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What is System Design?

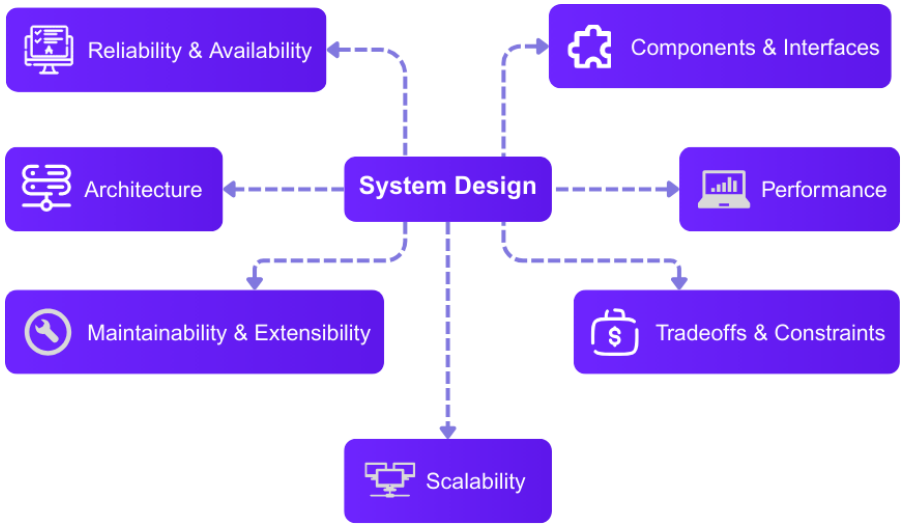
System design is the process of **defining the architecture, components, and interactions of a system** to satisfy specified requirements while meeting goals such as scalability, reliability, performance, and maintainability. It's the blueprint that guides how software or a system works end-to-end.

In simpler terms:

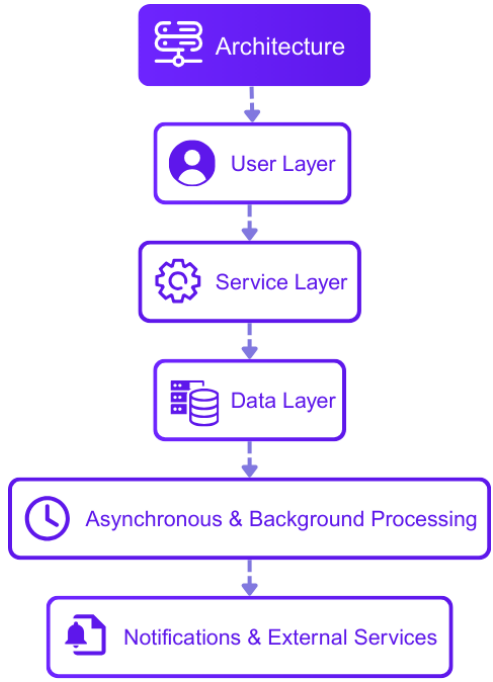
System design is about answering the question:

"How should this system be built so it can handle real-world challenges at scale?"

Key Aspects of System Design



Architecture

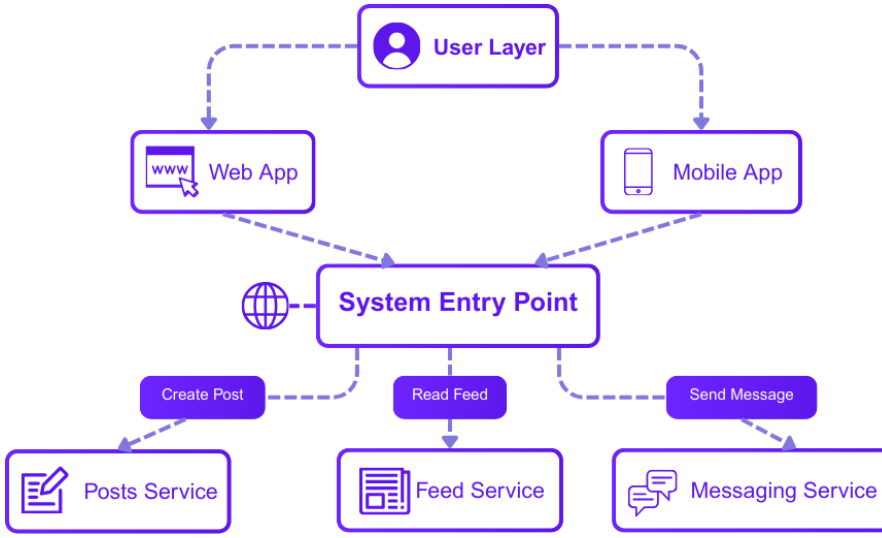


Architecture is the big-picture layout of a system. It shows how all the pieces fit together and communicate with each other.

Think of it like the blueprint of a house:

- Rooms, plumbing, and wiring need to be in the right place for everything to work. In software, good architecture ensures the system runs smoothly and can grow over time.

User Layer



The user interacts with the system through a client app, either web or mobile. The system receives requests like creating posts, reading feeds, or sending messages, and directs them to the appropriate services.

Users can perform actions like:

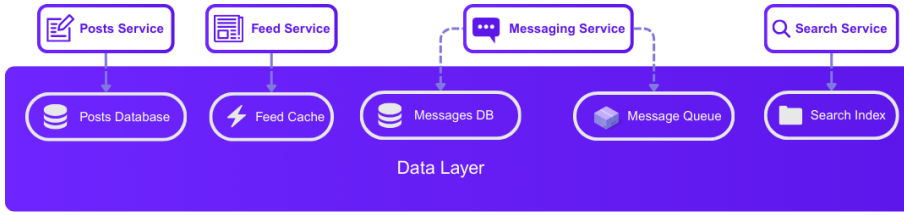
- Posting new content → goes to the **Posts Service**
- Viewing their timeline → goes to the **Feed Service**
- Sending messages → goes to the **Messaging Service**

Service Layer

This layer contains the **main services** that handle specific responsibilities:

- **Posts Service:** Creates and stores posts in a database.
- **Feed Service:** Aggregates posts from friends and delivers timelines. Often uses a cache to speed up repeated requests.
- **Messaging Service:** Handles sending and receiving private messages. Uses a message queue to ensure reliable delivery.
- **Notifications Service:** Sends alerts about likes, comments, and mentions.
- **Search Service:** Enables searching posts, users, or hashtags efficiently using a search index.

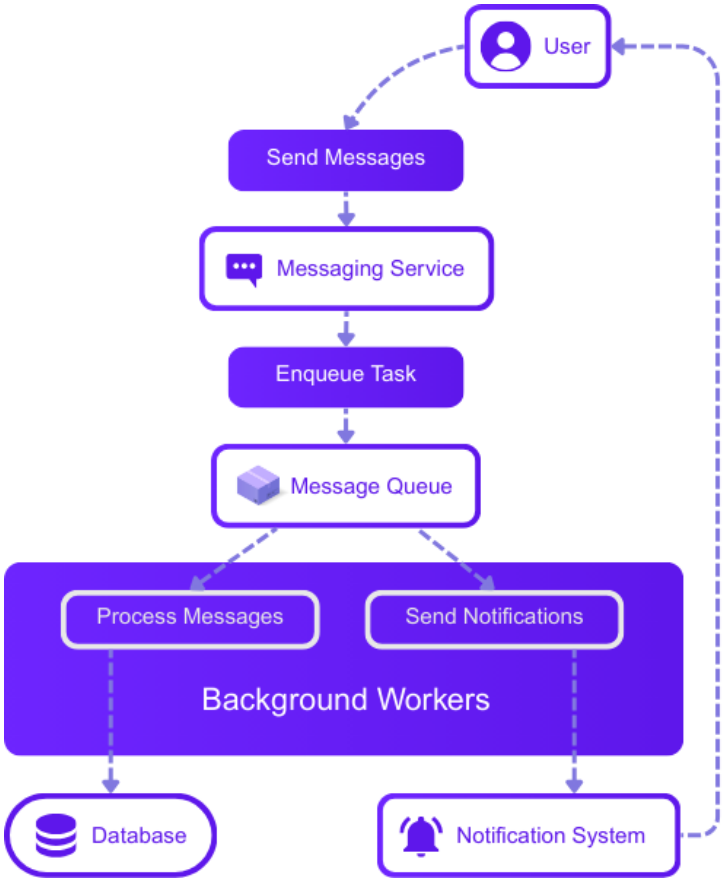
Data Layer



Services use different data storage options based on their needs:

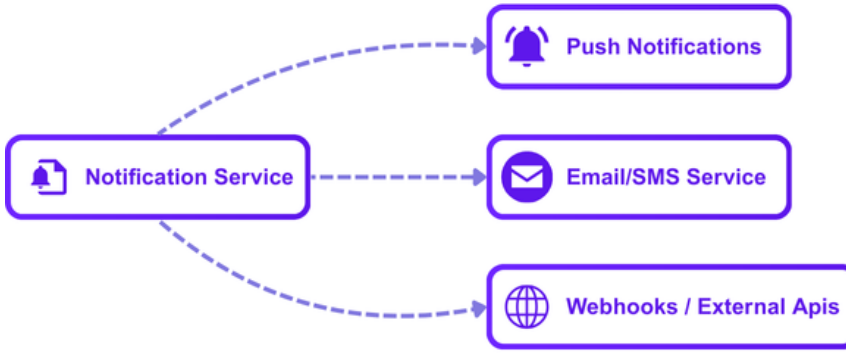
- **Databases:** Persist important data like posts or messages.
- **Caches:** Store frequently accessed data for faster responses, e.g., feed cache.
- **Search Index:** Optimized for search queries to quickly find posts, users, or hashtags.

Asynchronus & Background Processing



Some tasks, like sending messages or notifications, are handled asynchronously using queues. This improves reliability and system performance, ensuring users don't experience delays.

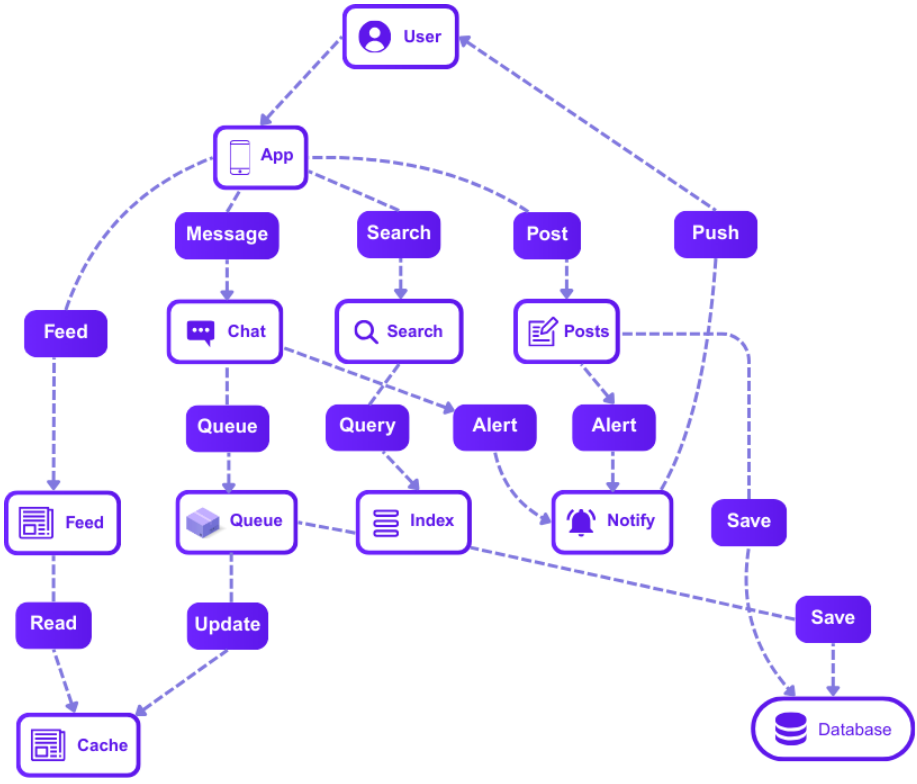
Notifications & External Services



External-facing services like push notifications deliver alerts in real time. They often sit at the edge of the system and interact with the core services.

Putting it together

The architecture ensures smooth communication between users, services, databases, caches, and external systems. Each service is independent but connected, making it easier to scale, maintain, and improve the system over time.



Components & Interfaces

Components are the building blocks of a system. Breaking a system into smaller, manageable parts makes it easier to design, maintain, and scale. Interfaces define how these components communicate with each other, like roads connecting different parts of a city. Together, they make sure each part does its job while working seamlessly with the rest of the system.

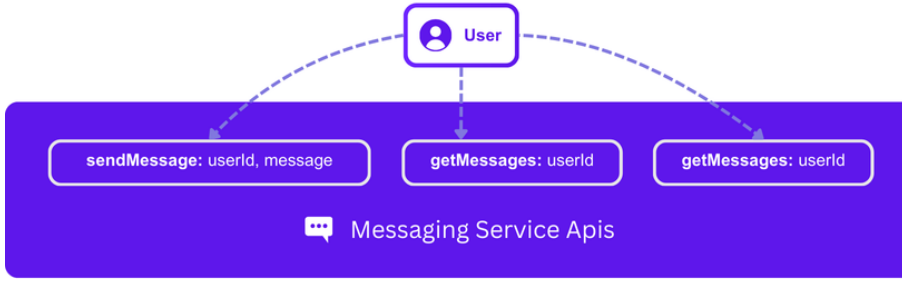
- Makes the system easier to understand and maintain
- Helps isolate failures so one part does not bring down the entire system
- Allows independent development of components by different teams
- Improves reusability because components can be used in multiple places

Example: Messaging Service

Suppose you are designing a messaging system.

Here is how components and interfaces might look:

APIs (Interfaces):



- `sendMessage(userId, message)` sends a message to a user
- `getMessages(userId)` retrieves the last N messages for a user
- `markAsRead(messageId)` marks a message as read

These APIs define how other services or clients interact with the messaging service.

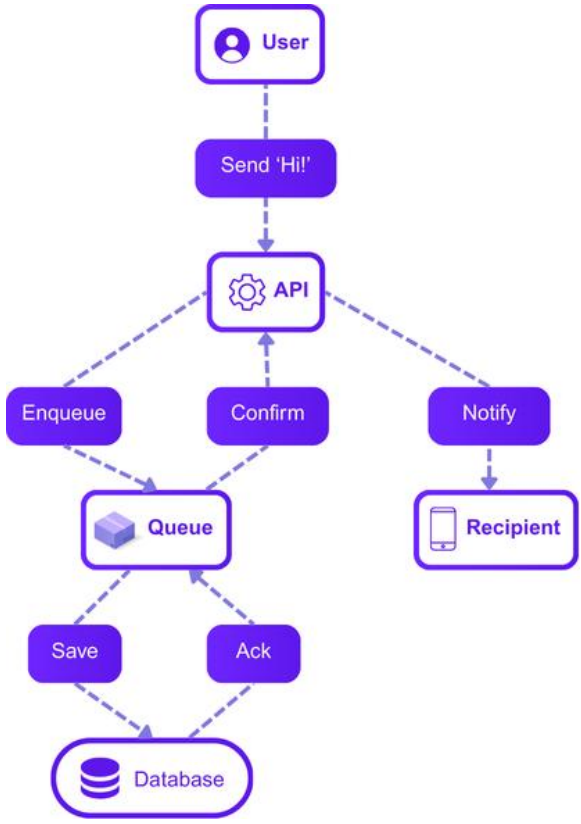
Components

- **Message Queue (e.g., Kafka)** ensures messages are delivered reliably and asynchronously
- **Database (e.g., PostgreSQL)** stores messages persistently
- **Notification System** sends alerts for unread messages to recipients
- **Service Layer** contains the logic for validating, storing, and retrieving messages

How They Work Together?

- A user sends a message using `sendMessage()`
- The message is placed in the **Message Queue** for reliable delivery
- The **Database** stores the message
- The **Notification System** alerts the recipient about the new message
- The recipient retrieves messages using `getMessages()`

This separation allows the system to continue working even if one part fails.



- Consider possible failure points. For example, what happens if the database crashes, the queue is full, or a notification fails
- Implement graceful error handling and retries to make the system resilient
- Keep APIs simple and consistent so other components or clients can use them easily
- Document each component and interface clearly to make scaling and onboarding easier
- Design for future extensibility, such as adding message reactions or read receipts without changing core logic

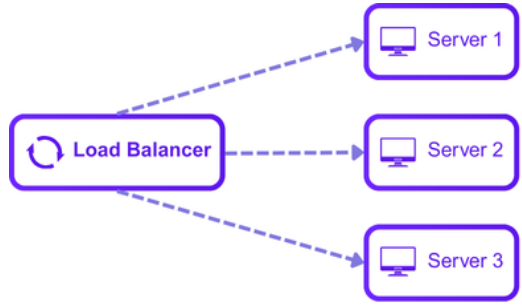
Scalability

Scalability is the ability of a system to handle growth in users, traffic, or data without breaking or slowing down. A scalable system performs well whether it has 100 users or 1 million. Designing for scalability ensures your system can grow over time without needing a complete rewrite.

- Prevents crashes or slowdowns as the number of users increases
- Reduces the need for frequent major redesigns
- Improves user experience by keeping response times fast
- Makes it easier to plan for future growth

Types of Scaling

Vertical Scaling:



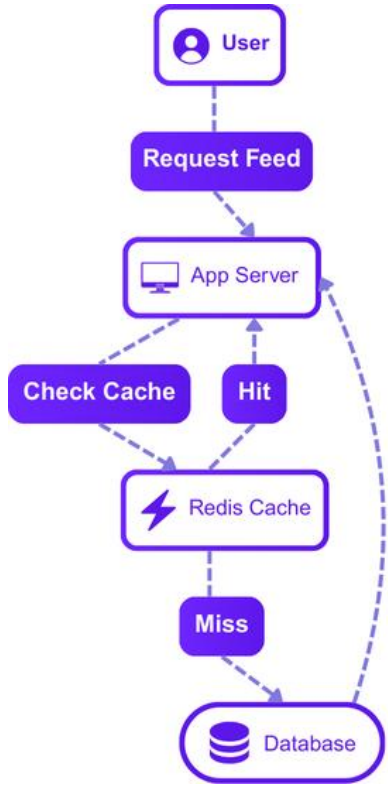
Vertical scaling, or scaling up, means upgrading your existing servers to be more powerful. For example, adding more CPU, RAM, or storage to a single server. This is simple to implement but has limits because there is a maximum capacity for a single machine.

Horizontal Scaling:

Horizontal scaling, or scaling out, means adding more servers to handle increased load. For example, running multiple instances of your web or database servers behind a load balancer. This approach is more flexible and allows the system to grow almost indefinitely, but it requires careful management of data consistency and distribution.

Scalability Techniques

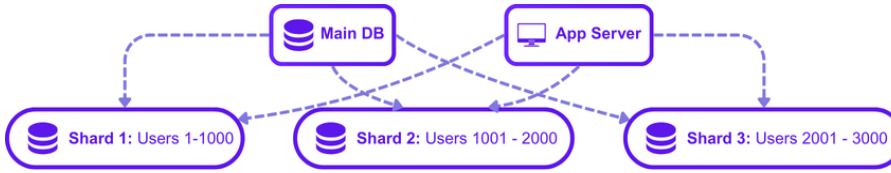
Caching:



Store frequently accessed data in memory for faster access.

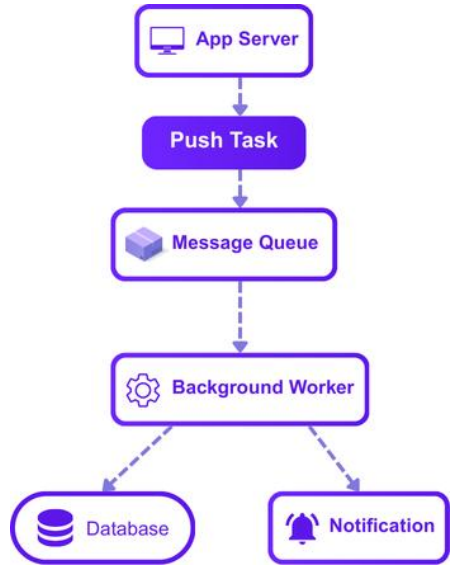
Example: Using Redis to cache user feeds or search results.

Database Sharding: Split a database into smaller, independent pieces (shards) to distribute load.



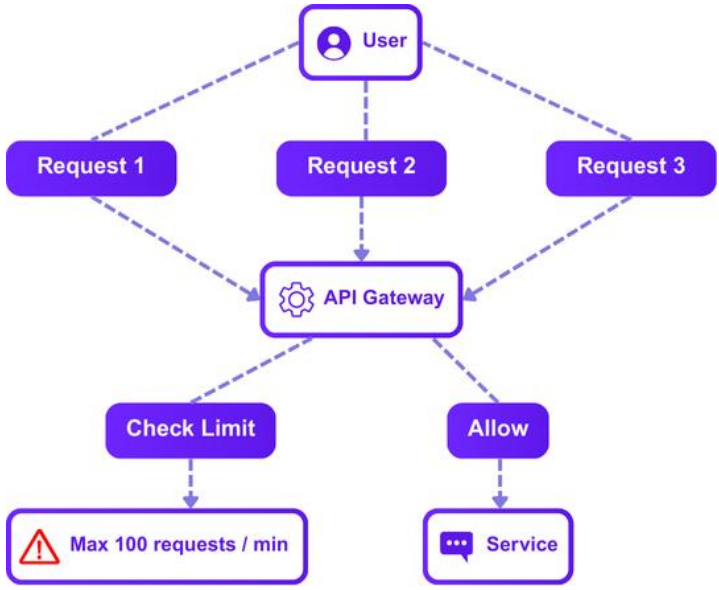
Example: Each shard stores messages for a range of user IDs.

Asynchronous Processing: Use queues and background workers to handle tasks that do not need to happen immediately.



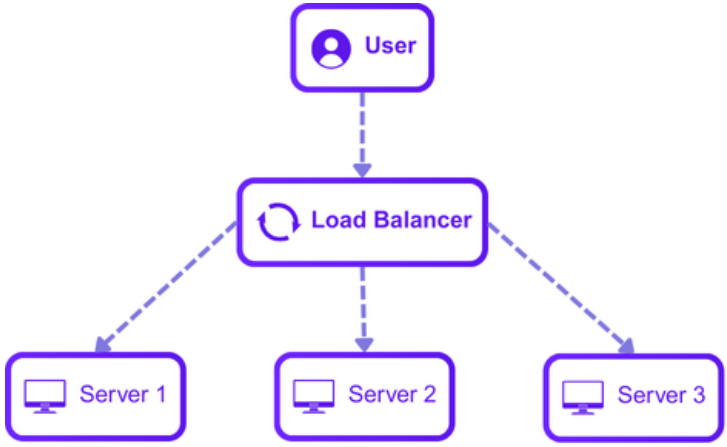
Example: Sending notifications after a message is saved in the database.

Rate Limiting: Control how many requests a user or service can make to prevent overloading the system.



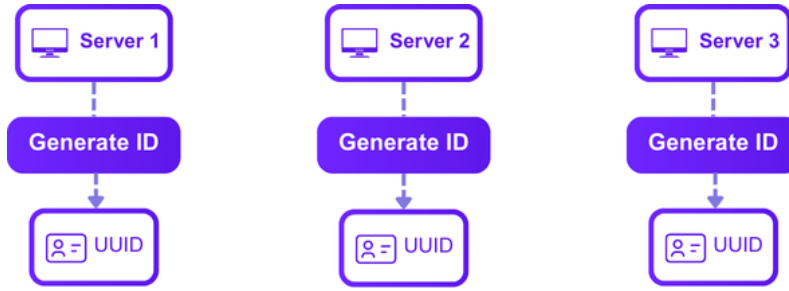
Example: Allowing each user to send 100 messages per minute.

Load Balancing: Distribute incoming requests across multiple servers to prevent any single server from being overwhelmed.



Example: Using Nginx or AWS ELB to distribute traffic across web servers.

Designing Unique ID Generators: Generate IDs in a way that avoids conflicts across multiple servers.



Example: Using UUIDs or Snowflake IDs for messages or posts.

Tips:

- **Start simple:** scale vertically first if your traffic is low, then scale horizontally as you grow.
- **Combine multiple techniques:** caching, asynchronous processing, and load balancing often work best together.
- Monitor your system to identify bottlenecks before they become critical.
- Always plan for **both current load and future growth**.

Reliability & Availability

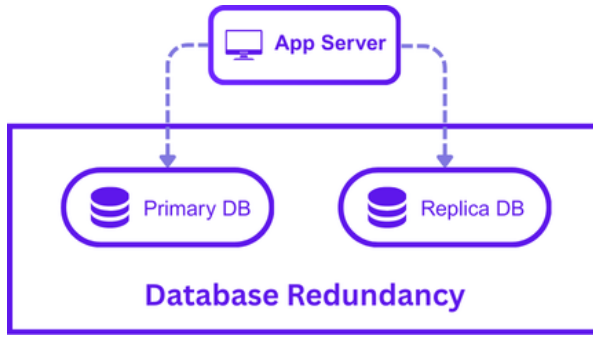
Reliability is the ability of a system to operate correctly and consistently over time. Availability is the measure of how often a system is accessible and functional for users. Together, they ensure that users can trust your system to work as expected, even when things go wrong.

- Prevents downtime that frustrates users or impacts business.
- Ensures critical data is not lost during failures.
- Builds trust and confidence in the system.

Reduces the impact of unexpected hardware or software failures.

Key Concepts

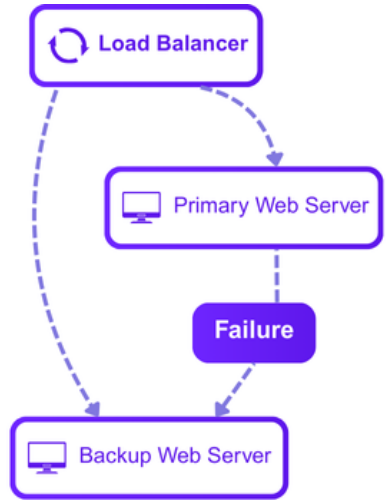
Redundancy:



Duplicate critical components so that if one fails, another can take over.

- **Example:** Two database servers in a primary/replica setup.

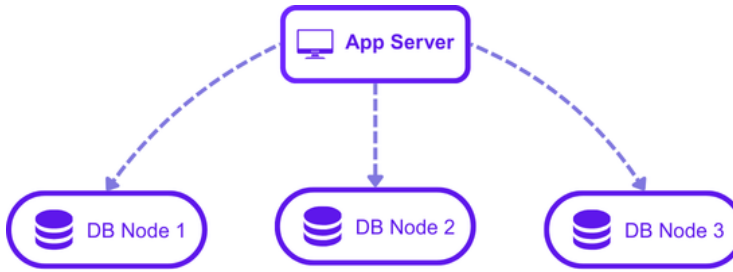
Failover:



Automatically switch to a backup component when the main one fails.

- **Example:** If the primary web server crashes, traffic is redirected to a standby server.

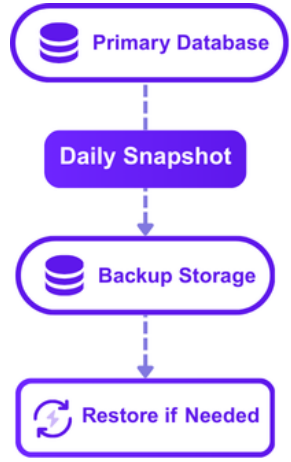
Replication:



Keep copies of data in multiple locations to prevent data loss and improve read performance.

- **Example:** Replicating user messages across multiple database nodes.

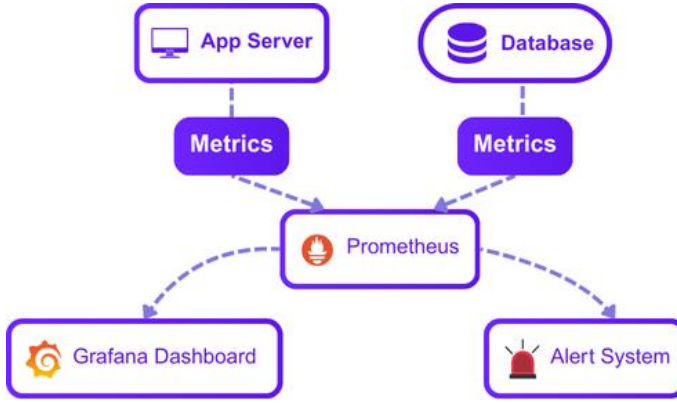
Backups:



Regularly store copies of data to recover from failures or corruption.

- **Example:** Daily snapshots of the posts database.

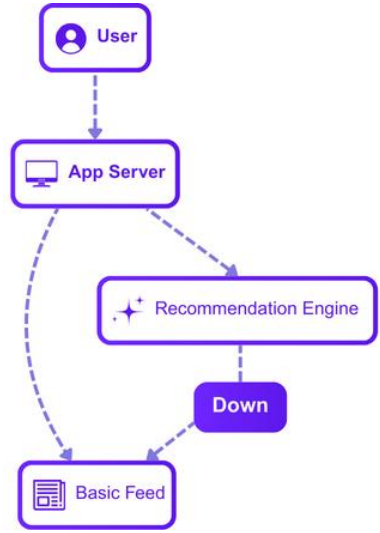
Health Checks & Monitoring:



Continuously monitor system components and automatically alert if something goes wrong.

- **Example:** Using Prometheus or Grafana to track server uptime and response times.

Graceful Degradation:



Ensure the system continues to function in a reduced capacity if some components fail.

- **Example:** If the recommendation engine is down, the feed still shows basic posts.

Practical Tips:

- Design for **no single point of failure**. Every critical component should have a backup or replica.
- Test failover mechanisms regularly to ensure they work when needed.
- Combine **replication, redundancy, and monitoring** for maximum reliability.
- Document recovery procedures so your team can respond quickly during incidents.
- Consider **user experience** during failures: inform users of limited functionality instead of crashing completely.

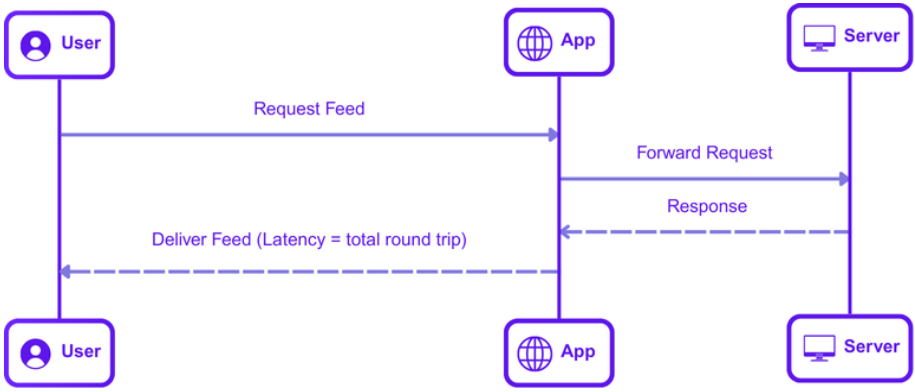
Performance:

Performance measures how fast and efficiently a system responds to requests and processes data. A high-performance system delivers results quickly, handles many requests at once, and provides a smooth experience for users.

- Users expect fast responses, especially in social media, messaging, or e-commerce apps.
- Poor performance can lead to frustration, lost engagement, or lost revenue.
- Efficient systems use resources wisely, reducing costs.
- Good performance supports scalability and reliability.

Key Concepts

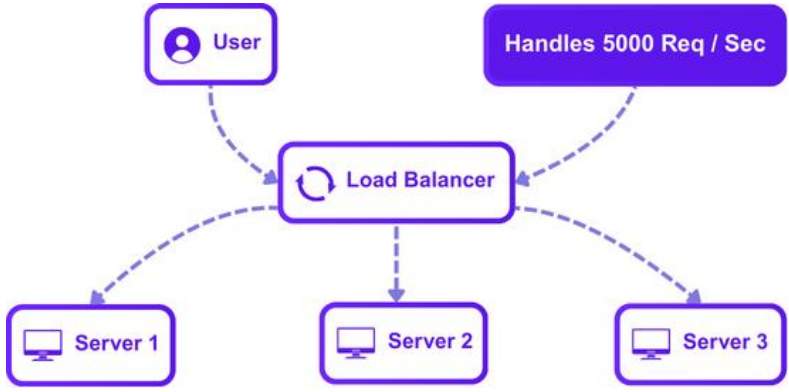
Latency:



The time it takes for a request to travel from the client to the server and back.

- **Example:** How long it takes to load a user's feed after opening the app.

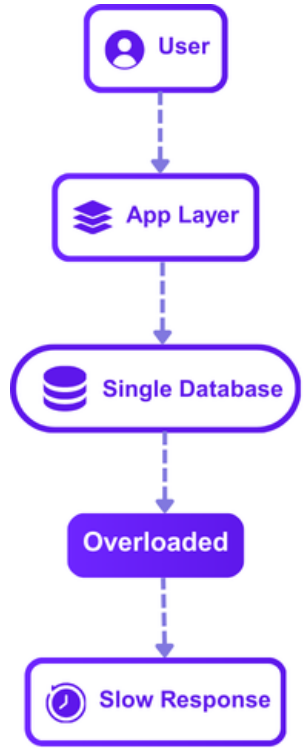
Throughput:



The number of requests a system can handle in a given period.

- **Example:** A server can process 5000 messages per second.

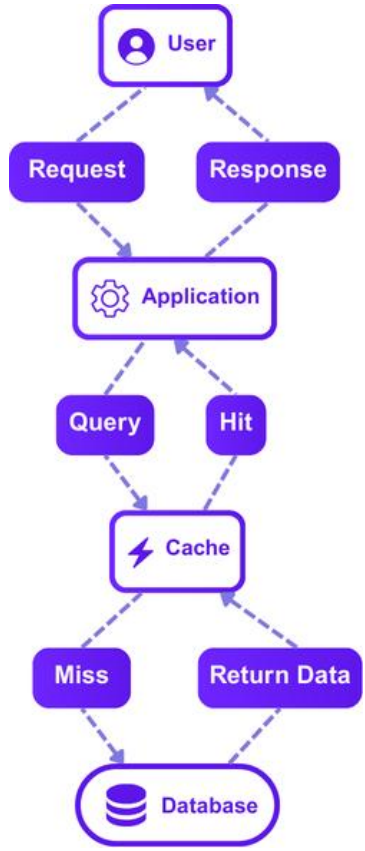
Bottlenecks:



Points in the system that slow down performance.

- **Example**: A single database server receiving too many requests at once.

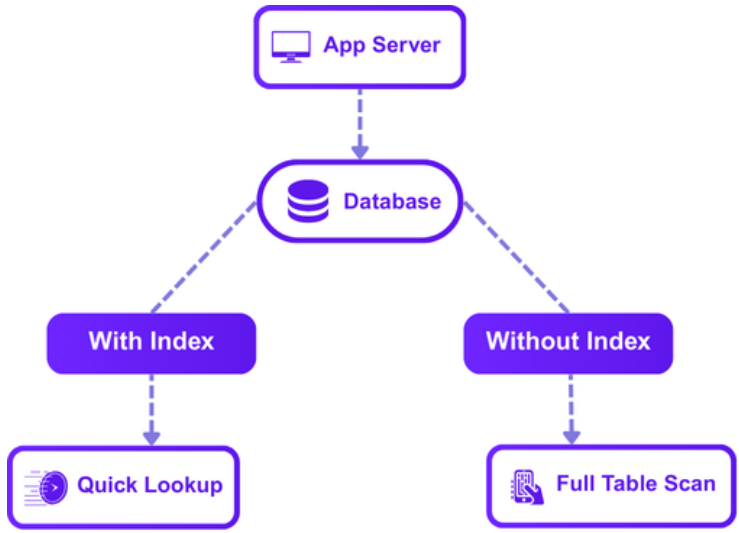
Caching:



Store frequently accessed data in memory to reduce load on databases.

- **Example:** Using Redis to cache user feeds.

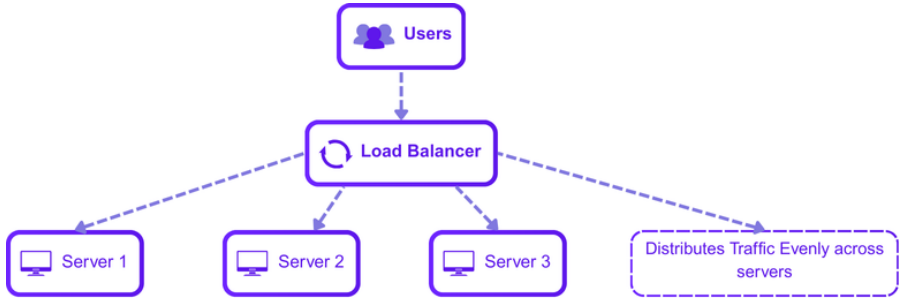
Database Indexing:



Optimize database queries by creating indexes on frequently queried fields.

- **Example**: Indexing usernames to quickly find users in a search.

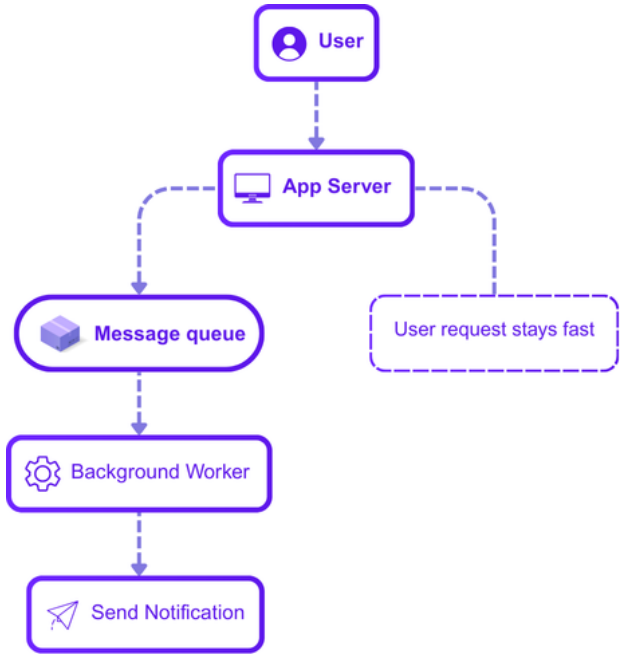
Load Balancing:



Distribute incoming requests across multiple servers to prevent any one server from becoming overwhelmed.

- **Example:** Using Nginx or AWS ELB to evenly distribute traffic.

Asynchronous Processing:



Handle long-running tasks in the background to keep the system responsive.

- **Example**: Sending email notifications via a message queue instead of during user requests.

Practical Tips:

- Identify and monitor **latency hotspots** in your system regularly.
- Use caching and indexing strategically to reduce repetitive computation and database load.
- Implement load balancing for critical services to prevent a single server from becoming a bottleneck.
- Process tasks asynchronously whenever possible to keep user-facing operations fast.
- Test system performance under realistic loads to identify potential bottlenecks before they affect users.

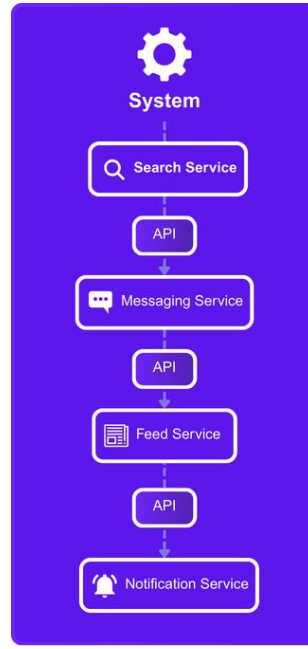
Maintainability & Extensibility

Maintainability refers to how easy it is to update, fix, or improve a system over time. Extensibility is the system's ability to add new features or expand functionality without major redesigns. Together, they ensure the system can evolve with changing requirements and continue to meet user needs.

- Reduces the cost and effort of fixing bugs or adding features.
- Makes it easier for new team members to understand the system.
- Improves system longevity and adaptability.
- Supports faster delivery of updates and new functionality.

Key Principles

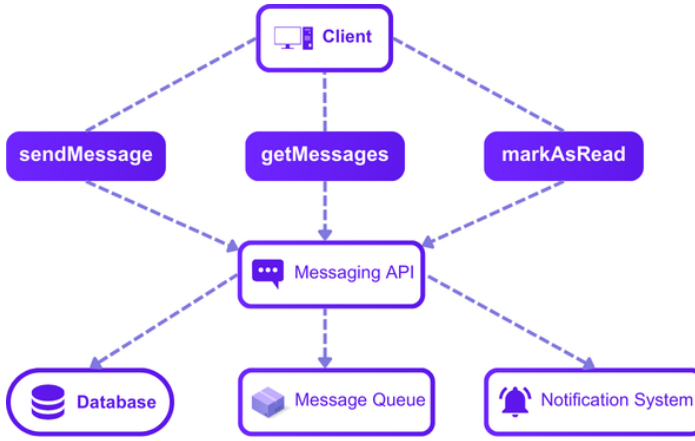
Modular Design:



Break the system into independent modules with clear responsibilities.

- **Example:** Separate services for messaging, feeds, notifications, and search.

Clear APIs:



Define consistent and well-documented interfaces between components.

- **Example:** A messaging service exposes **sendMessage()** and **getMessages()** methods with clear input/output rules.

Code Readability:

Write clean, well-structured code with descriptive names.

- **Example:** Functions and classes clearly indicate their purpose and behavior.

Documentation:

Maintain up-to-date documentation for code, APIs, and system architecture.

- **Example:** Use README files, diagrams, and API specifications for reference.