Message Queue & Event-Driven Design - 1 Hour Session

Duration: 60 minutes **Level:** Intermediate

Session Agenda

- ☐ Introduction to Message Queues (10 min)
- ☐ Message Queue Technologies (15 min)
- ☐ Event-Driven Patterns (15 min)
- ☐ Advanced Concepts: Event Sourcing & CQRS (10 min)
- ☐ Implementation & Best Practices (10 min)

Learning Objectives

By the end of this session, you will understand:

- What message queues are and when to use them
- Key differences between Kafka, RabbitMQ, and SQS
- Pub/Sub patterns and their applications
- Event sourcing and CQRS concepts
- Choreography vs orchestration in distributed systems
- Common pitfalls and how to avoid them

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1. Introduction to Message Queues (10 min)

What is a Message Queue?

A **message queue** is a form of asynchronous service-to-service communication used in distributed systems. Messages are stored in the queue until processed and deleted.

> [!quote] Fundamental Principle "Decouple components by communicating through messages rather than direct calls."

Why Use Message Queues?

Key Benefits:

- **Decoupling:** Services don't need to know about each other
- **Async Processing:** Non-blocking operations
- **Scalability:** Handle traffic spikes with buffering
- **Reliability:** Messages persist until processed
- **Load Leveling:** Smooth out traffic bursts

Synchronous vs Asynchronous Communication

```
flowchart LR
    subgraph sync["Synchronous (HTTP/REST)"]
        direction LR
        A1[Service A<br/>waits] -->|Request| B1[Service B<br/>processes]
        B1 -->|Response| A1
    end
```

```
    subgraph async["Asynchronous (Message Queue)"]
        direction LR
        A2[Service A<br/>continues] -->|Publish| Q[Queue<br/>buffers]
        Q -->|Consume| B2[Service B<br/>processes]
    end
```

Core Concepts

Concept	Description
Producer	Service that sends messages
Consumer	Service that receives messages
Queue/Topic	Storage for messages
Message	Data payload with metadata
Broker	Server managing queues

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2. Message Queue Technologies (15 min)

Apache Kafka

Distributed event streaming platform designed for high-throughput, fault-tolerant messaging.

```
flowchart TB
    subgraph kafka["Kafka Cluster"]
        subgraph topic["Topic: orders"]
            P0["Partition 0<br/>msg1, 4, 7"]
            P1["Partition 1<br/>msg2, 5, 8"]
            P2["Partition 2<br/>msg3, 6, 9"]
        end
    end
```

Key Features:

- Log-based storage (append-only)
- Consumer groups for parallel processing
- Message retention (configurable)
- Exactly-once semantics (with transactions)

```java
// Kafka Producer Example
Properties props = new Properties();
props.put("bootstrap.servers", "localhost:9092");
props.put("key.serializer", "org.apache.kafka.common.serialization.StringSerializer");
props.put("value.serializer", "org.apache.kafka.common.serialization.StringSerializer");

Producer<String, String> producer = new KafkaProducer<>(props);
producer.send(new ProducerRecord<>("orders", "order-123", orderJson));

// Kafka Consumer Example
props.put("group.id", "order-processor");
Consumer<String, String> consumer = new KafkaConsumer<>(props);
consumer.subscribe(Arrays.asList("orders"));

while (true) {
    ConsumerRecords<String, String> records = consumer.poll(Duration.ofMillis(100));
```

```
    for (ConsumerRecord<String, String> record : records) {
        processOrder(record.value());
    }
}
```

RabbitMQ

Traditional message broker implementing AMQP protocol with flexible routing.

```
flowchart LR
    subgraph rabbitmq["RabbitMQ"]
        P[Producer] --> E[Exchange]
        E -->|Binding| Q[Queue]
        Q --> C[Consumer]
    end
```

Exchange Types: - **Direct** - routing key match - **Fanout** - broadcast to all - **Topic** - pattern matching - **Headers** - header attributes

Key Features:

- Flexible routing with exchanges
- Message acknowledgments
- Dead letter queues
- Priority queues

```python
# RabbitMQ Producer Example
import pika

connection = pika.BlockingConnection(pika.ConnectionParameters('localhost'))
channel = connection.channel()

channel.queue_declare(queue='orders', durable=True)
channel.basic_publish(
    exchange='',
    routing_key='orders',
    body=order_json,
    properties=pika.BasicProperties(delivery_mode=2)  # Persistent
)

# RabbitMQ Consumer Example
def callback(ch, method, properties, body):
    process_order(body)
    ch.basic_ack(delivery_tag=method.delivery_tag)

channel.basic_consume(queue='orders', on_message_callback=callback)
channel.start_consuming()
```

Amazon SQS

Fully managed message queue service by AWS.

```
flowchart TB
    subgraph sqs["Amazon SQS"]
        subgraph standard["Standard Queue"]
            S1["At-least-once delivery"]
            S2["Best-effort ordering"]
```

```
            S3["Nearly unlimited throughput"]
        end
        subgraph fifo["FIFO Queue"]
            F1["Exactly-once processing"]
            F2["Strict ordering"]
            F3["300 msg/sec (3000 with batching)"]
        end
    end
```

```python
# SQS Example
import boto3

sqs = boto3.client('sqs')
queue_url = 'https://sqs.us-east-1.amazonaws.com/123456789/orders'

# Send message
sqs.send_message(
    QueueUrl=queue_url,
    MessageBody=order_json,
    MessageAttributes={
        'OrderType': {'DataType': 'String', 'StringValue': 'standard'}
    }
)

# Receive messages
response = sqs.receive_message(
    QueueUrl=queue_url,
    MaxNumberOfMessages=10,
    WaitTimeSeconds=20  # Long polling
)

for message in response.get('Messages', []):
    process_order(message['Body'])
    sqs.delete_message(
        QueueUrl=queue_url,
        ReceiptHandle=message['ReceiptHandle']
    )
```

Technology Comparison

Feature	Kafka	RabbitMQ	SQS
Model	Log-based	Queue-based	Queue-based
Ordering	Per partition	Per queue	FIFO only
Throughput	Very High	High	High
Retention	Configurable	Until consumed	14 days max
Replay	Yes	No	No
Managed	No (MSK yes)	No	Yes
Best For	Event streaming	Task queues	AWS integration

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3. Event-Driven Patterns (15 min)

Pub/Sub Pattern

Publishers send messages to **topics**, **subscribers** receive messages from topics they're interested in.

```
flowchart LR
    OS[Order Service] --> T[Topic: orders]
    T --> IS[Inventory Service]
    T --> NS[Notification Service]
    T --> AS[Analytics Service]
```

Use Cases:

- Event notifications
- Real-time updates
- Fan-out processing

Point-to-Point Pattern

One producer, one consumer per message. Messages are consumed once.

```
flowchart LR
    P[Producer] --> Q[Queue]
    Q --> C1[Consumer]
    Q -.->|backup| C2[Consumer<br/>backup]
```

Only one consumer receives each message

Use Cases:

- Task distribution
- Work queues
- Load balancing

Choreography vs Orchestration

Choreography: Services react to events independently (decentralized).

```
flowchart TB
    OC[Order Created Event]
    OC --> IS[Inventory Service<br/>reserves stock]
    IS --> SR[Stock Reserved Event]
    OC --> PS[Payment Service<br/>processes payment]
    PS --> PC[Payment Completed Event]
    OC --> NS[Notification Service<br/>sends confirmation]
```

Orchestration: Central coordinator manages the workflow.

```
flowchart TB
    subgraph orch["Order Orchestrator"]
        O1["1. Call Inventory Service"]
        O2["2. Call Payment Service"]
        O3["3. Call Shipping Service"]
        O4["4. Call Notification Service"]
    end
    orch --> IS[Inventory]
    orch --> PS[Payment]
    orch --> SS[Shipping]
    orch --> NS[Notification]
```

Aspect	Choreography	Orchestration
Coupling	Loose	Tighter
Visibility	Distributed	Centralized
Complexity	In events	In orchestrator
Failure Handling	Each service	Orchestrator
Best For	Simple flows	Complex workflows

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4. Advanced Concepts: Event Sourcing & CQRS (10 min)

Event Sourcing

Store state as a sequence of events rather than current state.

```
flowchart LR
    subgraph traditional["Traditional (State-based)"]
        T1["Account: 12345<br/>Balance: $500<br/>Last Updated: 2024-01-15"]
    end

    subgraph eventsourcing["Event Sourcing"]
        E1["Event 1: AccountCreated($0)"]
        E2["Event 2: Deposited($1000)"]
        E3["Event 3: Withdrawn($300)"]
        E4["Event 4: Deposited($200)"]
        E5["Event 5: Withdrawn($400)"]
        E6["Current State: $500 (computed)"]
        E1 --> E2 --> E3 --> E4 --> E5 --> E6
    end
```

Benefits:

- Complete audit trail
- Time travel (reconstruct past states)
- Event replay for debugging
- Natural fit for event-driven systems

```python
# Event Sourcing Example
class BankAccount:
    def __init__(self, account_id):
        self.account_id = account_id
        self.balance = 0
        self.events = []

    def apply_event(self, event):
        if event['type'] == 'Deposited':
            self.balance += event['amount']
        elif event['type'] == 'Withdrawn':
            self.balance -= event['amount']
        self.events.append(event)

    def deposit(self, amount):
        event = {'type': 'Deposited', 'amount': amount, 'timestamp': now()}
        self.apply_event(event)
        event_store.save(self.account_id, event)
```

```
    def rebuild_from_events(self, events):
        for event in events:
            self.apply_event(event)
```

CQRS (Command Query Responsibility Segregation)

Separate read and write models for different optimization.

```
flowchart TB
    subgraph CQRS[" CQRS Architecture "]
        direction TB

        subgraph CommandSide[" "]
            direction TB
            CT["  Commands (Write)"]
            C1[Create Order]
            C2[Update Order]
            C3[Cancel Order]
            WM[(Write Model<br/>Normalized)]

            CT ~~~ C1 & C2 & C3
            C1 & C2 & C3 --> WM
        end

        subgraph QuerySide[" "]
            direction TB
            QT["  Queries (Read)"]
            Q1[Get Orders]
            Q2[Search]
            Q3[Reports]
            RM[(Read Model<br/>Denormalized)]

            QT ~~~ Q1 & Q2 & Q3
            Q1 & Q2 & Q3 --> RM
        end

        WM -->|Sync| RM
    end
```

Benefits: - Optimize reads and writes independently - Scale read and write sides separately - Different data models for different needs

```
# CQRS Example
class OrderCommandHandler:
    def handle_create_order(self, command):
        order = Order.create(command.data)
        order_repository.save(order)
        event_bus.publish(OrderCreatedEvent(order))

class OrderQueryHandler:
    def get_order_summary(self, order_id):
        # Read from denormalized read model
        return read_db.query(
            "SELECT * FROM order_summaries WHERE id = ?",
            order_id
```

```
        )

# Event handler updates read model
class OrderProjection:
    def handle_order_created(self, event):
        read_db.insert('order_summaries', {
            'id': event.order_id,
            'customer_name': event.customer_name,
            'total': event.total,
            'status': 'created'
        })
```

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5. Implementation & Best Practices (10 min)

Message Design

```json
{
  "messageId": "msg-uuid-12345",
  "type": "OrderCreated",
  "version": "1.0",
  "timestamp": "2024-01-15T10:30:00Z",
  "source": "order-service",
  "correlationId": "req-uuid-67890",
  "data": {
    "orderId": "order-123",
    "customerId": "cust-456",
    "items": [...],
    "total": 99.99
  },
  "metadata": {
    "traceId": "trace-abc",
    "userId": "user-789"
  }
}
```

Idempotency

Ensure processing a message multiple times has the same effect as once.

```python
def process_order(message):
    message_id = message['messageId']

    # Check if already processed
    if processed_messages.exists(message_id):
        return  # Skip duplicate

    try:
        # Process the order
        create_order(message['data'])

        # Mark as processed
        processed_messages.add(message_id, ttl=7*24*60*60)  # 7 days
```

```python
    except Exception as e:
        # Don't mark as processed - allow retry
        raise e
```

Dead Letter Queues

Handle messages that can't be processed.

```
flowchart TB
    P[Producer] --> Q[Queue]
    Q --> C[Consumer]
    C -->|Failed 3x| Q
    Q --> DLQ[DLQ]
    DLQ --> A[Alert/Manual Review]
```

Monitoring & Observability

Key Metrics: - Queue depth (messages waiting) - Processing latency - Error rate - Consumer lag (Kafka) - Message age

```python
# Structured logging for tracing
import logging

def process_message(message):
    logger.info("Processing message", extra={
        'message_id': message['messageId'],
        'correlation_id': message['correlationId'],
        'trace_id': message['metadata']['traceId'],
        'message_type': message['type']
    })
```

Common Pitfalls & Solutions

1. Message Ordering

Problem: Messages processed out of order.

Solutions: - Use partition keys (Kafka) - FIFO queues (SQS) - Sequence numbers in messages

2. Duplicate Processing

Problem: Same message processed multiple times.

Solutions: - Idempotent consumers - Deduplication with message IDs - Exactly-once semantics (where available)

3. Poison Messages

Problem: Messages that always fail processing.

Solutions: - Dead letter queues - Retry limits - Circuit breakers

4. Consumer Lag

Problem: Consumers can't keep up with producers.

Solutions: - Scale consumers horizontally - Increase batch size - Optimize processing logic

Architecture Patterns

Event-Driven Microservices

```
flowchart TB
    subgraph services[Microservices Layer]
        direction LR
        OS[ Order<br/>Service]
        IS[ Inventory<br/>Service]
        PS[ Payment<br/>Service]
    end

    subgraph broker[Messaging Layer]
        MB[(" Message Broker<br/>(Kafka/RabbitMQ)")]
    end

    OS <-->|"order.created<br/>order.updated"| MB
    IS <-->|"inventory.reserved<br/>inventory.released"| MB
    PS <-->|"payment.processed<br/>payment.failed"| MB

    style MB fill:#6c5ce7,color:#fff
    style OS fill:#00b894,color:#fff
    style IS fill:#0984e3,color:#fff
    style PS fill:#e17055,color:#fff
```

```
flowchart LR
    subgraph saga["Order Saga"]
        S1[OrderCreated] --> S2[InventoryReserved]
        S2 --> S3[PaymentProcessed]
        S3 --> S4[OrderConfirmed]
    end

    subgraph compensation["Compensation (on failure)"]
        C1[PaymentFailed] --> C2[ReleaseInventory]
        C2 --> C3[CancelOrder]
    end
```

Key Takeaways

1. **Message queues enable loose coupling** and async communication
2. **Choose the right tool:** Kafka for streaming, RabbitMQ for routing, SQS for simplicity
3. **Pub/Sub vs Point-to-Point** depends on your use case
4. **Choreography vs Orchestration** - trade-offs in visibility and coupling
5. **Event Sourcing** provides audit trails and time travel
6. **CQRS** optimizes reads and writes separately
7. **Always design for idempotency** and handle failures gracefully

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Practical Exercise

Scenario: Design an e-commerce order processing system.

Requirements: - Order placement - Inventory check - Payment processing - Shipping notification - Email confirmation

Questions: 1. Which message queue technology would you choose? 2. Choreography or orchestration? 3. How to handle payment failures? 4. How to ensure exactly-once processing?

Session End - Thank You!

#message-queue #event-driven #kafka #rabbitmq #sqs #architecture #session-notes