Voting System Using Microservices for Secure and Scalable Elections

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1. Introduction to the Project

The project aims to develop a distributed voting system leveraging modern microservices architecture and distributed computing principles. The system will allow users to register, vote for candidates, and view real-time results while ensuring high availability, scalability, and fault tolerance. It will be built using Spring Boot, Eureka, Kafka, PostgreSQL, Docker, and Kubernetes, with a focus on distributed computing to handle high concurrency and large-scale data processing.

2. Problem Statement

Traditional monolithic voting systems face challenges such as:

- **Scalability Issues**: Inability to handle large volumes of concurrent users.
- **Single Point of Failure**: Lack of fault tolerance leading to system downtime.
- **Concurrency Problems**: Risks of duplicate votes or race conditions during high traffic.
- **Latency**: Slow response times due to centralized processing.
- **Complexity in Maintenance**: Difficulties in scaling, updating, and debugging monolithic systems.

This project addresses these challenges by designing a distributed, event-driven microservices architecture that ensures scalability, fault tolerance, and eventual consistency.

3. Objectives

- **Design a Distributed System**: Build a **scalable and fault-tolerant** voting system using **microservices**.
- **Ensure High Availability**: Use **Kubernetes** for orchestration and **auto-scaling** to handle traffic spikes.
- **Handle Concurrency**: Implement **distributed locking (Redis)** and **optimistic locking** to prevent duplicate votes.
- **Achieve Eventual Consistency**: Use **Kafka** for asynchronous communication and **Redis** for caching.
- **Provide Real-Time Results**: Aggregate voting results in real-time using **Kafka and Redis**.
- **Simplify Deployment**: Containerize services using **Docker** and orchestrate them using **Kubernetes**.

4. Scope of the Project

The project will focus on the following key functionalities:

- **User Management**: Registration, authentication, and authorization.
- **Candidate Management**: Adding and retrieving candidate details.
- **Voting Mechanism**: Secure and concurrent voting using **Kafka and Redis**.
- **Result Aggregation**: Real-time vote counting and result display.
- **Notifications**: Sending notifications (email/SMS) for successful votes.
- **API Gateway**: Centralized request routing and rate limiting.
- **Service Discovery**: Dynamic service registration and load balancing using **Eureka**.
- **Deployment**: Containerization with **Docker** and orchestration with **Kubernetes**.

5. Technologies Used

Frontend:

- **Flutter**

Backend:

- **Spring Boot** (Microservices)
- **Spring Cloud Gateway** (API Gateway)
- **Spring Cloud Eureka** (Service Discovery)
- **Spring Security + JWT** (Authentication)
- **Kafka** (Event Streaming)
- **Redis** (Caching and Distributed Locking)
- **PostgreSQL** (Database)

DevOps:

- **Docker** (Containerization)
- **Kubernetes** (Orchestration)

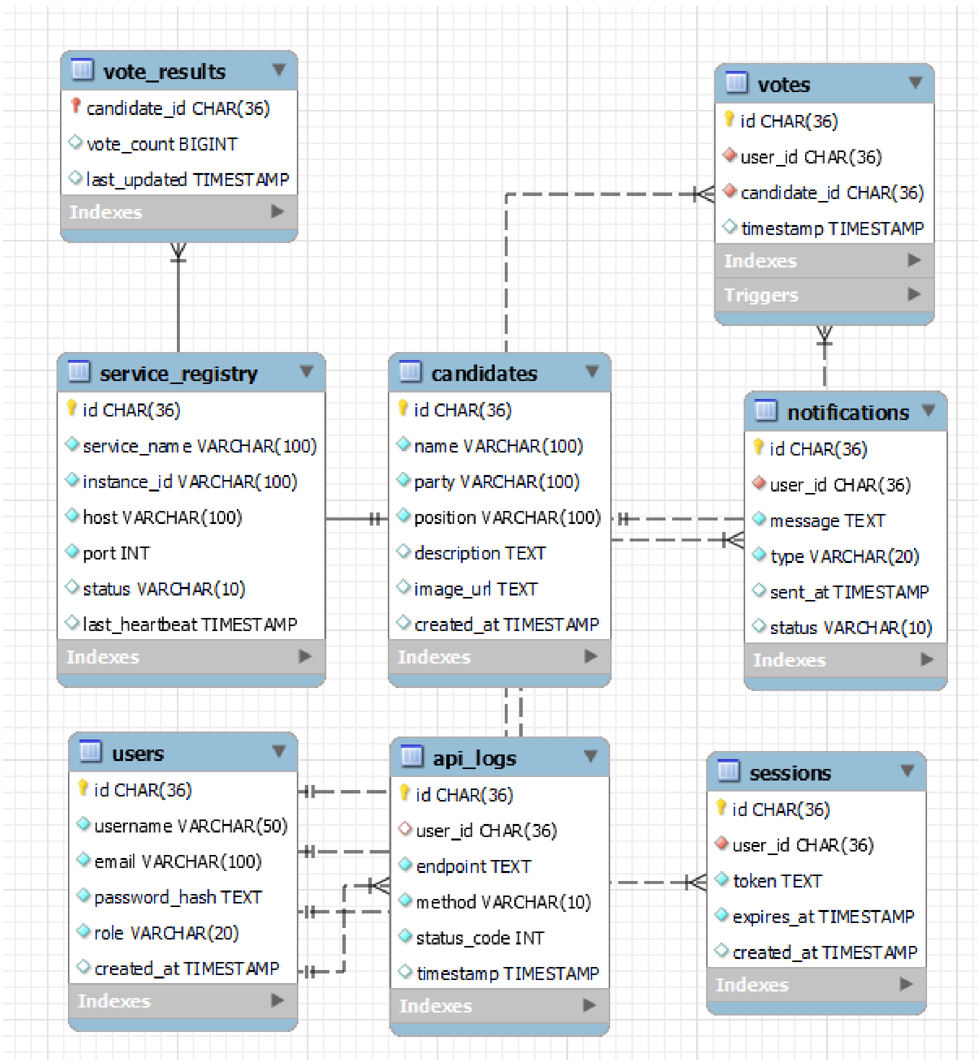
Distributed Computing:

- **Kafka** (Asynchronous Communication)
- **Redis** (Distributed Locks and Caching)
- **Kubernetes** (Auto-scaling and Load Balancing)
- **PostgreSQL Read Replicas** (Database Scalability)

6. Expected Outcome

- **Scalable System**: The system will handle high traffic and scale dynamically using **Kubernetes**.
- **Fault Tolerance**: The system will remain operational even if some components fail, thanks to **Kubernetes and distributed architecture**.
- **Real-Time Results**: Users will see real-time voting results with **eventual consistency**.
- **Secure Voting**: The system will prevent duplicate votes and ensure **data integrity** using **Redis locks and optimistic locking**.
- **Ease of Deployment**: The system will be **easy to deploy and manage** using **Docker and Kubernetes**.
- **Modular and Maintainable**: The **microservices architecture** will make the system modular, easy to update, and maintain.

7. Normalised Entity-Relation Diagram



8. Entity Relationships (ER)

Users Table (Voters & Admins)

- Each user (VOTER or ADMIN) can have multiple sessions.
- VOTER users can vote once in each election.
- ADMIN users manage candidates and view results.

Candidates Table

- Candidates belong to a political party.
- Users vote for candidates.
- Votes update results asynchronously.

Votes Table

- Each vote belongs to one user and one candidate.
- A user can vote only once (enforced by unique_vote constraint).

Vote Results Table

- Stores the aggregated vote count for each candidate.
- Updates asynchronously via Kafka and triggers.

Notifications Table

- Each vote triggers a notification to the user.
- Notifications are queued and sent asynchronously.

API Logs Table

- Logs API calls for audit and security.
- Tracks who accessed what and when.

Service Registry Table

- Stores active microservice instances for service discovery.

Normalization

First Normal Form (1NF)

- All tables store **atomic** values (no multivalued attributes).
- No repeating columns; relationships are represented through foreign keys.

Second Normal Form (2NF)

- No **partial dependencies** (each non-key attribute depends entirely on the primary key).
- Example: The votes table references both user_id and candidate_id but does not store unnecessary details like usernames or candidate names.

Third Normal Form (3NF)

- No **transitive dependencies** (non-key attributes depend only on the primary key).
- Example: The users table only stores user-specific details, while authentication details like session tokens are in a separate sessions table.

Boyce-Codd Normal Form (BCNF)

- **Every determinant is a candidate key** : In each table, any attribute that determines another must itself be a candidate key.
- **No partial dependencies** : Each non-key attribute fully depends on the entire primary key.
- **No transitive dependencies** : Attributes only depend on the primary key, not on other non-key attributes.
- **Example:** In the sessions table, id is the primary key, and all attributes (like user_id, token, and expires_at) depend only on id, ensuring there are no hidden dependencies.
- **Example:** In the votes table, id is the primary key, and user_id and candidate_id are foreign keys, ensuring votes are correctly referenced without redundant data.

Table	Primary Key	Foreign Keys	Relationships
users	id	-	One-to-Many with sessions, One-to-Many with votes, One-to-Many with notifications
sessions	id	user_id → users(id)	Many-to-One with users
candidates	id	-	One-to-Many with votes, One-to-One with vote_results
votes	id	user_id → users(id), candidate_id → candidates(id)	Many-to-One with users, Many-to-One with candidates
vote_results	candidate_id	candidate_id → candidates(id)	One-to-One with candidates
notifications	id	user_id → users(id)	Many-to-One with users
api_logs	id	user_id → users(id)	Many-to-One with users (nullable)
service_registry	id	-	Stores microservice instances