Cloud Architecture Patterns: Scale, Resilience, Security

A comprehensive guide for Technical Program Managers, Solution Architects, and Cloud Engineers

Agenda

1 Horizontal Scaling & Data Management

Partitioning, replication, and scaling strategies for modern systems

2 Performance Optimization

Caching strategies and event-driven architectures

3 Resilience Patterns

Circuit breakers, retries, rate limiting, and high availability

4 Security & Compliance

IAM, RBAC, secure design practices, and compliance frameworks

This training provides both theoretical concepts and real-world applications. We'll examine case studies from companies like Netflix, Amazon, and Shopify to see these patterns in action.

Horizontal Scaling, Partitioning & Replication

Building systems that scale without limits

Horizontal Scaling Fundamentals

Adding more machines instead of upgrading existing ones

- Distributes load across multiple nodes
- Enables near-linear scaling (with proper design)
- Provides resiliency against node failures
- Supports geographic distribution

ⓘ **TPM Insight:** Coordinate scaling events with downstream dependencies to prevent cascading failures

Data Partitioning Strategies

Horizontal (Sharding)

Splitting data across multiple databases based on a partition key

- Amazon DynamoDB: Partition by user ID
- YouTube: Video shards by popularity/access patterns

Vertical

Splitting different tables or columns across databases

- Shopify: Separating product data from customer data
- Netflix: Content metadata vs. user profiles

Functional

Splitting by business domain or function

- Microservice architectures
- Domain-driven design boundaries

Replication: Reading at Scale

Primary DB

Write Ops

Replicate

Read Replicas

Key Benefits

- Distributes read load
- Improves read performance

Challenges

- Replication lag (eventual consistency)
- Conflict resolution

Case Study: YouTube Traffic Spikes

Challenge

- Viral videos creating sudden traffic spikes
- 10-100x normal traffic in minutes
- Regional viewing patterns

Solution Components

- CDN caching at edge locations
- Dynamic re-sharding of popular content
- Read replicas with regional distribution
- Request buffering during peak loads

TPM Insight: Implement automated scaling triggers with clear thresholds and monitoring

Partitioning Trade-offs

Strategy	Advantages	Disadvantages
Hash-based	Even distribution, scalable	No range queries, repartitioning complex
Range-based	Efficient range queries	Potential hotspots, uneven distribution
Geography-based	Locality, compliance, performance	Complex replication, consistency challenges
Dynamic	Adapts to changing patterns	Complex implementation, monitoring overhead

TPM Guidance:

- Align partition strategies with access patterns and business requirements
- Implement partition observability to detect hotspots early
- Balance cost vs. performance gains when evaluating partition schemes

Caching Strategies

Accelerating performance through strategic data storage

Caching: Principles & Patterns

Store frequently accessed data in fast-access storage to reduce load and latency

Client-Side Cache

Browser cache, mobile app local storage

CDN Cache

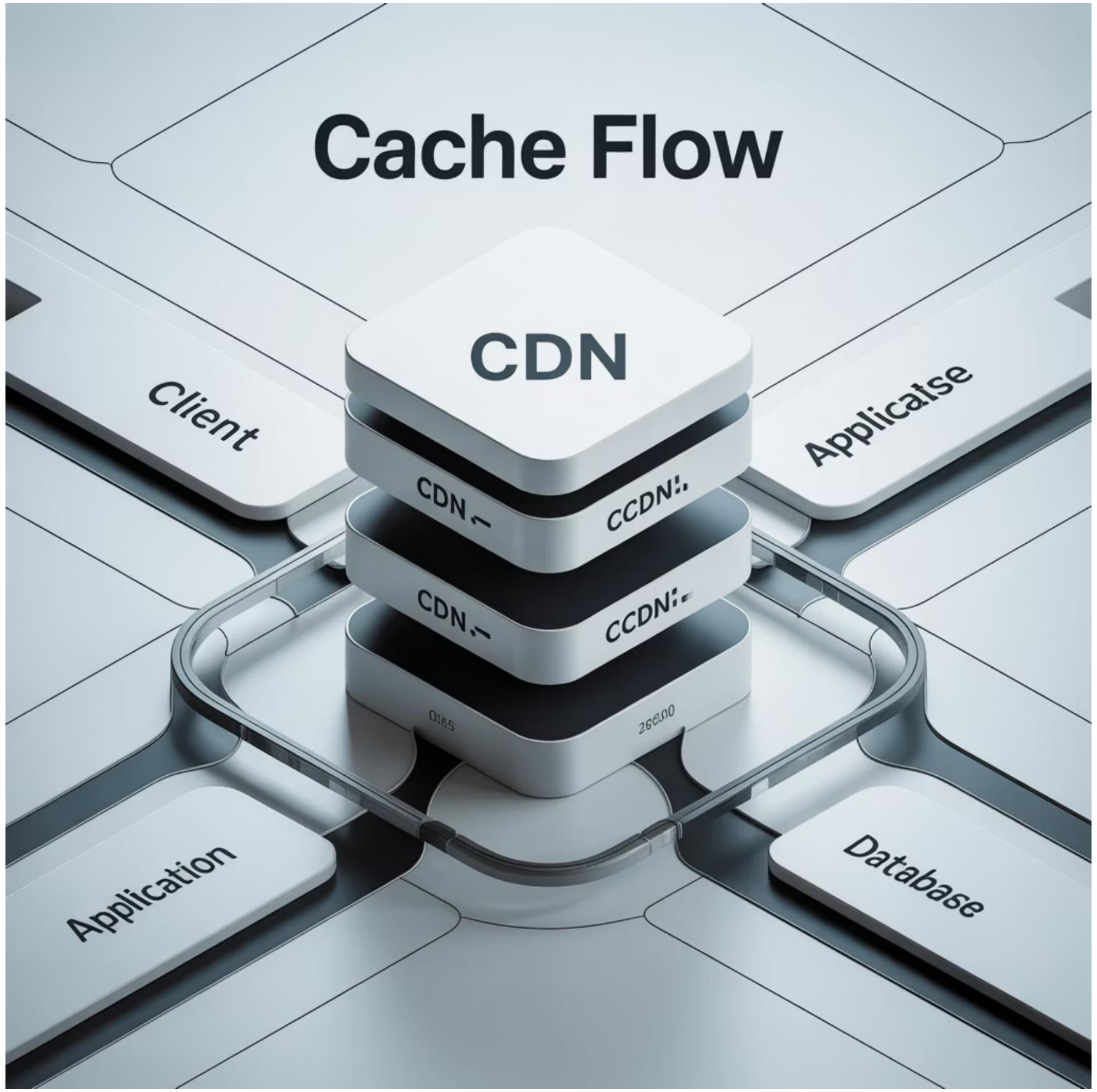
Akamai, Cloudflare, AWS CloudFront

Application Cache

In-memory (Redis, Memcached)

Database Cache

Query cache, materialized views



CDN Caching in Action

Reduced origin

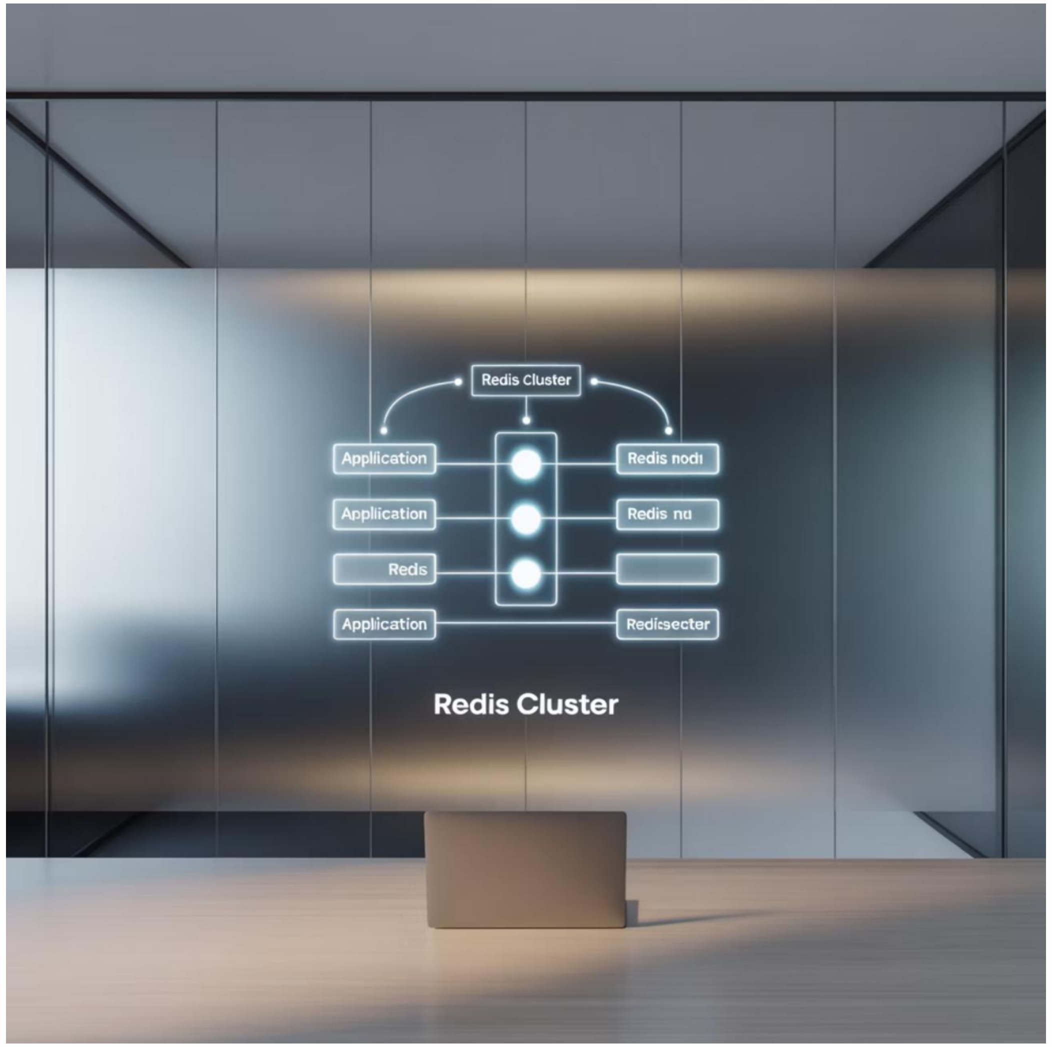
Lower latency

Cost savings

Improved conversion

DDoS protection

In-Memory Caching with Redis



Key Use Cases

- Session storage
- Real-time leaderboards
- Rate limiting
- Page rendering acceleration

Cache Invalidation Strategies

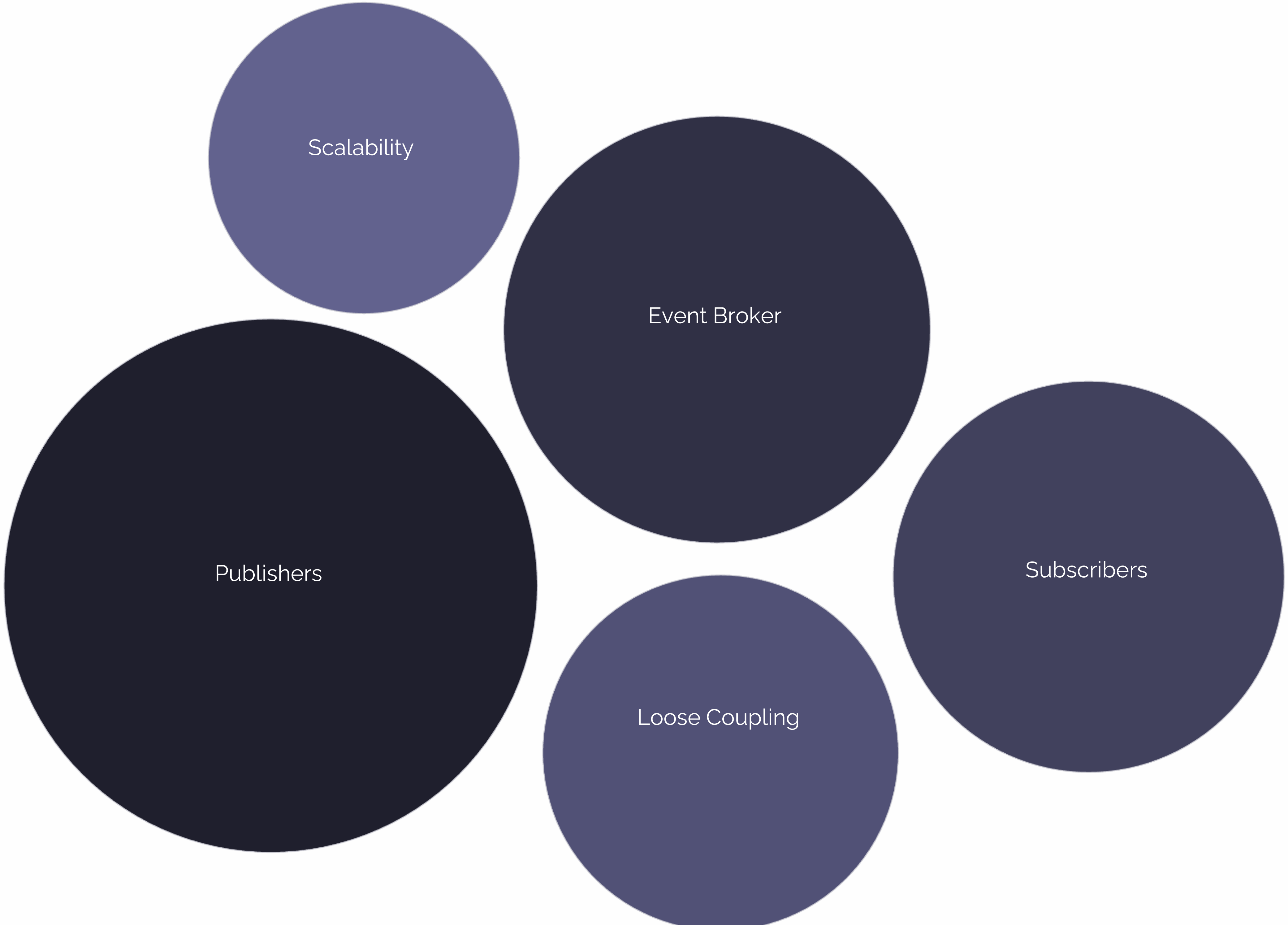
- Time-based (TTL)
- Write-through
- Write-behind
- Cache-aside (lazy loading)

TPM Discussion: When is stale cache data acceptable? Consider business context and user expectations.

Event-Driven Systems

Building resilient, decoupled architectures

Event-Driven Architecture Fundamentals



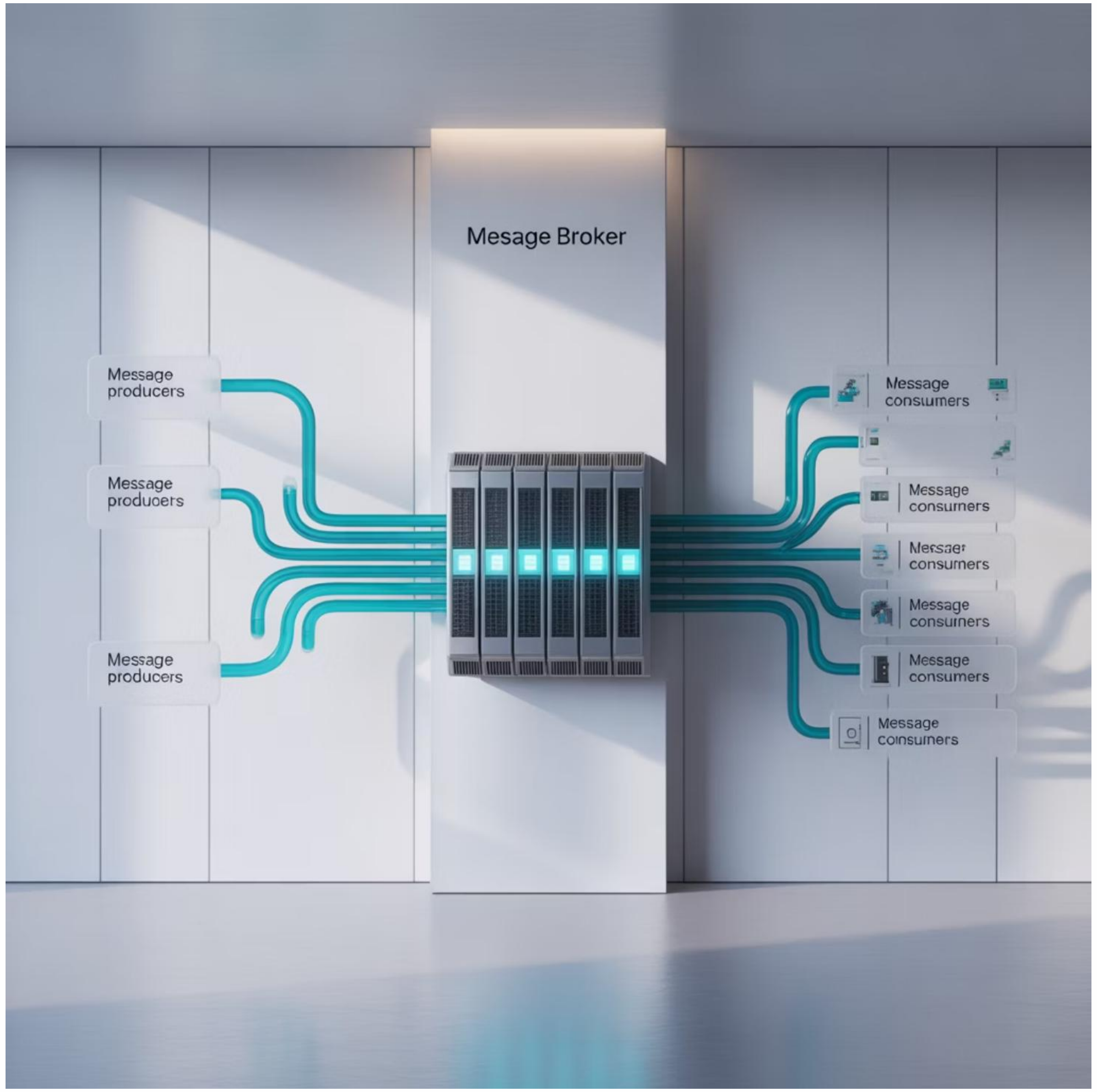
Pub/Sub Implementation Patterns

Common implementation platforms:

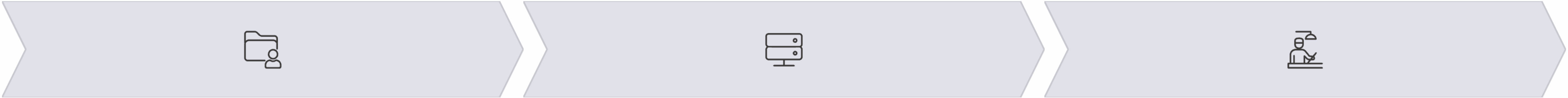
- AWS SNS/SQS
- Google Cloud Pub/Sub
- Azure Event Grid/Service Bus
- RabbitMQ
- Apache Kafka

Real-World Examples

- Zalando: Order processing pipeline
- Flipkart: Inventory updates
- Uber: Driver location updates



Kafka for High-Scale Event Processing



Producers

Write events to topics

- User service
- Order service
- Inventory service

Kafka Cluster

Distributed event store

- Partitioned topics
- Replicated logs
- Retention policies

Consumers

Process events

- Analytics
- Notifications
- Data pipeline

TPM Discussion: How to handle consumer downtime without data loss? Consider consumer group offsets, dead-letter queues, and replay capabilities.

Case Study

Retail Flash Sale: Scaling Under Pressure

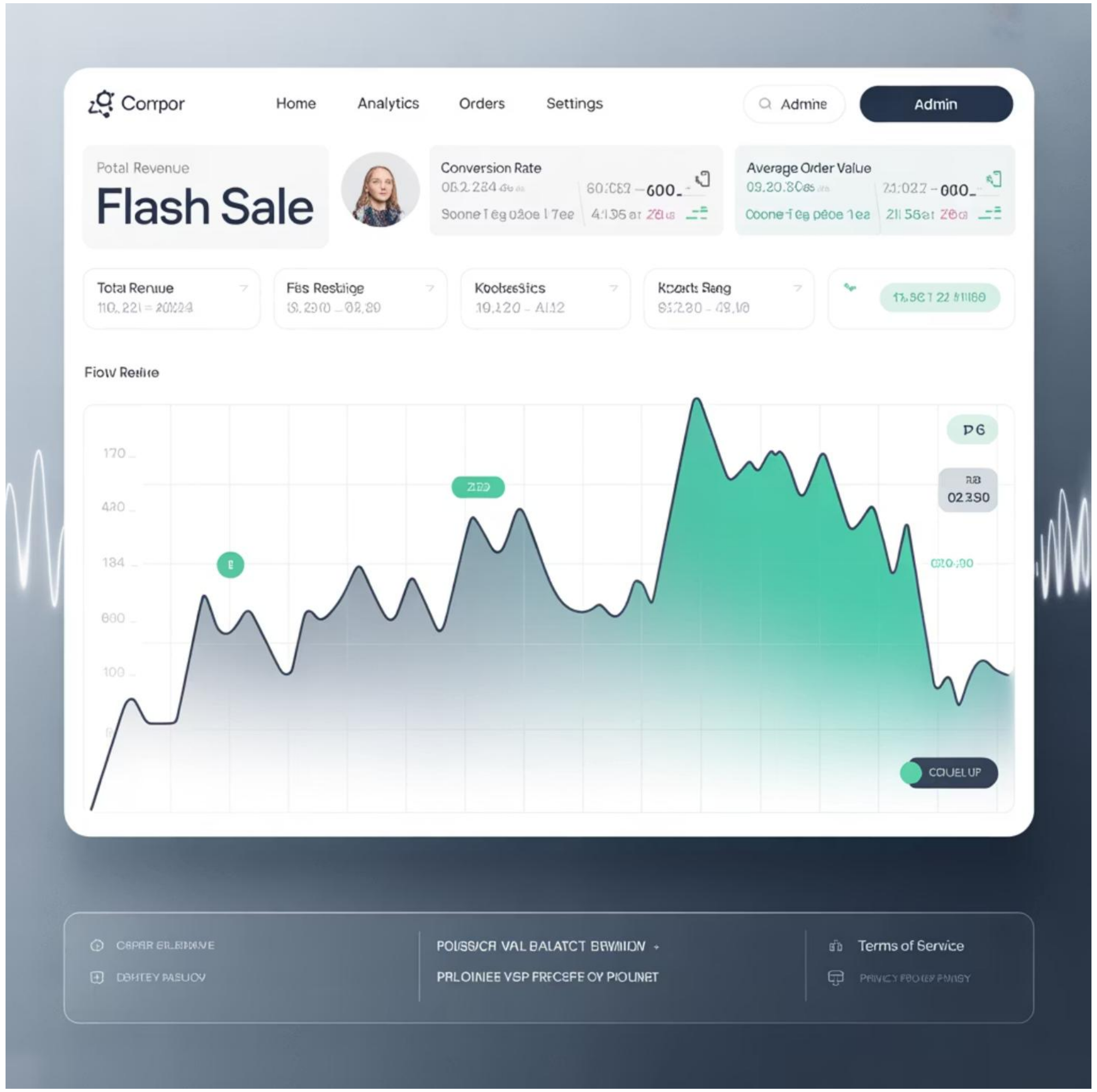
Retail Flash Sale: The Challenge

Scenario

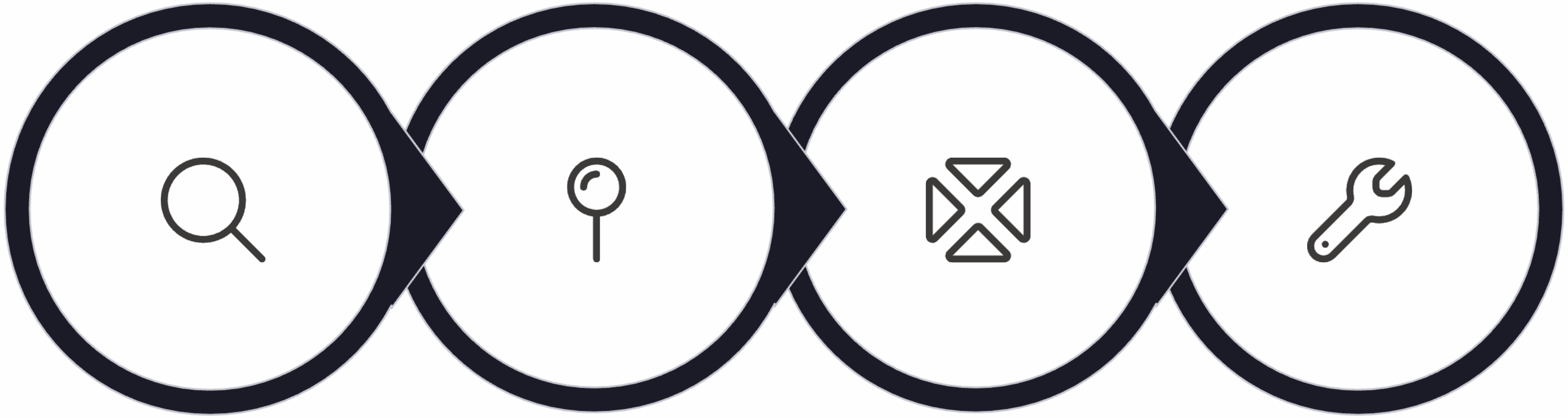
- E-commerce platform launching limited-time sale
- 50x normal traffic expected in first 30 minutes
- Limited inventory, high-demand products
- Previous sales resulted in site crashes and overselling

Critical Functions

- Product catalog and search
- Inventory status
- Cart operations
- Checkout process
- Order confirmation



Diagnosis Flow: Symptoms to Solutions



Identify

Locate

Determine

Apply

Real-World Examples:

- Myntra End of Reason Sale: 15x traffic increase managed through partitioning and CDN caching
- Amazon Prime Day: Dynamic scaling across service tiers with circuit breakers
- Shopify Black Friday: Gradual rollout of flash sales across geographic regions

Flash Sale: Architecture Solutions

Product Catalog & Search

- Read-only replicas
- Aggressive CDN caching
- Search service scaling

Inventory Management

- Distributed counters
- Optimistic locking
- Inventory service isolation

Cart & Checkout

- Redis-backed carts
- Checkout queuing
- Asynchronous order processing

Infrastructure

- Auto-scaling groups
- Rate limiting at API gateway
- Circuit breakers for non-critical services

TPM Discussion: What service degradations are acceptable during peak load? How do we communicate these to stakeholders?

Flash Sale: Operational Readiness

Pre-Sale Testing

- Load testing with realistic traffic patterns
- Failover drills
- Chaos engineering experiments

Coordination

- Cross-team war room
- Service-level dashboards
- Escalation paths defined

Monitoring

- Real-time traffic visualization
- Custom flash sale metrics
- Anomaly detection

TPM Coordination Points:

- Align marketing, inventory, and technical teams on timing and expectations
- Establish clear SLAs for each system component during the event
- Define acceptable degradation paths if systems approach limits

Resilience Patterns

Circuit Breakers, Retries, Rate Limiting

Circuit Breaker Pattern

Prevents cascade failures by temporarily "breaking the circuit" to failing services

1

Closed State

Normal operation: requests flow through

2

Open State

Circuit broken: requests fail fast without attempting downstream call

3

Half-Open State

Testing recovery: limited requests to test if system has recovered

Circuit Breaker Implementation

Key Parameters

- Failure threshold (e.g., 50% of 20 requests)
- Timeout duration (e.g., 5 seconds)
- Reset timeout (e.g., 30 seconds in open state)
- Fallback behavior

Real-World Examples

- Netflix Hystrix (now Resilience4j)
- Microsoft Azure Circuit Breaker
- Istio service mesh resilience

Implementation Best Practices

- Implement per service/endpoint
- Configure meaningful thresholds
- Provide graceful fallbacks
- Log state transitions
- Alert on circuit open events
- Test circuit behavior regularly

⊗ **TPM Risk:** Circuit breakers must be carefully tuned—too sensitive and services become unavailable unnecessarily; too lax and cascading failures occur.

Retry Strategies

Fixed Interval

Retry every X seconds

Simple but can amplify load spikes

Exponential Backoff

Progressively longer delays

Prevents thundering herd

Jitter

Random variation added to delay

Prevents synchronization

Retry with Timeout

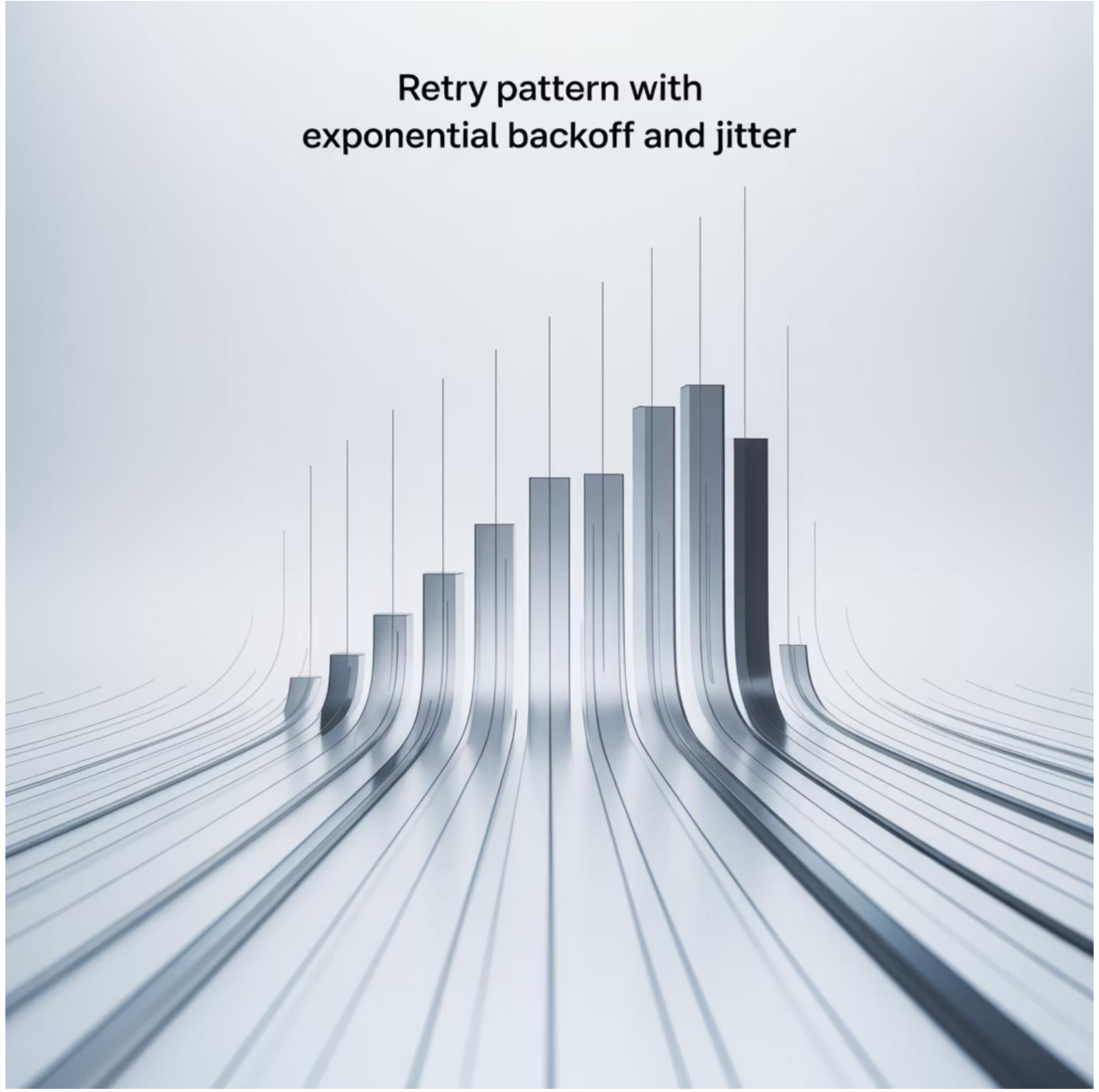
Maximum total retry duration

Prevents indefinite retries

Implementation Examples:

- AWS SDK built-in retry mechanisms
- Spring Retry module
- Polly (.NET resilience library)

Retry Pattern Implementation



When to Use Retries

- Transient failures (network glitches)
- Resource contention (database locks)
- Service temporarily unavailable
- Rate limit exceeded

When NOT to Retry

- Authentication failures
- Validation errors
- Resource not found
- Permission denied

⚠ **TPM Risk Alert:** Poorly implemented retries can cause "retry storms" that amplify system stress during outages. Always combine with circuit breakers and jitter.

Rate Limiting Patterns

Token Bucket

Tokens refill at fixed rate; requests consume tokens

Allows bursts up to bucket size

Used by AWS API Gateway, GitHub API

Leaky Bucket

Requests processed at constant rate

Excess requests queued or rejected

Smoother traffic flow, no bursting

Fixed Window

X requests per time window

Simple but edge effects at window boundaries

Common in simple API rate limiting

User-Based

Different limits per user tier

Prioritizes premium customers

Used by Stripe, Twilio APIs

Rate Limiting Implementation

Implementation Locations

- API Gateway (AWS, Azure, Kong, Apigee)
- Load Balancer (Nginx, HAProxy)
- Application Code (Redis-backed)
- Service Mesh (Istio, Linkerd)

Best Practices

- Return 429 (Too Many Requests) status code
- Include Retry-After header
- Expose limit information in headers
- Log and monitor rate limit events
- Implement graceful degradation

High Availability & Multi-Region Design

Building systems that never go down

High Availability Fundamentals

Eliminate single points of failure at every layer

Infrastructure Redundancy

- Multiple AZs/data centers
- N+1 or N+2 capacity
- Network path redundancy

Data Redundancy

- Multi-AZ databases
- Data replication
- Backup and recovery

Application Redundancy

- Stateless design
- Load balancing
- Auto-scaling