

# Social Media System Design - Progressive Stages

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## Stage 2: Search with Elasticsearch

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### Architecture Overview

Added full-text search capability with Elasticsearch, migrated to NoSQL, and implemented event-driven indexing.

```

graph TB
    subgraph "Stage 2: Search-Enabled Architecture"
        Client[Client/Browser]
        API[API Server<br/>User CRUD<br/>Post CRUD<br/>Search API]

        subgraph "Data Layer"
            MongoDB[(NoSQL Database<br/>MongoDB)]
            ES[(Elasticsearch<br/>Search Index)]
        end

        subgraph "Event Processing"
            Kafka[Apache Kafka<br/>Event Stream]
            Indexer[Indexer Service<br/>Consumes Events]
            Cron[Cron Job<br/>Reindex Service]
        end

        Client -->|HTTP Requests| API
        API -->|Write Operations| MongoDB
        API -->|Search Queries| ES
        API -->|Publish Events| Kafka
        Kafka -->|Subscribe| Indexer
        Indexer -->|Update Index| ES
        MongoDB -->|Read Data| Cron
        Cron -->|Bulk Reindex| ES
    end

    style API fill:#4A90E2
    style MongoDB fill:#47A248
    style ES fill:#FEC514
    style Kafka fill:#231F20
    style Indexer fill:#FF6B6B
    style Cron fill:#9B59B6

```

## Data Flow - Create Post with Indexing

```
sequenceDiagram
    participant C as Client
    participant A as API Server
    participant M as MongoDB
    participant K as Kafka
    participant I as Indexer Service
    participant E as Elasticsearch

    Note over C,E: Create Post Flow
    C->>A: POST /api/posts
    A->>M: Insert Post Document
    M->>A: Success (post_id)

    par Async Indexing
        A->>K: Publish "post.created" Event
        K->>I: Consume Event
        I->>E: Index Post Document
        E->>I: Indexed
    end

    end

    A->>C: 201 Created
```

## Data Flow - Search Posts

```
sequenceDiagram
    participant C as Client
    participant A as API Server
    participant E as Elasticsearch
    participant M as MongoDB

    Note over C,M: Search Flow
    C->>A: GET /api/posts/search?q=keyword
    A->>E: Query: match(content, keyword)
    E->>E: Rank by relevance,<br/>recency, votes
    E->>A: Post IDs + Scores

    opt Fetch Full Details
        A->>M: Get Posts by IDs
        M->>A: Post Documents
    end

    A->>C: 200 OK + Search Results
```

## Reindexing Flow

```
sequenceDiagram
    participant Cron as Cron Job
    participant M as MongoDB
    participant E as Elasticsearch

    Note over Cron,E: Scheduled Reindex (Daily 2 AM)
    Cron->>Cron: Trigger Reindex Job
    Cron->>M: Fetch All Posts (Batch)
    M->>Cron: Posts Data

    loop For Each Batch
        Cron->>E: Bulk Index Documents
        E->>Cron: Batch Indexed
    end

    Cron->>Cron: Log Completion
```

## Kafka Topics Structure

```
graph LR
    subgraph "Kafka Topics"
        T1[post.created]
        T2[post.updated]
        T3[post.deleted]
        T4[post.voted]
    end

    API[API Server] -->|Produce| T1
    API -->|Produce| T2
    API -->|Produce| T3
    API -->|Produce| T4

    T1 -->|Consume| Indexer[Indexer Service]
    T2 -->|Consume| Indexer
    T3 -->|Consume| Indexer
    T4 -->|Consume| Indexer

    style T1 fill:#2ECC71
    style T2 fill:#3498DB
    style T3 fill:#E74C3C
    style T4 fill:#F39C12
```

## Stage 3: Load Balancing & Caching

### Architecture Overview

Production-ready architecture with load balancing, caching layer, and horizontal scaling.

```

graph TB
    subgraph "Stage 3: Scaled Architecture with LB & Cache"
        Client[Clients/Browsers]
        LB[Load Balancer<br/>Nginx/AWS ALB]

        subgraph "Application Layer"
            API1[API Server 1]
            API2[API Server 2]
            API3[API Server 3]
        end

        subgraph "Cache Layer"
            Redis[(Redis Cache<br/>Session & Data)]
        end

        subgraph "Data Layer"
            MongoDB[(MongoDB<br/>Replica Set)]
            ES[(Elasticsearch<br/>Cluster)]
        end

        subgraph "Event Processing"
            Kafka[Kafka Cluster]
            Indexer1[Indexer 1]
            Indexer2[Indexer 2]
            Cron[Cron Service]
        end

        Client -->|HTTPS| LB
        LB -->|Round Robin| API1
        LB -->|Round Robin| API2
        LB -->|Round Robin| API3

        API1 -.→|Check Cache| Redis
        API2 -.→|Check Cache| Redis
        API3 -.→|Check Cache| Redis

        API1 -->|Write/Read| MongoDB
        API2 -->|Write/Read| MongoDB
        API3 -->|Write/Read| MongoDB

        API1 -->|Search| ES
        API2 -->|Search| ES
    end

```

```
API3 →|Search| ES

API1 →|Publish| Kafka
API2 →|Publish| Kafka
API3 →|Publish| Kafka

Kafka →|Consume| Indexer1
Kafka →|Consume| Indexer2
Indexer1 →|Update| ES
Indexer2 →|Update| ES

MongoDB →|Read| Cron
Cron →|Reindex| ES
end

style LB fill:#E67E22
style API1 fill:#4A90E2
style API2 fill:#4A90E2
style API3 fill:#4A90E2
style Redis fill:#DC382D
style MongoDB fill:#47A248
style ES fill:#FEC514
style Kafka fill:#231F20
```

## Detailed Request Flow with Cache

```
sequenceDiagram
    participant C as Client
    participant LB as Load Balancer
    participant A as API Server
    participant R as Redis Cache
    participant M as MongoDB
    participant E as Elasticsearch

    Note over C,E: Get User Profile (Cache Hit)
    C->>LB: GET /api/users/123
    LB->>A: Forward Request
    A->>R: GET user:123
    R->>A: Cache HIT (User Data)
    A->>LB: 200 OK + User Data
    LB->>C: Response

    Note over C,E: Get User Profile (Cache Miss)
    C->>LB: GET /api/users/456
    LB->>A: Forward Request
    A->>R: GET user:456
    R->>A: Cache MISS (null)
    A->>M: Find user by ID
    M->>A: User Document
    A->>R: SET user:456 (TTL: 1h)
    R->>A: OK
    A->>LB: 200 OK + User Data
    LB->>C: Response

    Note over C,E: Search Posts (with Cache)
    C->>LB: GET /api/posts/search?q=tech
    LB->>A: Forward Request
    A->>R: GET search:tech:page:1
    R->>A: Cache MISS
    A->>E: Search Query
    E->>A: Search Results
    A->>R: SET search:tech:page:1 (TTL: 5m)
    A->>LB: 200 OK + Results
    LB->>C: Response
```



## Cache Strategy Details

```
graph TB
    subgraph "Cache Strategy by Data Type"
        subgraph "User Data"
            U1[User Profile<br/>TTL: 1 hour<br/>Strategy: Cache-Aside]
            U2[User Sessions<br/>TTL: 30 min<br/>Strategy: Write-Through]
        end

        subgraph "Post Data"
            P1[Individual Posts<br/>TTL: 30 min<br/>Strategy: Cache-Aside]
            P2[Post Lists<br/>TTL: 5 min<br/>Strategy: Cache-Aside]
            P3[Trending Posts<br/>TTL: 2 min<br/>Strategy: Refresh-Ahead]
        end

        subgraph "Search Results"
            S1[Search Queries<br/>TTL: 5 min<br/>Strategy: Cache-Aside]
            S2[Popular Searches<br/>TTL: 10 min<br/>Strategy: Cache-Aside]
        end

        subgraph "Computed Data"
            C1[Vote Counts<br/>TTL: 1 min<br/>Strategy: Write-Behind]
            C2[User Stats<br/>TTL: 15 min<br/>Strategy: Cache-Aside]
        end
    end

    style U1 fill:#3498DB
    style U2 fill:#3498DB
    style P1 fill:#2ECC71
    style P2 fill:#2ECC71
    style P3 fill:#2ECC71
    style S1 fill:#F39C12
    style S2 fill:#F39C12
    style C1 fill:#9B59B6
    style C2 fill:#9B59B6
```

## Load Balancer Configuration

```
graph LR
  subgraph "Load Balancer Strategies"
    LB[Load Balancer]

    subgraph "Routing Rules"
      R1[/api/users/* → Round Robin]
      R2[/api/posts/* → Round Robin]
      R3[/api/search/* → Least Connections]
      R4[/api/uploads/* → IP Hash]
    end

    subgraph "Health Checks"
      H1[GET /health every 10s]
      H2[Timeout: 5s]
      H3[Unhealthy threshold: 3]
    end
  end

  LB → R1
  LB → R2
  LB → R3
  LB → R4
  LB -.→|Monitor| H1
  LB -.→|Monitor| H2
  LB -.→|Monitor| H3
end
```

## Write Operation with Cache Invalidation

```
sequenceDiagram
    participant C as Client
    participant LB as Load Balancer
    participant A as API Server
    participant R as Redis
    participant M as MongoDB
    participant K as Kafka

    Note over C,K: Update Post Flow
    C->>LB: PUT /api/posts/123
    LB->>A: Forward Request

    par Database Update
        A->>M: Update Post Document
        M->>A: Success
    and Cache Invalidation
        A->>R: DELETE post:123
        A->>R: DELETE post_list:*
        R->>A: Keys Deleted
    and Event Publishing
        A->>K: Publish "post.updated"
        K->>A: Acknowledged
    end

    A->>LB: 200 OK
    LB->>C: Response

    Note over K: Async: Indexer will update Elasticsearch
```

## Complete Data Flow

flowchart TB

Start([Client Request]) → LB{Load Balancer}

LB → |Route| API[API Server]

API → CheckCache{Check Redis Cache}

CheckCache → |HIT| ReturnCache[Return Cached Data]

CheckCache → |MISS| CheckType{Request Type}

CheckType → |Search| ES[Query Elasticsearch]

CheckType → |CRUD| DB[Query MongoDB]

ES → CacheResult[Cache Search Results]

DB → CacheData[Cache DB Results]

CacheResult → Return[Return Response]

CacheData → Return

ReturnCache → Return

API → |Write Op| PublishEvent[Publish to Kafka]

PublishEvent → Indexer[Indexer Service]

Indexer → UpdateES[Update Elasticsearch]

API → |Write Op| InvalidateCache[Invalidate Cache]

Return → End([Response to Client])

style LB fill:#E67E22

style API fill:#4A90E2

style ES fill:#FEC514

style DB fill:#47A248

style CheckCache fill:#DC382D

style PublishEvent fill:#231F20

## Comparison: Stage Evolution

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### Architecture Complexity

```
graph LR
    subgraph "Stage 1"
        S1C[Client] --> S1A[API]
        S1A --> S1D[(DB)]
    end

    subgraph "Stage 2"
        S2C[Client] --> S2A[API]
        S2A --> S2M[(MongoDB)]
        S2A --> S2E[(Elasticsearch)]
        S2A --> S2K[Kafka]
        S2K --> S2I[Indexer]
        S2I --> S2E
    end

    subgraph "Stage 3"
        S3C[Client] --> S3L[LB]
        S3L --> S3A1[API-1]
        S3L --> S3A2[API-2]
        S3A1 --> S3R[(Redis)]
        S3A2 --> S3R
        S3A1 --> S3M[(MongoDB)]
        S3A2 --> S3M
        S3A1 --> S3E[(ES)]
        S3A2 --> S3E
    end

    style S1A fill:#4A90E2
    style S2A fill:#4A90E2
    style S3A1 fill:#4A90E2
    style S3A2 fill:#4A90E2
    style S3L fill:#E67E22
    style S3R fill:#DC382D
```

## Performance Metrics Comparison

```
graph TB
    subgraph "Metrics Evolution"
        direction TB
        M1["M1[Stage 1<br/>—<br/>Response Time: 200ms<br/>Throughput: 100 req/s<br/>Availability: 95%]"]
        M2["M2[Stage 2<br/>—<br/>Response Time: 150ms<br/>Search Time: 50ms<br/>Throughput: 300 req/s<br/>Availability: 97%]"]
        M3["M3[Stage 3<br/>—<br/>Response Time: 50ms avg<br/>Search Time: 30ms<br/>Throughput: 2000 req/s<br/>Availability: 99.9%]"]
        M1 -.->|Added Search| M2
        M2 -.->|Added LB & Cache| M3
    end

    style M1 fill:#E74C3C
    style M2 fill:#F39C12
    style M3 fill:#2ECC71
```

## Key Features by Stage

FEATURE	STAGE 1	STAGE 2	STAGE 3
User CRUD	✓	✓	✓
Post CRUD	✓	✓	✓
Full-Text Search	✗	✓	✓
Search Ranking	✗	✓ (Relevance, Recency, Votes)	✓
Real-time Indexing	✗	✓ (Kafka)	✓
Batch Reindexing	✗	✓ (Cron)	✓
Load Balancing	✗	✗	✓
Caching	✗	✗	✓ (Redis)
Horizontal Scaling	✗	Partial	✓
High Availability	✗	✗	✓

## Technology Stack Summary

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Technology Stack			
Layer	Stage 1	Stage 2	Stage 3
Load Bal.	-	-	Nginx/ALB
API	Node.js	Node.js	Node.js (3x)
Cache	-	-	Redis
Database	PostgreSQL	MongoDB	MongoDB Cluster
Search	-	Elasticsearch	ES Cluster
Queue	-	Kafka	Kafka Cluster
Indexer	-	Node.js	Node.js (2x)
Scheduler	-	Cron	Cron Service