DHBW
Duale Hochschule
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Couchbase DB

Aktuelle DB Architekturen und Technologien

Vorlesung des Studienganges Informatik

an der Dualen Hochschule Baden-Württemberg Stuttgart

von

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Abkürzungsverzeichnis

EUV Lithographie Extreme Ultraviolet Lithographie

1 Type of Database & History

Couchbase is a distributed NoSQL database that combines document database and key-value store capabilities. Unlike traditional single-model NoSQL solutions, Couchbase offers a hybrid approach that makes it versatile for different use cases.

1.1 Key Characteristics and Features

Couchbase distinguishes itself through several core capabilities that combine to create a versatile database platform:

1.1.1 Data Model and Storage

- **JSON Document Storage**: Schema-flexible documents supporting nested attributes, arrays, and objects (up to 20MB per document)
- **Key-Value Operations**: Sub-millisecond CRUD operations with direct key access, optimistic concurrency (CAS), and TTL expiration
- **Memory-First Architecture**: Built-in caching layer with configurable memory quotas and background disk persistence

1.1.2 Query and Indexing

- **N1QL Query Language**: SQL-like syntax for JSON with support for JOINs, nested attributes, arrays, aggregations, and subqueries
- **Comprehensive Indexing**: Primary, secondary, composite, partial, and array indexes to optimize query performance

1.1.3 Distribution and Scalability

- **Distributed Architecture**: Automatic sharding, configurable replication, auto-failover, and online rebalancing

- **Multi-Service Design**: Independent scaling of data, query, index, search, analytics, and eventing services
- **Cross-Datacenter Replication**: Built-in XDCR for geographic distribution

1.1.4 Security and Enterprise Features

- **Access Control**: Role-Based Access Control (RBAC), LDAP integration, and operation auditing
- **Encryption**: TLS for data in transit and field-level encryption for sensitive data

1.2 Brief History

Couchbase was formed in 2010 through the merger of Membase (a key-value store with Memcached compatibility) and CouchDB technology (document database capabilities). Key milestones include:

- 2011: Release of Couchbase Server 1.0
- 2015: Introduction of N1QL, a SQL-like query language for JSON
- 2017: Launch of Couchbase Mobile for edge computing
- 2021: Couchbase goes public with IPO

The introduction of N1QL in 2015 was particularly significant, as it bridged the gap between NoSQL flexibility and SQL familiarity.

1.3 Use Case Examples

Couchbase excels in several common application scenarios:

User Profile Management: Document model for dynamic attributes, fast key-value access, and session expiration.

Product Catalogs: Flexible schema for product attributes, N1QL for advanced queries,

and full-text search.

Gaming Applications: Low-latency key-value operations, document model for player/-game data, and horizontal scaling.

Internet of Things: Mobile sync for edge devices, time-series support for sensor data, and schema flexibility for device diversity.

2 Which aspects of relational DBs are improved?

Couchbase addresses three fundamental limitations of relational databases: schema rigidity, scaling challenges, and query limitations for complex data structures.

2.1 Schema Flexibility

Relational limitation: Relational databases require predefined schemas where all data must conform to a fixed structure. Schema changes typically involve ALTER TABLE operations that often cause downtime, require data migrations, and necessitate application code updates.

Couchbase solution: Couchbase's document model eliminates rigid schemas by allowing each document to have its own structure, even within the same collection. This enables:

- Adding or removing fields without database migrations
- Evolving applications without downtime
- Supporting multiple document versions simultaneously

For example, while a simple product might contain just basic attributes (id, name, price), another can include nested structures like arrays of colors and specification objects—all without schema changes.

2.2 Scalability Improvements

Relational limitation: Traditional relational databases were designed for vertical scaling (bigger servers) rather than horizontal scaling. As data grows, this approach eventually hits hardware limits. Manual sharding requires complex application logic, and

joins become problematic across distributed data.

Couchbase solution: Couchbase is architected for distributed operations from the ground up, featuring automatic sharding, built-in replication, seamless cluster expansion, and multi-dimensional scaling that allows separate scaling of query, index, and data services.

2.3 Advanced Query Capabilities

Relational limitation: SQL struggles with hierarchical data structures common in modern applications. Complex nested structures must be split across multiple tables, requiring joins that become performance bottlenecks at scale. This creates a mismatch with object-oriented application code.

Couchbase solution: N1QL (SQL for JSON) combines SQL familiarity with direct operations on nested JSON structures:

```
SELECT product.name, product.specs.cpu
FROM products AS product
WHERE "black" IN product.colors;
```

This query directly accesses nested fields and array elements without complex joins or subqueries.

2.4 Relationship to Codd's Rules

Couchbase intentionally diverges from relational principles to address modern application needs. While relational databases store data in rigid tables (Codd's Information Rule), Couchbase uses flexible JSON documents. This design choice prioritizes adaptability and development speed over traditional relational constraints.

3 Advantages and Disadvantages

3.1 Technical Advantages

Performance Metrics:

- Sub-millisecond key-value operations (<1ms @ 99th percentile)
- Memory-first architecture with configurable ejection policies
- B-tree based global secondary indexes for query optimization
- Write-optimized storage engine with append-only commits
- 30-40

Technical Capabilities:

- Multi-model support: K-V, document, spatial, full-text within single platform
- ANSI JOIN and NEST operations in N1QL with pushdown optimization
- Cross Datacenter Replication (XDCR) with filtering and compression
- SSLv3/TLS 1.2+ encryption with FIPS 140-2 compliance
- SDK support for Java, .NET, Node.js, Python, Go with reactive extensions

3.2 Technical Limitations

Performance Constraints:

- Document size limit: 20MB (default)
- Memory overhead: 56 bytes metadata per document
- Transaction latency: increased by 15-30% for multi-document ACID
- Query performance degrades with >10 JOINs in single statement
- Minimum 4GB RAM recommended per node for production

Architectural Considerations:

- Default consistency: eventual for queries, strong for K-V operations
- CAP theorem positioning: CP for document operations, AP for cross-cluster
- Minimum 3 nodes recommended for high availability
- Scaling requires rebalance operations (minimal but measurable impact)
- Analytics segregation required for OLAP without OLTP impact

3.3 Technical Comparison

Feature	Couchbase	MongoDB	Cassandra
Query Latency	1-5ms K-V, 5-20ms N1QL	2-10ms K-V, 10-50ms query	1-3ms K-V, 5-15ms CQL
Scaling Model	Shared-nothing, auto-sharding	Replica sets with sharding	Masterless ring
Consistency	Tunable (BASE to ACID)	Tunable (Read preferences)	Quorum-based
Indexes	Memory-optimized, composite	B-tree, compound	LSM-tree, materialized views
Transactions	ACID within/across docs	ACID within/across docs	Lightweight transactions

Ideal Workloads: High-throughput OLTP with sub-ms requirements; mixed document/K-V operations; distributed multi-model applications requiring SQL compatibility.

Less Suitable: Graph-centric applications (high relationship traversal); pure analytics workloads; single-server deployments with <8GB RAM.

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