MicroServices Notes

Foundations of Microservices

1.What are Microservices?

Definition:
Microservices is an **architectural style** that structures an application as a **collection of small, autonomous services**, each responsible for a specific business capability.

Each microservice runs in its **own process** and communicates with others through **lightweight protocols** like **HTTP/REST**, **gRPC**, or **message queues**.

 Example:

In an **e-commerce application**:

- User Service → handles user authentication
- Product Service → manages product catalog
- Order Service → processes orders
- Payment Service → handles transactions

All these services work together but can be developed, deployed, and scaled **independently**.

2.Monolithic vs SOA vs Microservices

Aspect	Monolithic Architecture	SOA (Service-Oriented Architecture)	Microservices Architecture
Definition	Single unified application containing all components	Architecture based on reusable services across enterprise systems	Application built as independent small services
Deployment	Single deployable unit (e.g., one WAR/JAR file)	Services communicate via Enterprise Service Bus (ESB)	Each microservice is independently deployable
Scalability	Scales as a whole	Scales service-level, but depends on ESB	Scales individual services easily
Technology Stack	Single tech stack	Multiple, but often limited by ESB	Polyglot (different tech/language per service)
Communication	In-process calls	XML/SOAP via ESB	REST, gRPC, messaging

Aspect	Monolithic Architecture	SOA (Service-Oriented Architecture)	Microservices Architecture
Failure Impact	One failure can crash whole system	Partially isolated	High isolation; failure affects only one service
Example	A single Spring Boot app	Banking system integrated through ESB	Netflix, Amazon, Uber

Summary:

- **Monolithic:** Simple but hard to scale.
- **SOA:** Introduced service reuse but had ESB dependency.
- **Microservices:** Lightweight, decentralized, and highly scalable evolution of SOA.

3.Characteristics of Microservices

1. Independent & Autonomous

Each service is self-contained and focuses on a single business functionality.

2. Loosely Coupled

Services have minimal dependency on each other.
Changes in one service don't affect others directly.

3. Highly Scalable

Each microservice can be scaled horizontally or vertically based on demand.

4. Technology Agnostic

Teams can use **different programming languages, databases, and tools** for different services.

5. Continuous Delivery

Supports frequent and faster deployments since each service can be deployed independently.

6. Resilient & Fault-Tolerant

Failure in one service does not bring down the entire system.

7. Decentralized Data Management

Each service has its own database (no single shared DB).

4.Benefits of Microservices

1. Scalability

- Scale only the required components instead of the entire system.
- E.g., During sale events, only the *Order Service* can be scaled up.

2. Fault Isolation

- If one microservice fails, the rest of the system continues to work.
- Enhances **system resilience**.

3. Faster Development & Deployment

- Small teams can work on different services simultaneously.
- Enables **Continuous Integration/Continuous Deployment (CI/CD)**.

4. Technology Flexibility

- Each team can choose the **best tech stack** suited to their service.

5. Better Maintainability

- Smaller codebases are easier to understand, modify, and test.

6. Improved Reusability

- Services can be reused across projects or systems.

5.Challenges of Microservices

1. Increased Complexity

- Managing multiple services, builds, and deployments is challenging.
- Requires **DevOps expertise** and **containerization (Docker, Kubernetes)**.

2. Data Consistency

- Since each service has its own database, maintaining **transaction consistency** (ACID) across services is complex.
- Often solved using **Saga Pattern** or **event-driven architecture**.

3. Monitoring & Logging

- Need centralized tools for logs and metrics like:
    - **ELK Stack (Elasticsearch, Logstash, Kibana)**
    - **Prometheus & Grafana**

4. Communication Overhead

- Network calls (REST/gRPC) are slower than in-process calls.
- Requires **API Gateway** and **load balancing**.

5. Deployment & Versioning

- Managing multiple service versions can be difficult.
- Requires **Docker containers**, **Kubernetes**, and CI/CD pipelines.

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6. When to Use Microservices vs Monolithic

Criteria	Use Monolithic	Use Microservices
Project Size	Small or medium	Large and complex systems
Team Size	Small team (1–5 developers)	Multiple teams working in parallel
Deployment Frequency	Infrequent	Frequent and independent
Performance Requirement	Low to moderate	High scalability and reliability needed
Time to Market	Short	Long-term scalability required
Example	Portfolio website, School ERP	Netflix, Amazon, Uber, Banking apps

 Summary:

- Choose **Monolithic** for *simple, early-stage projects* — quick and easy.
- Choose **Microservices** when your application needs *high scalability, team autonomy,* and *frequent updates*.

Microservices Architecture

1.High-Level Architecture Flow

Overall Flow:

Client → API Gateway → Microservices → Database(s)

This is the **standard architecture pattern** followed in most production-grade microservice systems.

Let’s break it down step-by-step

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1. Client (Frontend Layer)

- Represents the **end user** or **external system** interacting with the application.
- Can be:
  - Web App (React, Angular, etc.)
  - Mobile App (Android/iOS)
  - External System consuming APIs

Responsibility:
Sends requests to the system (for example: *“Place Order”*, *“View Product Details”*, etc.).

Example:
A user clicks “Buy Now” on an e-commerce website → request goes to the **API Gateway**.

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2. API Gateway (Entry Point Layer)

- Acts as a **single entry point** for all client requests.
- Responsible for **routing, authentication, load balancing, rate limiting, and logging**.
- It hides the internal microservice details from clients.

 Key Responsibilities:

- **Request Routing:**
  Directs incoming requests to the correct microservice.
  → /user/login → User Service
  → /product/list → Product Service
  → /order/create → Order Service
- **Authentication & Authorization**
  Validates JWT tokens, API keys, etc.
- **Load Balancing**
  Distributes traffic evenly across service instances.
- **Response Aggregation**
  Combines data from multiple services before sending it to the client.

 Common API Gateway Tools:

- **Spring Cloud Gateway**
- **Netflix Zuul**
- **Kong API Gateway**
- **NGINX**
- **AWS API Gateway**

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3. Microservices (Business Logic Layer)

Each microservice is an **independent module** that handles a specific business capability.

 Example (E-commerce System)

Microservice	Responsibility
User Service	Manages registration, login, profiles
Product Service	Manages product catalog and details
Cart Service	Handles items added to cart
Order Service	Places and tracks orders
Payment Service	Handles payments and transactions
Email Service	Sends notifications and confirmations

Each microservice has:

- Its **own codebase**
- Runs in its **own process/container**
- Has its **own database**
- Communicates with others via **REST, gRPC, or message queues**

 Communication Between Microservices:

1. **Synchronous Communication**
   - Uses **REST API** or **gRPC**
   - Real-time and direct
   - Example: Order Service → Payment Service via REST call
2. **Asynchronous Communication**

  - Uses **Messaging Queues** (RabbitMQ, Kafka, etc.)
  - Services don’t wait for immediate response
  - Example: Order Service → sends message → Email Service sends confirmation email later

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4. Database(s) (Data Layer)

Each microservice typically manages its **own database** to ensure **data independence**.

 Database per Service Pattern:

- Avoids tight coupling between services
- Each service can use the **best-suited database type**
  - SQL (PostgreSQL, MySQL)
  - NoSQL (MongoDB, Cassandra)
  - In-memory (Redis)

 Example:

Microservice	Database
User Service	MySQL
Product Service	MongoDB
Order Service	PostgreSQL
Payment Service	Redis (for session/token cache)

 Challenge:

Maintaining **data consistency** across services — solved using:

- **Event-Driven Architecture**
- **Saga Pattern**
- **Distributed Transactions**

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2. Communication Patterns in Microservices

1. REST (HTTP-based Communication)

- Lightweight and widely used
- Uses JSON for request/response
- Simple and human-readable

Example:
GET /product/123 → Returns product details in JSON

2. gRPC (Binary Protocol)

- High-performance communication developed by Google
- Uses **Protocol Buffers (protobuf)** instead of JSON
- Ideal for internal microservice communication

Advantages:

- Faster and more efficient
- Supports bi-directional streaming

Example Use:
Communication between internal backend microservices in high-speed systems (e.g., Netflix, Uber).

3. Messaging (Asynchronous Communication)

- Uses **message brokers** like RabbitMQ, Kafka, or ActiveMQ
- Services communicate via **events/messages** rather than direct calls

Advantages:

- Decoupled communication
- Increases fault tolerance and scalability

Example:

- Order Service publishes "OrderCreated" event
- Payment and Email Services subscribe and react independently

Layers in Microservices Architecture

Microservices architecture is typically organized into **five key layers**, each with a specific responsibility that contributes to building a **scalable, maintainable, and independent** system.

The layers are:
 Client Layer → API Gateway Layer → Service Layer → Database Layer → Infrastructure Layer

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1.Client Layer (UI / Frontend)

 Purpose:

The **Client Layer** is the **entry point** for users or external systems. It provides the **user interface** and interacts with backend services via the **API Gateway**.

 Responsibilities:

- Display data and capture user inputs
- Send API requests to backend services
- Manage session state and authentication tokens (e.g., JWT)
- Handle user experience (UX) and presentation logic

 Typical Technologies:

- **Web:** React, Angular, Vue.js
- **Mobile:** Flutter, Android (Kotlin/Java), iOS (Swift)
- **Desktop:** Electron, .NET MAUI

 Example Flow:

User clicks **“View Order History” →**
Frontend sends GET /orders →
Request goes to **API Gateway**.

2.API Gateway Layer (Routing, Security, Load Balancing)

 Purpose:

The **API Gateway** is the **single entry point** to the microservices ecosystem.
It manages **client communication**, **authentication**, **routing**, and **load balancing** between services.

 Responsibilities:

- **Request Routing:** Directs requests to the appropriate microservice
- **Authentication & Authorization:** Validates tokens, API keys, etc.

- **Rate Limiting:** Controls request frequency to prevent abuse
- **Response Aggregation:** Combines data from multiple services
- **Logging & Monitoring:** Tracks performance and errors

□ **Technologies & Tools:**

- **Spring Cloud Gateway**
- **Netflix Zuul**
- **Kong API Gateway**
- **NGINX**
- **AWS API Gateway**

□ **Example:**

Frontend → /user/login → API Gateway → User Service
Frontend → /product/list → API Gateway → Product Service

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3. Service Layer (Independent Business Logic Services)

□ **Purpose:**

The **heart of Microservices architecture** — where actual **business logic** resides.
Each service handles one **specific business capability** and operates **independently**.

□ **Responsibilities:**

- Implement core business rules and workflows
- Expose REST/gRPC endpoints
- Communicate with other microservices
- Handle request processing, validation, and error handling

□ **Characteristics:**

- Loosely coupled and independently deployable
- Owns its logic and database
- Can be developed in different languages (polyglot development)

□ **Typical Technologies:**

- **Backend Frameworks:** Spring Boot (Java), Node.js, Python Flask, Go, .NET Core
- **Communication:** REST, gRPC, Kafka, RabbitMQ

□ **Example Services (E-commerce System):**

Service	Responsibility
User Service	Manages user profiles and login
Product Service	Handles catalog, pricing, inventory
Cart Service	Manages shopping cart data
Order Service	Processes and tracks orders
Payment Service	Handles transactions and refunds
Email Service	Sends confirmation emails

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4. Database Layer (Per-Service Databases & Polyglot Persistence)

□ **Purpose:**

Each microservice manages its **own database**, ensuring **data isolation** and **loose coupling** between services.

□ **Responsibilities:**

- Store service-specific data
- Maintain data integrity within the service
- Enable independent scaling and schema evolution
- Support **polyglot persistence** — using different databases for different needs

□ **Polyglot Persistence Example:**

Service	Database Type	Example
User Service	Relational	MySQL, PostgreSQL
Product Service	Document	MongoDB
Payment Service	In-memory	Redis
Analytics Service	Big Data / NoSQL	Cassandra, Elasticsearch

□ **Challenge:**

Cross-service transactions are complex — handled using **Saga Pattern**, **Event Sourcing**, or **CQRS**.

5.Infrastructure Layer (Cloud, Containers, Orchestration)

□ **Purpose:**

Provides the **environment and tools** required to **deploy, run, scale, and manage** microservices efficiently.

 Responsibilities:

- **Containerization:** Packaging each microservice (Docker)
- **Orchestration:** Managing containers (Kubernetes, Docker Swarm)
- **Service Discovery:** Finding services dynamically (Eureka, Consul)
- **Load Balancing:** Distributing traffic efficiently
- **Monitoring & Logging:** Observing performance and health (Prometheus, Grafana, ELK Stack)
- **Cloud Deployment:** Hosting services on cloud providers

 Common Cloud Platforms:

- AWS (ECS, EKS, Lambda)
- Microsoft Azure (AKS, App Service)
- Google Cloud (GKE, Cloud Run)
- IBM Cloud, Oracle Cloud

 Infrastructure Tools:

Category	Tools
Containerization	Docker
Orchestration	Kubernetes, Docker Swarm
CI/CD	Jenkins, GitHub Actions, GitLab CI
Monitoring	Prometheus, Grafana
Logging	ELK Stack (Elasticsearch, Logstash, Kibana)
Configuration	Spring Cloud Config, Consul
Service Mesh	Istio, Linkerd

 Summary: Microservices Architecture Layers

Layer	Responsibility	Technologies/Tools
Client Layer	User interface, interacts via API calls	React, Angular, Flutter
API Gateway Layer	Request routing, security, load balancing	Spring Cloud Gateway, Kong
Service Layer	Independent business logic services	Spring Boot, Node.js, gRPC
Database Layer	Decentralized data storage per service	MySQL, MongoDB, Redis

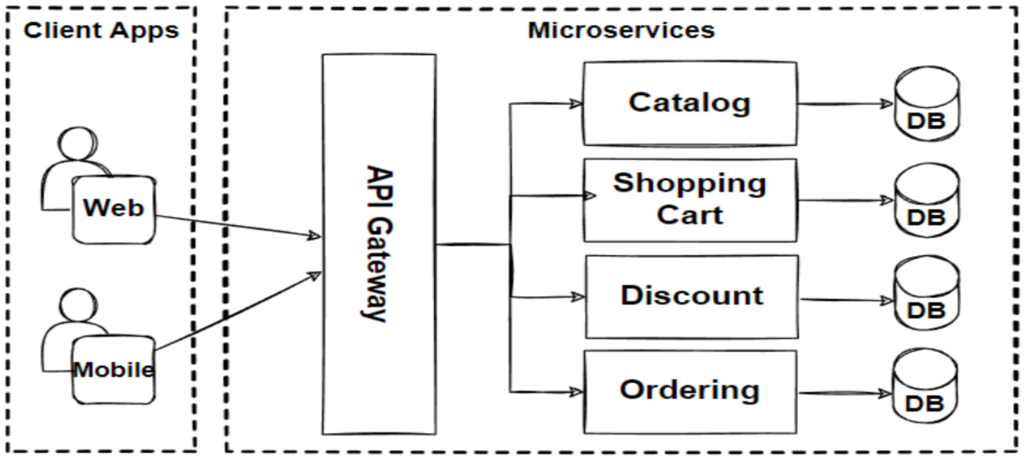
Layer	Responsibility	Technologies/Tools
Infrastructure Layer	Deployment, scaling, monitoring	Docker, Kubernetes, Prometheus, AWS

 Complete Architecture Flow:

Client Layer → API Gateway → Service Layer → Database Layer → Infrastructure (Cloud/Container)

Example (E-Commerce Application):

1. Client requests order → API Gateway routes → Order Service
2. Order Service calls Payment Service → updates DB
3. Infrastructure manages scaling & health monitoring
4. Each service stores data in its own database



Core Components of Microservices

Microservices rely on a **set of core components** to ensure **scalability, reliability, observability, and security**. Each component plays a specific role in making microservices production-ready.

1.API Gateway

 Purpose:

Acts as a **single entry point** for client requests and abstracts the internal microservices structure.

 Responsibilities:

- Request routing to services
- Authentication & authorization
- Rate limiting and throttling
- Response aggregation
- Caching and protocol translation

 Popular Tools:

- **Zuul** (Netflix OSS)
- **Kong**
- **NGINX**
- **Spring Cloud Gateway**

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2. Service Registry & Discovery

 Purpose:

Enables **dynamic discovery of microservices** in the ecosystem.

 Responsibilities:

- Keeps a **list of available services** and their instances
- Helps **load balancers** and clients find service endpoints dynamically

 Popular Tools:

- **Eureka** (Netflix OSS)
- **Consul** (HashiCorp)
- **Zookeeper** (Apache)

Example:

- When Order Service needs Payment Service, it queries **Eureka** to find an available instance.

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3. Load Balancer

 Purpose:

Distributes **incoming traffic** evenly across service instances to improve performance and reliability.

 Responsibilities:

- Horizontal scaling support
- Fault tolerance by routing around failed instances
- Session persistence if needed

 Popular Tools:

- **Ribbon** (Client-side load balancing)
- **NGINX** (Server-side load balancing)
- **Envoy** (Modern service mesh proxy)

4.Configuration Server

 Purpose:

Centralized configuration management for microservices, allowing **dynamic updates** without redeployment.

 Responsibilities:

- Store application configuration centrally
- Provide **version control** and secure storage
- Support environment-specific configurations

 Popular Tools:

- **Spring Cloud Config**
- **HashiCorp Vault** (for secrets management)

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5. Message Broker

 Purpose:

Facilitates **asynchronous communication** between services using messages/events.

 Responsibilities:

- Decouples services

- Ensures reliable message delivery
- Supports event-driven architecture

 Popular Tools:

- **Kafka** (high throughput, event streaming)
- **RabbitMQ** (lightweight messaging)
- **ActiveMQ** (enterprise-grade message broker)

6.Databases

 Purpose:

Each microservice typically maintains its **own database** for isolation and independence.

 Types:

- **SQL (Relational)** – MySQL, PostgreSQL
- **NoSQL (Document, Key-Value, Graph)** – MongoDB, Cassandra
- **Database-per-Service Pattern** – Ensures each service has its own storage

 Challenge:

Maintaining **consistency across databases** requires patterns like **Saga** or **Event Sourcing**.

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7. Service Mesh

 Purpose:

Manages **service-to-service communication** in a microservices architecture with observability, security, and reliability.

 Responsibilities:

- Traffic routing
- Service discovery
- Security (mTLS)
- Observability (tracing, metrics)

 Popular Tools:

- **Istio**

- **Linkerd**

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8. Security Layer

 Purpose:

Protects microservices from unauthorized access and ensures secure communication.

 Responsibilities:

- Authentication and authorization
- Secure communication between services
- Token management

 Common Techniques:

- **OAuth2 / OpenID Connect**
- **JWT (JSON Web Token)**
- **mTLS (mutual TLS)** for service-to-service encryption

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9. Monitoring & Logging Tools

 Purpose:

Provide **visibility and observability** into microservices for troubleshooting, performance tuning, and alerting.

 Responsibilities:

- Track metrics (CPU, memory, response time)
- Centralized logging for multiple services
- Distributed tracing for microservice interactions

 Popular Tools:

- **ELK Stack** (Elasticsearch, Logstash, Kibana)
- **Prometheus & Grafana** (metrics & dashboards)
- **Jaeger / Zipkin** (distributed tracing)

CI/CD Pipeline Tools

□ **Purpose:**

Automates **build, test, and deployment** processes for microservices, enabling continuous delivery.

□ **Responsibilities:**

- Automate builds, tests, and deployments
- Ensure consistent deployments across environments
- Support versioning, rollback, and artifact management

□ **Popular Tools:**

- **Jenkins**
- **GitHub Actions**
- **GitLab CI/CD**

Service Design Principles in Microservices

Microservices architecture relies heavily on **well-designed services**. Following design principles ensures **maintainability, scalability, and flexibility**.

1.Single Responsibility Principle (SRP)

□ **Purpose:**

Each microservice should focus on **one business capability** or responsibility.

□ **Key Points:**

- Simplifies maintenance and testing
- Makes deployment and scaling easier
- Reduces inter-service dependencies

□ **Example:**

- **Order Service** → only handles orders
- **Payment Service** → only handles payments
- **Email Service** → only sends notifications

Avoid combining multiple responsibilities into a single service (e.g., Order + Payment + Email)

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2. Bounded Context (Domain-Driven Design, DDD)

□ **Purpose:**

Each microservice operates within a **bounded context**, meaning it owns **its own domain logic and terminology**.

□ **Key Points:**

- Encapsulates business logic
- Prevents overlap between services
- Encourages **clear boundaries** in large systems

□ **Example:**

In an e-commerce system:

- **User Context** → manages user profiles, authentication
- **Order Context** → manages orders, status, and tracking
- **Payment Context** → handles transactions and refunds

Bounded contexts reduce confusion and maintain **independent service evolution**.

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3. Database-per-Service Rule

□ **Purpose:**

Each microservice should have its **own database** to ensure **data independence**.

□ **Key Points:**

- Avoids shared database schema (reduces coupling)
- Allows different microservices to choose **best-suited database type**
- Facilitates service isolation, scaling, and fault tolerance

□ **Example:**

- User Service → MySQL
- Product Service → MongoDB
- Payment Service → PostgreSQL

Cross-service transactions require **Saga Pattern** or **event-driven architecture**.

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4. Loose Coupling & High Cohesion

□ **Purpose:**

- **Loose Coupling:** Services should interact minimally with each other
- **High Cohesion:** Internal functionality of a service should be highly related

□ **Benefits:**

- Easier maintenance and testing
- Independent deployment
- Flexible to changes without affecting other services

□ **Example:**

- Order Service depends on **Payment Service** only via API call
- Internal logic for processing orders is self-contained

5.API-First Design

□ **Purpose:**

Design **APIs first** before implementing the service logic.

□ **Key Points:**

- Ensures clear contracts between services
- Enables frontend and other teams to work independently
- Facilitates consistent API documentation

□ **Tools:**

- OpenAPI / Swagger
- Postman Collections

Example: Define /orders/{id} API response schema before coding the Order Service.

6.Backward Compatibility for APIs

□ **Purpose:**

Changes in a microservice should **not break existing clients**.

 Key Points:

- Avoid removing fields from API responses
- Add new features without affecting older clients
- Supports **gradual migration** and multiple API versions

 Example:

- Adding deliveryStatus to /orders/{id} response
- Existing clients ignoring new field → no disruption

7.Versioning of Services

 Purpose:

Maintain **multiple versions** of an API/service to support old and new clients.

 Strategies:

1. **URI Versioning:** /v1/orders, /v2/orders
2. **Header Versioning:** Accept: application/vnd.myapi.v1+json
3. **Query Parameter Versioning:** /orders?id=123&version=2

 Benefits:

- Avoids breaking changes
- Supports gradual migration to new APIs
- Simplifies testing and rollback

Communication in Microservices

Microservices rely heavily on **inter-service communication**. Choosing the right communication pattern is critical for **performance, reliability, and scalability**.

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1. Synchronous Communication

 Definition:

Communication where the **caller waits** for the response from the service before proceeding.

□ **Common Protocols:**

1. **REST APIs (HTTP/HTTPS)**
    - Lightweight, widely used
    - Uses **JSON** for data transfer
    - Human-readable and easy to debug
2. **gRPC (Google Remote Procedure Call)**
    - High-performance, binary protocol
    - Uses **Protocol Buffers (protobuf)**
    - Supports streaming and bi-directional communication
    - Ideal for internal service-to-service calls

□ **Example Flow:**

Client → API Gateway → Order Service → Payment Service (sync) → Response back

Pros:

- Simple and predictable
- Easy to implement

Cons:

- Tightly coupled (caller waits for response)
- Higher latency if service is slow or down

2.Asynchronous Communication

□ **Definition:**

Communication where the **caller does not wait** for a response. Services communicate via **events/messages**.

□ **Key Patterns:**

1. **Event-driven Architecture**
    - Services emit **events** when something happens
    - Other services **subscribe** and react asynchronously
2. **Pub/Sub Model (Publish/Subscribe)**
    - Publishers send events to a **message broker**
    - Subscribers receive events independently
    - Decouples services and improves scalability

 Popular Messaging Tools:

- **Kafka** (high-throughput event streaming)
- **RabbitMQ** (lightweight message broker)
- **Pulsar** (distributed pub/sub messaging)

 Example Flow:

Order Service → publishes "OrderCreated" event →
Payment Service subscribes → processes payment →
Email Service subscribes → sends confirmation

Pros:

- Loosely coupled
- Better fault tolerance and scalability

Cons:

- More complex to implement
- Eventual consistency instead of immediate consistency

3.Request/Response vs Event-driven Communication

Aspect	Request/Response (Sync)	Event-driven (Async)
Caller Behavior	Waits for response	Does not wait
Coupling	Tightly coupled	Loosely coupled
Latency	Can be high if service is slow	Independent, low blocking
Failure Handling	Needs retries or fails immediately	Can use retry queues, more resilient
Use Case	Fetching user details, payment processing	Notifications, analytics, inventory updates

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4.Service-to-Service Communication Challenges

1. Latency

- Multiple network hops increase **response time**
- Can degrade performance if not monitored

Solution:

- Use caching, local service calls, and optimize payload size

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2. Timeouts

- Services may hang waiting for response
- Can cascade failures across microservices

Solution:

- Set proper timeout thresholds
- Use **async communication** where feasible

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3. Circuit Breakers

- Prevents a failing service from **taking down the entire system**
- Monitors failures and **short-circuits calls** to unhealthy services

Popular Tools:

- Netflix **Hystrix** (Java)
- **Resilience4j** (Java)
- Istio (Service Mesh Circuit Breaking)

Data Management in Microservices

Managing data in microservices is **different from monolithic systems** because each service owns its **own database**, leading to **decoupled, scalable, and resilient systems**.

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1. Database per Service Principle

□ **Purpose:**

- Each microservice has its **own dedicated database**
- Avoids tight coupling and shared schemas
- Enables independent scaling and evolution

□ **Benefits:**

- Data isolation
- Technology flexibility (choose best DB for the service)
- Easier to maintain and deploy independently

□ **Example:**

Microservice	Database
User Service	MySQL
Product Service	MongoDB
Payment Service	PostgreSQL

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2. Polyglot Persistence

□ **Definition:**

- Different services use **different types of databases** based on requirements.

□ **Example:**

- **Relational DB** → Transactions, Order Service (PostgreSQL)
- **Document DB** → Product Catalog (MongoDB)
- **Key-Value DB** → Session caching, Payment Service (Redis)
- **Graph DB** → Social relations, Recommendations (Neo4j)

Choosing the **right database for each service** improves performance and flexibility.

3.Distributed Databases Challenges

Challenge	Explanation
Data Consistency	Hard to maintain ACID across multiple services
Transactions	Distributed transactions are complex
Latency	Network overhead for cross-service data access
Backup & Recovery	Harder to ensure atomic recovery across DBs
Schema Evolution	Changes must be isolated and backward compatible

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4.Transactions in Microservices

□ **2-Phase Commit (2PC)**

- Traditional distributed transaction protocol
- Ensures **all-or-nothing** commit across multiple databases
- **Not preferred** in microservices due to:
  - High latency
  - Tight coupling
  - Reduced availability

□ **Saga Pattern (Preferred)**

- **Sequence of local transactions** across services
- Each service performs its transaction and publishes an **event**
- Compensating transactions are used for failures

Example Flow:

1. Order Service → create order
2. Payment Service → process payment
3. If payment fails → Order Service cancels order (compensating transaction)

Enables **eventual consistency** and decouples services

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5. Event Sourcing

□ **Definition:**

- Instead of storing the **current state**, microservices store **all events** that led to the state.

□ **Benefits:**

- Full **audit trail** of all changes
- Enables **rebuilding state** at any point in time
- Works well with **CQRS** and **event-driven systems**

□ **Example:**

- Events: OrderCreated, PaymentProcessed, OrderCancelled
- Replaying events reconstructs the current order state

6.CQRS (Command Query Responsibility Segregation)

□ **Definition:**

- **Separate models** for **reading** (queries) and **writing** (commands) data.

 Benefits:

- Optimizes read and write workloads independently
- Improves scalability
- Supports eventual consistency with asynchronous updates

 Example:

- **Command:** CreateOrderCommand → writes to database
- **Query:** GetOrderDetailsQuery → reads from a separate optimized read store

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7. Consistency Models

Model	Definition / Use Case
Strong Consistency	Data is immediately consistent across services (rare in microservices)
Eventual Consistency	Updates propagate asynchronously; services eventually see the same state (preferred in microservices)

Example:

- Eventual consistency → Order Service publishes OrderCreated → Inventory Service updates stock later → temporary inconsistency is acceptable

Microservices Patterns

Microservices patterns are **proven solutions** to common problems in designing, integrating, and deploying microservices. They are classified into **Decomposition, Integration, Data, Resilience, and Deployment patterns**.

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1. Decomposition Patterns

 Purpose:

Divide a monolithic application into smaller, independently deployable services.

 Types:

1. **By Business Capability**
    - Each service represents a **specific business function**
    - Example: E-commerce → User Service, Order Service, Payment Service
2. **By Subdomain (Domain-Driven Design)**
    - Decompose based on **domain boundaries** or bounded contexts
    - Example: Inventory Context, Shipping Context, Billing Context
3. **Strangler Fig Pattern**
    - Gradual migration from **monolith → microservices**
    - New functionality is developed as microservices, slowly **replacing old monolith parts**
    - Reduces risk of full rewrite

2.Integration Patterns

 Purpose:

Ensure **communication and coordination** between microservices.

 Key Patterns:

1. **API Gateway Pattern**
    - Single entry point for clients
    - Handles routing, authentication, rate limiting, and response aggregation
2. **Aggregator Pattern**
    - Combines data from **multiple services** before sending to the client
    - Reduces multiple client requests
3. **Proxy Pattern**
    - A service acts as a **proxy** to forward requests to internal services
    - Often used for **security and protocol translation**

3.Data Patterns

 Purpose:

Manage **data consistency and persistence** across microservices.

 Key Patterns:

1. **Database per Service**
    - Each microservice owns its own database
    - Ensures loose coupling and independent scaling
2. **Saga Pattern**

   - **Choreography:** Services communicate via events
   - **Orchestration:** A central coordinator manages the saga
   - Ensures **eventual consistency** for distributed transactions
3. **Event Sourcing & CQRS**
   - **Event Sourcing:** Store state as a sequence of events
   - **CQRS:** Separate read and write models for optimized scalability

---

4. Resilience Patterns

□ **Purpose:**

Improve system **fault tolerance, stability, and availability**.

□ **Key Patterns:**

1. **Circuit Breaker Pattern**
   - Stops calling a failing service to prevent cascading failures
   - Tools: **Hystrix, Resilience4j**
2. **Retry Pattern**
   - Retry failed requests with **exponential backoff**
   - Prevents transient errors from failing operations
3. **Bulkhead Pattern**
   - Isolate resources for different services
   - Prevents failure in one part from affecting others
4. **Timeout Pattern**
   - Limit waiting time for responses from other services
   - Protects system from hanging requests

---

5. Deployment Patterns

□ **Purpose:**

Safely deploy microservices without downtime and risk.

□ **Key Patterns:**

1. **Blue-Green Deployment**
   - Two identical environments: **Blue (current)** & **Green (new)**
   - Switch traffic to the new environment after testing
2. **Canary Release**
   - Gradually release new version to **subset of users**
   - Monitor for issues before full rollout

3. **Rolling Updates**
    - Deploy new version **incrementally** across service instances
    - Avoid downtime and maintain availability

Observability in Microservices

Observability ensures you can **understand, monitor, and troubleshoot** microservices effectively. It involves **collecting data about system behavior** and responding to anomalies before they affect users.

---

1. Logging

 Purpose:

Capture detailed information about service execution and errors. Centralized logging allows **aggregating logs from multiple services** for easier analysis.

 Key Points:

- Each microservice writes logs in a **structured format** (JSON recommended)
- Centralized log storage enables **search, filtering, and analysis**
- Useful for debugging and auditing

 Popular Tools:

- **ELK Stack** (Elasticsearch, Logstash, Kibana)
- **Fluentd** (log collection & forwarding)
- **Graylog** (centralized log management)

 Example:

Order Service Log:
```
{
  "timestamp": "2025-10-06T12:00:00Z",
  "level": "ERROR",
  "service": "OrderService",
  "message": "Payment failed for OrderID 1234"
}
```

---

2. Monitoring

□ **Purpose:**

Track the **health, performance, and usage metrics** of services in real time.

□ **Key Metrics:**

- Service uptime
- CPU and memory usage
- Response time / latency
- Request throughput

□ **Popular Tools:**

- **Prometheus** (metrics collection & storage)
- **Grafana** (visualization dashboards)

---

3. Distributed Tracing

□ **Purpose:**

Understand **how a request flows** across multiple microservices.

□ **Key Points:**

- Assigns a **trace ID** to a request
- Helps identify **bottlenecks, latency issues, and failed calls**
- Visualizes service dependencies

□ **Popular Tools:**

- **Jaeger**
- **Zipkin**

□ **Example Flow:**

Client → API Gateway → Order Service → Payment Service → Inventory Service
Trace ID: abc123
Duration: 250ms

---

4. Metrics & Alerts

□ **Purpose:**

Provide actionable insights and **notify teams about anomalies**.

 Key Metrics:

- CPU & memory utilization
- Latency and response time
- Error rates & exceptions
- Database connections and queue lengths

 Alerting Tools:

- Prometheus Alertmanager
- Grafana alerts
- PagerDuty / Opsgenie integration

Example Alert: "Error rate > 5% for Order Service in last 5 mins"

---

5. Health Checks & Readiness Probes

 Purpose:

Automatically check if services are **alive and ready** to serve traffic.

 Types:

1. **Liveness Probe** – checks if service is running
2. **Readiness Probe** – checks if service is ready to handle requests

 Benefits:

- Kubernetes can restart failing containers
- Load balancers route traffic only to ready services
- Improves system reliability

Security in Microservices

Security is **critical in microservices** because a system consists of **many distributed services**, each potentially exposed to internal or external threats.

1.Authentication & Authorization

□ **Purpose:**

Ensure only **authorized users or services** can access microservices.

□ **Key Techniques:**

- **OAuth2 / OpenID Connect:** Standard protocols for delegated authentication
- **JWT (JSON Web Token):** Secure, compact token to carry authentication and authorization info

□ **Flow Example:**

Client logs in → Auth Server issues JWT →
API Gateway validates JWT → Request routed to services

---

2. Secure API Gateway

□ **Purpose:**

Protect microservices by **centralizing security controls**.

□ **Key Responsibilities:**

- Validate incoming requests
- Enforce authentication and authorization
- Rate limiting to prevent abuse
- SSL/TLS termination

□ **Example Tools:**

- **Kong**, **NGINX**, **Spring Cloud Gateway**

---

3. Role-Based Access Control (RBAC)

□ **Purpose:**

Grant access to services/resources based on **user roles**.

□ **Key Points:**

- Roles define **permissions**
- Fine-grained control over which API endpoints can be accessed

□ **Example:**

Role	Allowed Actions
Admin	Create/Update/Delete Products
User	View Products, Place Orders
Guest	View Products Only

---

4. Transport Security

□ **Purpose:**

Encrypt communication between clients and services to **prevent data tampering and eavesdropping**.

□ **Techniques:**

- **HTTPS (TLS/SSL)** → Encrypt client ↔ API Gateway traffic
- **mTLS (Mutual TLS)** → Encrypt service-to-service communication, ensures both parties are trusted

---

5. Security in Service Mesh

□ **Purpose:**

Enhance security for service-to-service communication in microservices architecture.

□ **Features:**

- **mTLS encryption** automatically applied to all service communication
- Centralized policy enforcement for authentication and authorization

□ **Example Tools:**

- **Istio**, **Linkerd**

6.Zero-Trust Security Model

□ **Purpose:**

Assume **no service or user is trusted by default**. Security is **continuously verified**.

 Principles:

- Authenticate & authorize every request, every time
- Use **least privilege access**
- Encrypt all communication
- Monitor, audit, and log all interactions

Deployment & Infrastructure in Microservices

Microservices require a **modern deployment and infrastructure approach** to ensure **scalability, resilience, and efficient management**.

1.Containers – Docker Basics

 Purpose:

Package microservices along with all dependencies into **portable, consistent environments**.

 Key Concepts:

- **Image:** Read-only template with application code, runtime, libraries
- **Container:** Running instance of an image
- **Volumes:** Persistent storage outside the container for data

 Benefits:

- Environment consistency (dev, test, prod)
- Lightweight compared to VMs
- Easy to deploy, replicate, and scale

---

2. Orchestration – Kubernetes (K8s)

 Purpose:

Automates **deployment, scaling, and management** of containerized applications.

 Key Components:

- **Pod:** Smallest deployable unit, can contain one or more containers
- **Deployment:** Declarative configuration for managing pods

- **Service:** Exposes pods internally or externally, load balances traffic
- **Ingress:** Manages external access to services, including routing and SSL termination

□ **Benefits:**

- Automatic scaling and healing of pods
- Rolling updates and rollbacks
- Service discovery and load balancing

---

3. Service Mesh

□ **Purpose:**

Manages **service-to-service communication**, security, and observability at the infrastructure level.

□ **Features:**

- Traffic routing and load balancing
- Service-to-service **mTLS encryption**
- Distributed tracing and monitoring

□ **Popular Tools:**

- **Istio**
- **Linkerd**

4.Cloud Platforms

□ **Purpose:**

Host microservices on **scalable, reliable cloud environments** with managed infrastructure.

□ **Popular Providers & Services:**

Provider	**Microservices Services**
AWS	ECS, EKS (Kubernetes), Lambda (serverless)
Azure	AKS (Kubernetes), App Service, Functions
GCP	GKE (Kubernetes), Cloud Run, Cloud Functions

□ **Benefits:**

- Managed infrastructure
- Easy scaling and deployment pipelines
- Global availability

---

5. Scaling

 Purpose:

Handle **increasing load** efficiently to maintain performance.

 Types of Scaling:

1. **Horizontal Scaling:** Add more instances of a service (preferred in microservices)
2. **Vertical Scaling:** Increase resources (CPU/RAM) of existing instance
3. **Auto-scaling:** Automatically scale based on **CPU, memory, or custom metrics**

 Example:

- Kubernetes Horizontal Pod Autoscaler (HPA) scales pods automatically based on CPU usage

DevOps & CI/CD for Microservices

Microservices benefit greatly from **DevOps practices** and **CI/CD pipelines** to enable **faster, reliable, and automated deployments**.

---

1. CI/CD Pipelines

 Purpose:

Automate **building, testing, and deploying microservices** to ensure faster and consistent releases.

 Key Steps:

1. **Continuous Integration (CI):**
   - Automatically build and test code on each commit
   - Tools: **Jenkins, GitHub Actions, GitLab CI/CD**
2. **Continuous Delivery / Deployment (CD):**
   - Automatically deploy microservices to staging or production

- Supports automated rollbacks on failures

 Benefits:

- Faster release cycles
- Reduced human errors
- Early detection of integration issues

2.Infrastructure as Code (IaC)

 Purpose:

Manage infrastructure **programmatically** instead of manually.

 Tools:

- **Terraform:** Declarative provisioning of cloud resources
- **Ansible:** Configuration management and deployment automation

 Benefits:

- Version-controlled infrastructure
- Reproducible and consistent environments
- Automates setup of complex microservices infrastructure

3.Deployment Strategies

 Blue-Green Deployment

- Two identical environments: **Blue (current)** & **Green (new)**
- Switch traffic to new version after validation

 Canary Deployment

- Gradually release the new version to a **subset of users**
- Monitor metrics before full rollout

 Rolling Deployment

- Incrementally update microservice instances
- No downtime, old versions replaced gradually

4.Container Registry

 Purpose:

Store and manage **Docker images** for deployment in different environments.

 Popular Registries:

- **Docker Hub** → Public or private images
- **AWS ECR** (Elastic Container Registry) → AWS managed
- **GCP GCR** (Google Container Registry) → GCP managed

 Benefits:

- Centralized image storage
- Version control for microservices images
- Easy integration with CI/CD pipelines

Advanced Topics in Microservices

Advanced topics in microservices help **improve reliability, scalability, maintainability, and modern architecture practices**.

---

1. 12-Factor App Methodology

 Purpose:

Guidelines to build **cloud-native, scalable microservices**.

 Key Factors:

1. Codebase – single codebase tracked in version control
2. Dependencies – explicitly declared
3. Config – stored in environment variables
4. Backing services – treat as attached resources
5. Build, release, run – strict separation
6. Processes – stateless processes
7. Port binding – self-contained services
8. Concurrency – scale out via process model
9. Disposability – fast startup and graceful shutdown

10. Dev/prod parity – keep environments similar
11. Logs – treat logs as event streams
12. Admin processes – run one-off tasks as processes

Helps microservices remain **portable, maintainable, and scalable**.

2.Chaos Engineering

 Purpose:

Test **resilience and fault tolerance** by intentionally introducing failures.

 Tools:

- **Netflix Chaos Monkey** – kills random instances to test recovery
- **Gremlin** – simulates failures like CPU spikes, network latency

 Benefits:

- Identify weak points in microservices architecture
- Improve fault tolerance and reliability

3.Serverless Microservices

 Purpose:

Run microservices without managing servers, automatically scaling based on demand.

 Popular Platforms:

- **AWS Lambda**
- **Azure Functions**
- **GCP Cloud Run**

 Benefits:

- No server management
- Pay-per-use pricing
- Auto-scaling and event-driven execution

---

4. Micro Frontends

 Purpose:

Apply microservices principles to **frontend development**.

 Key Points:

- Split frontend into independently deployable modules
- Teams can work on separate UI components
- Reduces coordination overhead and improves scalability

 Example:

- E-commerce frontend → separate micro frontends for **catalog, cart, and checkout**

5.Event-driven Architecture with Kafka / Event Mesh

 Purpose:

Enable **asynchronous, decoupled communication** between microservices.

 Key Points:

- Microservices **emit events** and other services **subscribe**
- Event mesh ensures **reliable delivery and routing**

 Benefits:

- Loose coupling
- Improved scalability
- Event-driven workflows

6.Multi-tenancy in Microservices

 Purpose:

Support **multiple clients (tenants) on the same service** efficiently.

 Approaches:

1. **Database-per-tenant** – isolated DB for each tenant

2. **Schema-per-tenant** – separate schema in same DB
3. **Shared schema** – tenant ID in tables

 Benefits:

- Cost efficiency
- Tenant isolation and security
- Easier to scale for multiple clients

7.API Versioning & Backward Compatibility

 Purpose:

Ensure **existing clients do not break** when services evolve.

 Techniques:

- **URI Versioning:** /v1/orders, /v2/orders
- **Header Versioning:** Accept: application/vnd.myapi.v1+json
- **Query Parameter Versioning:** /orders?id=123&version=2

 Benefits:

- Smooth migration for clients
- Supports multiple versions concurrently
- Maintains service stability

Load Balancer in Microservices

A **Load Balancer (LB)** is a critical component in **microservices architecture**. It ensures **even distribution of traffic**, improves **availability**, and enhances **fault tolerance**.

1.What is a Load Balancer?

 Definition:

A Load Balancer **distributes incoming network traffic** across multiple servers or service instances to:

- Prevent overloading a single service
- Increase **availability and reliability**
- Improve **system performance** and response time

 Key Goals:

- Scalability
- High availability
- Fault tolerance
- Efficient resource utilization

---

2. Types of Load Balancers

Type	Description	Use Cases
Hardware Load Balancer	Dedicated appliance for LB	Enterprise networks, large-scale deployments
Software Load Balancer	LB implemented in software	Microservices, cloud-native deployments
DNS Load Balancer	Distributes traffic via DNS resolution	Global traffic distribution
Cloud Load Balancer	Managed LB by cloud providers	AWS ELB, Azure Load Balancer, GCP Load Balancing

---

3.Load Balancing Algorithms

 Purpose:

Determine **how traffic is distributed** across service instances.

Algorithm	Description	Pros/Cons
Round Robin	Requests sent in order to each server	Simple, works if all servers similar
Least Connections	New request to server with fewest connections	Better for variable workloads
IP Hash	Requests distributed based on client IP	Ensures session stickiness
Weighted Round Robin	Servers assigned weights based on capacity	Optimizes utilization for heterogeneous servers
Random	Requests sent randomly	Simple, may not balance load perfectly

---

4.Load Balancing in Microservices

 Purpose:

Microservices often have **multiple instances of a service**, requiring LB for **service discovery and traffic routing**.

 Types of Microservices Load Balancing:

1. **Client-side Load Balancing**
   - Client or service chooses which service instance to call
   - Requires a **service registry** (e.g., Eureka, Consul)
   - Tools: Netflix Ribbon, Spring Cloud LoadBalancer
2. **Server-side Load Balancing**
   - External LB receives requests and forwards them to available instances
   - Tools: NGINX, HAProxy, Envoy, AWS ELB

---

5. Benefits of Using Load Balancers

- **High Availability:** Detects unhealthy instances and reroutes traffic
- **Scalability:** Distributes traffic across multiple instances
- **Fault Tolerance:** Ensures no single point of failure
- **Performance Optimization:** Reduces response time by balancing load
- **Session Management:** Can implement sticky sessions for stateful services

---

6.Challenges & Considerations

Challenge	Explanation / Solution
Health Checking	LB must detect unhealthy instances (use heartbeat or ping)
Sticky Sessions	Needed for stateful services; can impact scalability
Dynamic Scaling	LB must integrate with orchestration tools like Kubernetes for auto-scaling
Latency & Overhead	LB introduces extra network hop; optimize placement and routing
Security	LB can terminate SSL/TLS for services, ensuring secure communication

---

7.Popular Load Balancer Tools

Category	Examples	Notes
Software LB	NGINX, HAProxy	Widely used in microservices and cloud

Category	Examples	Notes
Cloud LB	AWS ELB/ALB/NLB, Azure Load Balancer, GCP Load Balancing	Managed and scalable
Service Mesh LB	Envoy, Istio	Integrated LB with service mesh features like mTLS & retries

---

8. Load Balancer in Kubernetes

- **Service object** acts as a load balancer for Pods
- **Ingress Controller** manages external traffic to services
- **Horizontal Pod Autoscaler (HPA)** works with LB to scale Pods based on demand

Flow Example:

Client → Ingress → Service (LB) → Pod Instances → Response

Scaling in Microservices

Scaling is a core concept in microservices architecture that ensures the system can **handle increasing load**, maintain **performance**, and remain **highly available**.

---

1. What is Scaling?

□ **Definition:**

Scaling is the process of **adjusting resources** (compute, memory, instances) to meet **application demand**.

□ **Key Goals:**

- Handle **high traffic**
- Maintain **low latency** and fast response times
- Ensure **availability and fault tolerance**

2.Types of Scaling

Type	Definition	Pros	Cons
Horizontal Scaling (Scale Out/In)	Add or remove **instances of a service**	Easy to implement in microservices; improves availability	Requires load balancer; more infrastructure overhead
Vertical Scaling (Scale Up/Down)	Increase or decrease **resources (CPU, RAM) of existing instances**	Simple; no changes to load balancer	Limited by hardware; downtime possible
Diagonal Scaling	Combination of **horizontal + vertical scaling**	Flexible; optimizes resources	Complex to manage

---

3. Horizontal Scaling in Microservices

□ **Purpose:**

Distribute workload across **multiple instances** of a microservice.

□ **Key Points:**

- Works well with **stateless services**
- Requires **load balancer** for routing traffic
- Can scale **automatically** using orchestration tools like Kubernetes

---

4. Vertical Scaling in Microservices

□ **Purpose:**

Increase capacity of **existing instances**.

□ **Key Points:**

- Increase **CPU, RAM, or disk** of a service instance
- Suitable for **stateful services** or legacy apps
- Usually involves **manual changes or cloud instance resizing**

---

5. Auto-scaling

□ **Purpose:**

Automatically scale services **up or down based on demand**.

 Triggers:

- CPU or memory usage
- Request latency
- Queue length or custom business metrics

 Benefits:

- Cost-efficient (only pay for what's needed)
- Handles **traffic spikes** automatically
- Reduces **manual intervention**

 Example Cloud Tools:

- AWS Auto Scaling Groups (ASG)
- Azure Virtual Machine Scale Sets
- Kubernetes Horizontal Pod Autoscaler (HPA)

6.Considerations in Scaling Microservices

Consideration	Explanation
Statelessness	Stateless services are easier to scale horizontally
Service Dependencies	Scaling one service may require scaling its dependencies
Data Consistency	Scaling stateful services can lead to challenges in database consistency
Load Balancing	Proper LB configuration ensures even traffic distribution
Cost & Resource Management	Over-scaling increases costs; under-scaling affects performance

---

7.Scaling Strategies

1. **Reactive Scaling** – Scale after monitoring metrics and load
2. **Proactive Scaling** – Predict traffic patterns and scale in advance
3. **Hybrid Scaling** – Combine reactive and proactive approaches