SYSTEM Design I

Problem statement:

Produce a high-level followed by a low-level drawing of the structure for System Design Architecture for a high throughput volume of millions of requests with real-time data systems for the following vertical services: Pricing, SEARCH, Booking and Reviews for the Backend, Frontend, Database and middlewares. Consider the following key pillars (Scalability, reliability, flexibility, observability and security) in the system design - good architecture - scale, failure, performance, and so on. Weigh up different choices of technologies to use. Efficiency and scalability: What kind of data structures do you want to use? Which size estimations do you put up front? How will you know that it's working as intended once it's in production? What sort of checks and tests will you perform? Begin by listing the types of architectural designs that exist for consideration for Frontend and Backend. Consider the following in as part of the Architecture and where they manifest: API Gateway, Vertical Services(Pricing, Booking, SEARCH, Reviews), Services communication, Data Layer, Configuration Management, Loggin and Monitoring, Authentication and Authorisation, Error Handling, CI/CD, Containerisation and Orchestration, Reporting Service (Prometheus, ELK). Consider Challenges like ensuring message reliability, managing schema evolution, and maintaining consistent processing during service failures.

Designing a high-throughput system capable of **handling millions of real-time requests** for services like Pricing, Search, Booking, and Reviews requires a robust architecture that emphasizes scalability, reliability, flexibility, observability, and security (**SREFOS**). Below is a structured approach to this system design, including high-level and low-level architectural considerations, technology choices, and best practices.

1. Architectural Design Patterns for Consideration

Frontend Architectures:

- **Monolithic Architecture:** A single unified codebase. Simpler but less scalable and flexible.

- **Micro-Frontend Architecture:** Decomposes the frontend into smaller, manageable pieces corresponding to different services. Enhances scalability and independent deployment.

Backend Architectures:

- **Monolithic Architecture:** All backend services are part of a single application. Easier to develop initially but challenging to scale and maintain.

- **Microservices Architecture:** Each service (Pricing, Search, Booking, Reviews) is developed, deployed, and scaled independently. Offers better scalability and fault isolation.

- **Event-Driven Architecture:** Services communicate via events, promoting loose coupling and real-time processing. Suitable for real-time data systems.

- **SOA**

2. High-Level Architecture

The high-level architecture integrates various components to ensure seamless interaction between users and services.

Components:

- **API Gateway:** Serves as a **single entry point** for all client requests, routing them to appropriate services. Handles concerns like rate limiting, authentication, and request logging.

- **Vertical Services:**
    - **Pricing Service:** Manages pricing information and calculations.
    - **Search Service:** Handles search queries and retrieval of relevant data.
    - **Booking Service:** Manages reservations and booking transactions.
    - **Reviews Service:** Handles user reviews and ratings.
- **Service Communication:** Facilitated through synchronous (REST/gRPC) and asynchronous (message queues) methods.

- **Data Layer:** Comprises databases and data storage solutions for each service, ensuring data integrity and availability.

- **Configuration Management:** Centralised management of service configurations to maintain consistency across environments.

- **Logging and Monitoring:** Implements observability tools to monitor system health, **and** performance and detect anomalies.

- **Authentication and Authorization:** Ensures secure access to services and data, managing user identities and permissions.

- **Error Handling:** Standardized mechanisms to handle exceptions and failures gracefully, ensuring system resilience.

- **CI/CD Pipeline:** Automates the build, test, and deployment processes to ensure rapid and reliable releases.

- **Containerization and Orchestration:** Uses containers to package services and orchestration tools to manage deployment, scaling, and operations.

- **Reporting Service:** Aggregates logs and metrics for analysis, using tools like Prometheus and ELK stack for monitoring and alerting.

High-Level Architecture Diagram:

```
+-------------------+
|                   |
|   API Gateway     |
|                   |
+--------+----------+
         |
+--------+----------+
|             |
| Service Mesh     |
|             |
+--------+----------+
         |
+--------+----------+
|                   |
| Vertical Services|
|                   |
+--------+----------+
      |
+--------+----------+
|                   |
|   Data Layer    |
|                   |
+-------------------+
```

3. Low-Level Architecture

The low-level architecture delves into the specifics of each component, detailing interactions, data flow, and technology choices.

API Gateway:

- **Responsibilities:**
  - Routing requests to appropriate services.
  - Load balancing incoming traffic.
  - Implementing security measures like SSL termination and request authentication.
  - Rate limiting to prevent abuse.
- **Technology Choices:**
  - **Kong:** An open-source API gateway with a rich plugin ecosystem.
  - **NGINX:** High-performance web server and reverse proxy.
  - **AWS API Gateway:** Managed service for creating and managing APIs.

Vertical Services:

- **Design:**
  - Each service is a microservice with its own codebase, database, and deployment pipeline.
  - Services communicate over well-defined interfaces (APIs).
- **Technology Choices:**
  - **Programming Languages:**
    - **Node.js:** Suitable for I/O-bound services like Search.
    - **Python:** Ideal for data-intensive services like Pricing.
    - **Java:** Preferred for transaction-heavy services like Booking.
  - **Frameworks:**
    - **Express.js** for Node.js.
    - **Spring Boot** for Java.
    - **Django** for Python.

Service Communication:

- **Synchronous Communication:**
  - **REST:** Simple and widely adopted.
  - **gRPC:** High-performance, suitable for internal service communication.
- **Asynchronous Communication:**
  - **Message Queues:**
    - **RabbitMQ:** Reliable message broker.
    - **Apache Kafka:** Suitable for high-throughput, real-time data streaming.

Data Layer:

Databases:

- **Relational Databases:**
    - **PostgreSQL:** For transactional data like bookings and pricing that need ACID compliance.
    - **MySQL:** Optional for horizontal scalability with clustering (e.g., Percona or Galera Cluster).
- **NoSQL Databases:**
    - **MongoDB:** For schema-less data, e.g., user-generated reviews and logs.
    - **Cassandra:** High availability and linear scalability for distributed data storage.
- **Search Engine Database:**
    - **Elasticsearch:** Optimized for text search queries used in the Search service.
- **Caching Layer:**
    - **Redis:** Fast in-memory key-value storage for caching frequently accessed data.
    - **Memcached:** Lightweight and optimized for fast lookups.
- **Message Queues:**
    - **Apache Kafka:** Distributed streaming for event-driven systems, ensuring reliable and scalable communication.
    - **RabbitMQ:** For lightweight messaging in services requiring ordered processing.

Configuration Management:

- **Consul or etcd:** Centralized storage for configurations.
- **Kubernetes ConfigMaps and Secrets:** Manage sensitive and non-sensitive configurations in containerized systems.

Logging and Monitoring:

- **Log Aggregation:**
    - **ELK Stack (Elasticsearch, Logstash, Kibana):** Logs collection, storage, and visualization.
    - **Fluentd:** Unified log processing and forwarding.
- **Monitoring Tools:**
    - **Prometheus:** Monitoring metrics and alerts.
    - **Grafana:** Data visualization.
    - **Jaeger/Zipkin:** Distributed tracing for debugging service interactions.

Authentication and Authorization:

- **OAuth2.0 and OpenID Connect:** For user identity management.
- **Keycloak/Okta:** Identity provider and Single Sign-On solutions.
- **JSON Web Tokens (JWT):** Token-based authentication for secure API requests.

Error Handling:

- **Retry Mechanisms:** Implement exponential backoff for transient errors.
- **Dead Letter Queues (DLQ):** Handle unprocessable messages in Kafka or RabbitMQ.
- **Fallback Strategies:** Circuit breaker pattern using tools like Resilience4j or Hystrix.

CI/CD Pipeline:

- **Jenkins/GitLab CI/CD:** Build, test, and deploy pipelines.
- **Docker and Kubernetes:** Containerization and orchestration.
- **ArgoCD or Spinnaker:** Continuous delivery for Kubernetes.

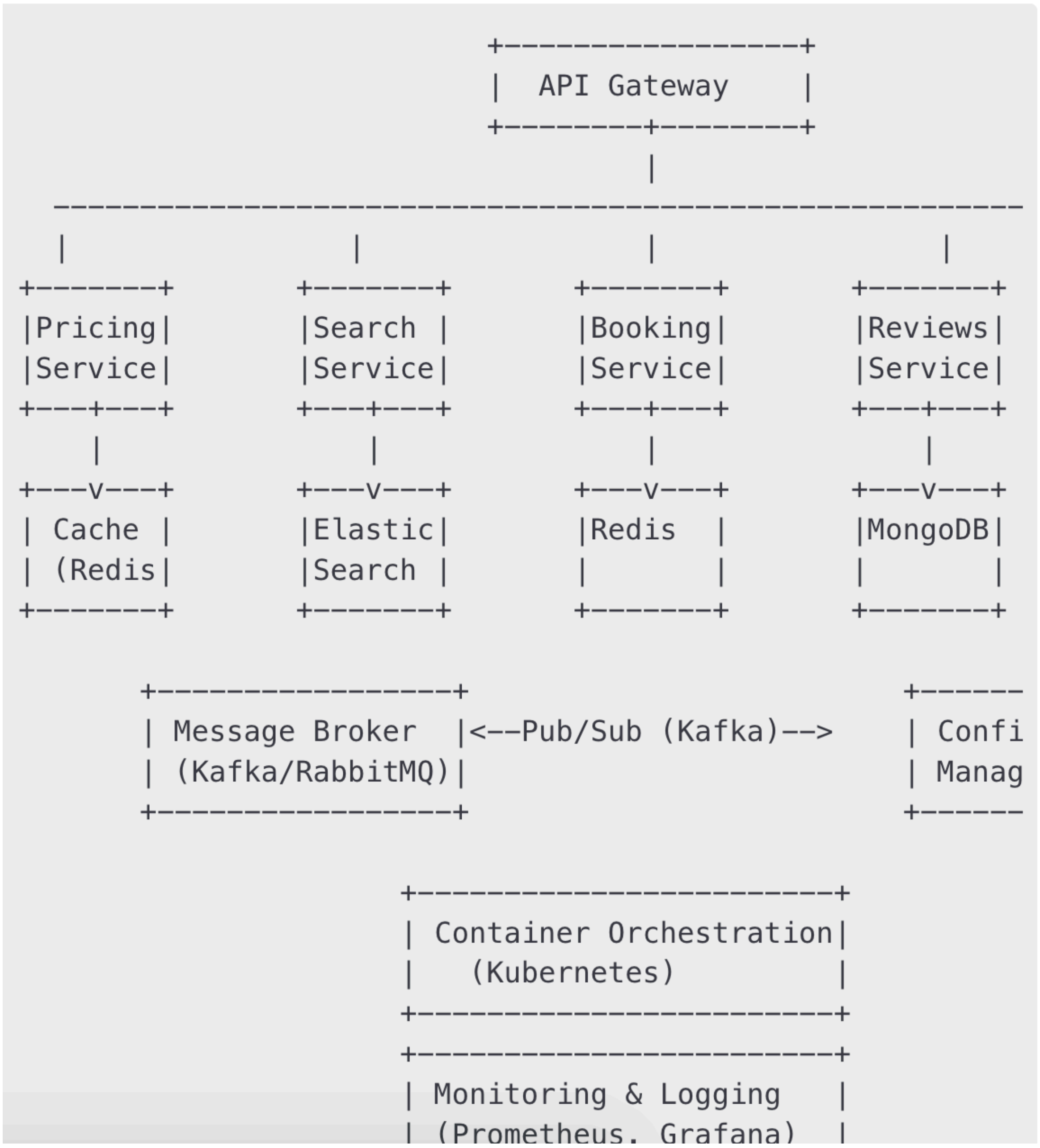
Containerization and Orchestration:

- **Docker:** Lightweight containers for services.
- **Kubernetes:** Manages containerized services, enabling scalability and fault tolerance.
- **Helm Charts:** For defining, installing, and upgrading Kubernetes applications.

Reporting Service:

- **Prometheus:** Metrics collection for observability.
- **Grafana Dashboards:** Real-time visual analytics and alerts.
- **ELK Stack:** Aggregates logs and errors for auditing and compliance.

Low-Level Architecture Diagram



```
                          +-----------------+
                          |  API Gateway    |
                          +--------+--------+
                                   |
  ------------------------------------------------------
  |               |                |                |
+-------+      +-------+      +-------+      +-------+
|Pricing|      |Search |      |Booking|      |Reviews|
|Service|      |Service|      |Service|      |Service|
+---+---+      +---+---+      +---+---+      +---+---+
    |              |              |              |
+---v---+      +---v---+      +---v---+      +---v---+
| Cache |      |Elastic|      |Redis  |      |MongoDB|
| (Redis|      |Search |      |       |      |       |
+-------+      +-------+      +-------+      +-------+

       +-----------------+                      +------
       | Message Broker  |<--Pub/Sub (Kafka)-->  | Confi
       | (Kafka/RabbitMQ)|                      | Manag
       +-----------------+                      +------

                     +-------------------------+
                     | Container Orchestration|
                     |   (Kubernetes)          |
                     +-------------------------+
                     +-------------------------+
                     | Monitoring & Logging    |
                     | (Prometheus, Grafana)   |
```

Key Pillars (System Design)

4. Efficiency and Scalability Considerations

1. **Data Structures:**
   - Use **B-Trees** and **Hash Indexes** for database indexing (**B-Trees** are balanced tree data structures used for ordered data storage and efficient range queries, while **Hash Indexes** use hash tables for fast, exact-match lookups but do not support range queries).
   - Utilize **Bloom Filters** in search services for **fast lookups**.
   - Implement **Trie Structures** for **autocomplete** and **search suggestions.**
2. **Size Estimations:**
   - Plan database sharding for horizontal scaling from the start.
   - Estimate **peak loads** using **traffic simulation** tools (e.g., Locust, JMeter).
3. **Production Testing:**
   - Perform **Load Testing** using Apache JMeter and Gatling.
   - Monitor performance metrics and optimize SQL queries.
   - Simulate **Fault Injection Testing** using Chaos Engineering tools (e.g., Gremlin).
4. **Observability Tests:**
   - Validate metrics and logs collection.
   - Implement alerts for anomalies and latency spikes.
5. **Security Tests:**
   - Conduct **Penetration Testing** and **Vulnerability Scans** (SONARQ).
   - Ensure proper encryption (TLS) and secure secrets management.

The provided document outlines the architecture design, components, technologies, and strategies for building a high-volume throughput, real-time data system. It ensures scalability, reliability, flexibility, observability, and security while addressing challenges like **schema evolution** and **fault tolerance** and also handling millions of requests with real-time data processing capabilities..

Front end low level and High Level Architecture

Produce a Front end low level and High Level Architecture diagrams of the System Design "Produce a high level followed by a low level drawings of the structure for Sytem Design Architecture for a high throughput volume of millions of request with real time data systems for the following vertical services Pricing, SEARCH, Booking and Reviews for the Frontend. Consider the following key pillars (Scalability, reliability,flexibility, observability and security) in the system design - good architecture - scale, failure, performance, and so on. Weigh up different choices of technologies to use. Efficiency and scalability: What kind of data structures do you want to use? Which size estimations do you put up front? How will you know that it's working as intended once it's in production. What sort checks and tests will you perform. Begin by listing the types of types of Architecture designs for the Front end that exist for consideration . Consider the following in as part of the Architecture and where they manifest - Vertical Services(Pricing, Booking, SEARCH, Reviews), Services communication, Data Layer, Configuration Management, Loggin and Monitoring, Authentication and Authorization, Error Handling, CI/CD, Containerisation and Orchestration, Reporting Service (Prometheus, ELK). Consider Challenges like **ensuring message reliability,managing schema evolution, and maintaining consistent processing during service failures.**

Summarise the dependencies of the components as well as challenges. Including resolutions. Focus on the following - Do you design for the key pillars of a good architecture - scale, failure, performance, and so on? Can you weigh up different choices of technologies to use? Efficiency and scalability: What kind of data structures do you want to use? Do you put size estimations up front? How will you know that it's working as intended once it's in production?

Overview:

This high-level architecture outlines a scalable, reliable, and flexible frontend system design for high-throughput services such as Pricing, Search, Booking, and Reviews. It incorporates modern architectural practices to handle millions of requests and ensure observability, security, and performance.

High-Level Architecture Diagram (Frontend)

```sql
+-----------------------------------------------------------+
|                         Client Browser                    |
|                          (User Device)                    |
|                                                           |
|   +-------------------+        +-------------------+      |
|   | Authentication    |        | Search Service    |      |
|   | & Authorization   |        | UI Component      |      |
|   +-------------------+        +-------------------+      |
|                                                           |
|   +---------------------------+   +---------------------+ |
|   | Pricing Component         |   | Booking Component   | |
|   | (Real-Time Updates)       |   | (Interactive UI)    | |
|   +---------------------------+   +---------------------+ |
|                                                           |
|   +-------------------------------+   +-----------------+ |
|   | Reviews Component             |   | Shared State    | |
|   | (Infinite Scrolling)          |   | Management (Redux| |
|   +-------------------------------+   | or Context API)  | |
|                                                           |
|              Frontend Logic Layer (Controller)            |
+-----------------------------------------------------------+
|                                                           |
|               API Gateway for Frontend Services           |
| (Handles all API requests/responses from the backend)     |
+-----------------------------------------------------------+
```

1. Key Components in the Frontend High-Level Design:

1. **Client Application (React, Next.js):**
   - CSR (Client-Side Rendering - Loading on demand) and SSR (Server-Side Rendering - Static compiled data) hybrid model for fast loading.
   - Tailwind CSS for styling and responsive design.
2. **API Gateway:**
   - Unified entry point for API calls.
   - Load balancer for distributing traffic.
   - Handles authentication, rate limiting, and CORS.
3. **Service Communication Layer:**
   - GraphQL for flexible query structures.
   - REST API fallback for legacy services.
   - WebSockets for real-time updates (e.g., booking status).
4. **Authentication and Authorization (Auth Service):**
   - OAuth 2.0 (User Identity) and JWT for secure token-based access.
   - Role-based access control (RBAC).
5. **Data Caching and CDN (Content Delivery Network):**
   - Redis or Varnish for caching frequently accessed data (kEY/VALUES).
   - CDN (e.g., Cloudflare) for static asset delivery.

6. **Logging and Monitoring (Observability):**
    - Prometheus for metrics collection.
    - ELK Stack (Elasticsearch, Logstash, Kibana) for centralized logging and visual dashboards.
7. **CI/CD Pipeline:**
    - GitHub Actions / Jenkins for automated builds, tests, and deployments.
    - **Canary** deployments for **rolling out update**s with minimal risk.
8. **Containerization and Orchestration:**
    - Docker for containerization.
    - Kubernetes for container orchestration, scaling, and failover.

Low-Level Architecture Diagram (Frontend)

```sql
+-----------------------------------------------------------+
|                          CLIENT                           |
|                                                           |
|   +-------------------+   +-------------------+           |
|   | React Components  |   | TailwindCSS for   |           |
|   | (UI Elements)     |   | Styling           |           |
|   +-------------------+   +-------------------+           |
|                                                           |
|   +-----------------------------------------------------+ |
|   | State Management (Redux/Context API)                | |
|   |  - Centralized Store                                | |
|   |  - Actions/Reducers                                 | |
|   +-----------------------------------------------------+ |
|                                                           |
|   +------------------+     +---------------------------+ |
|   | Component Logic  |     | Data Fetching Layer       | |
|   | - Handles events |     | - Axios/Fetch API         | |
|   |   and actions    |     | - Caching via SWR or RTK  | |
|   +------------------+     |                           | |
|                             +---------------------------+ |
+-----------------------------------------------------------+
|                                                           |
|                Communication with Backend                 |
|  - API Gateway for Data Fetching                          |
|  - GraphQL/REST Integration                               |
|  - Error Handling and Retry Mechanism                    |
```

1. Component Breakdown:

UI Layer:

- **Component Library (Storybook):** Standardized UI components.
- **Pages:**
  - Home, Search Results, Booking Flow, Pricing Details, and Reviews.
- **Reusable Components:**
  - Buttons, forms, and modals.

State Management (Redux/RTK Query):

- **Local State:**
  - UI state (e.g., modal visibility).
- **Global State:**
  - Cached API responses and shared data.
- **Middleware:**
  - Redux Thunk or Redux Saga for handling side effects like asynchronous calls.

Controller Layer:

- **API Service Handlers:** Abstracted layer for handling API requests (fetch, axios).
- **Event Handling:**
  - WebSockets for real-time updates (e.g., bookings and reviews).

Data Layer:

- **Caching Strategies:**
  - SWR (stale-while-revalidate) for optimized data fetching.
- **Schema Validation:**
  - JSON Schema or TypeScript interfaces.

2. Dependencies:

1. **API Gateway:**
   - Manages communication between services and frontend.
   - Ensures high availability and load balancing.
2. **Service Communication (GraphQL/REST):**
   - GraphQL for optimized data fetching and flexibility.
   - REST for backward compatibility.
3. **Authentication and Security:**
   - Secure sessions and tokens (JWT).
   - XSS and CSRF prevention.
4. **Error Handling and Monitoring:**
   - Centralized logging via ELK.
   - Frontend crash monitoring (e.g., Sentry).

3. Challenges and Resolutions:

Challenge 1: Scalability

- **Issue:** Handling millions of concurrent requests.
- **Resolution:** Implement CDN, Redis caching, and Kubernetes autoscaling.

Challenge 2: Real-Time Updates

- **Issue:** Booking and pricing require real-time data.
- **Resolution:** Use WebSockets and Event-Driven Architecture with message queues.

Challenge 3: Observability

- **Issue:** Monitoring user interactions and failures.
- **Resolution:** Integrate Prometheus and ELK for real-time metrics and logs.

Challenge 4: Security

- **Issue:** Authentication, data breaches, and fraud prevention.
- **Resolution:** Role-based access, OAuth2, encryption (TLS), and WAF.

4. Testing and Validation:

- **Unit Testing:** Jest and React Testing Library.
- **Integration Testing:** Cypress for end-to-end testing.
- **Performance Testing:** Load tests with JMeter.
- **CI/CD Tests:** Automated test pipelines with GitHub Actions.

5. Key Technologies Considered:

- **Frontend Framework:** React.js with Next.js for SSR and CSR.
- **State Management:** Redux Toolkit or Recoil.
- **Caching:** Redis and SWR.
- **API Communication:** GraphQL and REST.
- **Containerization and Orchestration:** Docker and Kubernetes.
- **Monitoring and Logs:** Prometheus and ELK Stack.

Final Thoughts:

This frontend architecture combines modern patterns, technologies, and observability to support scalability, fault tolerance, and performance for high-throughput services. Let me know if you need deeper insights into specific modules or workflows!

II - Microservices Distributed Messaging Service

Overview:

This architecture work comes from the gchq.gov.uk data communication hub, the official website for the UK's Government Communications Headquarters (GCHQ), a cybersecurity and intelligence agency.

- The platform provides information about GCHQ's mission, history, and initiatives to protect national security through signals intelligence and cyber operations. Secondly, it also promotes career opportunities, public engagement, and resources for individuals and businesses to improve cybersecurity awareness and practices.

- The backbone of the earlier architecture was a Monolithic data harvesting hub built with Ruby on Rails that collected metadata from various systems and put them into one big data set for processing.

- The throughput and efficiency of the architecture began to compromise with bottlenecks when availability couldn't meet peeking and spiking rates, leading to BREXIT resulting from high latencies. This affected delivery of insightful report the stakeholders were expecting.

A. How to Lead the Design Conversation

1. **Clarity of Thought and Communication**:
   - Start by asking targeted questions to clarify the requirements and constraints:
     - "What are the most **critical SLA**s for this system (e.g., **latency**, **availability**)?"
     - "Are **there specific technologies or frameworks already in use**?"
     - "How does this **service interact with others** (synchronous or asynchronous)?"
2. **Problem Solving**:
   - Break down the system into smaller, manageable components and address the hardest challenges first, e.g., ensuring consistent data across distributed services or handling spikes in traffic.
3. **System Design**:
   - Explain the rationale behind each choice:
     - "I chose RabbitMQ over Kafka because we prioritize message delivery guarantees over extreme throughput."
     - "Kubernetes provides us with container orchestration and scalability."
4. **Efficiency and Scalability**:
   - Highlight specific strategies to handle scale:
     - "We'll use Redis for caching to reduce database queries."
     - "The system will autoscale using Kubernetes' Horizontal Pod Autoscaler based on CPU and memory usage."
5. **Validation**:
   - Describe how you'd test and monitor the system in production:
     - "We'll use synthetic tests to simulate user traffic and validate performance.". Including Digital Twin and JMeter
     - "Prometheus and distributed tracing will help us monitor system health/ Health Check."

This comprehensive and modular approach ensures Skyscanner's microservices architecture remains scalable, secure, and highly performant.

B. Key pillars for consideration:

I suggest we begin with key pillars that are relevant from business point of view i.e efficiency for processing millions of booking requests per month. What do you think:

- Speed
- Scalability
- User-centric design mindset- Providing seamless experience
- QUICK Search STEPS (mention experience with BAE). Types of SEARCH algorithms. Get INTERVIEWER TO PARTICIPATE COLLABORATIVELY:

Anything else

Expanding SEARCH STEPS

1. Ranking and Relevance
2. AutoComplete and suggest
3. Aggregate SEARCH.
4. Personalisation through BROWSER History
5. Fuzzy SEARCH
6. A/B

Propose a distributed architecture that supports the core services booking, pricing, SEARCH to be developed as independent services that can redeployed independently and incrementally to bring constant revenue and cost effective. Ask of thoughts of interviewer.

==> NEXT SEE COMPONENTS
==> DISCUSS LOGICAL DIAGRAM
==> DIVE INTO DESIGNING **BOOKING** SERVICE (Use how to build a MCROSERVICE)

C. HIGH LEVEL

Matters to consider in designing the Architecture are:

- **Key PILLARS in architecture (SREFOS)**
- **Key CONSIDERATIONS**
- **COMPONENTS**
- **CHALLENGES**

D. Key PILLARS in the Architecture (SSREFOS)

1. **Scalability**: Independent scaling of microservices ensures that services can handle their unique workloads without impacting others.
2. **Speed**
3. **Resilience**: Asynchronous communication and circuit breakers mitigate the risk of cascading failures.
4. **Flexibility**: A modular approach allows for iterative development, making it easier to introduce new features or update existing ones.
5. **Observability**: Centralized logging and monitoring enable debugging and performance analysis for distributed services.
6. **Security**: API Gateway and token-based authentication (OAuth2) ensure a secure entry point for external users.

E. Key Considerations for Adopting Microservices away from Monolith:

Types of Architecture designs:

- SOA
- MVC
- Even Driven
- Monolith
- Microservices

Microservice*Architecture* - https://www.figma.com/board/4kkSR0KdbgOCJilUwUAVeI/Architectural-Diagrams?node-id=0-1&node-type=canvas&t=dLnC8yVc6OiJvR0u-0

The **key considerations** for adopting a Microservice were a result of bottlenecks from the Monolith architecture, which included:

Monolith

- Tight coupling
- Slow Release Cycle
- Manual Releases
- No Continuous Deployment
- Not Scalable
- Lack of log management, observation and Monitoring

Example:
The Monolithic Ruby on Rails had to perform many functionalities at the same time. Namely:

- Routing
- Data Harvesting
- Searching and Indexing
- Data persistence
- etc

No Continuous Deployment but Continuous Integration was using Travis and manual Releases using AWS Ops Works. The System was not designed to work in Containers and, hence not scalable. Many times, engineers had to intervene to scale instances in production, and there was a lack of log management and monitoring resulting in countless hours of debugging.

By leveraging tools like RabbitMQ, Amazon SQS, ElasticSearch, DynamoDB (to host jobs), Docker to host and isolate the services, Kubernetes for orchestration and scaling (detecting CPU and traffic (Cloud Watch) usage to scale horizontally adding more EC2 instances), Jenkins for deployments, IaC(Terrform to host environment configurations and migrations), NodeJS and Express Framework for API, Prometheus, ELK for Monitoring and Observability, I implemented the Microservice architectures where services communicated asynchronously, allowing them to operate independently and reliably.

Motivation for Microservice

My motivation for adopting a Microservices architecture was a result to improve the efficiency, scalability, usability, high availability, and fault tolerance of the data harvesting hub:

- Small individual components
- Easily maintainable
- Parallel development
- Rapid iteration
- Feature addition - enrichment
- Confidence in CI/CD
- Fault-tolerant
- Language-agnostic

The architecture decoupled functionalities, ensuring scalability and maintaining security and observability. RESTful API for data ingestion and transformation, message brokers (e.g., RabbitMQ) for job queues, and worker nodes for processing.

F. Key Components

Summary for components

Containers (**Docker**) were used for **service isolation, orchestrated and scaled** with **Kubernetes. SQS was leveraged for message queuing** between dispatchers and workers, while **ElasticSearch handled processed job indexing for real-time search.** Logging and **monitoring were centralised using Prometheus** and the **ELK** stack to ensure **visibility into system health and operations**. **Security** was reinforced with rate **limiting**, **authentication mechanisms** (e.g., OAuth), and secure communication protocols, especially for third-party integrations.

Modules:

1. **API Gateway**:
   - Acts as a single entry point for external requests.
   - Handles request routing, authentication, rate limiting, and load balancing.
   - Ensures clients interact with a unified API while hiding internal microservice complexity.
2. **Microservices Layer**:
   - Decomposed services based on specific domains (e.g., Search, Reporting, Pricing, User Management, Payments).
   - Each service owns its data and communicates with others through well-defined APIs or messaging systems.
   - Services are stateless and independently deployable.
3. **Service Communication**:
   - **Synchronous**: REST or gRPC for direct communication between services when low latency is required. Circuit Breakers to mitigate cascading of faulty messages
   - **Asynchronous**: Message brokers like Kafka or RabbitMQ for event-driven communication and decoupling.
4. **Data Layer**:
   - **Database per Service**: Each microservice has its database (SQL or NoSQL) to ensure modularity and data ownership.
   - Distributed data management strategies like eventual consistency or CQRS (Command Query Responsibility Segregation).
5. **Configuration Management**:
   - Centralized dynamic configuration through tools like Consul or etcd to manage service-specific configurations.
6. **Logging and Monitoring**:
   - Centralized logging using tools like the ELK stack (Elasticsearch, Logstash, Kibana).
   - Monitoring and observability with tools like Prometheus and Grafana to track service health and performance.
7. **Authentication and Authorization**:
   - OAuth2 or OpenID Connect for centralized identity management.
   - Role-based access control (RBAC) implemented through the API Gateway.
8. **Error Handling**:

   - Distributed error tracking (e.g., Sentry) for debugging and managing failures across services.
   - Retry mechanisms and circuit breakers to prevent cascading failures.

9. **CI/CD, Containerisation using docker to main consistency in environment dependencies and Orchestration with Scalability to support reliability of deployment and autoscaling through Health Checks by monitoring CPU usage.**

10. **Reporting Service**:

   - Decoupled from the core application and implemented as a separate service.
   - Aggregates and processes data from other microservices as needed.

G. Challenges and resolution

MSC

- ensuring **message reliability**
- **managing schema evolution**
- **maintaining consistent processing during service failures.**

To address these, I implemented :

- idempotent event handling to prevent duplicate processing, used schema registries (e.g., Confluent Schema Registry) to manage versioning
- Set up **dead-letter queues** to handle poison messages.
- Use Circuit breakers to stop the cascading of poisoned messages

Characteristics of monolithic architecture to look out for. redundant steps and unnecessary components often include the following:

LOOKING OUT FOR DEFICIENCIES FOR IMPROVEMENT

1. **Tightly Coupled Business Logic:**
   Legacy monoliths typically have tightly coupled modules where unrelated functions are interdependent. For example, **a payment module might also handle notifications and**

reporting, leading to redundant dependencies that make the system harder to scale and maintain.

2. **Centralized Databases:**
   A single database shared across all components often results in tightly coupled data models. This can lead to redundant queries and increased complexity when accessing or updating unrelated data.

3. **Overloaded APIs:**
   Monolithic systems often have large, **catch-all APIs that return excessive, irrelevant data or require multiple endpoints for simple operations, increasing redundancy and inefficiency**.

4. **Duplicated Functionality:**
   In legacy systems, similar tasks (e.g., validation, authentication) are often implemented multiple times across different parts of the application, leading to maintenance overhead and potential inconsistencies.

5. **Hardcoded Configurations:**
   Many monolithic systems rely on hardcoded configurations for workflows and connections, making it difficult to reconfigure or scale parts of the system independently.

6. **Centralized Error Handling:**
   Legacy systems may have a single error-handling mechanism, making it harder to pinpoint and isolate issues within specific functionalities.

Example Unnecessary Components Found in a Migration Process:

- A *reporting/SEARCH/BOOKING module* baked into the main application instead of being decoupled as a separate service.
- Logging mechanisms tied to the monolith's main runtime, making it challenging to implement distributed logging later.
- Redundant data processing pipelines handling similar transformations across different modules.

By identifying these inefficiencies, migrating to microservices allows the system to decouple functionalities into independent, scalable services. For instance, reporting, authentication, and notification services can become separate components, each managed and deployed independently. This not only streamlines operations but also simplifies scaling and future

Monitoring and debugging were enhanced with Prometheus, Grafana, and ELK stacks to track message flow and latency. These approaches have consistently delivered resilient, high-performing systems that met real-time and high-availability requirements.

How would you best describe a microserves system architecture for SKYSCANNER and its operation. Name the types of system design architectures that exist and which you will consider for distributed system. Demonstrate how you will design an architecture using your skills for the design condsidering the following factors: • Clarity of thought and communication: are you able to ask good questions to clarify the problem, make your assumptions explicit, and design a solution collaboratively with your interviewer? • Problem solving: Do you solve the problem, deal with the more complex parts head on and get to a viable solutionn? Can you do this collaboratively with your interviewer, but with you leading the conversation? • System design: Do you design for the key pillars of a good architecture - scale, failure, performance, and so on? Can you weigh up different choices of technologies to use? • Efficiency and scalability: What kind of data structures do you want to use? Do you put size estimations up front? How will you know that it's working as intended once it's in production?

Microservices System Architecture for Skyscanner

- key pointers
- key considerations
- components

Areas to consider for improvement from my perspective will be:

DIS

1. Data Harvesting
2. Improved SEARCH and discoverability
3. Scalability

Microservices architecture for Skyscanner involves decomposing the application into a collection of loosely coupled, independently deployable services. Each service is responsible for a specific business capability, such as **flight search, pricing**, **user reviews, or notifications**. The architecture focuses on enabling scalability, resilience, and faster deployment cycles while accommodating the company's need for a seamless and performant global travel platform.

Key Characteristics of Skyscanner's Microservices Architecture:

1. **Decoupling and Modularity**:
   - Each service handles a distinct function (e.g., search, booking, payments) and communicates asynchronously via APIs or message brokers like RabbitMQ or Amazon SQS.
2. **Scalability and Fault Isolation**:
   - Services are containerized (e.g., Docker) and orchestrated with Kubernetes to allow for independent scaling. Faults in one service don't cascade to others.
3. **Real-Time Operations**:
   - Features like price alerts, real-time updates, and personalized recommendations are enabled using asynchronous communication mechanisms.
4. **Observability and Monitoring**:
   - Tools like Prometheus, Grafana, and ELK (Elasticsearch, Logstash, Kibana) ensure robust logging, monitoring, and distributed tracing to maintain system health.
5. **Security**:

- Secure APIs with OAuth2, encrypted communication, and rate limiting to prevent abuse while adhering to GDPR and other regional regulations.

Types of System Design Architectures

1. **Monolithic Architecture**:
    - All functionality is bundled into a single codebase.
    - Suitable for small teams or early-stage startups but lacks flexibility and scalability.
2. **Service-Oriented Architecture (SOA)**:
    - Uses a shared bus for communication between services, unlike microservices, which prefer lightweight communication (e.g., REST, gRPC).
3. **Event-Driven Architecture**:
    - Services communicate by exchanging events via message brokers like Kafka.
    - Useful for systems that require asynchronous and real-time interactions.
4. **Serverless Architecture**:
    - Functions are deployed independently, and scaling is managed automatically by the cloud provider.
    - Ideal for reducing infrastructure management.
5. **Microservices Architecture**:
    - Services are independent, use APIs or message brokers for communication, and scale independently.
    - Best for large, distributed systems like Skyscanner, where scalability, modularity, and resilience are paramount.

Designing Microservices for Skyscanner

1. Problem Understanding

- Clarify the specific requirements:
    - Are we designing the flight search or booking module?
    - What are the expected user volumes and traffic patterns?
    - What data consistency requirements exist for critical services (e.g., payments)?
    - Is low latency or high throughput the primary goal?

2. High-Level Architecture

1. **API Gateway**:
    - Acts as the entry point for external traffic.
    - Handles request routing, authentication, and rate limiting.
2. **Services**:
    - **Flight Search Service**: Handles querying and aggregation of flight data from multiple providers.
    - **Pricing Service**: Computes and updates dynamic pricing in real time.
    - **Booking Service**: Processes user bookings and handles payment integrations.
    - **Notification Service**: Sends price alerts and travel updates.

3. **Communication**:
    - Use REST APIs or gRPC for synchronous communication and RabbitMQ/Kafka for asynchronous communication (e.g., between search and pricing services).
4. **Data Storage**:
    - Use a combination of **RDBMS** (e.g., PostgreSQL) for relational data (e.g., user profiles) and **NoSQL** (e.g., DynamoDB) for high-throughput operations like session management or caching.
5. **Orchestration**:
    - Containerized services using Docker, orchestrated by Kubernetes, with autoscaling enabled for high-traffic scenarios.
6. **Monitoring and Observability**:
    - Use Prometheus for system metrics and ELK for centralized logging.
    - Distributed tracing (e.g., Jaeger) to track requests across services.

3. Detailed Considerations

1. **Scalability and Performance**:
    - Design services to scale independently.
    - Implement caching (e.g., Redis) for frequently accessed data like flight results.
2. **Resilience**:
    - Use circuit breakers (e.g., Hystrix) to handle service failures gracefully.
    - Deploy redundant instances to ensure high availability.
3. **Security**:
    - Implement OAuth2 for API authentication.
    - Use HTTPS for secure communication between services and clients.
4. **Efficiency**:
    - Optimize data structures for core use cases, such as a priority queue for processing price alerts.
    - Pre-compute aggregates where possible to minimize database load.

High-Level Architecture Diagram

```
+--------------------------+
|        API Gateway       |
| (Routing, Auth, Rate Lim)|
+--------------------------+
           |
 +-------+------+----------------------+
 |             |                       |
Flight Search  Pricing Service      Booking Service
   Service       Service               (DB + Payments)
     |              |                       |
     +---------- Message Broker (Kafka / RabbitMQ) --------+
                |                                          |
        Notification Service                          Logging &
Monitoring
                                                     (Prometheus /
ELK Stack)
```

Data Structures in Microservices Architecture

Microservices architecture involves multiple independent services working together. The choice of data structures plays a critical role in facilitating data storage, processing, communication, and state management. Below are key types of data structures you might encounter and examples of how they can be processed.

1. Core Types of Data Structures

Key-Value Pairs

- **Use Case**: Ideal for caching or storing session data, configuration settings, or any data that can be accessed with a unique key.
- **Example**:
  - **Tools**: Redis, DynamoDB.
  - **Scenario**: Caching frequently accessed flight search results in Skyscanner.
- **Processing**: Retrieve and update values based on keys efficiently (O(1) operations).

JSON / BSON Documents

- **Use Case**: Used for unstructured or semi-structured data in document stores.
- **Example**:
  - **Tools**: MongoDB, CouchDB.
  - **Scenario**: Storing user travel preferences or booking details.
- **Processing**: Query and modify specific fields in the document, such as retrieving all bookings for a user.

Relational Tables

- **Use Case**: For structured data requiring relationships between entities.
- **Example**:
  - **Tools**: PostgreSQL, MySQL.
  - **Scenario**: Managing user accounts, bookings, and payments.

- **Processing**: Perform SQL operations like `SELECT`, `JOIN`, and `GROUP BY` to fetch or aggregate data.

Graphs

- **Use Case**: For relationships and connections between entities.
- **Example**:
  - **Tools**: Neo4j, ArangoDB.
  - **Scenario**: Representing and querying travel routes or user connections.
- **Processing**: Use graph traversal algorithms like Depth-First Search (DFS) or Breadth-First Search (BFS) for recommendations or shortest path discovery.

Queues

- **Use Case**: For message passing and asynchronous processing.
- **Example**:
  - **Tools**: RabbitMQ, Amazon SQS, Kafka.
  - **Scenario**: Processing price alerts or booking notifications in Skyscanner.
- **Processing**: Messages are enqueued by producers and dequeued by consumers for further handling.

Logs

- **Use Case**: For sequential, append-only data.
- **Example**:
  - **Tools**: Kafka, Elasticsearch.
  - **Scenario**: Capturing user activity logs or transaction histories.
- **Processing**: Use batch processing or streaming frameworks (e.g., Apache Flink, Spark) to analyze logs in real-time.

Distributed Hash Tables

- **Use Case**: For distributed storage of key-value data across nodes.
- **Example**:
  - **Tools**: Cassandra, DynamoDB.
  - **Scenario**: Handling distributed storage of travel deals or search indexes.
- **Processing**: Partition and replicate data across nodes using consistent hashing.

Blob Storage

- **Use Case**: For storing unstructured data like images, PDFs, or videos.
- **Example**:
  - **Tools**: Amazon S3, Azure Blob Storage.
  - **Scenario**: Storing user-uploaded passport images or itineraries.

- **Processing**: Retrieve, update, or delete blobs as needed.

2. How to Process These Data Structures in Microservices

1. **Data Storage**:
   - Use appropriate databases (SQL for structured data, NoSQL for unstructured data).
   - Apply indexing for efficient query execution.
2. **Data Caching**:
   - Use in-memory key-value stores like Redis to reduce database load and improve response times.
3. **Data Streaming**:
   - Leverage message brokers like Kafka to process data streams asynchronously for real-time insights.
4. **State Management**:
   - Use distributed hash tables or external session stores for scaling state across services.
5. **Data Analytics**:
   - Batch processing: Use tools like Apache Hadoop or Spark for historical data processing.
   - Real-time analytics: Use tools like Apache Flink or Storm to process logs or queues.
6. **Communication Between Services**:
   - REST APIs or gRPC for synchronous communication.
   - Queues (RabbitMQ, Kafka) for asynchronous communication to ensure reliability.

Summary

In a microservices architecture, data structures must align with the use cases and operational needs of each service. For example, relational tables handle structured relationships, queues manage asynchronous communication, and key-value stores facilitate fast lookups. Efficient processing and selection of the right tools enable scalability, reliability, and performance for distributed systems like Skyscanner.

Follow-Up Questions to Clarify Problem

1. Are there specific service-level agreements (SLAs) for the support issues?
2. What is the primary goal of the strategic project, and how is its success measured?
3. How are support requests currently logged and tracked?
4. Are any technical debt or system inefficiencies contributing to delays?

Best Practices:

- Authentication and Authorization: Implemented OAuth 2.0 for access delegation and API keys with strict scopes and expiration policies for secure access control.
- Certificate Management: Used mutual TLS (mTLS) for bidirectional authentication between the service system and third-party integrations.
- Rate Limiting and Throttling: Mitigate denial-of-service risks by enforcing rate limits on third-party API calls.
- Regular Audits: Conducted periodic security audits of third-party integrations to ensure compliance with security standards and best practices.
- Data Encryption: Sensitive data was encrypted both in transit (TLS, HTTPS) and at rest AES-256.

The outcome

The resulting architecture provided significant benefits: increased scalability with Kubernetes, better fault isolation, faster deployments through Jenkins CI/CD pipelines, and improved search capabilities with ElasticSearch.

The outcome was a robust, scalable, and secure system that ensured high availability and flexibility, enabling easier future feature integrations and updates.

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https://github.com/DataSolutionSoftware/Portfolio
https://github.com/kukuu?tab=repositories