System Design

High Level Design

→ Network Protocols and System Design: Client-Server vs. Peer-to-Peer, WebSocket vs. WebRTC

Client Server uses HTTP, FTP, SMTP and Web Sockets. Peer to Peer uses WebRTC. Client Server is a centralized architecture where clients talk (request) to server, and servers gives response. It's a one way communication.

WebSocket is bi-directional (two way communication) i.e. server can also initiate talk with the client. WebSocket is used when we want to design messaging app like WhatsApp and Telegram etc.

HTTP is connection oriented and we access web pages in this.

FTP is not used generally because the data is not encrypted in this.

SMTP is used to send the email and it's generally used with IMAP which reads/access the email from server.

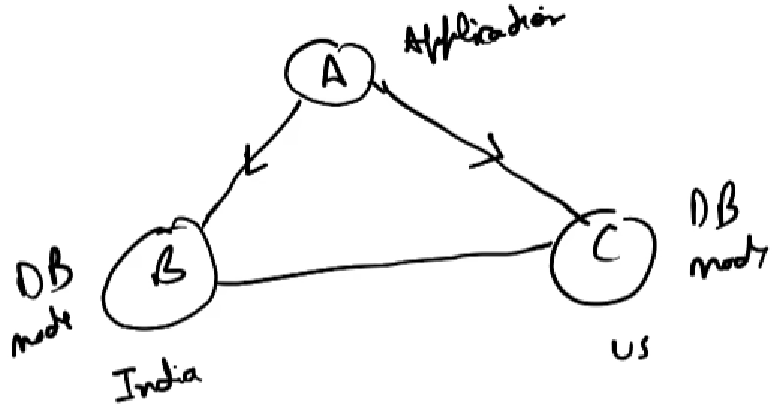
TCP and UDP are used to transport/transfer the data.

In TCP/IP, we create a virtual connection to send (transfer) the data packets (they have sequences like 1, 2, 3 etc.) to the server. So, it can maintain ordering of these packets and it sends the acknowledgement when packet is received. If it misses the acknowledgement for packet 3 then it resends.

In UDP/IP, the data packets are sent parallelly. No ordering is maintained in this. UDP is fast because there is no acknowledgement, no ordering and no connection is maintained. UDP is used in live streams, or video calling etc.

Peer to Peer is when server and clients can all talk to each other. WebRTC is Peer to Peer. They are fast as they use UDP to transfer data.

→ Understanding the CAP Theorem in Distributed Systems



Application A can query from server B or C.

In any distributed data system, it's impossible to simultaneously guarantee all three of the following:

- **Consistency (C):** Every read receives the most recent write or an error.
  If A writes a=5 then B will replicate data to DB node C. So, when read happens using C then it should be same (a=5).
- **Availability (A):** Every request should receive a (non-error) response, without guarantee that it contains the most recent write.
- **Partition Tolerance (P):** The system continues to operate despite arbitrary partitioning due to network failures.
  If for example, there happens a communication breakage during replication. Application can still query (request) the server and get a response back. Basically system is up.
- In real work we don't wanna trade-off (**P**). In the presence of a network partition, a distributed system must choose between consistency and availability.

→ Microservices

What are Microservices?

Microservices is an architectural style where an application is broken into smaller, independent services that work together.

Why it matters today:

As apps grow more complex, this style helps teams move faster, scale better, and deploy independently.

Monolithic vs Microservices:

Monolithic Architecture: One big codebase; all features are tightly connected.

Microservices Architecture: Each feature/module is a separate service that can be updated or deployed on its own.

❌ Disadvantages of Monolithic Architecture

1. **Scalability Issues:**

   If one part of the app gets heavy traffic, the whole system might need to scale unnecessarily, increasing load times and costs.

2. **Hard to Maintain & Deploy:**

   Even a small change means redeploying the whole app — risky and time-consuming.

3. **Tight Coupling:**

   Components depend too much on each other; a change in one area can break others.

✅ **Advantages of Microservices**

1. **Service Division:**

   Breaks a big app into smaller parts (like user service, product service, etc.) — each with its own purpose.

2. **Scalability & Flexibility:**

   You can scale only the services you need — for example, just the login service during heavy traffic.

3. **Independent Deployment:**

   One team can deploy updates to a service without affecting the whole app.

⚠️ **Challenges of Microservices**

1. **Service Decomposition:**

Deciding *how* to split services can be tricky. If done poorly, services might talk to each other too much.

2. **Transactions Across Services:**

   Keeping data consistent across multiple services (like when placing an order) can get complex.

3. **Monitoring Multiple Services:**

   More services = more logs, more things to track, harder to debug.

🔁 Integration Patterns

- **Communication Between Services:**

  Could be REST APIs, message queues, or event-driven architecture (like using Kafka).

- **Database Management:**

  Typically, each service has its own database to ensure loose coupling — but this can make querying data across services harder.

🌟 Best Practices

1. **Understand Business Capabilities:**

   Design services based on what the business needs, not just technical boundaries.

2. **Keep Services Small:**

   Small enough to manage easily, but big enough to be useful on their own.

3. **Monitoring & Troubleshooting:**

   Use centralized logging, distributed tracing, and monitoring tools (like Prometheus, Grafana, or ELK stack) to keep track of everything.

🚀 Phases in a Microservices Journey

When a team moves from monolith to microservices, it typically goes through several phases:

1. **Understanding the Monolith**

- Analyze the existing monolithic application.
- Identify tightly coupled modules and dependencies.
- Understand how features are grouped together.

2. **Service Identification & Decomposition**
    - Find logical boundaries for splitting.
    - Choose how to break it up — either by business functions or subdomains (more on that below).
3. **Building Independent Services**
    - Develop services that can run, deploy, and scale independently.
    - Each service should have its own logic and database.
4. **Implementing Communication Mechanisms**
    - Decide how services talk to each other — REST, gRPC, messaging (Kafka, RabbitMQ, etc.)
5. **Deploying and Monitoring**
    - Use CI/CD pipelines for deployment.
    - Set up tools for logging, monitoring, and tracing service calls.
6. **Evolving and Scaling**
    - Gradually migrate more parts of the monolith.
    - Improve, refactor, and scale individual services as needed.

🧩 Decomposition Patterns

These are strategies or "ways" to break a large system into microservices:

1. Decomposition by Business Capability :

Imagine you are building an **E-commerce Platform** like **Amazon**.

You would divide your microservices based on **business capabilities** (what the business needs functionally):

- **User Service** – handles user registration, login, profile management.

- **Product Catalog Service** – manages products, categories, and product search.
- **Order Service** – handles shopping carts, checkout, order placement.
- **Payment Service** – manages payment processing, refunds.
- **Shipping Service** – manages delivery, tracking shipments.
- **Notification Service** – sends emails, SMS, push notifications.

👉 Here, each service matches a **core business function**.

This way, different teams can work independently on users, payments, shipping, etc.

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2. Decomposition by Subdomains (Domain-Driven Design - DDD):

You apply **subdomain decomposition** based on **bounded contexts** within the domain:

- **Core Subdomain** (most important to business):
  - **Ordering Subdomain** → Manages order lifecycle (cart → checkout → order placed).
- **Supporting Subdomain** (supports the core but isn't core itself):
  - **Inventory Subdomain** → Tracks stock levels and warehouse data.
  - **Payments Subdomain** → Deals with payment authorization and processing.
  - **Shipping Subdomain** → Organizes delivery and logistics.
- **Generic Subdomain** (common tasks, can even use third-party tools):
  - **Authentication Subdomain** → Manages login, registration (could use something like OAuth/Identity Providers).

👉 Here, decomposition happens based on **domain knowledge**, focusing on how different parts of the business work internally, not just services.

Bounded contexts are isolated to prevent confusion between, say, payment logic and order logic.

→ Strangler Pattern, CQRS, SAGA Pattern

Strangler Pattern is used when we are refactoring our code from monolithic to microservices. We start creating services and we test those created services by sending traffic to them using controller like 10% to microservice and check if they are performing well. And at last we sends the 100% traffic to microservice and strangling the monolithic part.

Data Management in Microservice -

1. **Database for each individual microservice**
   We can scale only a single service and increase only the database of that service. Modification is easy in this because the data does not impact the other service database.

   Issues:
   Easy part of Shared database is hard for this.

2. **Shared Database**
   Query Join and maintaining transactional property (ACID) is easy in this.

   Issues:
   In shared database, if we want to scale one service we have to increase the capacity of whole database. If we want to modify our database, so we have to check if adding or deleting anything in database impact any other service.

SAGA is used for Transactional property (ACID property) because we can maintain the ACID property in the individual database. So SAGA makes it easier for us to maintain the Transactional property in all of the database that if the request need all the service together like (Order will next go to the Payment Service and its database) that was hard for individual database.
One service publish an event and other service listen that event and check if there was failure then it will send failure event back. So it will rollback.

CQRS (Command Query Request Segregation) help in query JOIN like tables in different database. It creates a view which have both the tables in this and then can JOIN them together.