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EVALUATING RELATIONAL DATABASE SCALING STRATEGIES IN WEB ENGINEERING

In web engineering, relational databases remain the basis for storing structured information, which enables the operation of numerous online services [1, 2]. With the growth of data volumes and the number of users, there is a need to ensure stable operation of databases under high loads, which makes scaling a critical aspect of their architecture [3-5]. Choosing the right scaling strategy affects the efficiency of web applications, but implementation comes with some challenges. Namely, maintaining consistency, distributing the load and adapting the architecture. This necessitates an assessment of existing approaches and the definition of practical recommendations for their application.

Database scaling is the adaptation of the system to the growth of data volumes or an increase in the number of queries. There are two basic approaches to scaling: scale-up and scale-out. Vertical scaling involves increasing the capacity of a single server, such as adding RAM, a more powerful processor, or a faster SSD storage. The implementation of this approach is simple, but it has physical and economic limitations, which makes it less effective when working with large systems. Horizontal scaling, in turn, distributes the load across multiple servers. This allows for

high availability and performance, however, requires a more complex architecture and careful management of data consistency.

Another aspect to consider when choosing a scaling strategy is the type of database load. For transactional systems, write speed and data integrity are key, while for analytical systems, read and aggregation efficiency is important. However, web applications typically work with hybrid workloads, which also requires an integrated approach to scaling.

Relational databases, unlike many NoSQL solutions, follow a strict data schema and provide support for transactions, making them difficult to scale horizontally. However, traditional scaling approaches, such as replication, sharding, or clustering, require a deep understanding of the database architecture and application program logic.

Next, we will consider the key strategies for horizontal scaling of relational databases that are used in practice in web engineering.

One of the most common approaches is replication, where copies of a database are synchronized between multiple nodes. The classic version uses the master-slave model, where one server (master) accepts all records and updates, and the rest (slaves) serve read requests. This allows you to reduce the load on the main server and improve performance with a large number of reads. But this approach requires synchronization mechanisms and accounting for replication delays, which can lead to data inconsistency.

More complex, but also more flexible, is multi-master replication, where all nodes can both read and modify data. This scheme provides high availability and resilience to failures, but creates risks of change conflicts, which requires additional algorithms to resolve them, for example, using node priority.

The next method of horizontal scaling is sharding – distributing data between independent databases, where each stores only a part of all information. For example, users can be categorized by geographic region.

The advantage of sharding is the ability to process a large number of requests in parallel and avoid overloading a single server. But the implementation of sharding requires changes in the logic of the application, since requests must be routed to the appropriate shard, and combining data from different shards becomes more difficult.

Another option is clustering, including the use of solutions such as Galera Cluster for MySQL, which enables synchronous replication between nodes with simultaneous write support. This approach provides a high level of consistency, but requires low network latency between servers and more complex administration.

An auxiliary but extremely important practice is the use of caching (such as Redis or Memcached), which allows you to reduce the number of database accesses, especially for repetitive, infrequently changed queries. Caching is not scalable in the literal sense, but it provides quick access to the information you need and improves system performance.

Thus, horizontal scaling is based on a combination of approaches that allow you to distribute the load, increase fault tolerance, and ensure the efficient operation of relational databases in scalable web applications.

Now that the most effective methods for scaling relational databases have been identified, let's evaluate them. A comparative analysis of these strategies will allow you to assess their feasibility depending on the requirements of a particular web application. The main evaluation criteria are: performance, reliability, complexity of implementation, data consistency and scalability.

Replication is effective when read operations predominate, as in content platforms or analytics systems. On the other hand, in systems with a large number of concurrent entries or transactions (such as financial services), master-slave replication quickly becomes a bottleneck. Multi-master configurations reduce this limitation, but make it more difficult to maintain

consistency. This method provides good readability, medium reliability, and low implementation complexity, but requires compromises in consistency.

Sharding allows data to be distributed across nodes and provides the highest scalability. It is optimal for systems with a large amount of data and millions of users (marketplaces, social networks), but it is too complex and inefficient for small applications or projects with closely related tables. Provides the best performance and scalability, but requires complex routing logic and consistency control.

Clustering (for example, based on Galera Cluster or MySQL Group Replication) will be appropriate in financial or medical systems where data loss is unacceptable, but will be excessive for less critical projects. It provides high data consistency and reliability, but requires a stable infrastructure and complex administration.

No strategy is universal. A combination of multiple approaches, such as replication with caching or sharding with clustering, is often effective. This allows for a balance between scalability, performance, and data consistency. Preliminary architecture analysis and modeling of scaling scenarios contribute to the creation of adaptive and stable systems.

After all, scaling relational databases is not only a technical task, but a strategic decision that determines the durability and competitiveness of a web project.

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