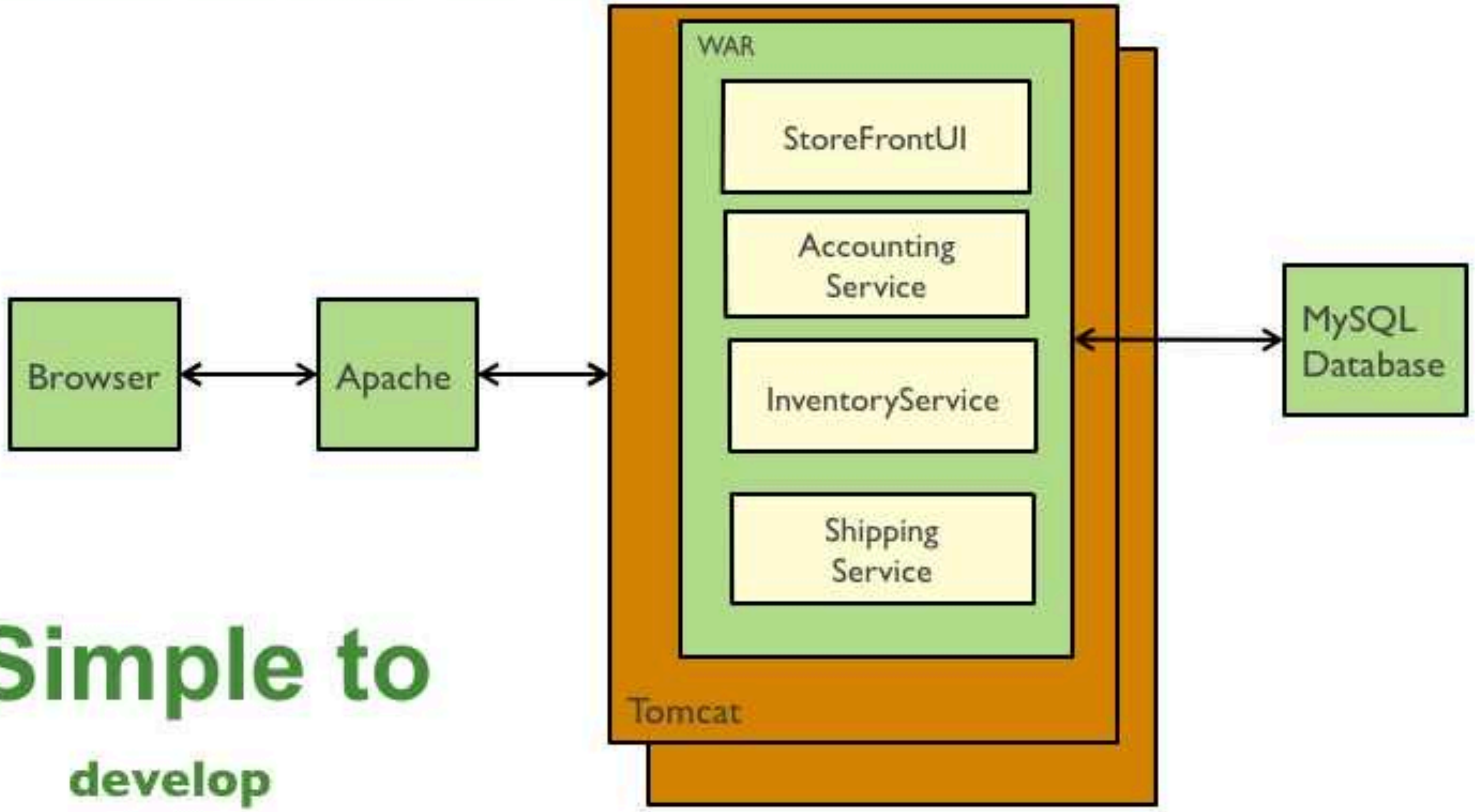
Microservices Review

Microservices use distributed systems concepts to build scalable, “cloud native” applications

Monolithic Web Application

Traditional web application architecture

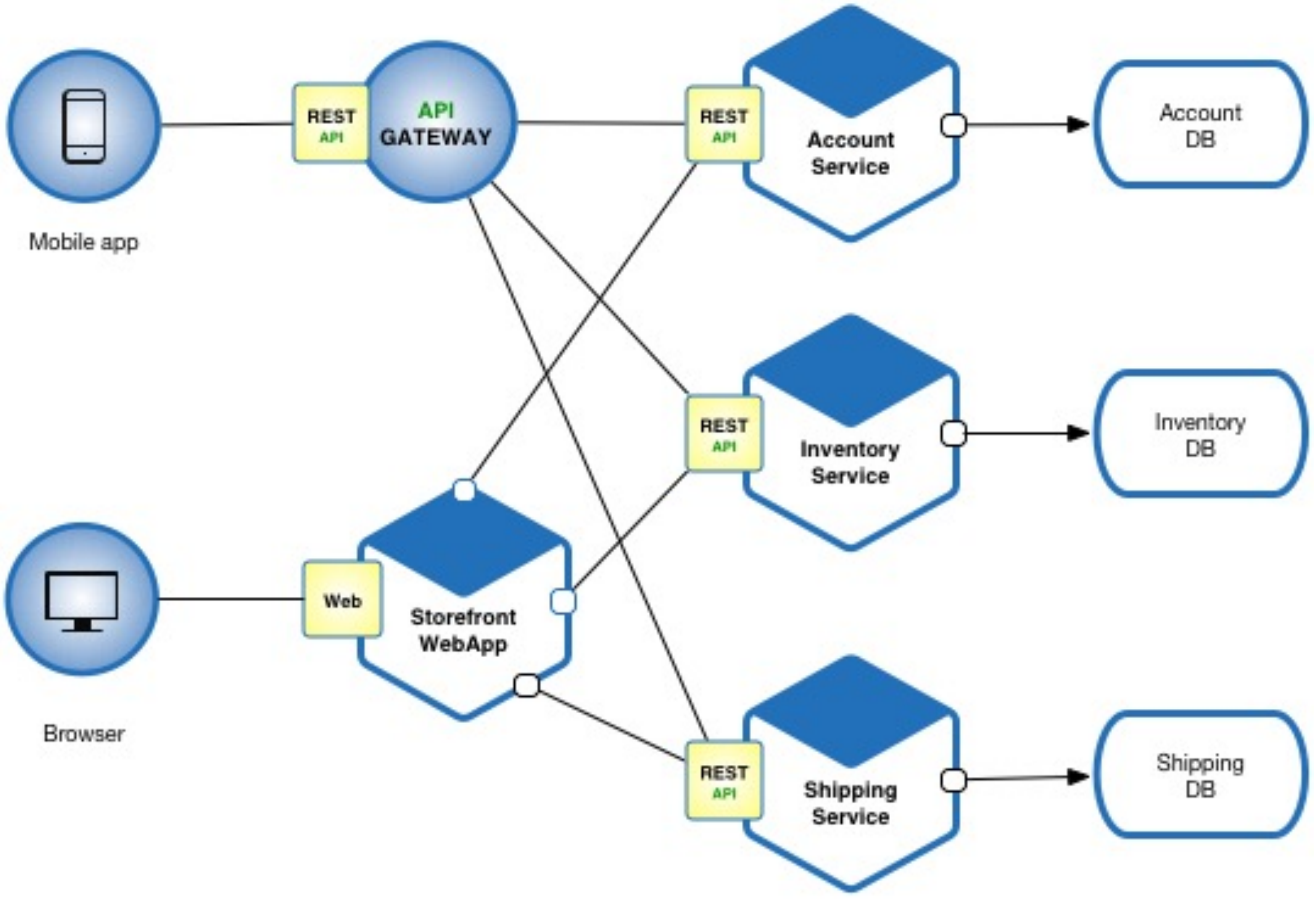


Simple to

develop
test
deploy
scale

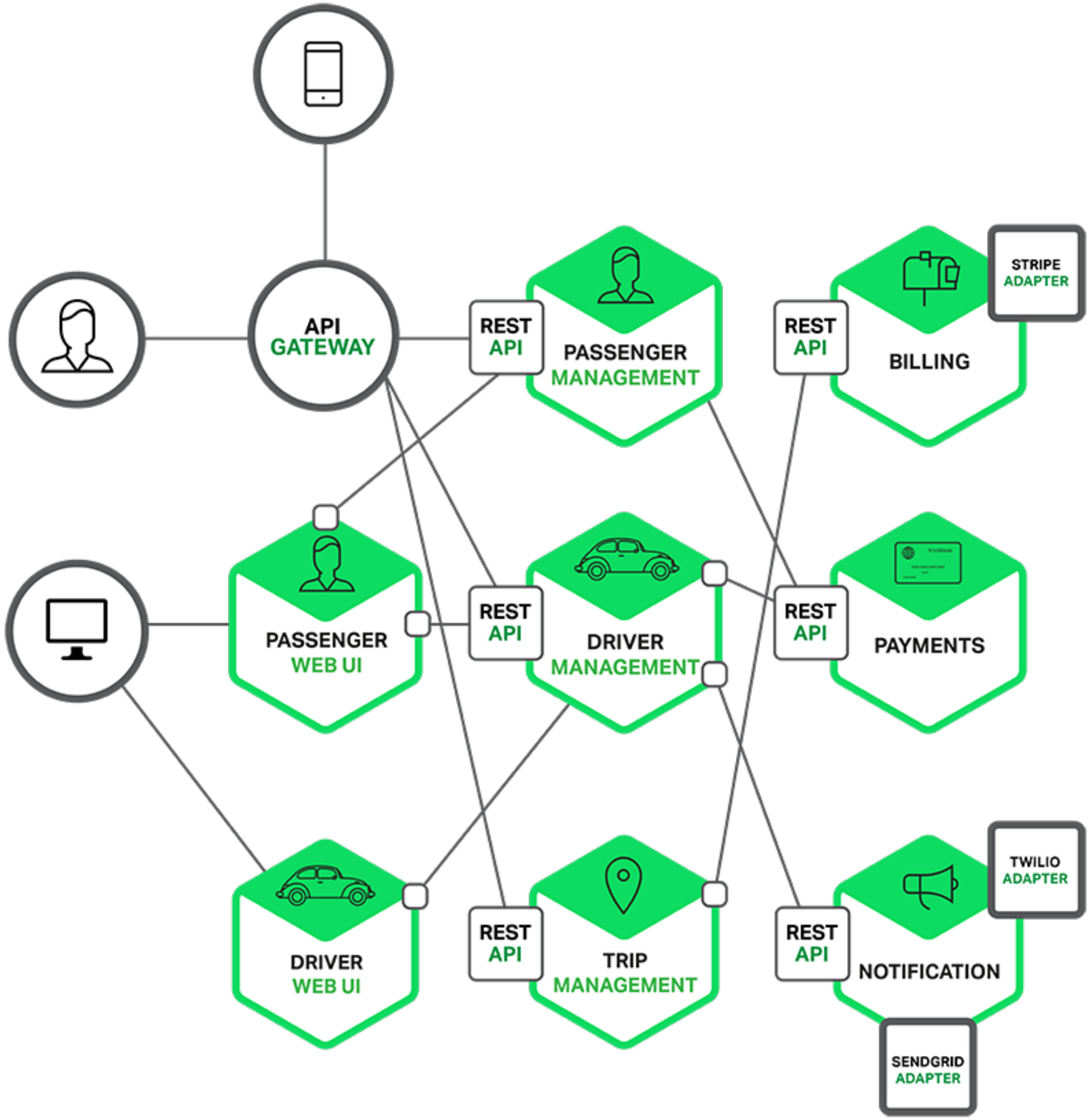
https://microservices.io/patterns/monolithic.html

Microservice-Style Web Application: First Cut



https://microservices.io/patterns/microservices.html

You get a combinatorial explosion problem as you increase the number of microservices



Limitations of the Simple REST Approach

- Each service is a single point of failure: no redundancy.
- All the connections and logic are hard-coded
- Request-response may not be the right message exchange pattern
- We only have a data plane, not a control plane
- **What do we do if we need to replay messages?**

Messaging Systems Offer an Improvement

- Last week, we looked at RabbitMQ
- You can use RabbitMQ to build a more robust microservice system
- But RabbitMQ itself is not “cloud native”.
- What does a “cloud native” messaging system look like?

A Distributed System Case Study: Apache Kafka

High throughput messaging for diverse consumers

Lecture Sources

- Kreps, J., Narkhede, N. and Rao, J., 2011, June. Kafka: A distributed messaging system for log processing. In *Proceedings of the NetDB* (pp. 1-7).
- Wang, G., Koshy, J., Subramanian, S., Paramasivam, K., Zadeh, M., Narkhede, N., Rao, J., Kreps, J. and Stein, J., 2015. Building a replicated logging system with Apache Kafka. *Proceedings of the VLDB Endowment*, *8*(12), pp.1654-1655.
- https://kafka.apache.org/documentation/
- https://sookocheff.com/post/kafka/kafka-in-a-nutshell/

Why Look at Kafka?

You can use Kafka to build sophisticated, log-centric distributed systems

- LinkedIn does this at a huge scale

You can examine how Kafka works to understand how to build distributed systems generally

- Choices, tradeoffs, strategies, design patterns

Log-Centric Architecture

"The Log: What every software engineer should know about real-time data's unifying abstraction", Jay Kreps, https://engineering.linkedin.com/distributed-systems/log-what-every-software-engineer-should-know-about-real-time-datas-unifying

What Is a Log?

Not the logs that capture debugging and error messages

Logs are a record of the commands issued to your system in a sequential order

A log is not a queue

Logs and State Machines: Databases

Every time you do a Create, Update, or Delete, you change the DB state

You need to store both the data and all the operations that got you to the current state.

You can use this information to completely replicate the state of the DB on another server if you have a crash

Logs and State Machines: Git

Git stores all the commits as diffs from the previous commit.

You can restore any previous state of the code base

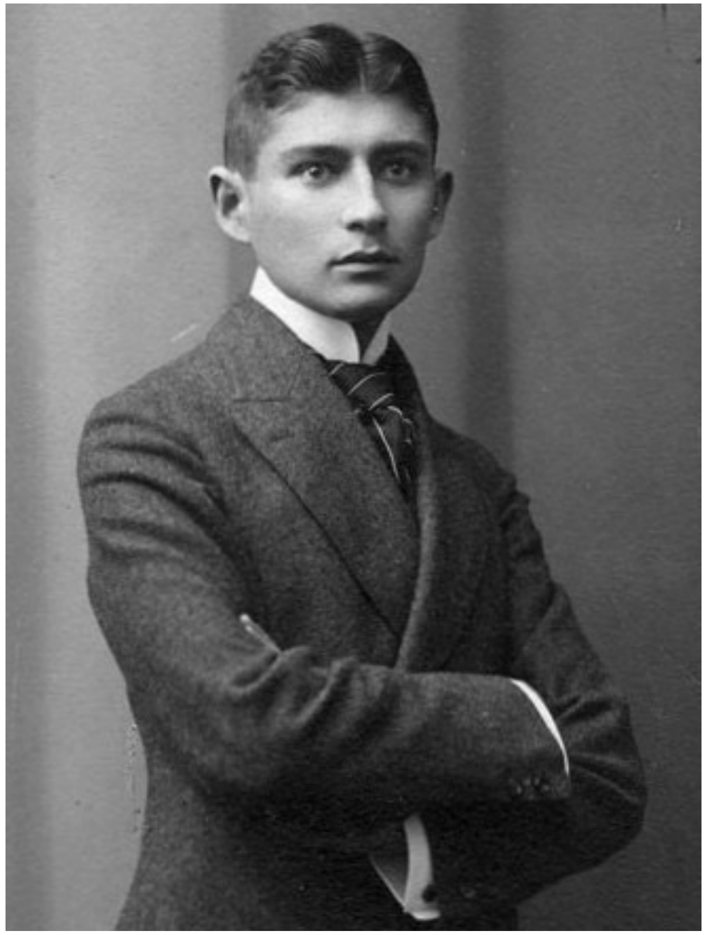
Event Sourcing

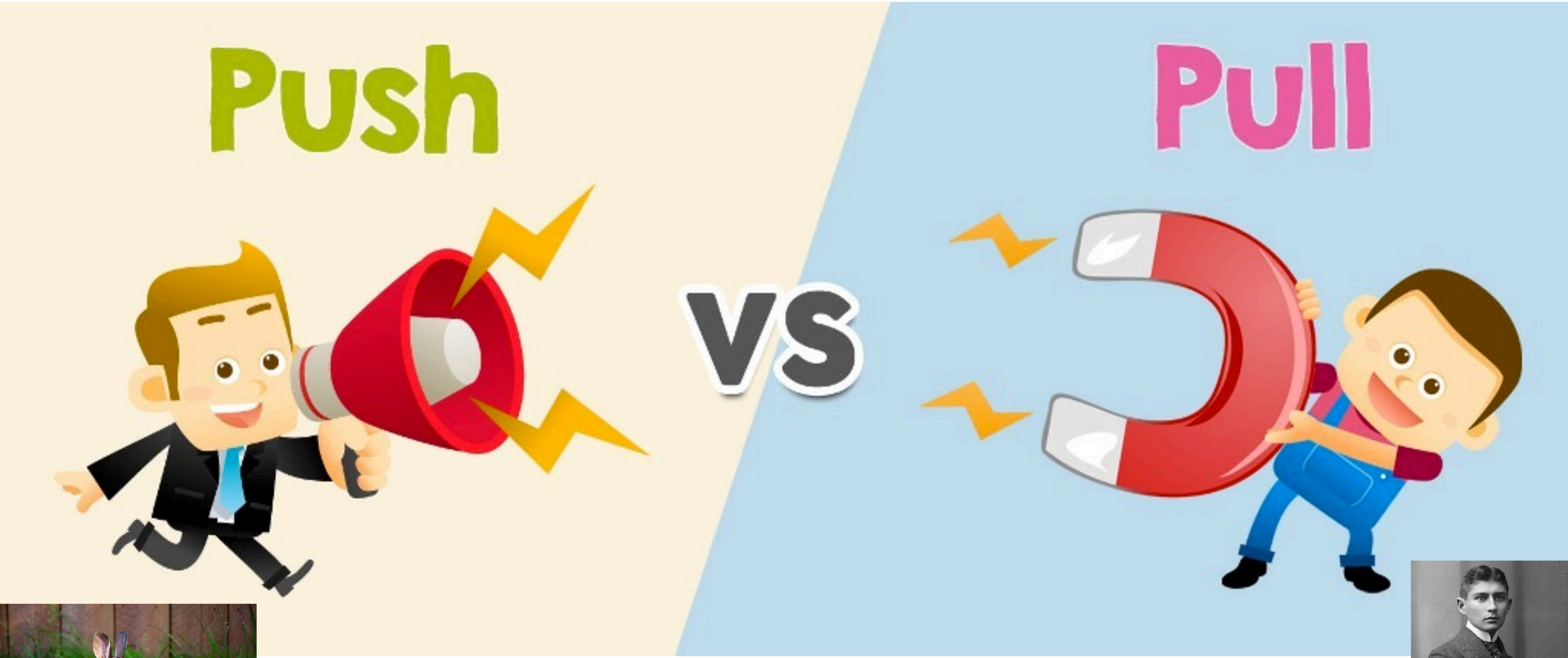
- “Event Sourcing ensures that **all changes to application state are stored as a sequence of events**. Not just can we query these events, **we can also use the event log to reconstruct past states**, and as a foundation to automatically adjust the state to cope with retroactive changes.”
- Fowler was thinking of a monolithic applications. What about distributed applications with distributed state?

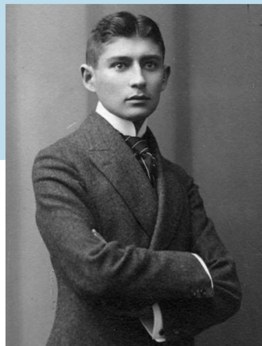
https://martinfowler.com/eaaDev/EventSourcing.html

RabbitMQ versus Apache Kafka

OR



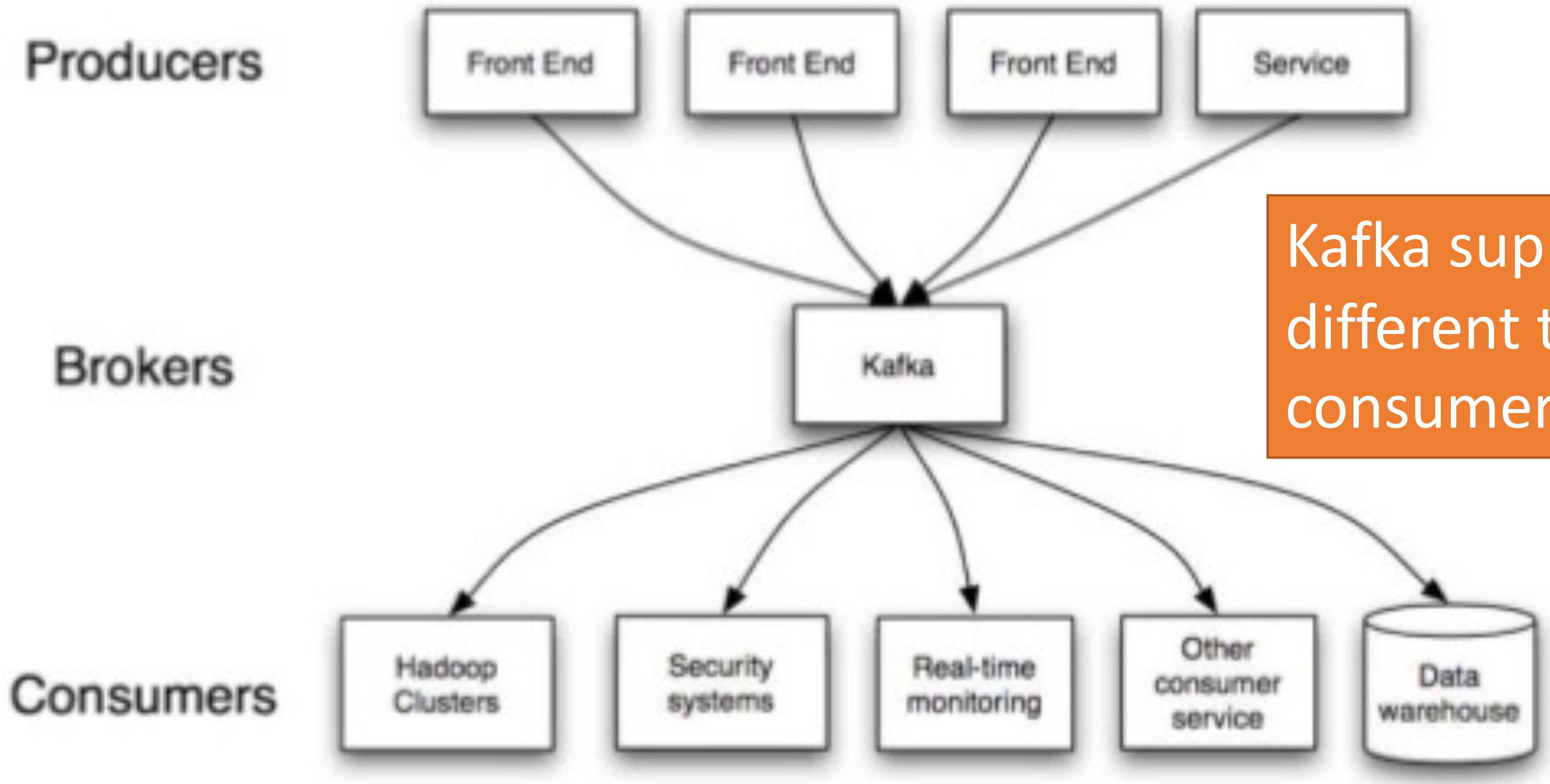

Push
VS
Pull



LinkedIn’s Requirements

- Volume: LinkedIn needs to push billions of messages per day to a wide variety of consumers
- Real-time processing applied to activity streams
- Asynchronous processing for log analysis
- Need to support both user-facing applications and system applications
- And they needed a way to recover a large-scale infrastructure in cases of failures at all scales.

Kafka decouples data-pipelines



Kafka supports many different types of consumers

https://image.slidesharecdn.com/current-141113081750-conversion-gate02/95/current-and-future-of-apache-kafka-9-638.jpg?cb=1415866728

Consequences of Use Case Requirements

- Consumers must decide when to pull the data
  - Fast or slow, small or large
- This means that the messaging system needs to store a lot of data (TBs)
  - This is not what traditional message systems are designed to do.
  - Kafka will need an efficient way to find the requested message
- Virtue from Necessity: support message rewind and replay
  - This is not a normal operation for a queue, which removes messages after they are delivered.
  - **Treat the accumulated, ordered messages as input for a state machine**

Cloud-Native Messaging: Kafka	Enterprise Messaging: AMQP
Brokers are stateless.	Brokers are state-full.
Messages can be delivered in batches	Messages are individually delivered
”At least once” delivery	“Exactly once” delivery
Eventual consistency across multiple brokers	Strong consistency: single broker or tightly coupled primary/backup pair
Optimized for highly variable latency, large message throughput	Optimized for low latency delivery of smaller messages
The system is designed to replay messages.	Replay is an add-on

Apache Kafka resembles in some ways the REST architecture (idempotency)

Let’s Look at Some Details

Apache Kafka Terminology: Topic-Based Publish-Subscribe

Component	Description
Topic	The label for a stream of messages of a particular type. Kafka further divides topics into **partitions**.
Producer	An entity that publishes to a topic by sending messages to a broker
Broker	An entity on a network that receives, stores, and routes messages.
Consumer	An entity that subscribes to one or more topics. Kafka generalizes this to **Consumer Groups**

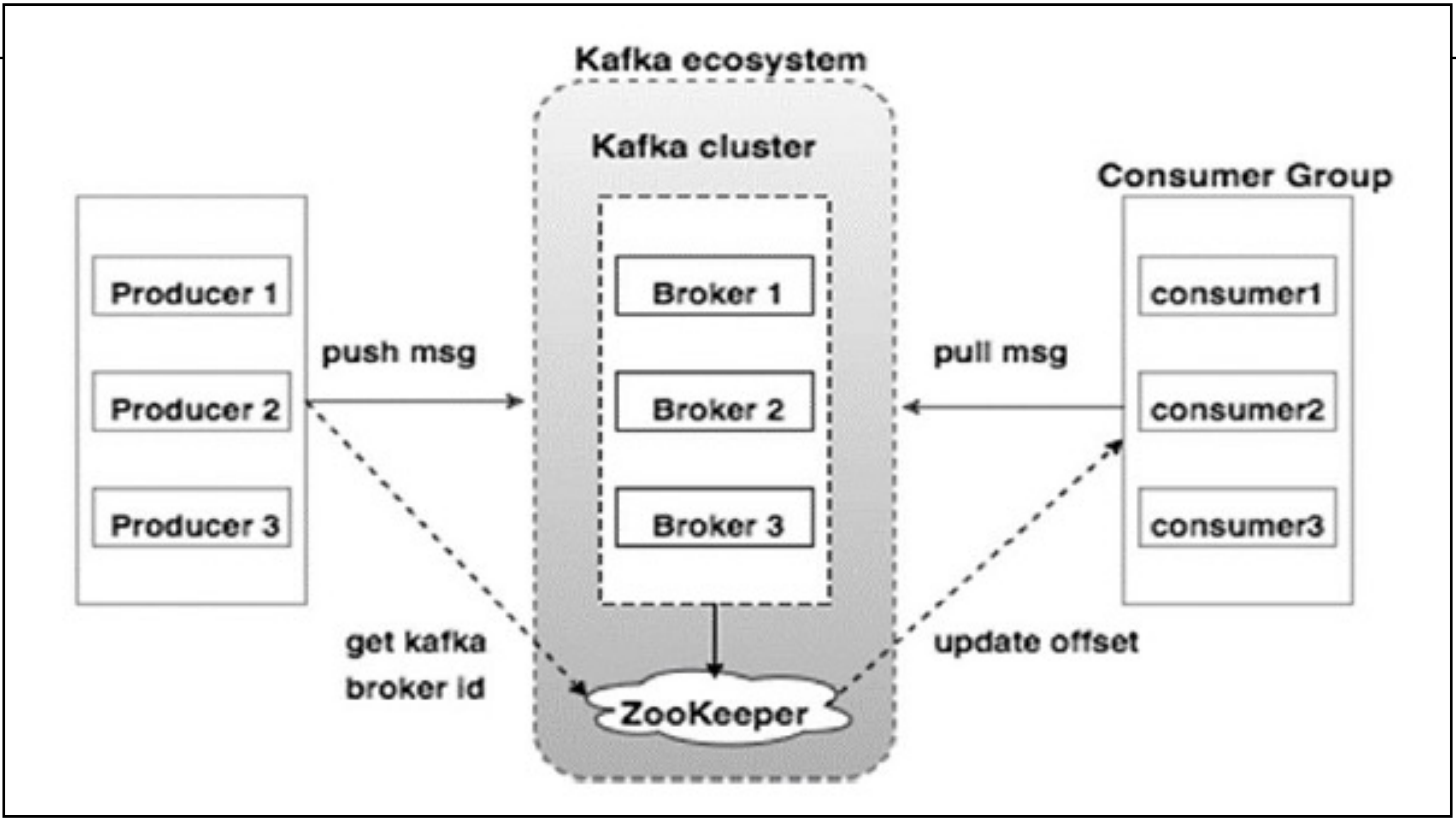
What's an example of a topic in your projects?

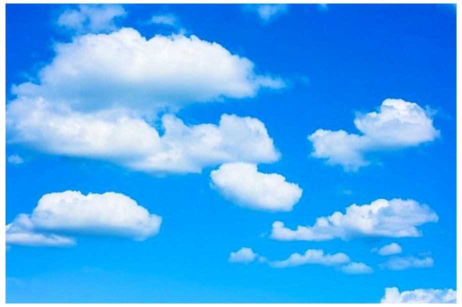
Kafka Brokers

Connecting message producers to consumers

Kafka Uses Clusters of Brokers

- Kafka is run as a cluster of brokers on one or more servers.

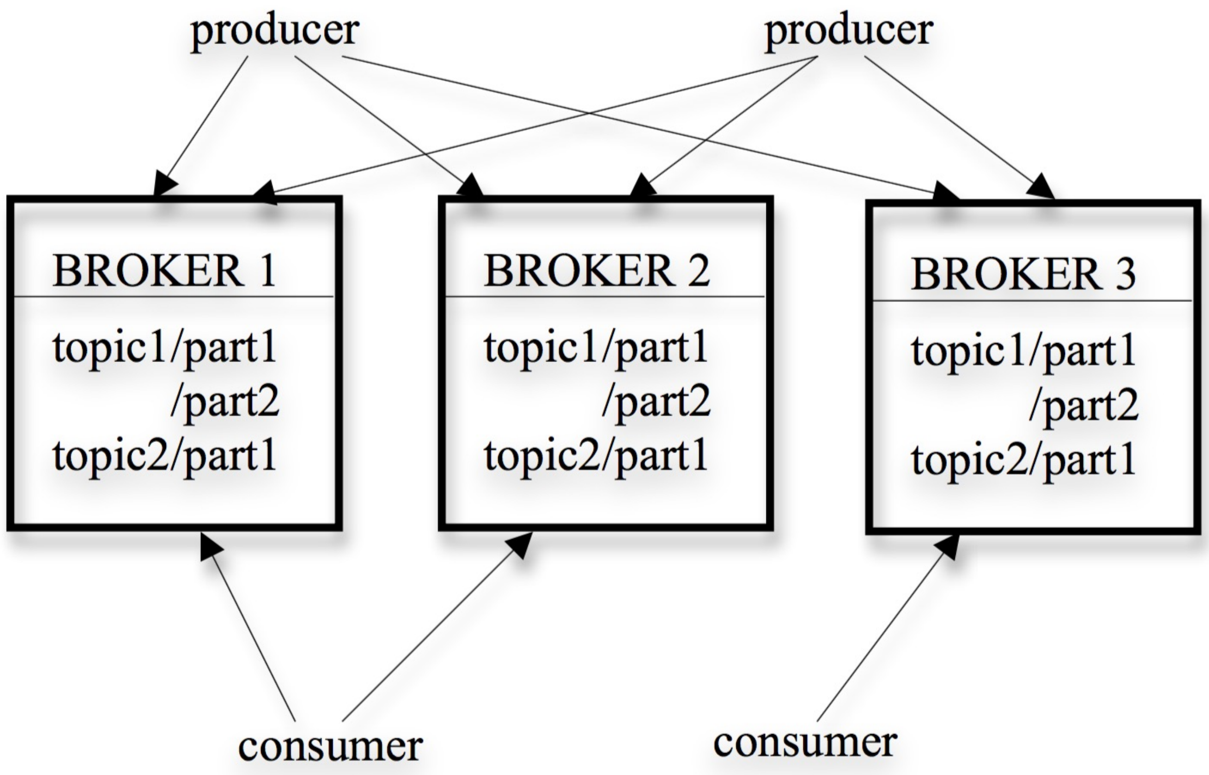




Producers and consumers use Zookeeper to know which broker to contact

Distributed Brokers

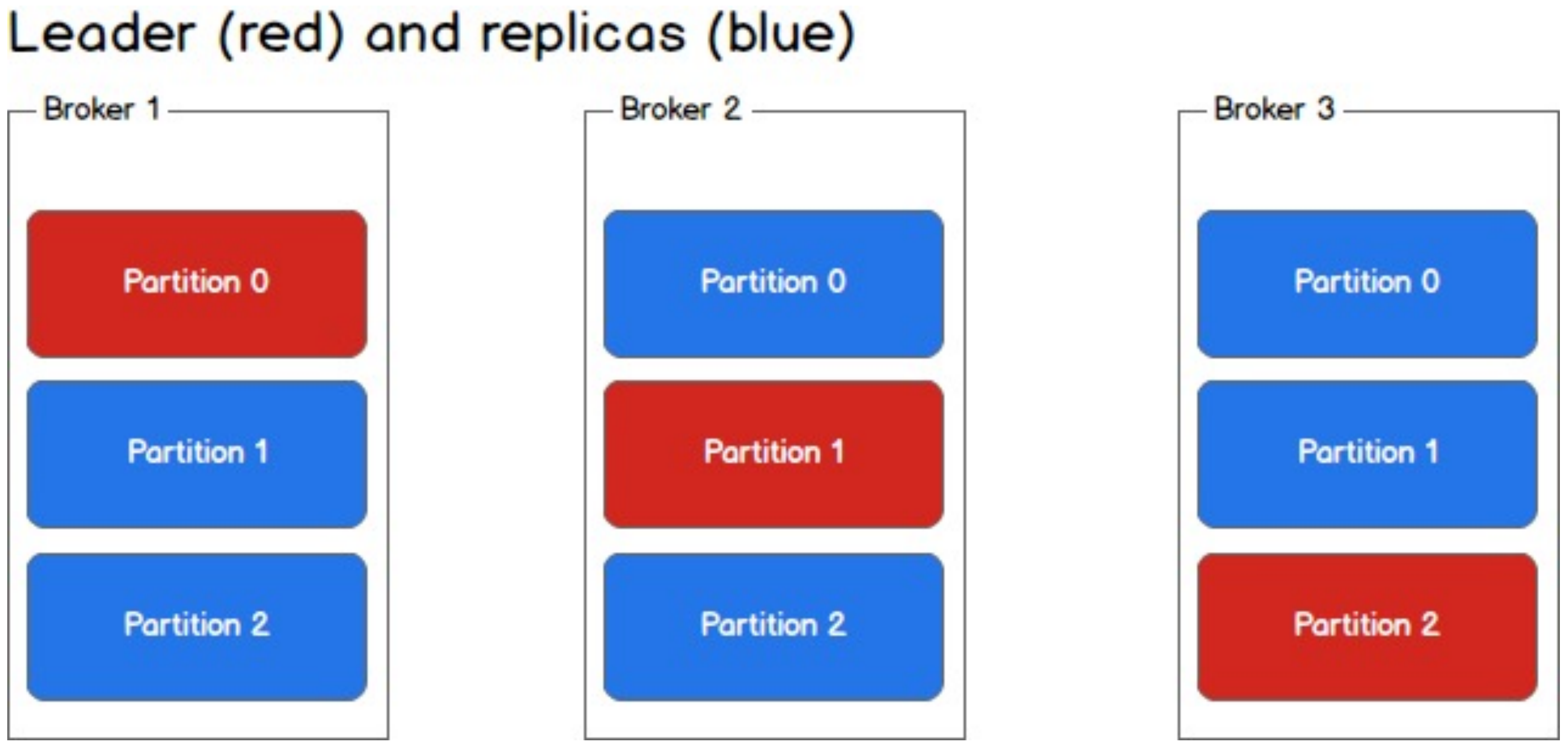
- Kafka brokers are distributed
- Topics are broken into multiple partitions
- Partitions are allocated across brokers



Topics and Partitions

Topics are broken up into partitions that span multiple brokers

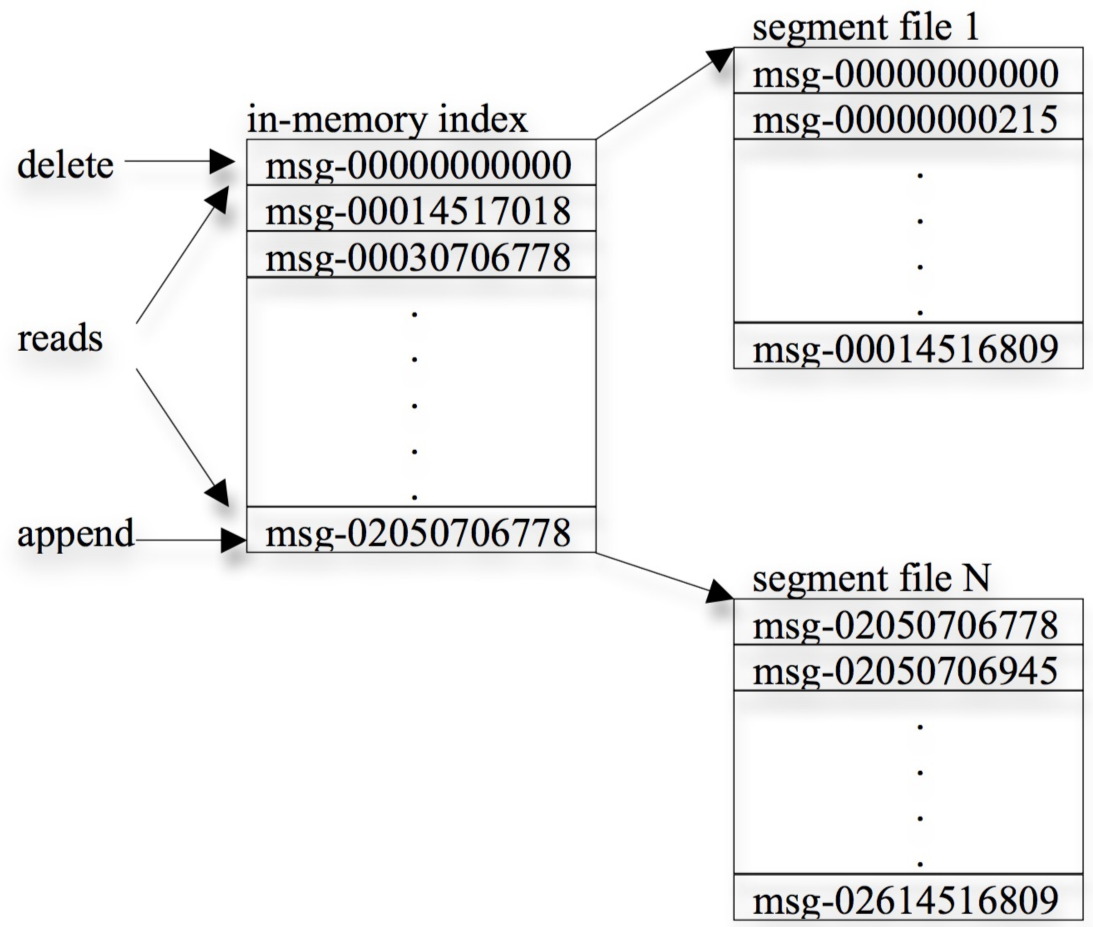
Kafka Topic Partitions Are Replicated



If a leader for a partition replica fails, a follower becomes the new leader

Sequential, Deterministic Lookups

- Random access is slow
- Partitions consist of one or more segment files
- Each message stored in a segment file has a local ID that is determined by the size of all the messages that come before.
- An index stores the message ID of the first message in a segment
- Similar approaches are used by other systems, like Delta Lake



Aside: Write-Ahead Logging

- Write-Ahead Logging: this is a technique of writing your file first and then having your broker read the file.
    - Why? If the broker needs to be restarted, it reads it log to recover its state.
    - The way a broker works in recovery mode is the same as the way it works ordinarily.
- Kafka uses the file system
    - Linux file systems already have many sophisticated features for balancing in-memory versus on-disk files
- Write-ahead logging is an important technique for lots of distributed systems

Kafka Producers

Producers publish data to the topics of their choice.

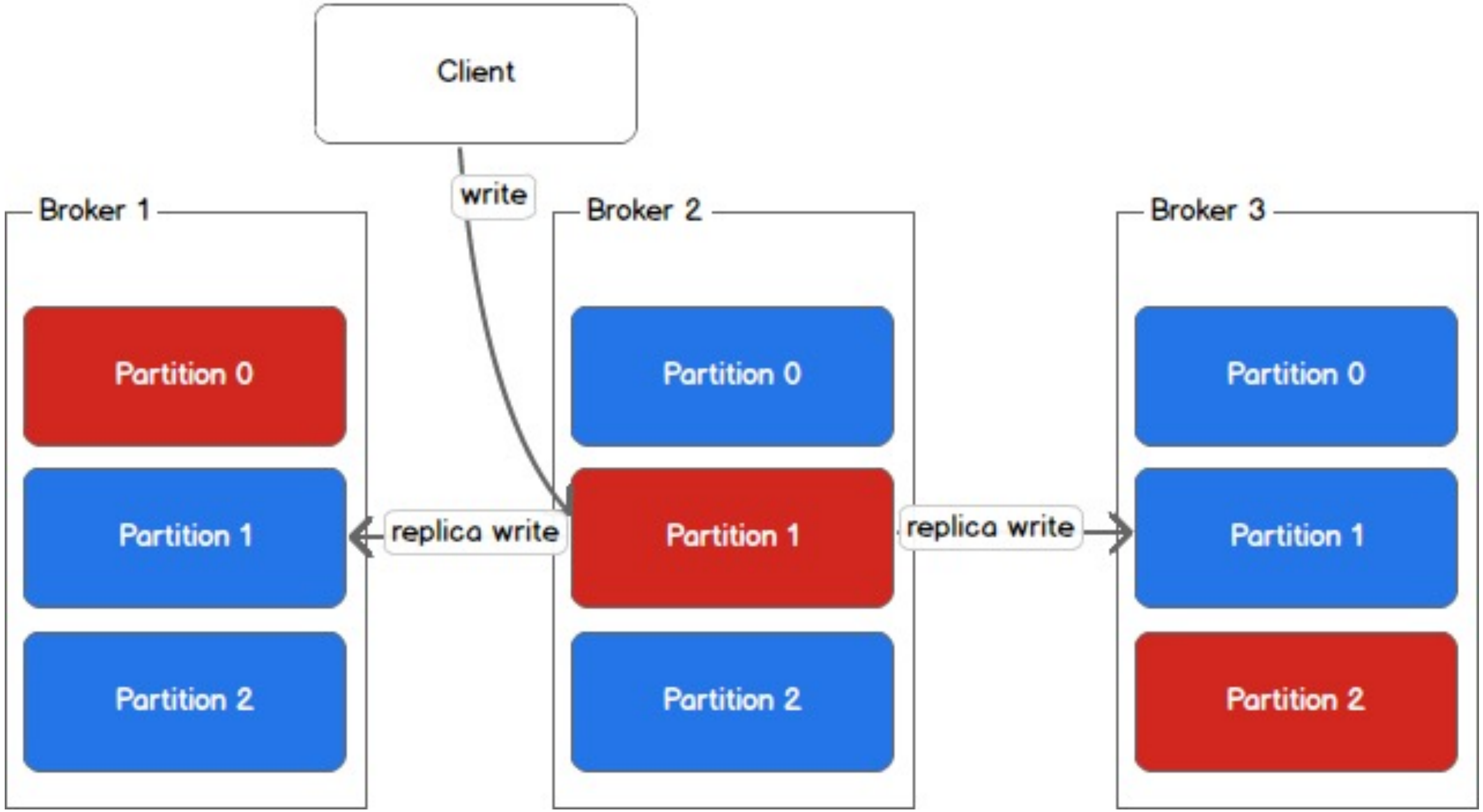
The producer is responsible for choosing which record to assign to which partition within the topic.

This can be done in a round-robin fashion

Producers write to the partition’s leader.

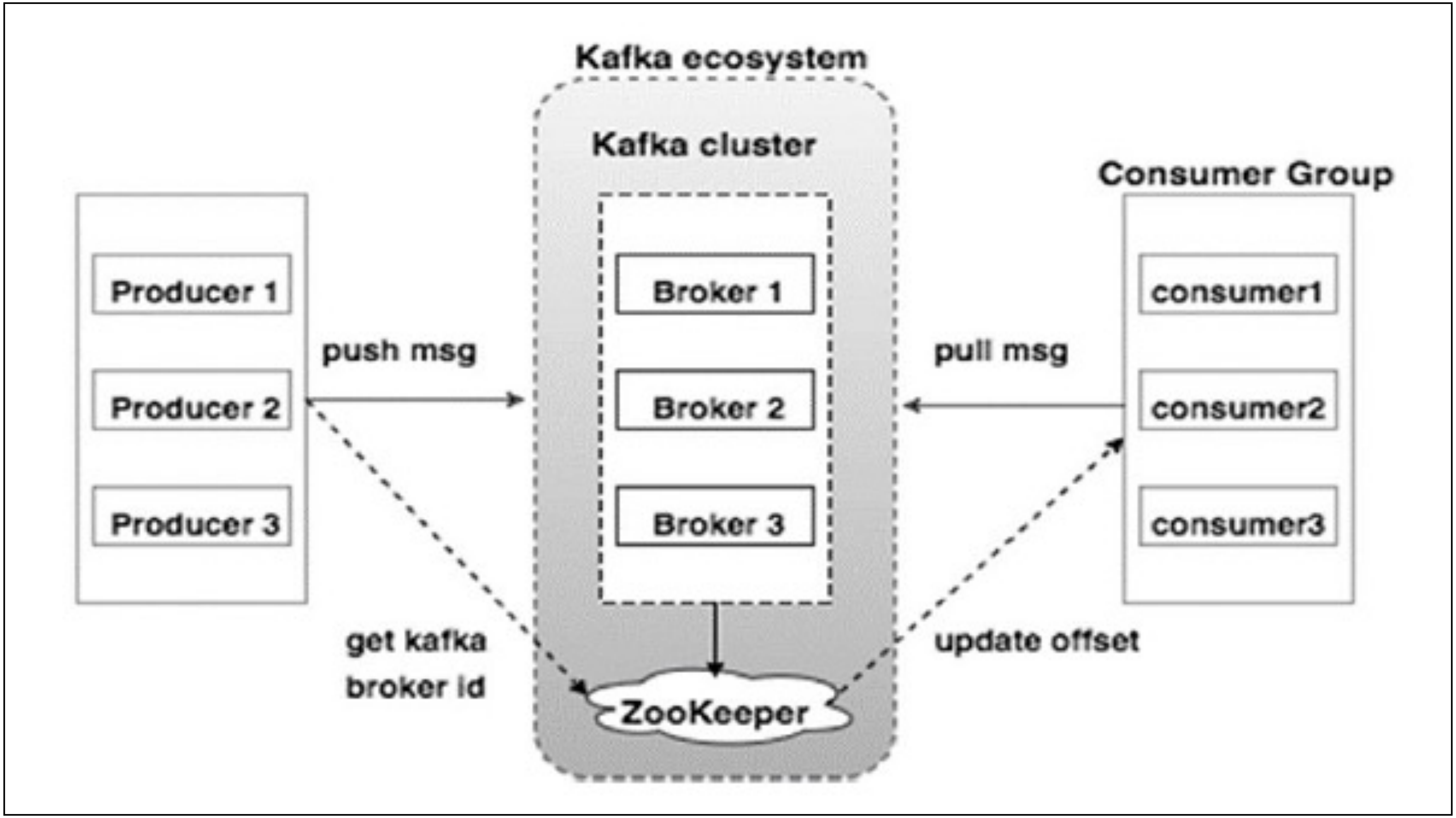
The broker acting as lead for that partition replicates it to other brokers

Leader (red) and replicas (blue)



A producer writes to Partition 1 of a topic. Broker 2 is the leader. It writes replicas to Brokers 1 and 3

Consumer Groups


Kafka ecosystem
Kafka cluster
Consumer Group
Producer 1
Producer 2
Producer 3
push msg
Broker 1
Broker 2
Broker 3
pull msg
consumer1
consumer2
consumer3
get kafka
broker id
ZooKeeper
update offset

Kafka Consumer Groups

Consumer groups contain one or more consumers of a given topic.

Many consumer groups can subscribe to the same topic.

Only one member of a consumer group consumes the messages on a given partition

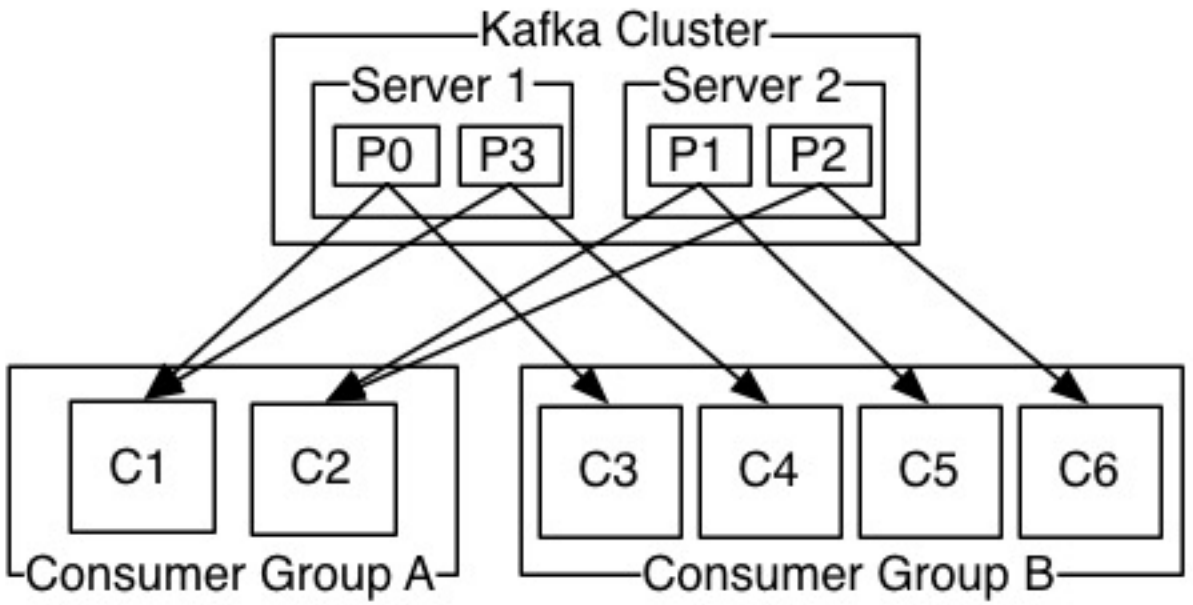
Avoid locking and other complicated state management issues

A consumer group is whatever is useful for a given consuming application

You can use consumer groups to implement work queues

Consumers and Consumer Groups

- In a consumer group, each member is associated with a specific partition.
- Collectively, a consumer group receives all messages on a topic.
- If the group expands or contracts, it can rebalance using Kafka's built-in Zookeeper



Rewinding and Replaying Messages

- Kafka persistently stores messages much longer than conventional messaging systems
  - Doesn’t assume low-latency delivery.
- The state of a topic is the message order, stored in partition files.
- A consumer can request the same messages many times if it needs to.
  - Why? Rollback. A consumer may have had a bug, so fix the bug and consume the message again with the corrected code.
    - Recall Blue-Green deployments
  - Or the consumer may have crashed before processing the message
- Rewinding is much more straightforward in a pull-based architecture.

Is Kafka a Good Choice for You?

Think about your requirements for routing messages to replicated services.

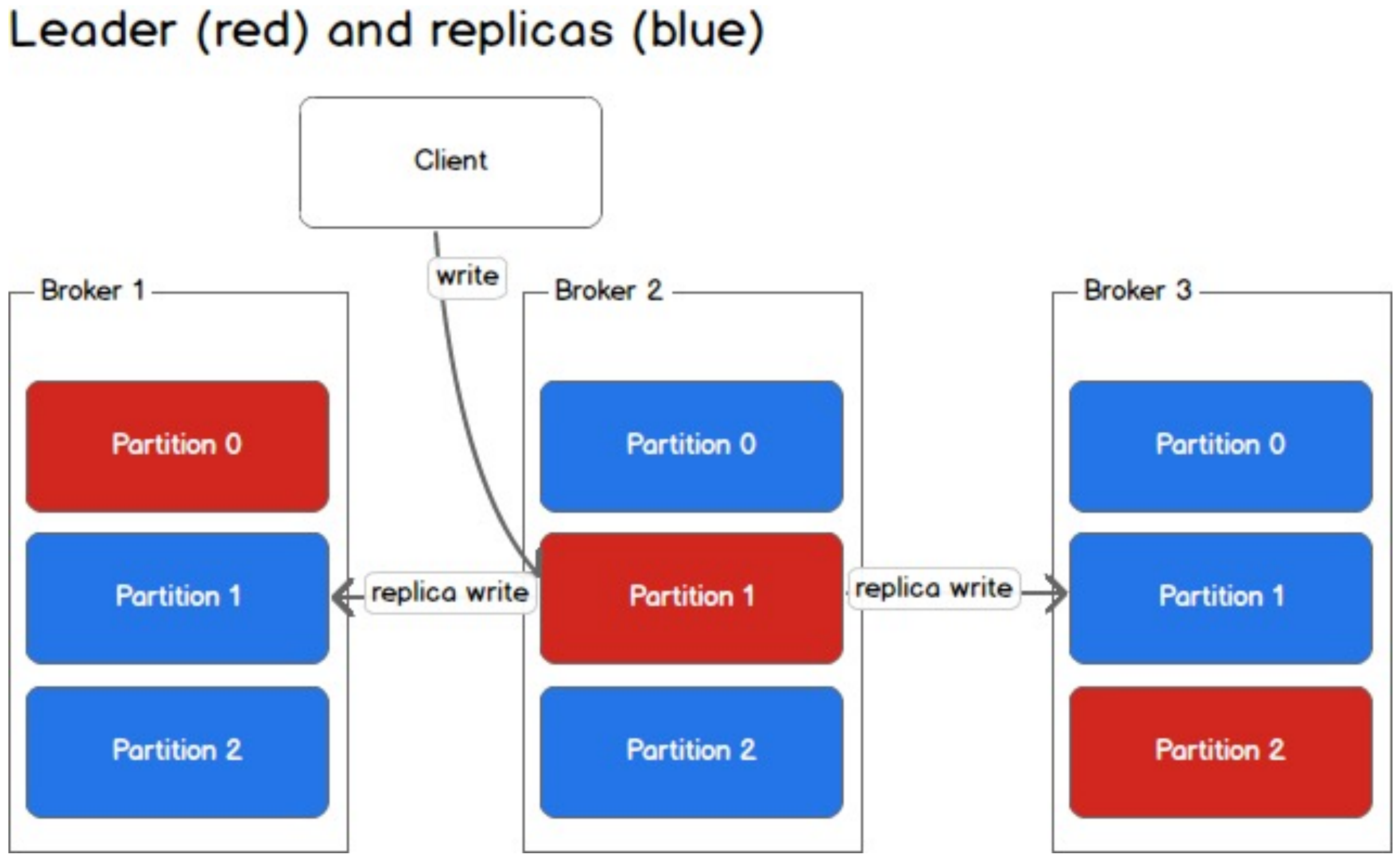
Can you map your system to topics and partitions?

Do you need a log-centric system?

You can still build microservices using RPC or REST style systems

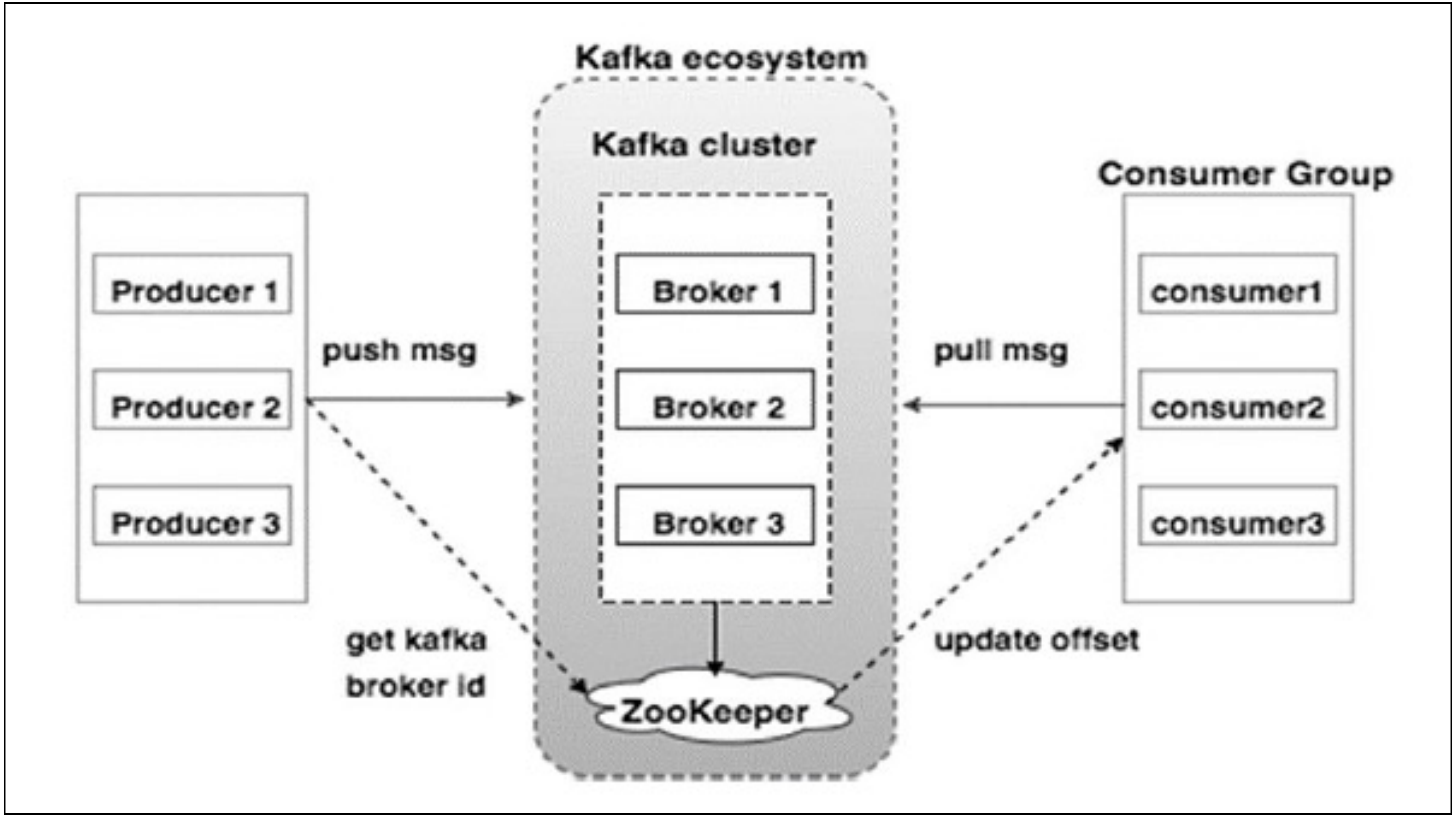
But you'll need to expose the control plane more directly

Next Time: Message ordering and leader election across brokers in detail



Kafka and Zookeeper

Managing brokers, consumers, and producers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update offset

Zookeeper Registry	Description	Node Type
Broker Registry	Contains brokers' host names, ports, topics, and partitions. Used by the brokers to coordinate themselves. Ex: deal with a broker failure.	EPHEMERAL
Consumer Registry	Contains the consumer groups and their constituent consumers.	EPHEMERAL
Ownership Registry	Contains the ID of the consumer of a particular consumer group that is reading all the messages. This is the "owner".	EPHEMERAL
Offset Registry	Stores the last consumed message in a partition for a particular consumer group.	PERSISTENT

Each consumer places a watch on the broker registry and the consumer registry and will be notified if anything changes.

Delivery Guarantees

- Kafka chooses “at least once” delivery.
  - It is up to the consuming application to know what to do with duplicates
  - Duplicates are rare, occur when an “owning” consumer crashes and is replaced
  - **Two-phase commits** are the classic way to ensure “exactly once” delivery.
- Messages from a specific partition are guaranteed to come in order.
- Kafka stores a **CRC** (a hash) for each message in the log to check for I/O errors

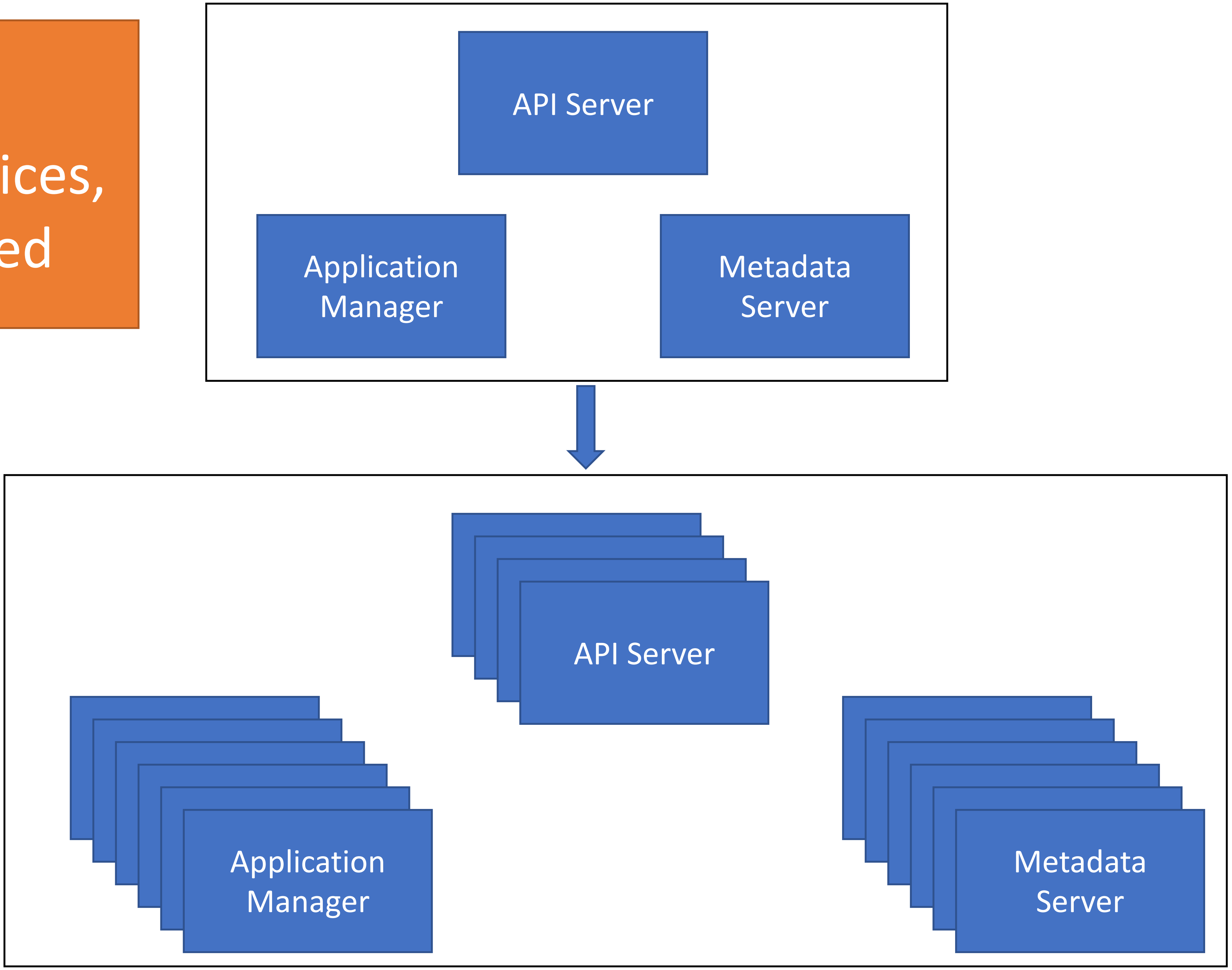
What About the Message Payload?

- Apache Kafka supports clients in multiple programming languages.
- This means that the message must be serialized in a programming language-neutral format.
- You can make your own with JSON or XML
- Kafka also supports Apache Avro, which is a schema-based binary serialization format.
    - Compare Avro with Apache Thrift and Protobuf
- Efficient message formats are essential for high throughput systems

Kafka, Airavata, and Microservices

Some thought exercises

Three microservices, replicated



Some General Distributed Systems Principals

Kafka, logs, and REST

Log-Centric Architecture

- Distributed servers use a replicated log to maintain a consistent state
- The log records system states as sequential messages.
- New servers can be added to expand the system or replace malfunctioning servers by reading the log
  - No in-memory state needs to be preserved
- The server just needs to know that it has an uncorrupted (not necessarily latest) version of the log.
- You can use this approach for both highly consistent and highly available systems (CAP)

Kafka is a log-oriented system that can be used to build other log-oriented systems

This just leaves one little problem…

How do you keep the log replicas up to date?

Primary-Backup Replication	Quorum-Based Replication
1 leader has the master copy and followers have backups	1 leader has the master copy and followers have backups
On WRITE, the master awaits the appending to **all** backup for acknowledging the client	On WRITE, the master waits on **only a majority** of the followers to confirm backups before it returns
Supports strong consistency for distributed READS, but doesn’t scale easily and has lower throughput	Supports eventual consistency and higher throughput; doesn’t require good networking between leader and followers
If the master is lost, restore from a backup	If a master is lost, elect a new leader from the replicas that have the latest data
F+1 replicas can tolerate F failures	2F+1 replicas can tolerate F failures

Kafka State Management

- Kafka brokers are stateless
    - They don’t track which messages a client has consumed or not.
    - This is the client’s job
    - Brokers simply send whatever the client requests
    - Compare to REST
- Brokers eventually must delete data
    - How does a broker know if all consumers have retrieved data?
    - It doesn’t. Kafka has a Service Level Agreement:
        - “Delete all data older than N days” for example