High-Scale Event-Driven Architecture

Design Patterns for Zero-Downtime Financial Processing

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Agenda & Presentation Structure

- **System Foundations & SLA Guarantees**: Core objectives, throughput targets, and sub-10ms p99 requirements.
- **Event Sourcing & CQRS Pattern**: Decoupling state mutations from read-side query materialization.
- **Consensus & Storage Architecture**: Raft-backed metadata consensus and partitioned event stream stores.
- **Topology & Stream Engine**: End-to-end pipeline design from regional gateways to workers.
- **Resilience & Operating Patterns**: Backpressure mechanisms, circuit breaking, and zero-downtime rollouts.
- **Architectural Takeaways**: Proven engineering guidelines for mission-critical financial systems.

Section 1: System Foundations & SLA Guarantees

Architectural Core Focus

Establishing the foundational pillars for high-throughput, low-la
earizable event processing across distributed financial nodes.

Architectural Drivers & SLA Requirements

Throughput & Latency SLAs

- ☐ **Peak Volume**: 500,000 ops / sec continuous stream ingestion.
- ☐ **p99 Latency**: Sub-8ms end-to-end processing across regions.
- ☐ **Ingestion Gateway**: Distributed Nexa API gateway clusters with TLS termination.

Correctness & Availability

- ☐ **Consensus Model**: Strict linearizable state machine replication.
- ☐ **Uptime SLA**: 99.999% availability with zero planned downtime.
- ☐ **Auditing**: Immutable cryptographic ledger append for all transactions.

Distributed Systems Lecture Agenda
Presentation Structure
Section 1: System Foundations & SLA
Guarantees
Architectural Drivers & SLA Requirements
Event Sourcing & CQRS Pattern
Section 2: Consensus & Storage Architecture
Raft-Backed Replicated State Machine
Storage Engine Internals
& Operating Patterns
Fault Tolerance & Backpressure Strategies
Zero-Downtime Canary Deployment Pipeline
Production Scale & Operational Metrics
Architectural Takeaways & Engineering Guidelines
Summary & Engineering Q&A

Event Sourcing & CQRS Pattern

Write-Path Isolation: Commands mutate domain state strictly by appending immutable events to the stream store.

Optimistic Concurrency Control: Sequence numbers validate state transitions without locking database tables.

Read-Path Projections: Asynchronous projection workers consume events to populate read-optimized indexes.

Auditability & Time Travel: Complete historical sequence retention enables exact point-in-time state reconstruction.

Design Rule: *Never allow read-side queries to contend with write-side event log appends.*

Section 2: Consensus & Storage Architecture

Storage Engine Architecture

Deep dive into Raft consensus, log partitioning, and comparat
mark metrics across Meridian platform components.

Raft-Backed Replicated State Machine

Consensus Mechanics

- ☐ **Leader Election**: Heartbeat interval of 150ms with randomized election timeouts.
- ☐ **Log Replication**: Two-phase commit protocol guaranteeing quorum consensus before acknowledgment.
- ☐ **Membership Changes**: Single-server configuration changes to prevent split-brain states.

Log Compaction & Snapshots

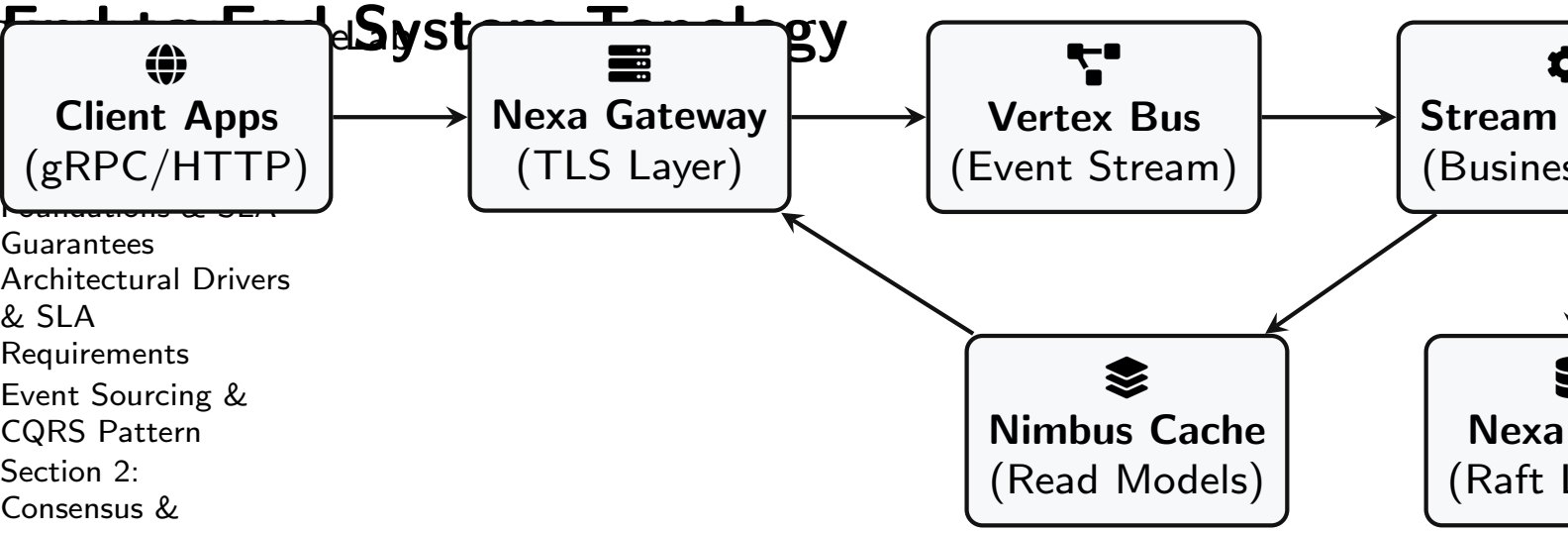
- ☐ **Snapshot Trigger**: Automatic memory compaction every 100,000 committed entries.
- ☐ **Recovery Speed**: Fast startup initialization from state snapshot + recent log segment.
- ☐ **Storage Bounding**: Bounded disk memory consumption across node clusters.

Storage Engine Benchmark Comparison

Engine	Primary Use Case	Consensus Protocol	Read (p99)	Write (p99)
Nexa-Store	Immutable Event Ledger	Raft Quorum	2.1 ms	4.5 ms
Vertex-Log	Partitioned Stream Bus	Segment Lock	1.4 ms	3.1 ms
Nimbus-KV	Materialized Read Cache	Eventual Sync	0.8 ms	1.9 ms
Meridian-DB	Operational State Store	Multi-Paxos	3.2 ms	6.8 ms

Benchmark Summary: Nexa-Store and Vertex-Log deliver consistent single-digit millisecond latency under 500k ops / sec load testing.

End-to-End System Topology



Data Flow: Ingestion via Nexa Gateway → Vertex Stream Bus → Stream Workers → Nexa Store (Write) & Nimbus Cache (Read).

Section 3: Resilience & Operating Patterns

Operational Reliability

Implementation of reactive backpressure, automated circuit bre
canary deployment pipelines for zero-downtime operations.

Fault Tolerance & Backpressure Strategies

Credit-Based Backpressure: Downstream worker capacity dynamically signals ingestion gateways to adjust TCP window sizes.

Automated Circuit Breaking: Triggers fallback routing if node error rate exceeds 0.05% over a 10-second rolling window.

Dead Letter Queues (DLQ): Malformed poison-pill payloads are isolated to DLQs without stalling partition streams.

Self-Healing Partition Rebalance: Failed cluster nodes trigger immediate partition reassignment within 3 seconds.

Zero-Downtime Canary Deployment Pipeline

Phase 1: Shadow

- ☐ 1% traffic shadow.
- ☐ Compare response.
- ☐ Zero regression.

Phase 2: Canary

- ☐ 25% traffic shift.
- ☐ Monitor latency.
- ☐ Automated SLAs.

Phase 3: Rollout

- ☐ 100% promotion.
- ☐ DNS cutover.
- ☐ Auto-rollback.

Production Scale & Operational Metrics

Daily Ingestion Volume

14.2 Billion Events / Day

Continuous global processing across 8 regional data centers.

Event Replay Performance

1,200,000 Events / sec

Per-node recovery throughput during cold-start rebuilds.

Recovery Time Objective (RTO)

< 5 Seconds

Automatic failover and consensus recovery window.

Data Integrity SLA

Zero Loss (RPO = 0)

Guaranteed by Raft synchronous multi-region quorum write.

Architectural Takeaways & Engineering Guidelines

- ✔ **Strict CQRS Separation**: Keep write-side state log append isolated from read-side projection serving.
- ✔ **Bounded Snapshot Compaction**: Always bound event log recovery time with automated periodic snapshotting.
- ✔ **Schema Evolution Contracts**: Enforce backward and forward schema compatibility across message schemas.
- ✔ **End-to-End Idempotency**: Ensure consumers handle duplicate message delivery without state corruption.

Summary & Engineering Q&A

Thank You for Attending

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Architecture Repository: `https://arch.meridian-systems.internal/docs/event-driven`