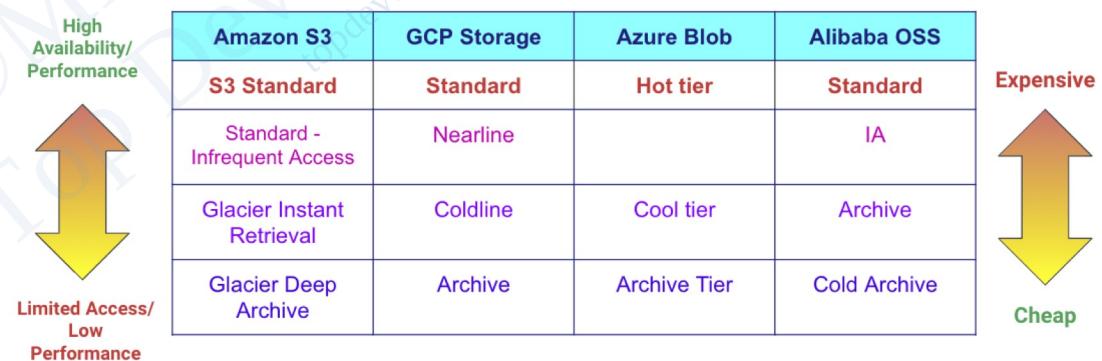
- **Availability**
 - "Every request receives a non-error response, without the guarantee that it contains the most recent write."



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:

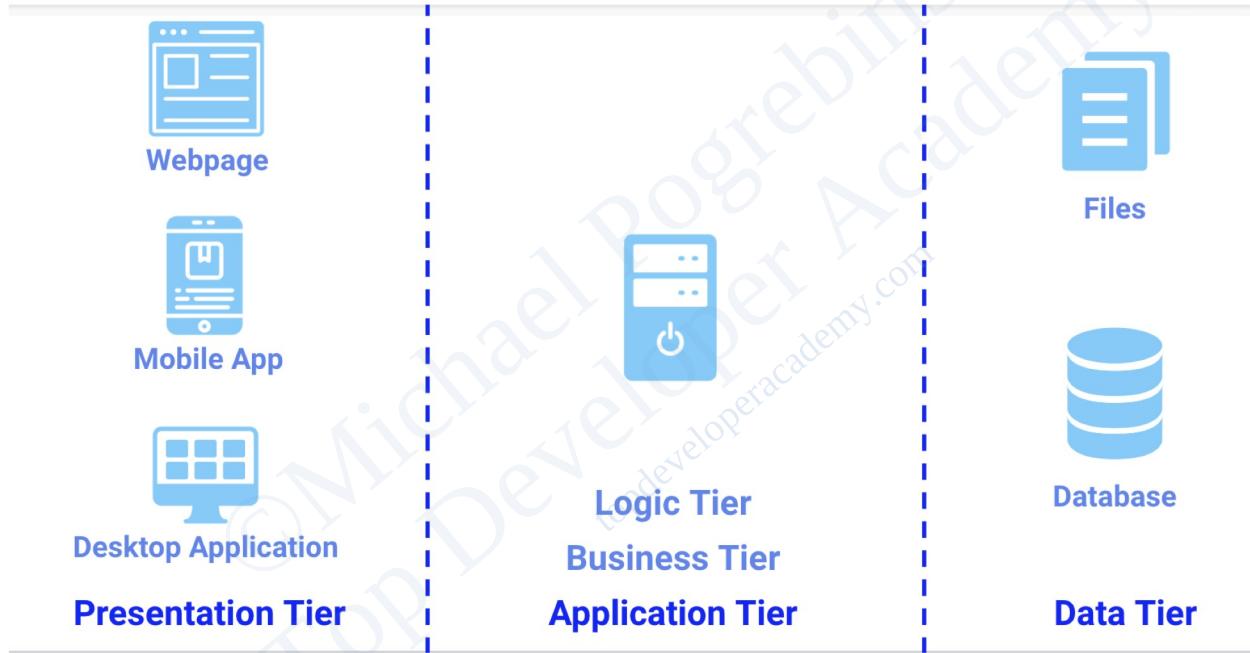


High Availability/ Performance	Amazon S3	GCP Storage	Azure Blob	Alibaba OSS
Limited Access/ Low Performance	S3 Standard	Standard	Hot tier	Standard
	Standard - Infrequent Access	Nearline		IA
	Glacier Instant Retrieval	Coldline	Cool tier	Archive
	Glacier Deep Archive	Archive	Archive Tier	Cold Archive

Notes:

Software Architecture Patterns

Multi-Tier Architecture

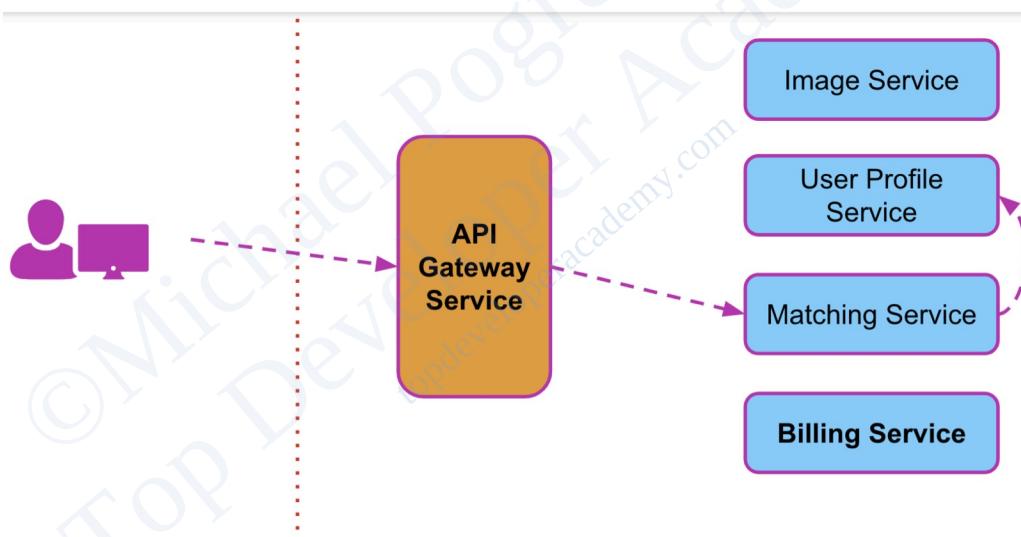


- **Advantages:**
 - Fits a large variety of use cases
 - Easy to scale horizontally
- **Drawbacks:**
 - Monolithic structure of our logic tier

Notes:

Microservices Architecture

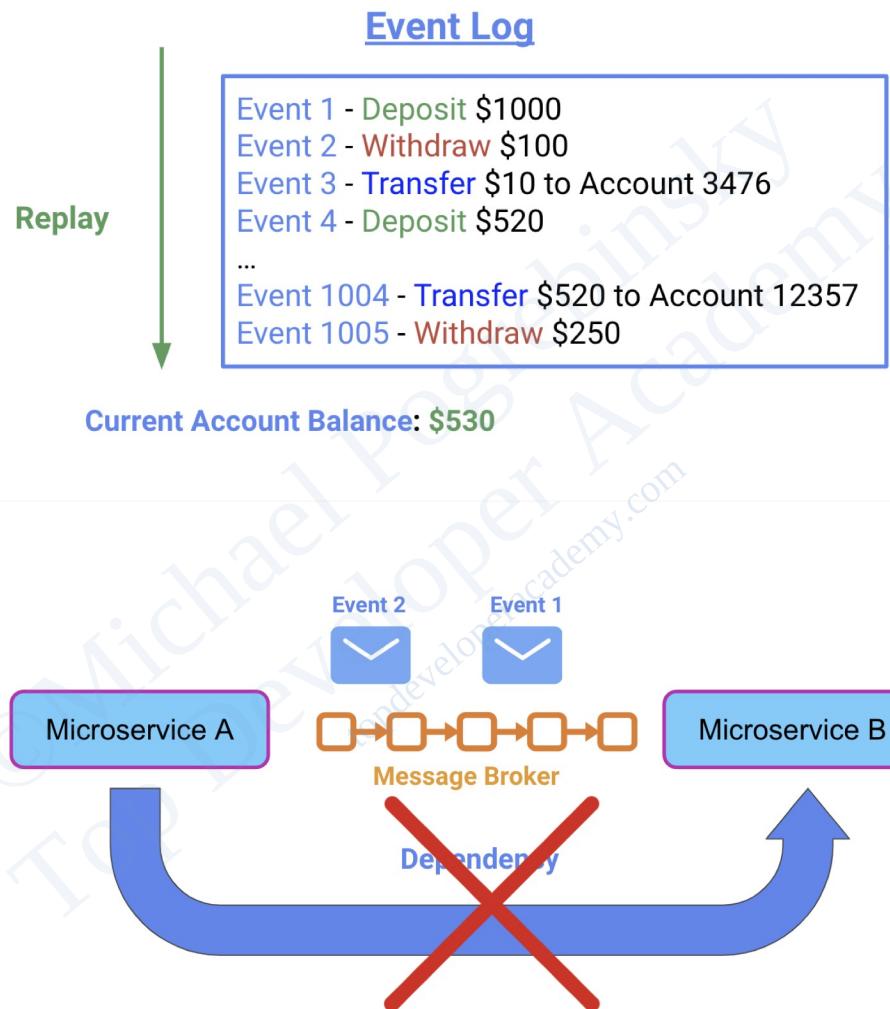
- Definition:
 - “*Microservices Architecture organizes our business logic as a collection of loosely coupled and independently deployed services.*”
- Best Practices:
 - Single Responsibility Principle
 - Separate Database Per Service



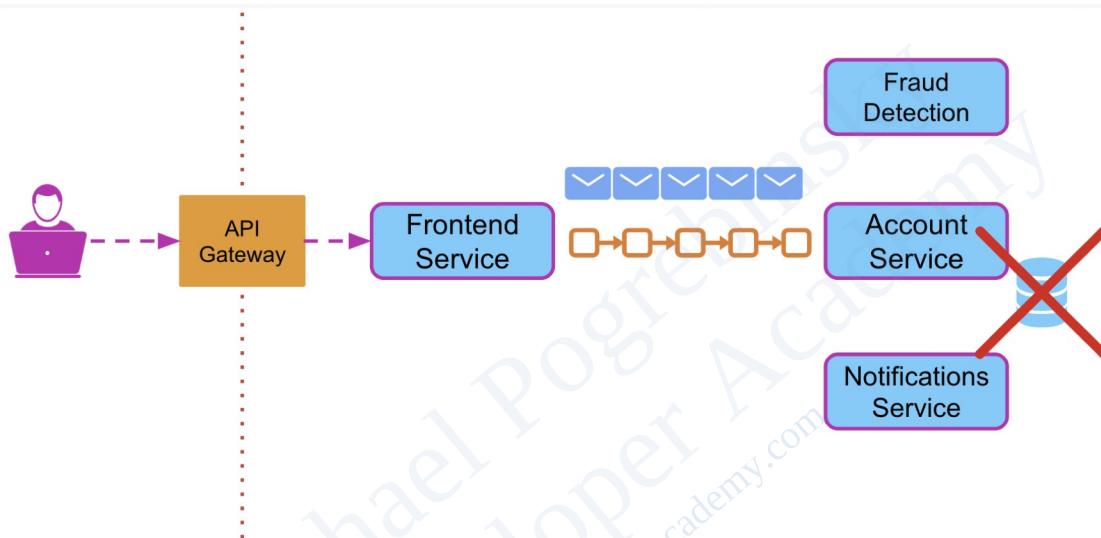
Notes:

Event-Driven Architecture

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

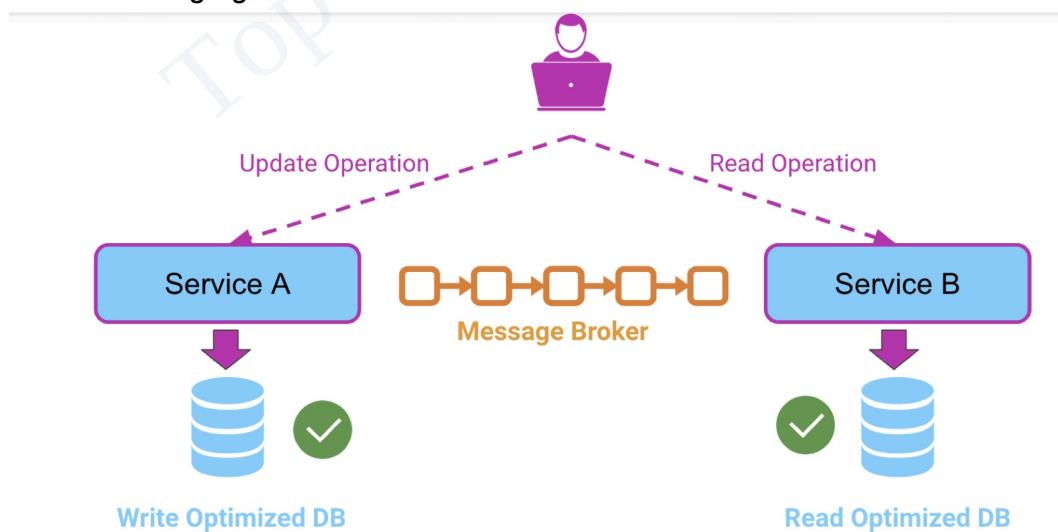


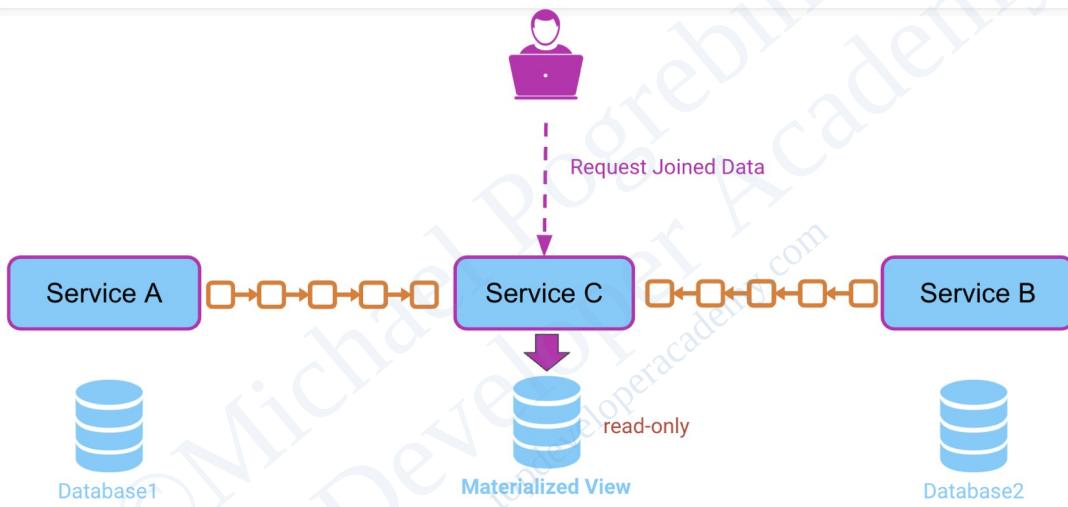
- Event Sourcing Pattern



- CQRS

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



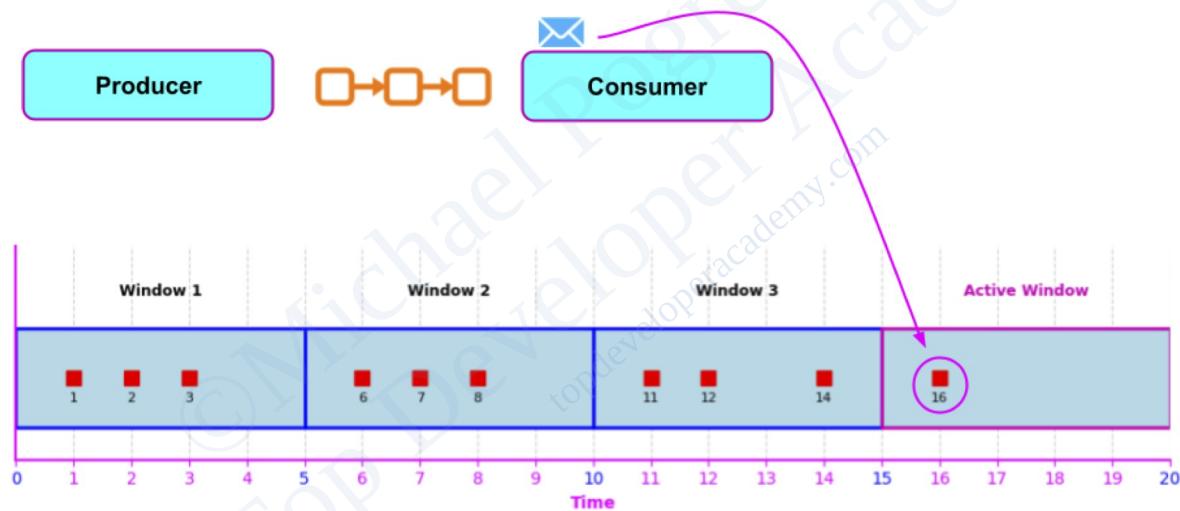


Notes:

Strategies for Processing Infinite Streams of Events

Introduction to Event-Stream Processing and Tumbling Window Strategy

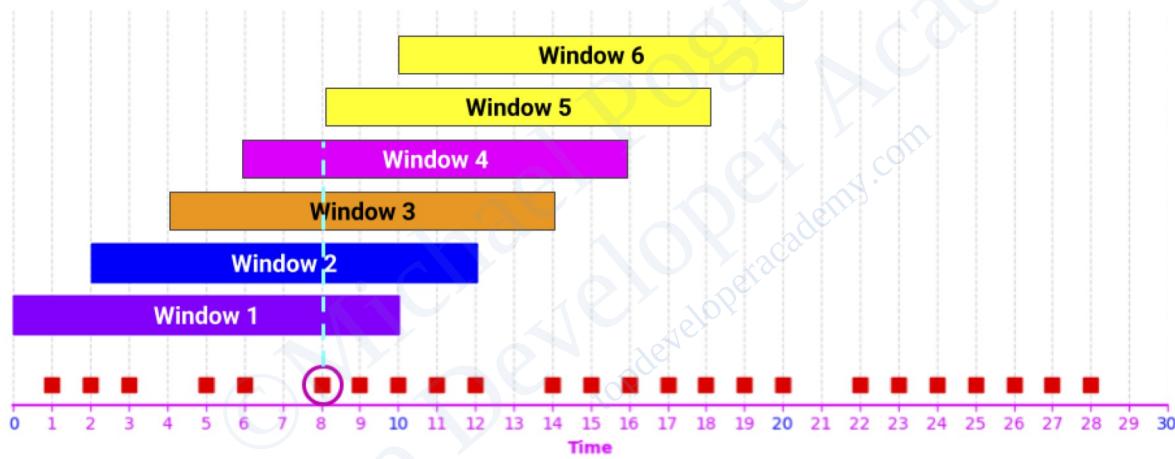
- Processing infinite (unbounded) streams of events requires windowing strategies
- Tumbling Window
 - Fixed sized
 - Back-to-back
 - No overlapping



Notes:

Hopping Window Event-Stream Processing Strategy

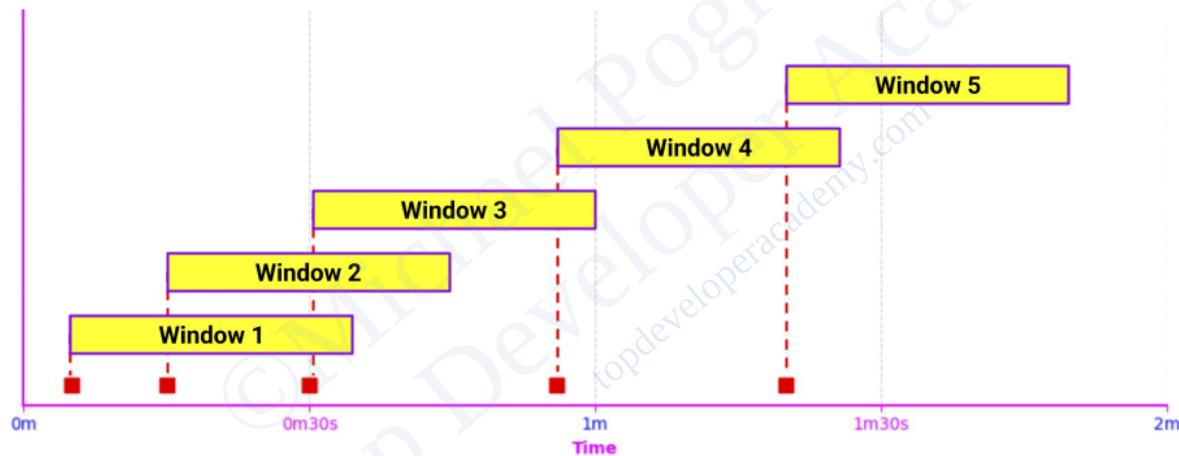
- Hopping Window Strategy
 - Fixed-size windows
 - Overlapping with an advanced interval
 - Each event potentially belongs to more than one window



Notes:

Sliding Window Event-Stream Processing Strategy

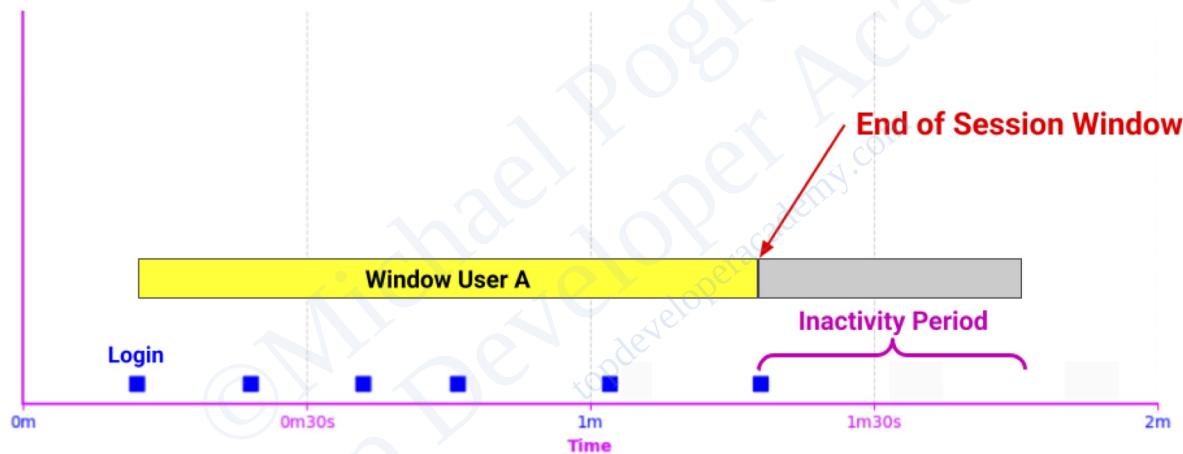
- Sliding window strategy
 - Fixed-size windows
 - Dynamic advance interval
 - A new window is created for every new event
 - Each event potentially belongs to multiple windows



Notes:

Session Window Event-Stream Processing Strategy

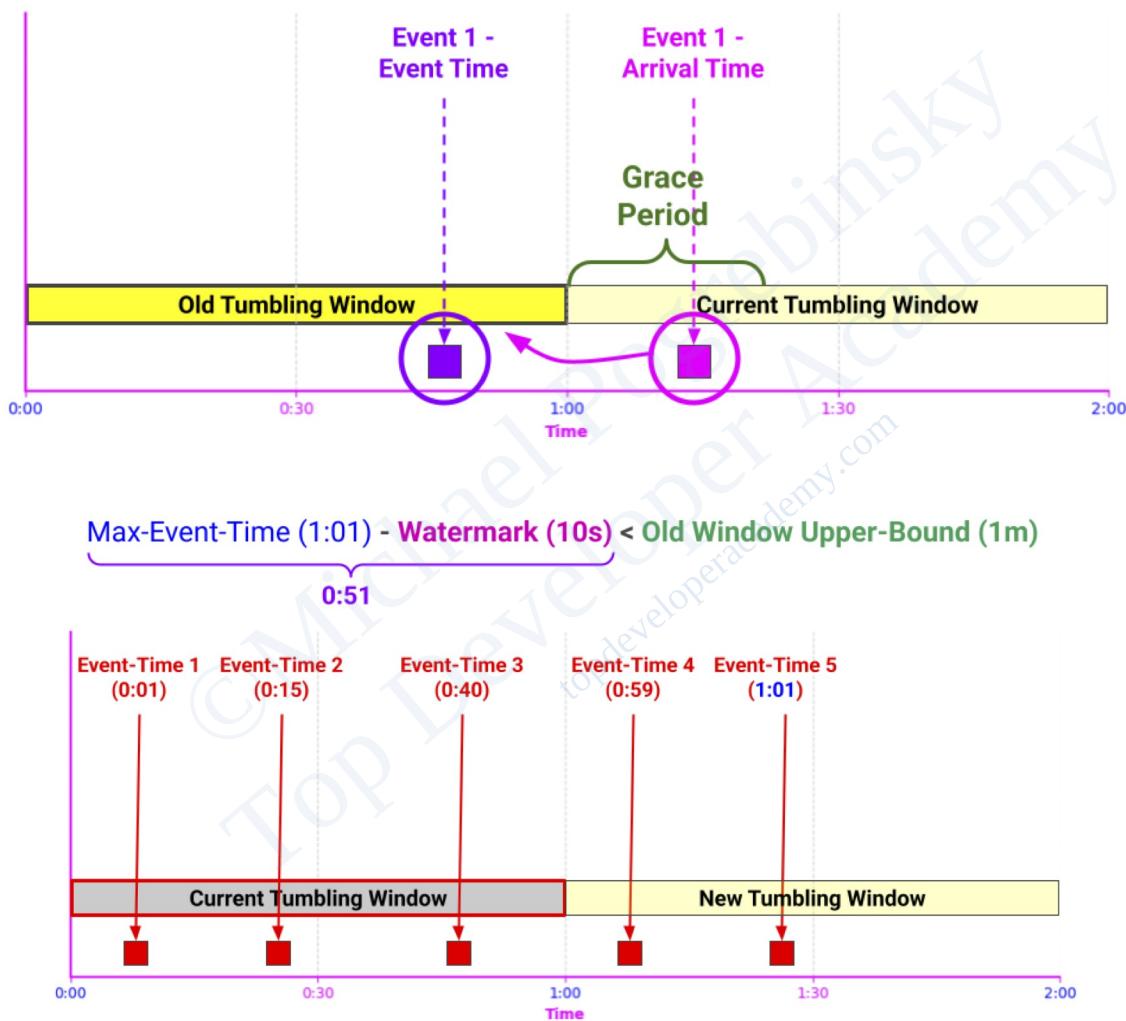
- Session Window strategy
 - No global
 - Dynamic window size
 - Opens for specific events
 - Closes after an inactivity threshold is met



Notes:

Time in Stream Processing and Handling Late Arrival of Events

- **Types of timestamps:**
 - Event Time
 - Application Time / Arrival Time
 - Processing Time
- **Options for handling the late arrival of events**
 - Discarding events
 - Grace period
 - Watermarking

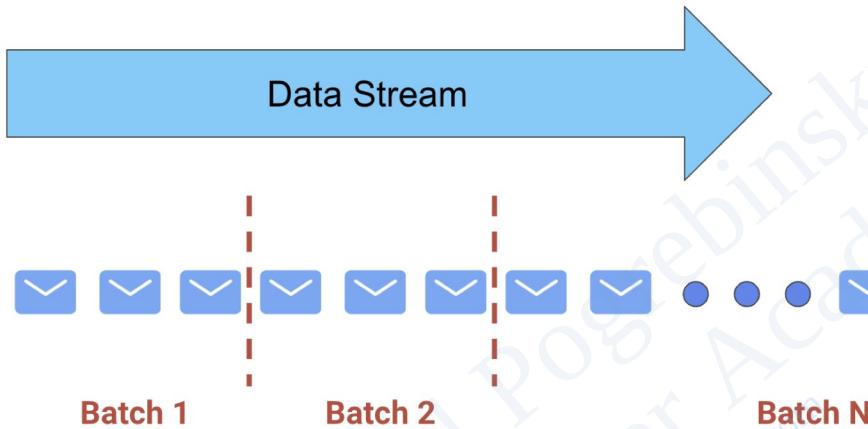


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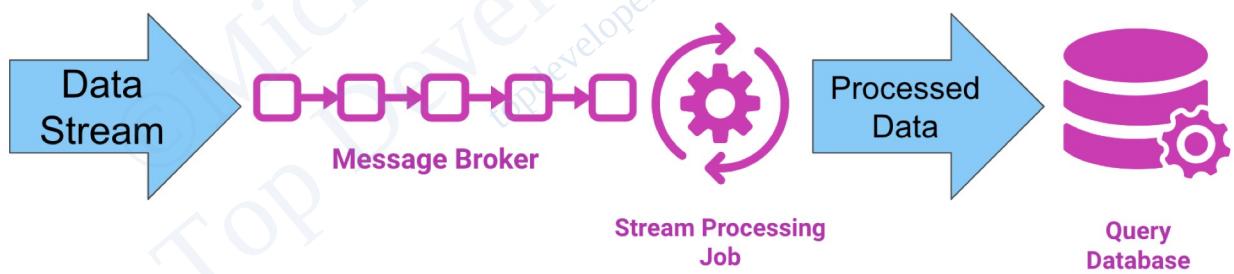
Big Data Architecture Patterns

Big Data Processing Strategies

- **Batch Processing**



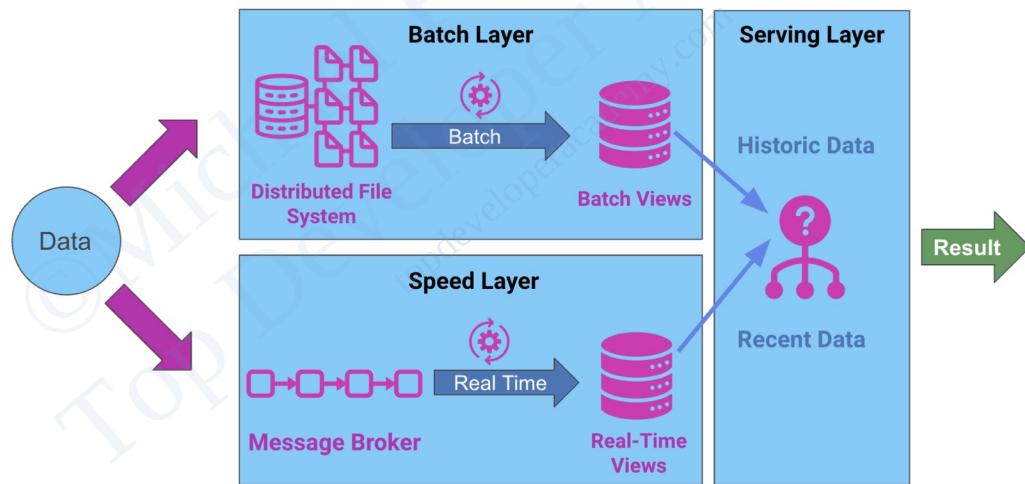
- **Real-Time Processing**



Notes:

Lambda Architecture

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



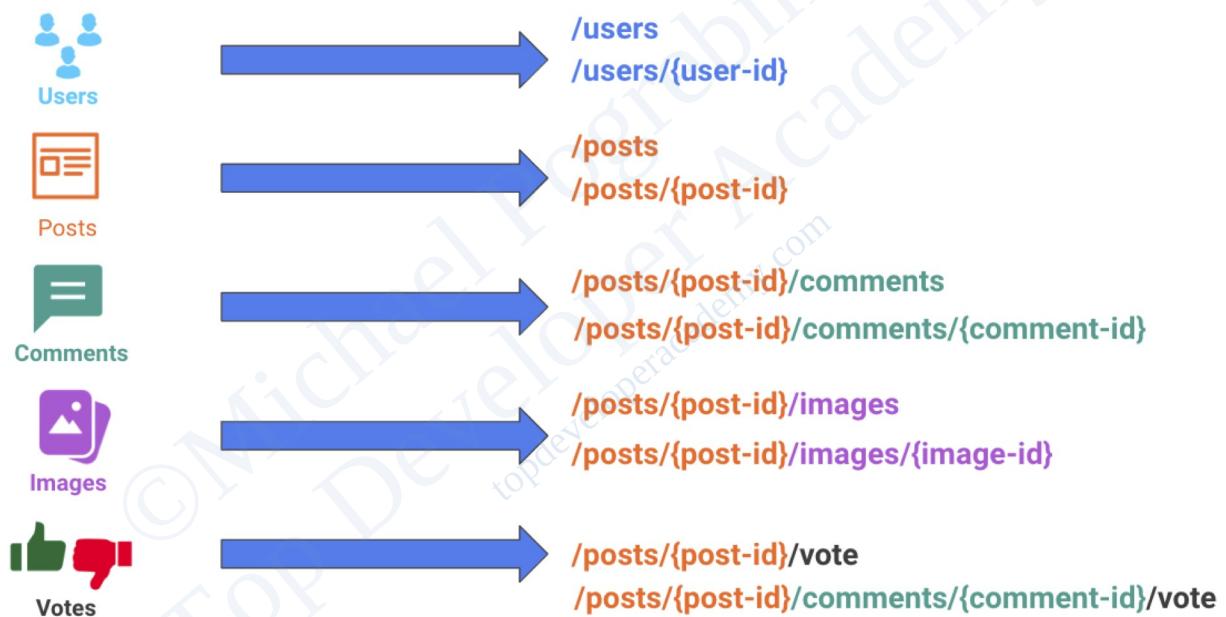
Notes:

Software Architecture & System Design Practice

Design a Highly Scalable Discussion Forum 1 - Requirements & API

- **API Definition:**

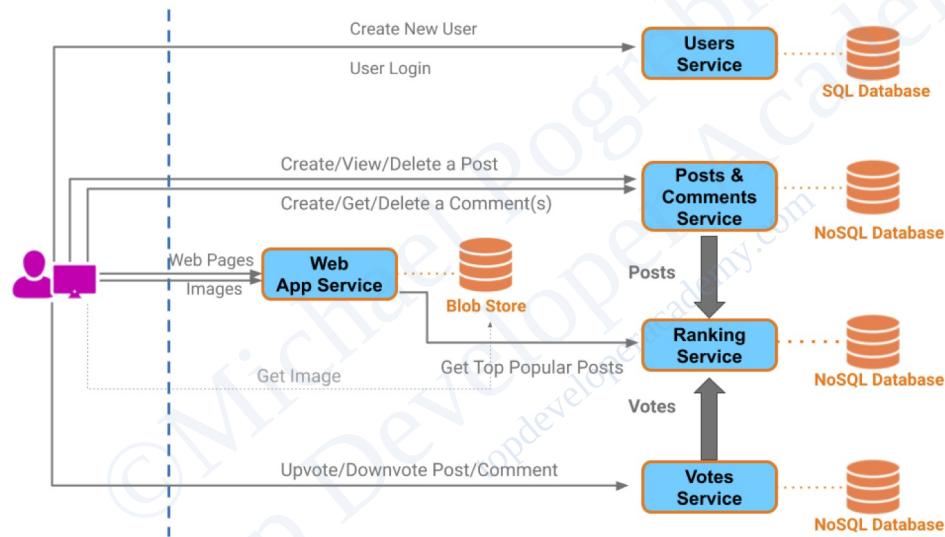
- Entity URLs:



Notes:

Design a Highly Scalable Discussion Forum 2 - Functional Architecture Diagram

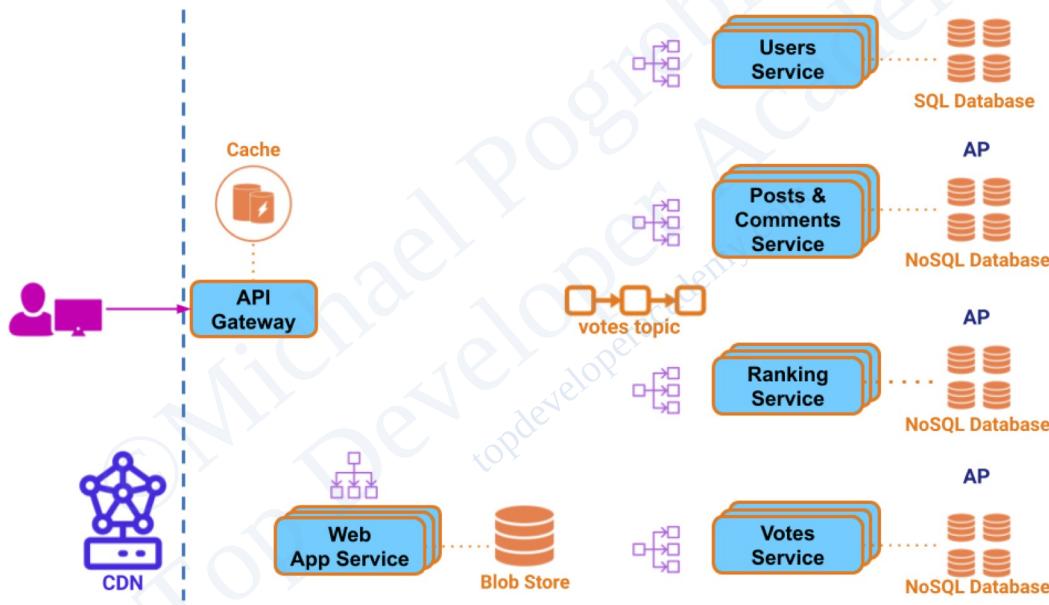
- Functional Software Architecture Diagram:



Notes:

Design a Highly Scalable Discussion Forum 3 - Final Software Architecture

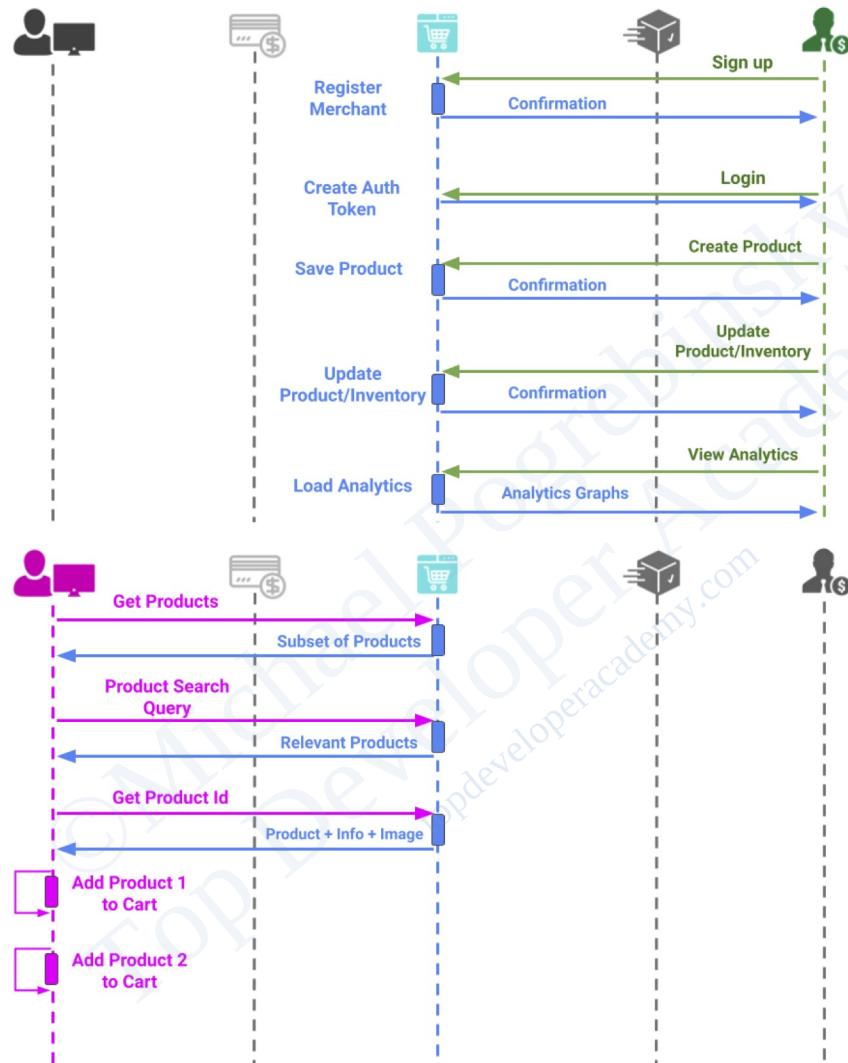
- Final Software Architecture Diagram:

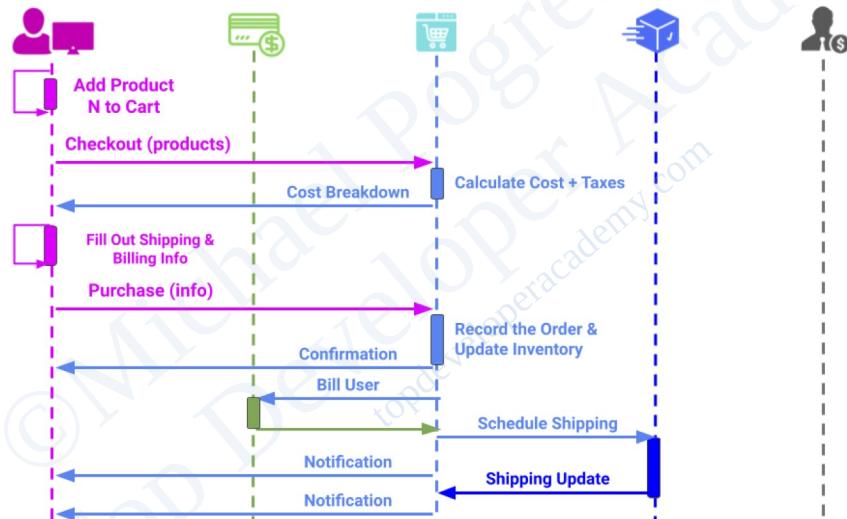


Design an E-Commerce Marketplace Platform 1

- Requirements & Sequence Diagram

- Sequence Diagram:



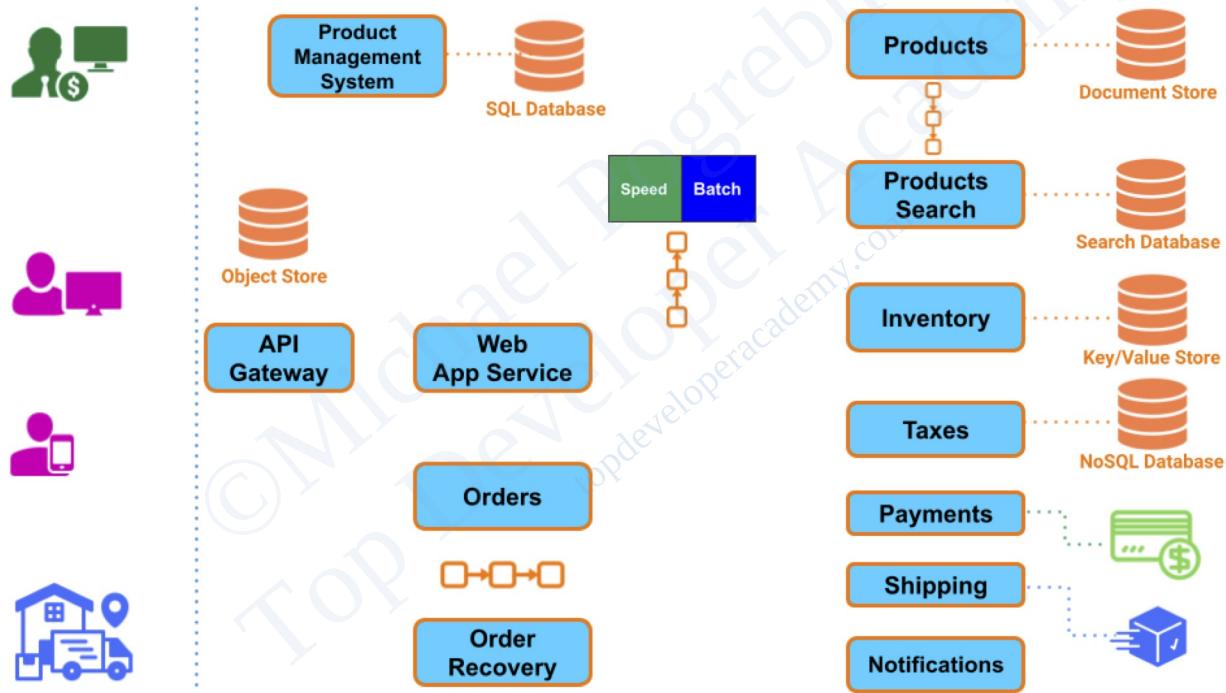


Notes:

Design an E-Commerce Marketplace Platform 2

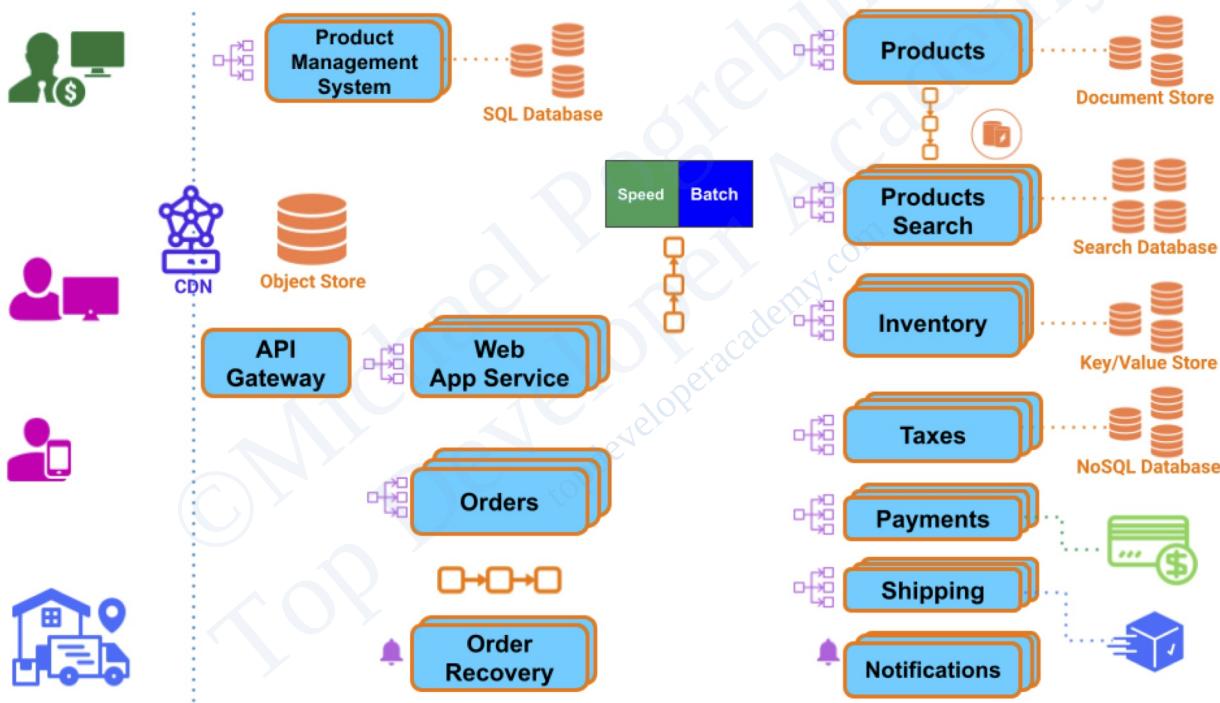
- Functional Diagram

- Functional Software Architecture Diagram:



Notes:

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



Notes: