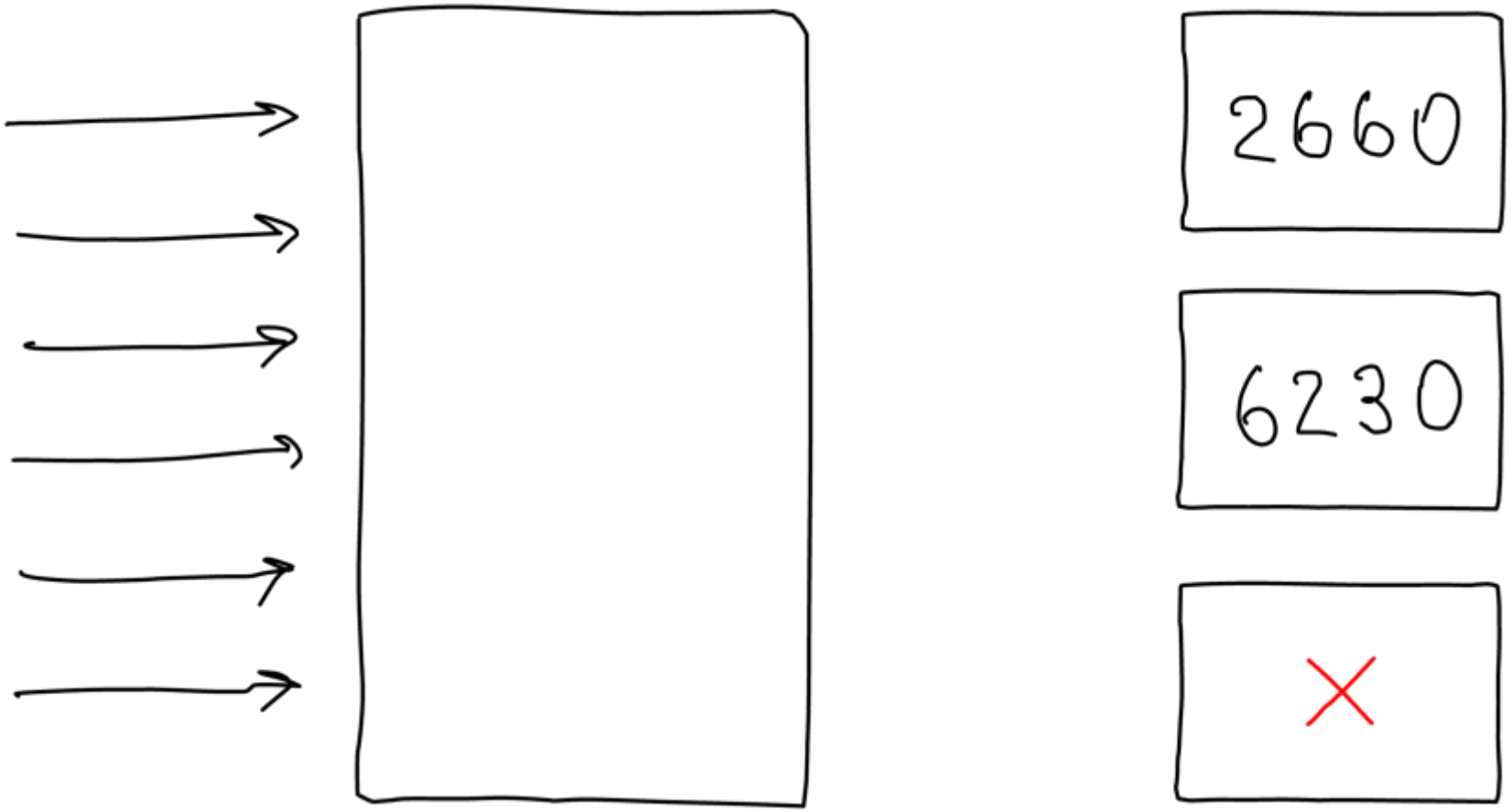
What is a queue?

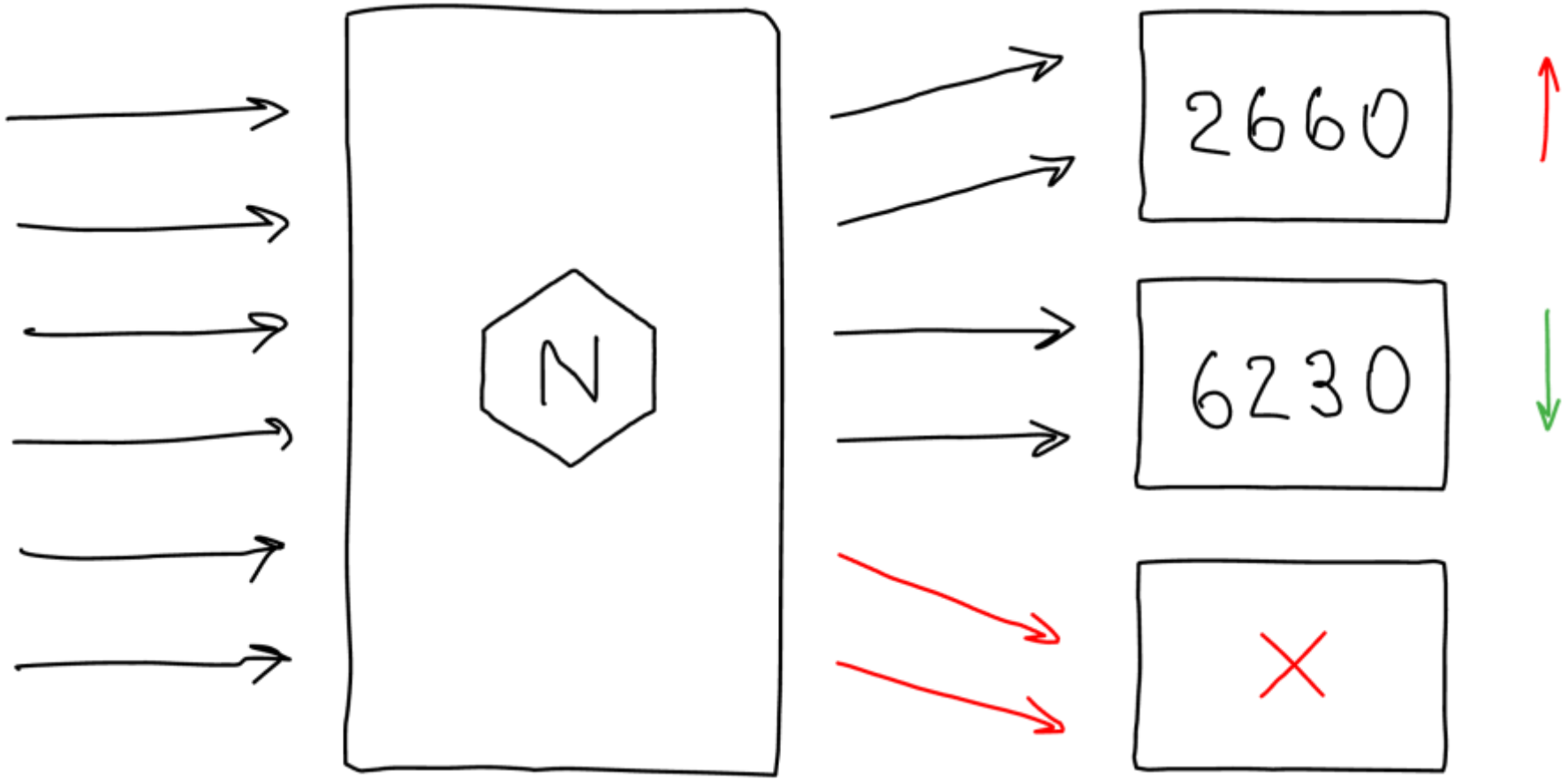
What are queues for?

- Task distribution

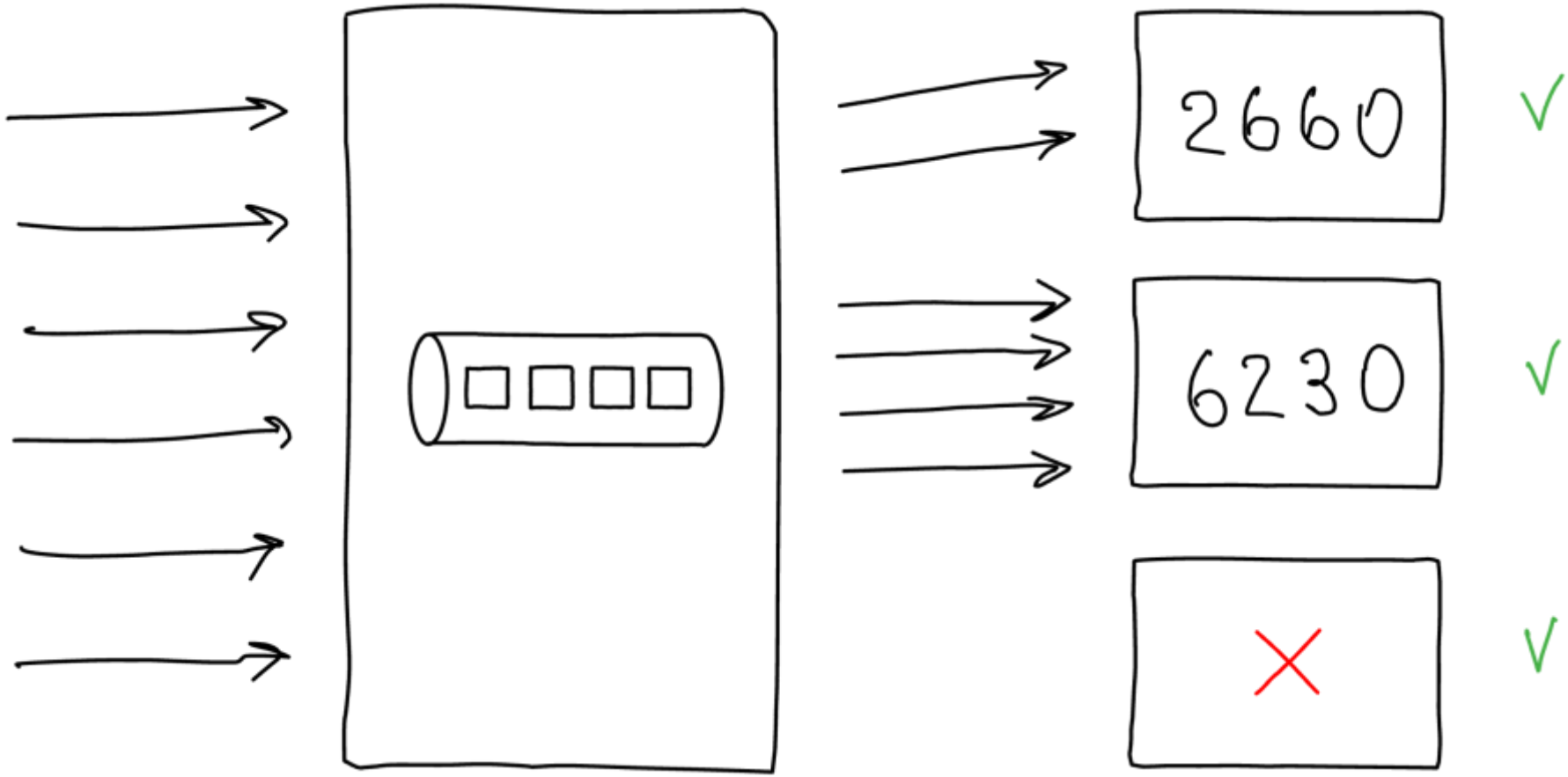
Task distribution



Task distribution



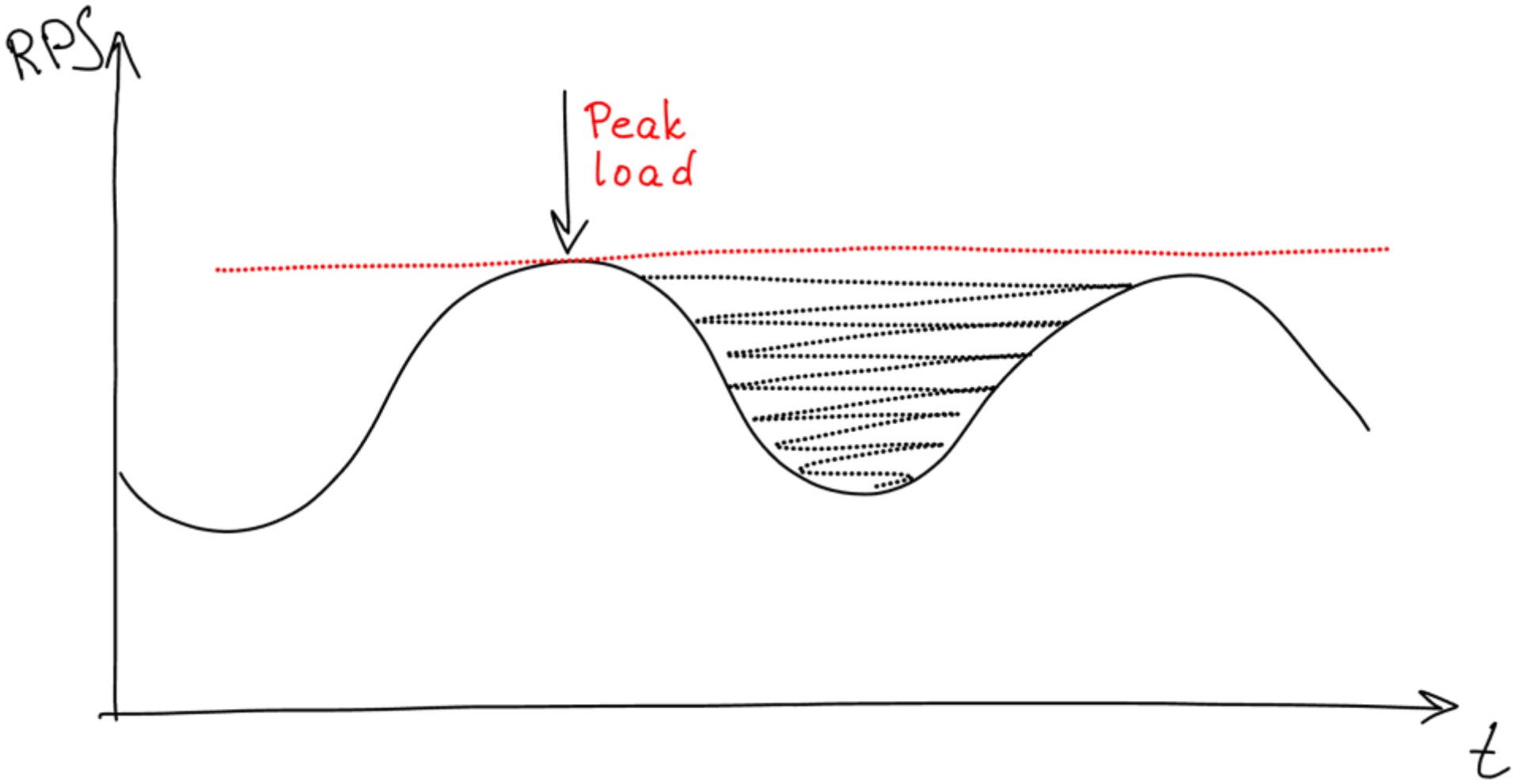
Task distribution



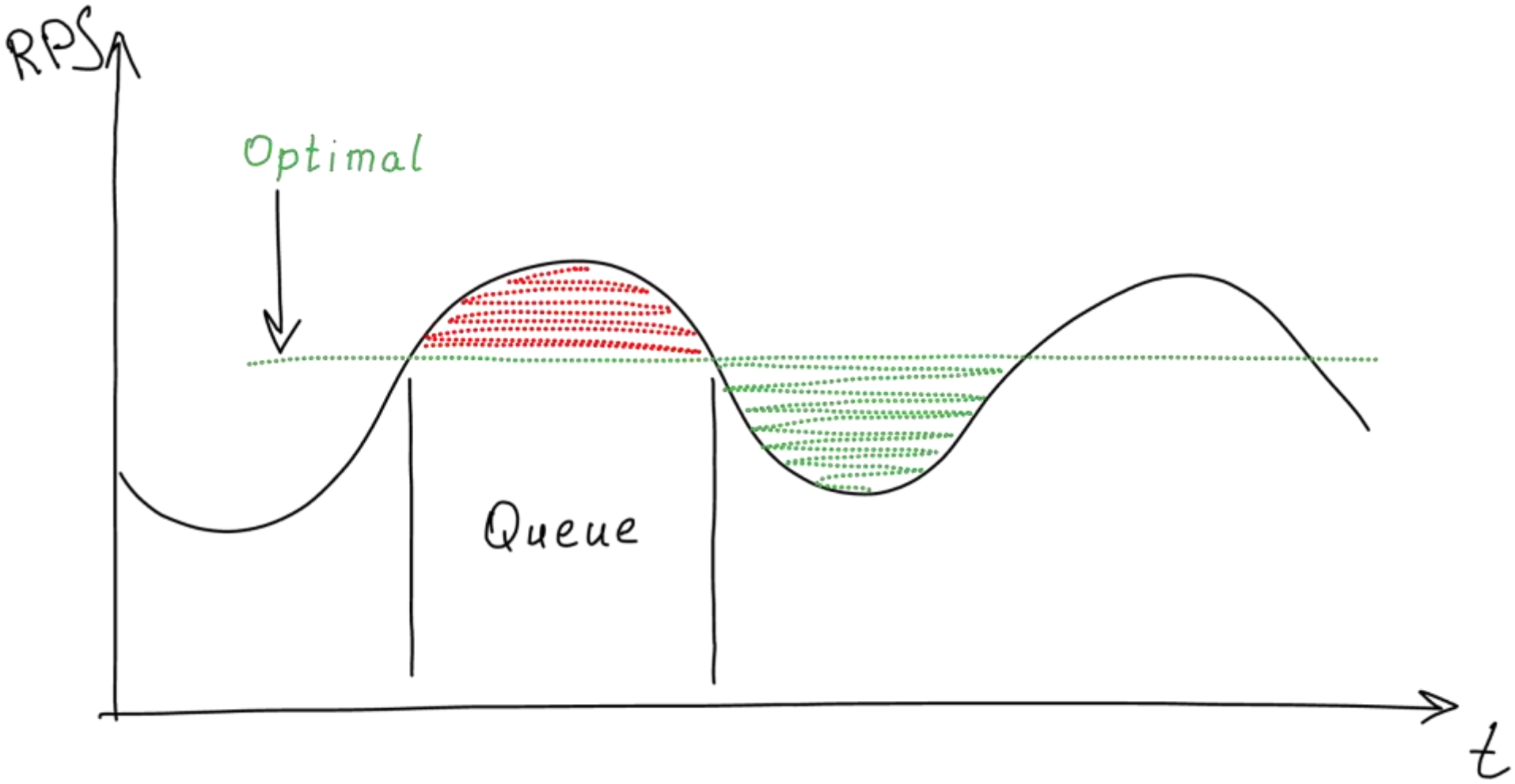
What are queues used for?

- Task distribution
- Execution scheduling

Execution scheduling



Execution scheduling



What are queues used for?

- Tasks distribution
- Scheduling of execution
- Fair resource allocation

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What are queues used for?

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What are queues used for?

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- Microservices communication

What are queues used for?

- Tasks distribution
- Scheduling of execution
- Fair resource allocation
- Messages replication
- Fault tolerance, durability, delivery guarantee
- Microservices communication
- Event-driven architecture (Event Sourcing)
- Streaming architecture

Where are queues used?

- Hardware

IRQ
NCQ
Hardware Buffers

Where queues are used?

- Hardware
- OS Kernel

epoll / kqueue
networking
signal handling

Where queues are used?

- Hardware
- OS Kernel
- Applications

Cross thread
IPC

Where queues are used?

- Hardware
- OS Kernel
- Applications
- Network interactions

Where queues are used?

- Hardware
- OS Kernel
- Applications
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- Distributed systems

Where queues are used?

- Hardware
- OS Kernel
- Applications
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- In fact — everywhere

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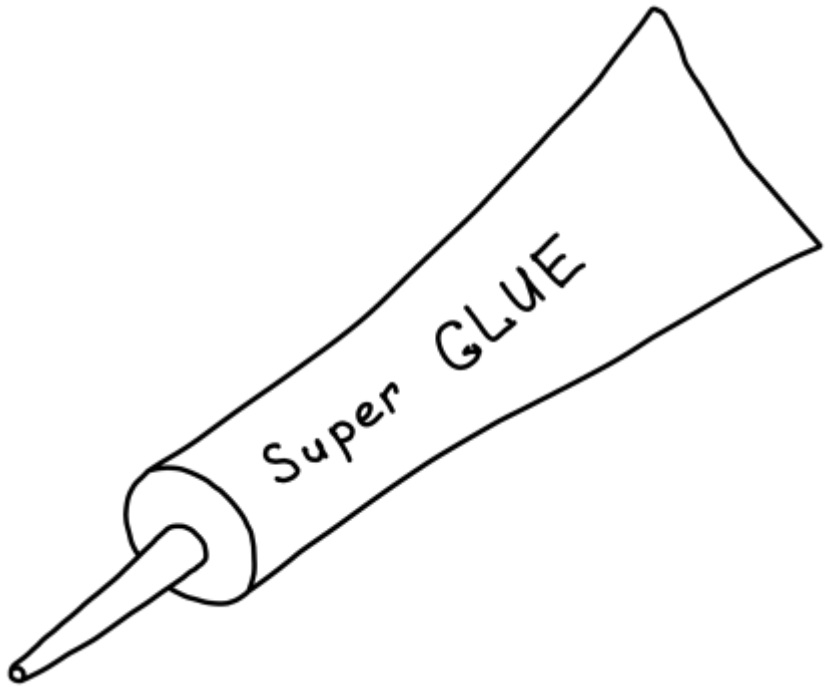


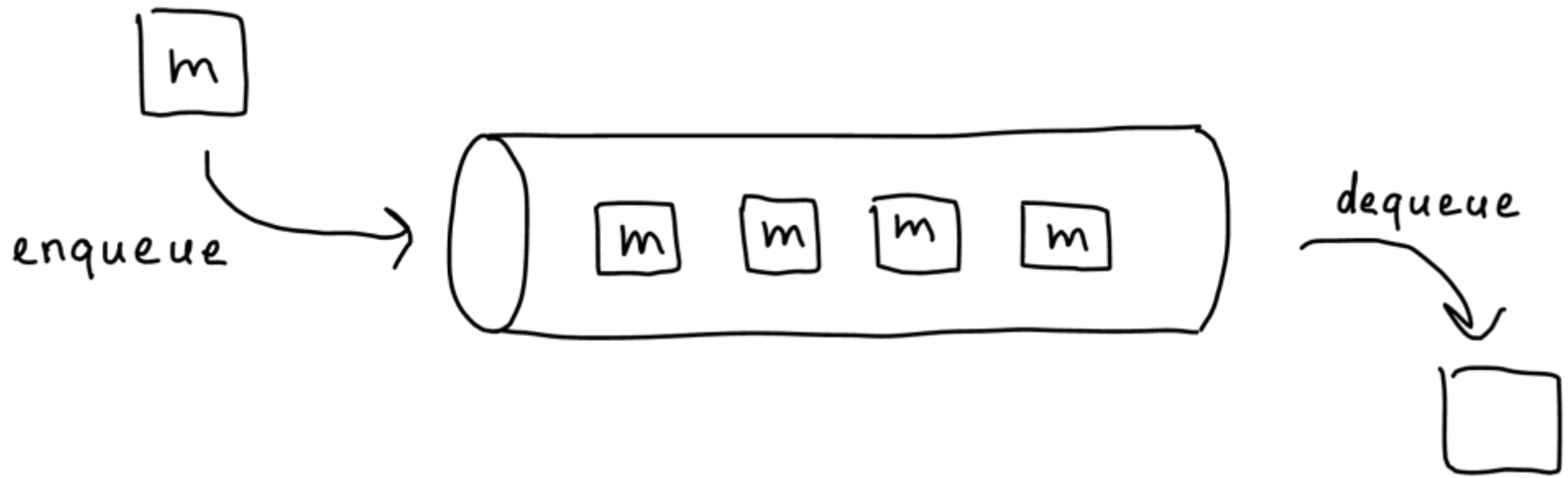
- In fact — everywhere

Queues are the glue

What is a queue?

- A media for communication using messages

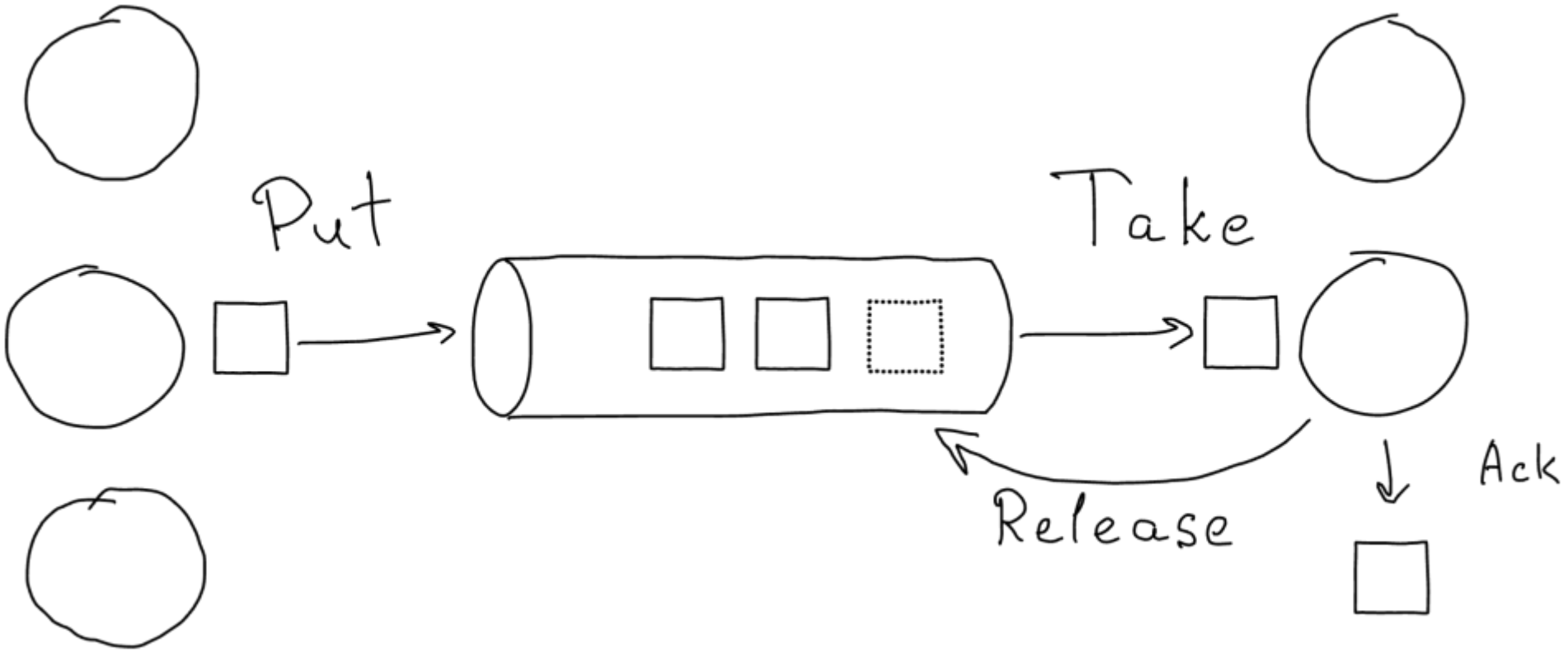
What is a queue?



What is a queue?

- A media for communication using messages
- One-to-one approach (Put/Take): 1 → 1

Put/Take



What is a queue?

- A media for communication using messages
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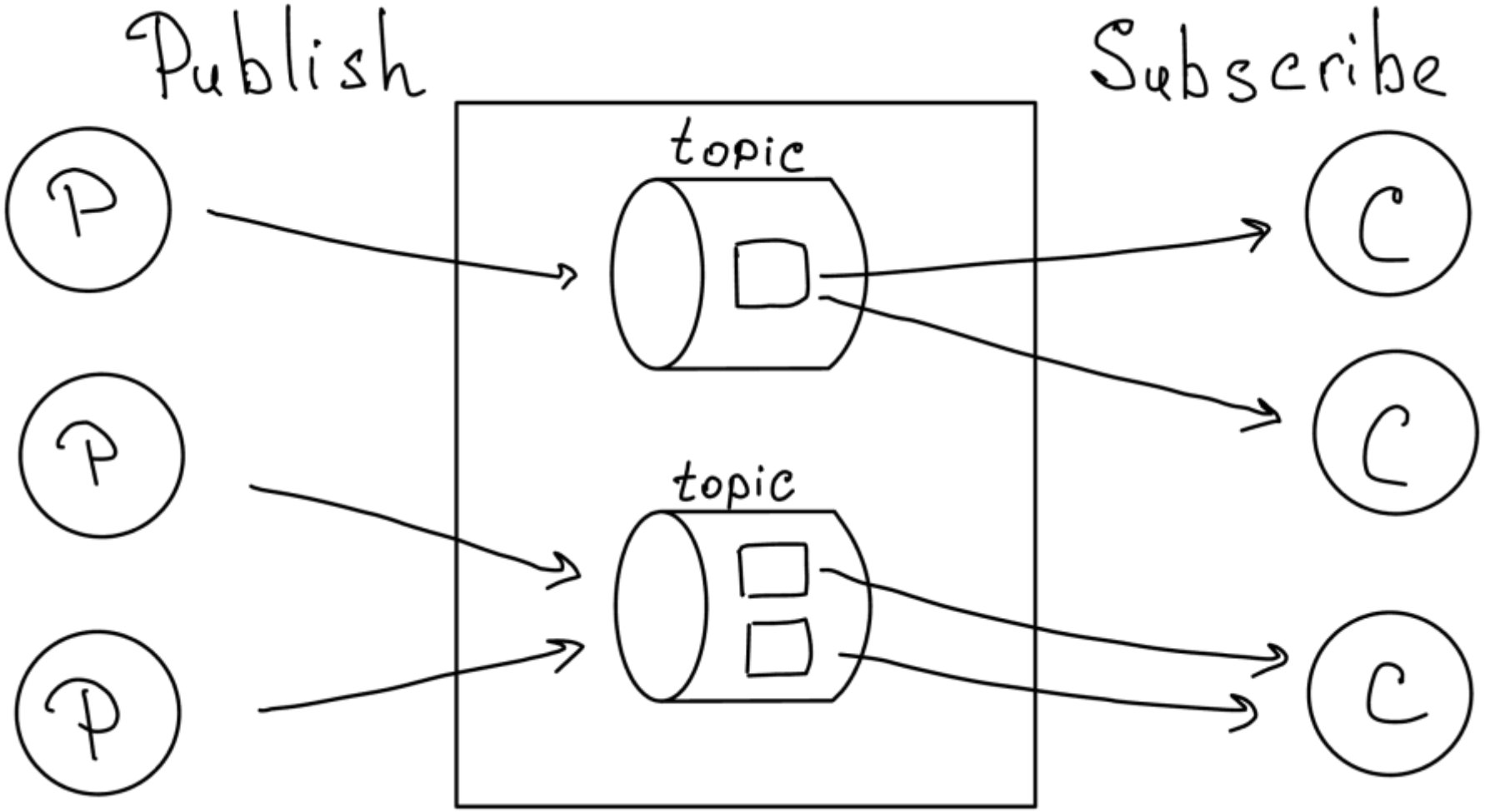
- One-to-many approach (Publish/Subscribe): 1 → *

Pub/Sub



What is a queue?

- A media for communication using messages
- One-to-one approach (Put/Take): 1 → 1
- One-to-many approach (Publish/Subscribe): 1 → *
- Synchronous flow (Request/Response): 1 ⇆ 1

What is a queue?

- A media for communication using messages
- One-to-one approach (Put/Take): $1 \rightarrow 1$
- One-to-many approach (Publish/Subscribe): $1 \rightarrow *$
- Synchronous flow (Request/Response): $1 \leftrightarrows 1$
- Protocols: AMQP, MQTT, STOMP, NATS, ZeroMQ, …

What are the options?

Major players

What are the options?

- Cloud solutions
  - Amazon SQS, EventBridge
  - Google Cloud Tasks
  - CloudAMQP
  - …

What are the options?

- Cloud solutions
  - Amazon SQS, EventBridge, Google Cloud Tasks, CloudAMQP, …
- Message brokers
  - RabbitMQ
  - Apache Kafka
  - ActiveMQ
  - Tarantool Queue
  - NATS
  - NSQ

What are the options?

- Cloud solutions
  - Amazon SQS, EventBridge, Google Cloud Tasks, CloudAMQP, …
- Message brokers
  - RabbitMQ, Apache Kafka, Tarantool Queue, NATS, NSQ, …
- Database-backed queues
  - PgQueue
  - Tarantool
  - Redis

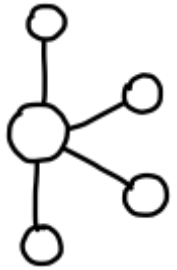
What are the options?

- Cloud solutions
  - Amazon SQS, EventBridge, Google Cloud Tasks, CloudAMQP, …
- Message brokers
  - **RabbitMQ**, Apache **Kafka**, Tarantool Queue, **NATS**, NSQ, …
- Database-backed queues
  - PgQueue, Tarantool, Redis, …
- “Sockets on steroids”
  - NATS, ZeroMQ

Who are the players?

- Apache Kafka
  - Distributed message log for streaming
- RabbitMQ
  - Traditional broker with AMQP protocol
- Managed Cloud Queue (SQS/EventBridge/MQ/…)
  - The solution to be used in clouds
- NATS
  - Microservices communication bridge
- Redis
  - The simplest queue-in-a-database
- Tarantool
  - The platform for custom built solutions

Apache Kafka

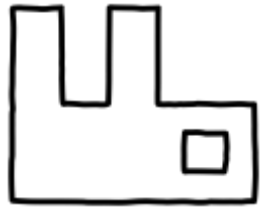


- Replicated & sharded message log
- Strict delivery order (FIFO)
- A limited number of consumers
- Stream replay
- Apache ecosystem integration
- Mainly used for
  - Data analysis. Logs, metrics, audit
  - High performance stream data processing
  - Consistent data replication

Red Panda

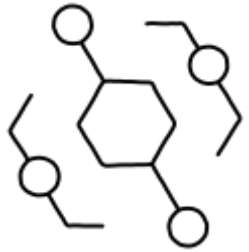
- Kafka rewritten in C++
- No ZK or JVM
- Thread-per-core approach
- Multitiered storage
- Mainly used for
  - Everywhere as Kafka

RabbitMQ



- Protocols: AMQP, MQTT, STOMP
- Prioritized, delayed and background tasks
- Unlimited number of consumers
- Flexible storage: memory, disk, replication, quorum
- Easy to learn. Hard to master
- Mainly used for
  - Microservices communication
  - As a message bus
  - As a traditional pub/sub broker

Managed Cloud Queue



- Reliable and scalable queue
- Stateless protocol, simple interaction
- Standard API
- Pay-as-you-go: low consumption — low expenses
- Mainly used for
  - Communication between cloud components
  - Serverless architecture

NATS Messaging

- Fast non-persistent message communication
- High performance and scalability
- Multi-paradigm: pub/sub, put/take, req/res
- Expandable with JetStream
  - Streaming support
  - Durable storage, RAFT cluster
- Mainly used as
  - Messaging media for distributed systems

Redis

- Easy to bootstrap
- Simple queue-like approach based on lists
- Simple pub/sub implementation (not durable)

- Mainly used when
  - Redis already present
  - Very simple message delivery
  - Non-reliable pub/sub

Tarantool

- High-performance broker
- Integration with streaming systems
- The platform for building custom queues
- Arbitrary logic and event processing
- Transaction support within exchange
- Mainly used for
  - High performance and high throughput message delivery
  - Building complex event processing with custom logic

Problems and Algorithms

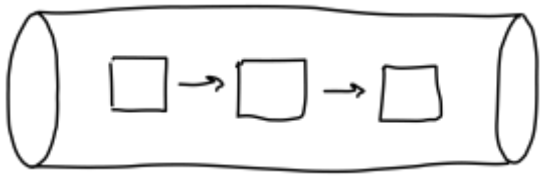
Possible problems

Or what is worth to know?

- Algorithms of queues
- Network problems
- “Exactly once”
- Network (again) and disk problems
- Outages & failures

Algorithms

- FIFO, LIFO, Best Effort, QoS



Algorithms

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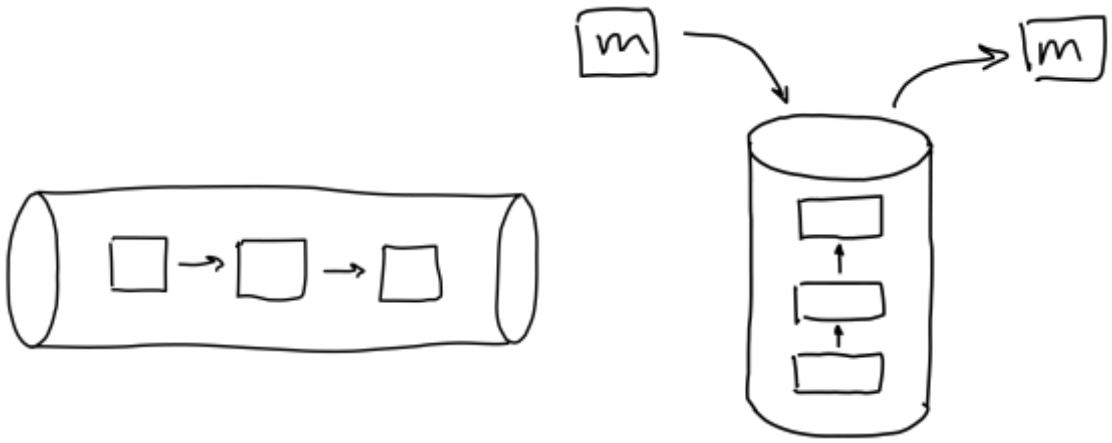

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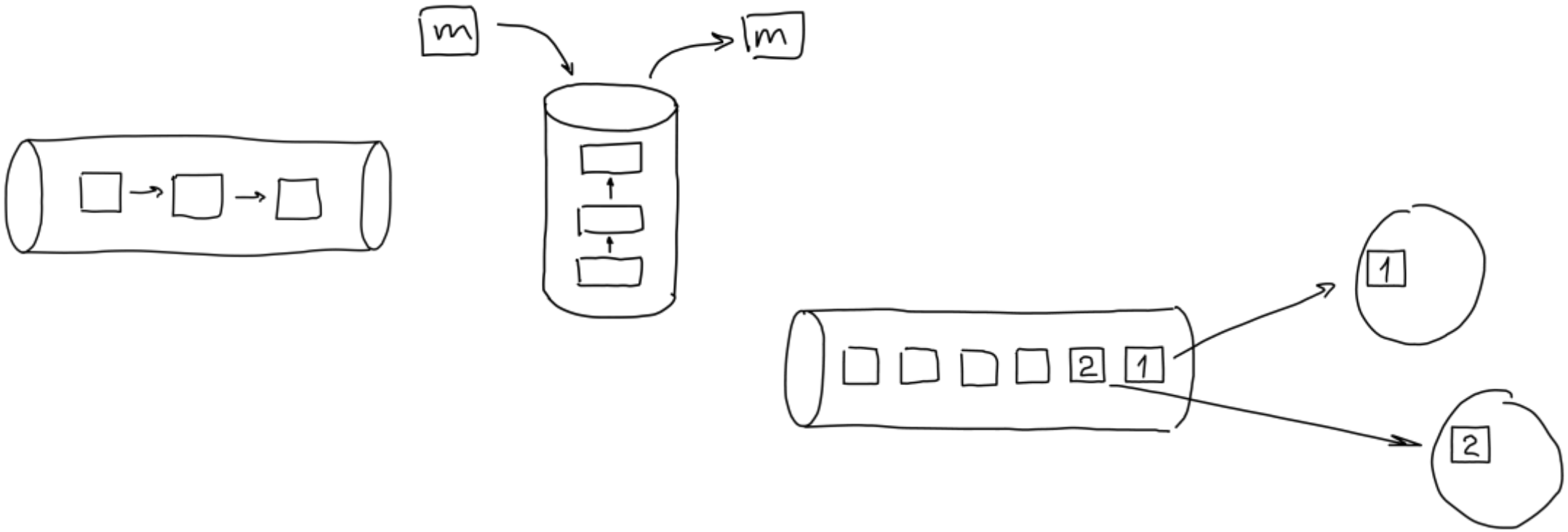
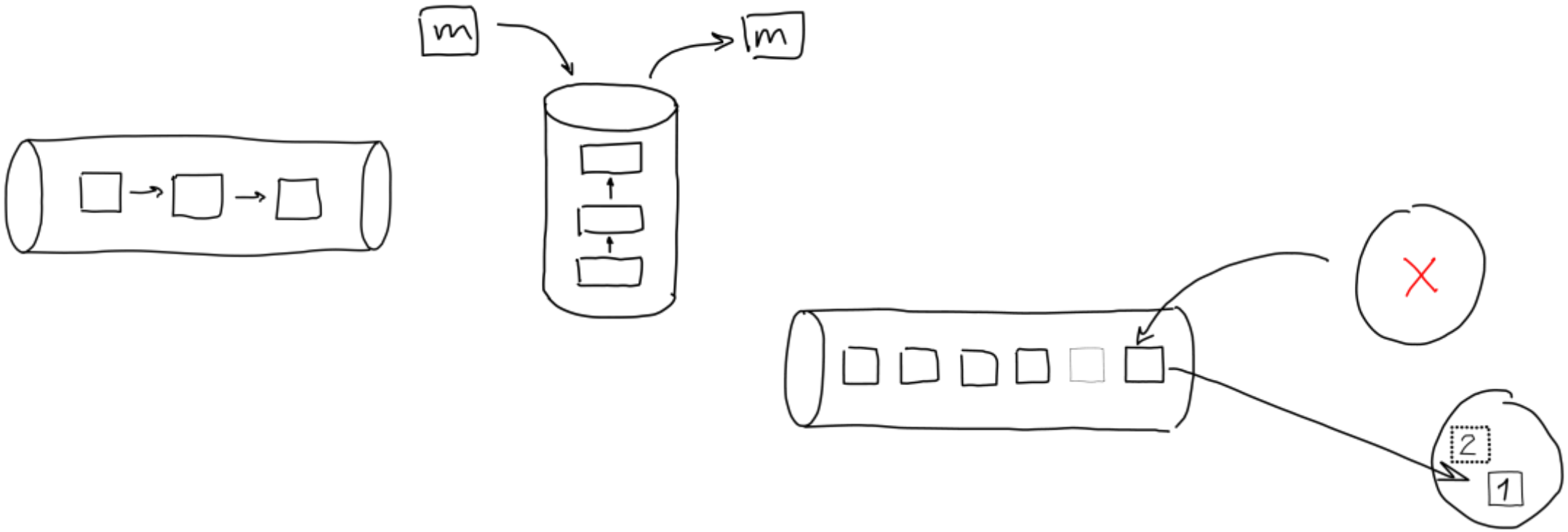


Algorithms

- FIFO, LIFO, **Best Effort**, QoS



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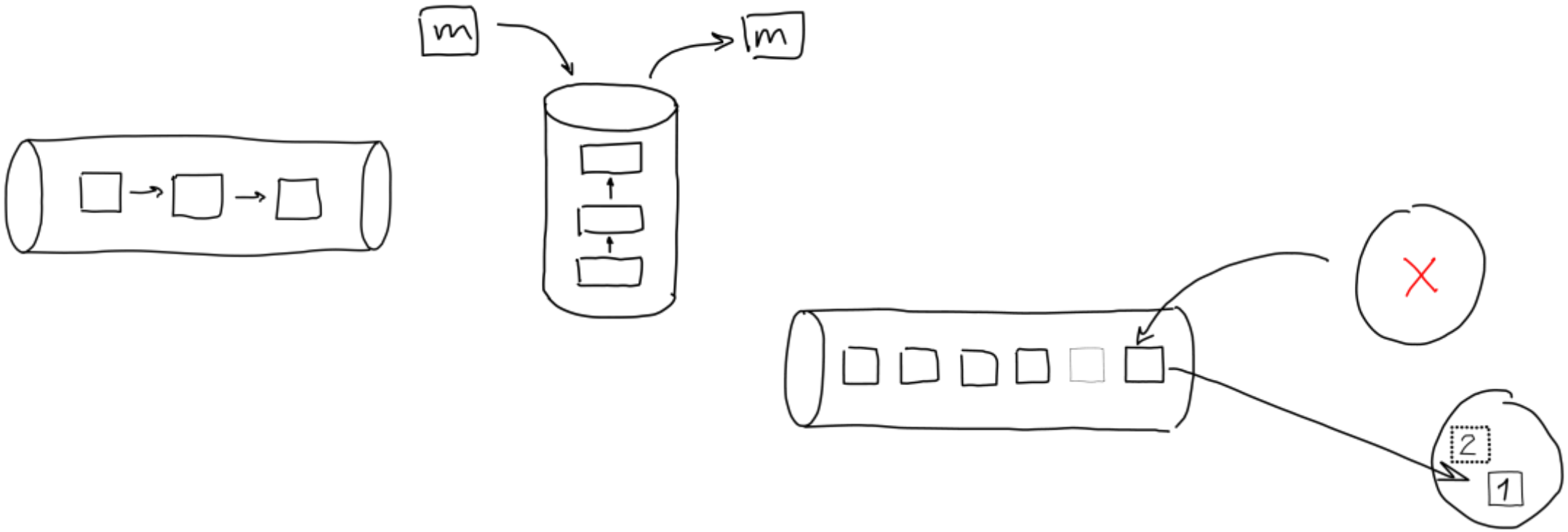
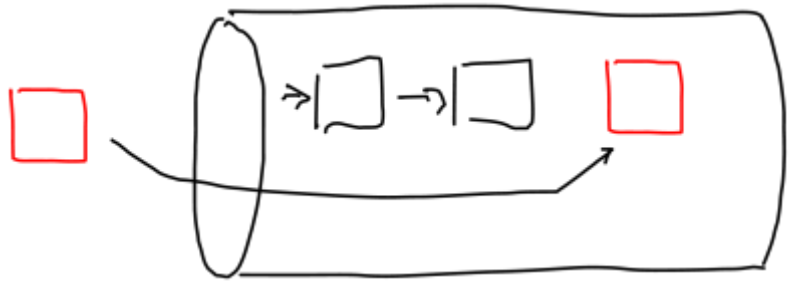


Algorithms

- FIFO, LIFO, Best Effort, QoS
- Message prioritization: Heap vs List



Algorithms

- FIFO, LIFO, Best Effort, QoS
- Message prioritization
- Nested queues, hierarchy

Algorithms

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- Message prioritization
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- Retry, delay, retry with delay

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- Dead letter queue (and reordering)

Algorithms

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- Task dependency

Algorithms

- FIFO, LIFO, Best Effort, QoS
- Message prioritization
- Nested queues, hierarchy
- Retry, delay, retry with delay
- Dead letter queue (and reordering)
- Task dependency
- TTL, TTR, Putback

Would you like yet more?

- Prioritization and Starvation

Would you like yet more?

- Prioritization and Starvation
- Throughput
- Performance

Would you like yet more?

- Prioritization and Starvation
- Throughput
- Performance
- Scalability

Would you like yet more?

- Prioritization and Starvation
- Throughput
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- Scalability
- Limits and Capacity

Would you like yet more?

- Prioritization and Starvation
- Throughput
- Performance
- Scalability
- Limits and Capacity
- Reliability

Would you like yet more?

- Prioritization and Starvation
- Throughput
- Performance
- Scalability
- Limits and Capacity
- Reliability → Availability + Durability

What’s next? Network

- Undefined behavior

Two Generals’ Problem

Two Generals’ Problem

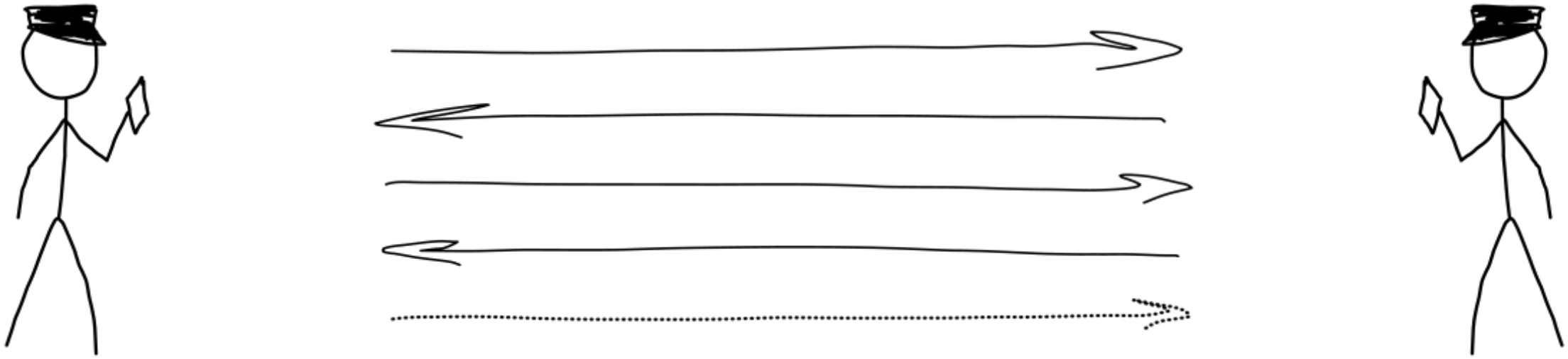
Also known as:

- Two Generals' Paradox
- Two Armies Problem
- Coordinated Attack Problem

Two Generals' Problem

How to reach an agreement
on both "do" or "don't"
with unreliable media in between them

Two Generals' Problem



Two Generals' Problem

Problem was the first
computer communication problem
to be proved to be unsolvable*

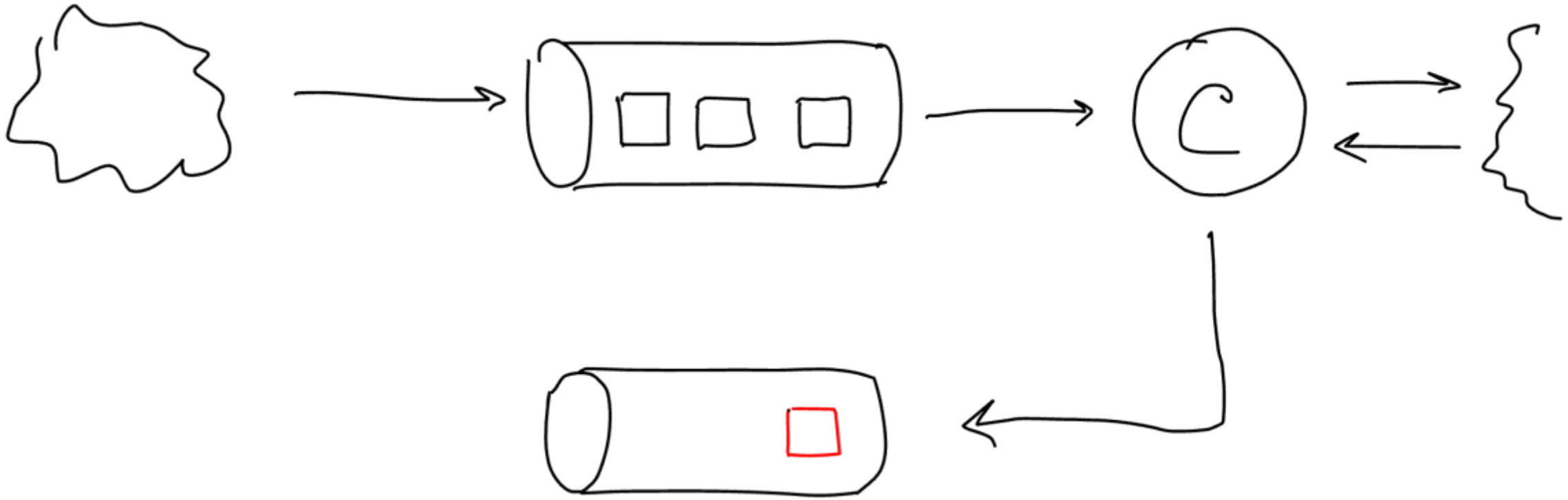
* Leslie Lamport. "Solved Problems, Unsolved Problems and Non-Problems in Conc

Two Generals' Problem

There are two complex problems in distributed systems:

2. Exactly once delivery
    1. Strict message order
2. Exactly once delivery

Solution for “exactly once”



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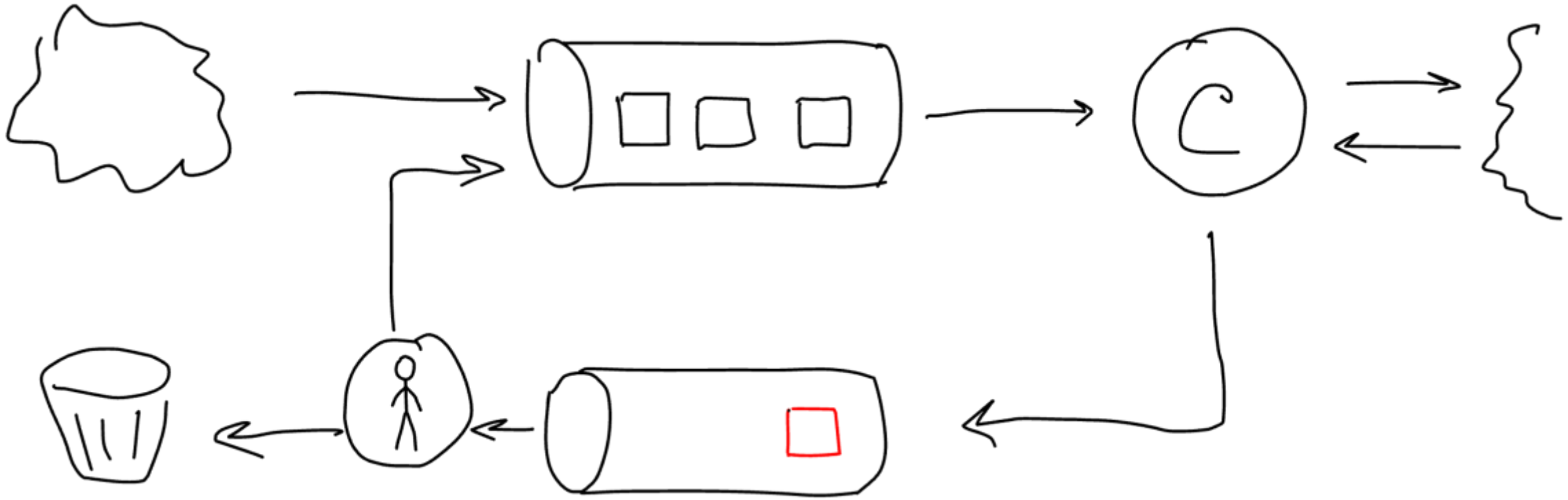

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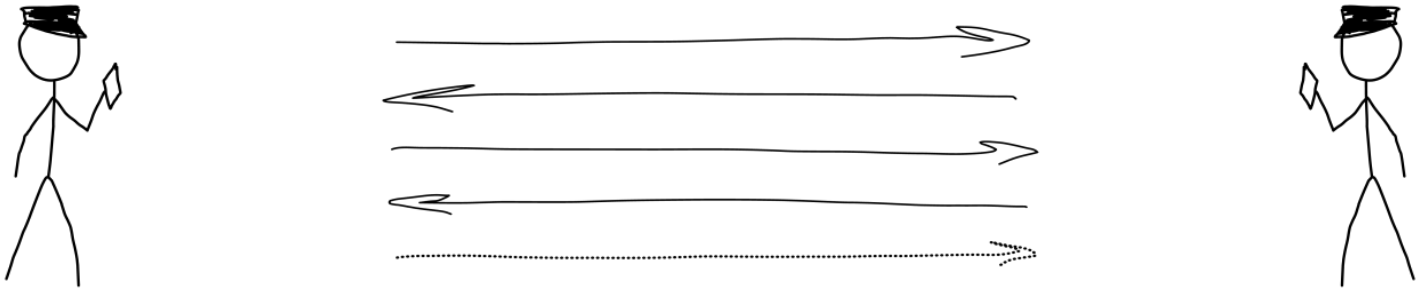

Problems: network & disk

- Throughput
- Latency

Outages & failures

- Hardware failures
  - Disk
  - Host
  - Datacenter

Outages & failures

- Hardware failures
  - Disk
  - Host
  - Datacenter
- Temporary failures
  - Power
  - Network
  - Split brain

Outages & failures

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Reliability explained

- Availability

- Durability

Reliability explained

- Availability
  - Ability to receive messages
  - Ability to store messages
- Durability

Reliability explained

- Availability
  - Ability to receive messages
  - Ability to store messages
- Durability

The queue is ***available***
if ***producer*** could produce message

Reliability explained

- Availability
  - Ability to receive messages
  - Ability to store messages
- Durability
  - Ability to not lose received and confirmed messages

Reliability explained

- Availability
  - Ability to receive messages
  - Ability to store messages
- Durability
  - Ability to not lose messages

The queue is ***durable***
if ***concumer*** receives
all the messages from producer

Main queue properties

- Availability
  - Ability to receive & store messages
- Durability
  - Ability to not lose received messages
- Delivery guarantee
  - A promise to deliver a message
  - “At least once” ($X \geq 1$)
  - “At most once” ($X \leq 1$)
  - “Exactly once”

Main queue properties

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  - “At least once” ($X \geq 1$)
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  - “Exactly once” is impossible, while stated by many*

Main queue properties

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  - A promise to deliver a message
  - “At least once” ($X \geq 1$)
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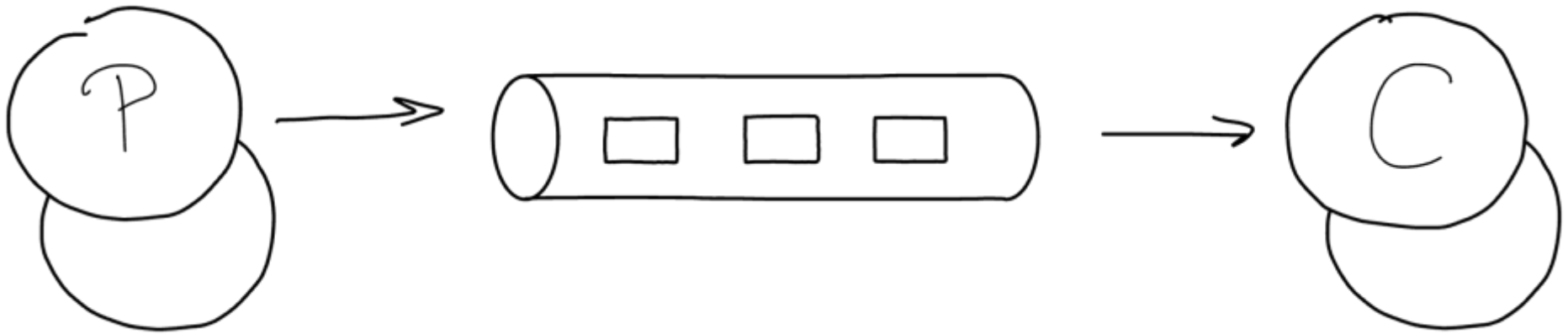
  - “Exactly once” = “At least once” + Idempotence

Main queue properties

- Availability
  - Ability to receive & store messages
- Durability
  - Ability to not lose received messages
- Delivery guarantee
  - A promise to deliver “At least once” or “At most once”
- Scalability
  - Ability to increase throughput by adding nodes

Topology overview

Topology: single instance



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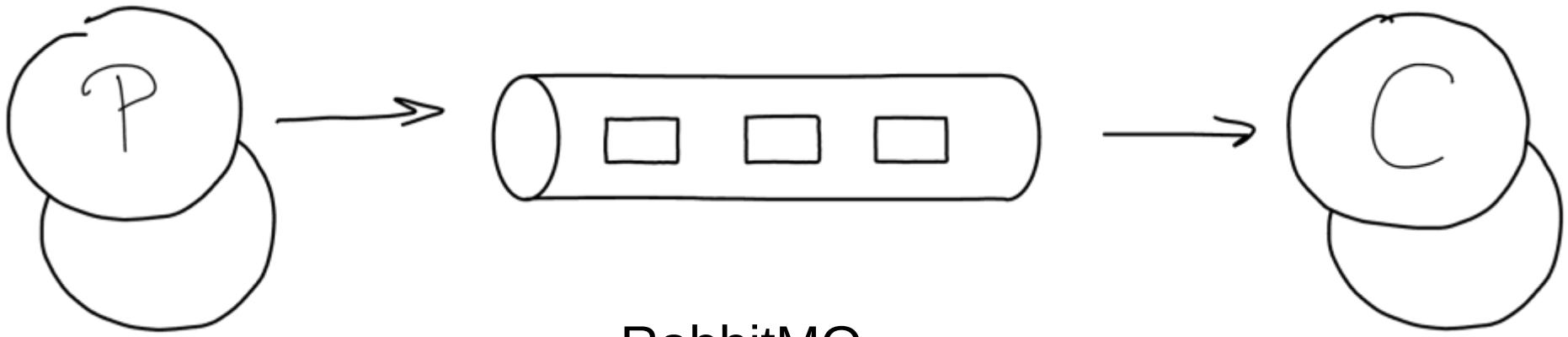
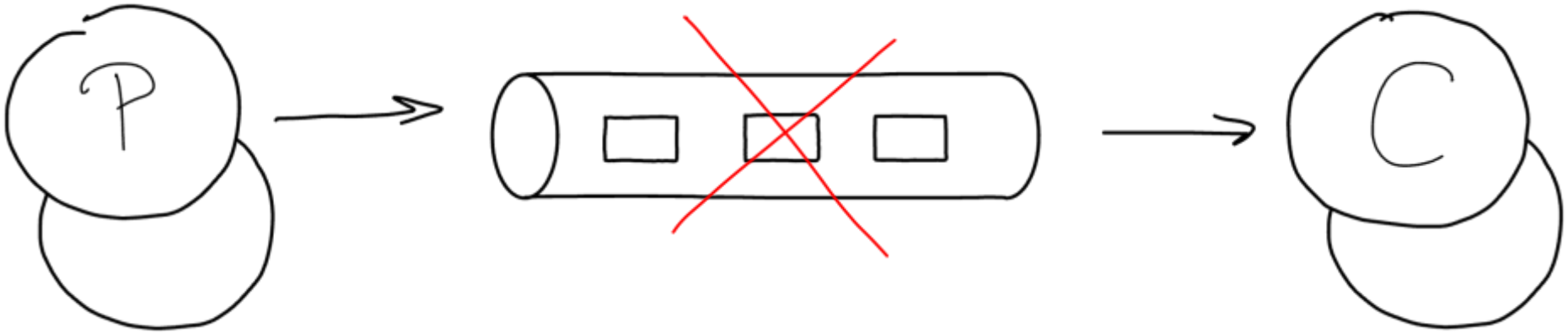


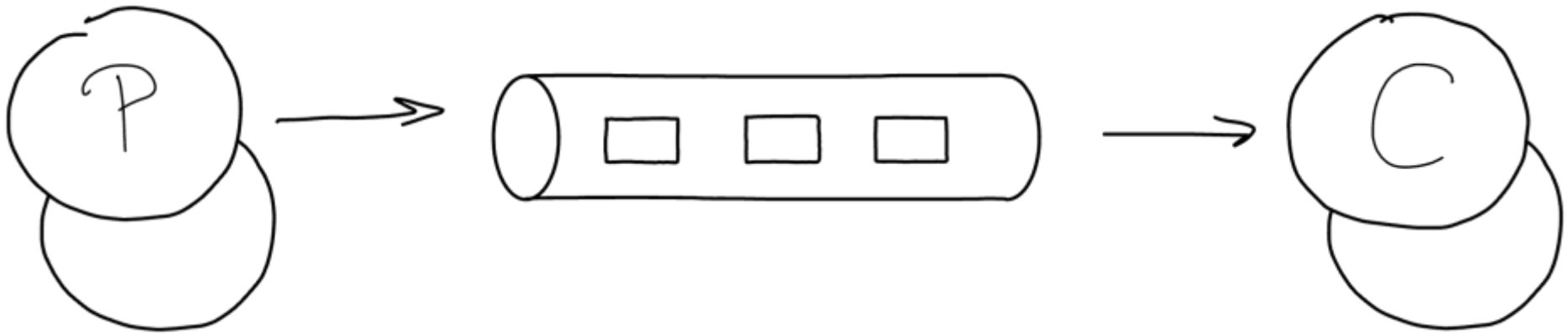
RabbitMQ
Redis
ActiveMQ
Beanstakld
…

Topology: single instance



Availability: low
Durability: low

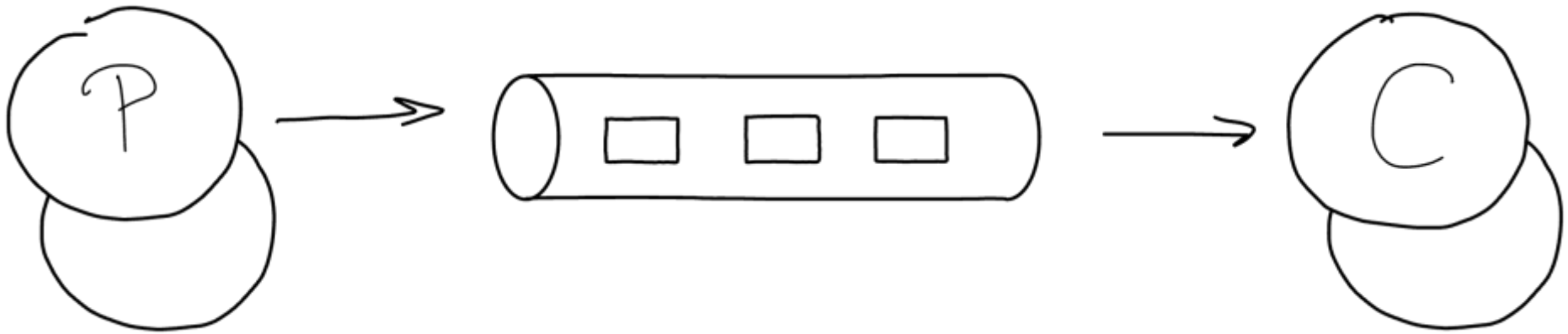
Topology: single instance



Scalability: no

Availability: low
Durability: low

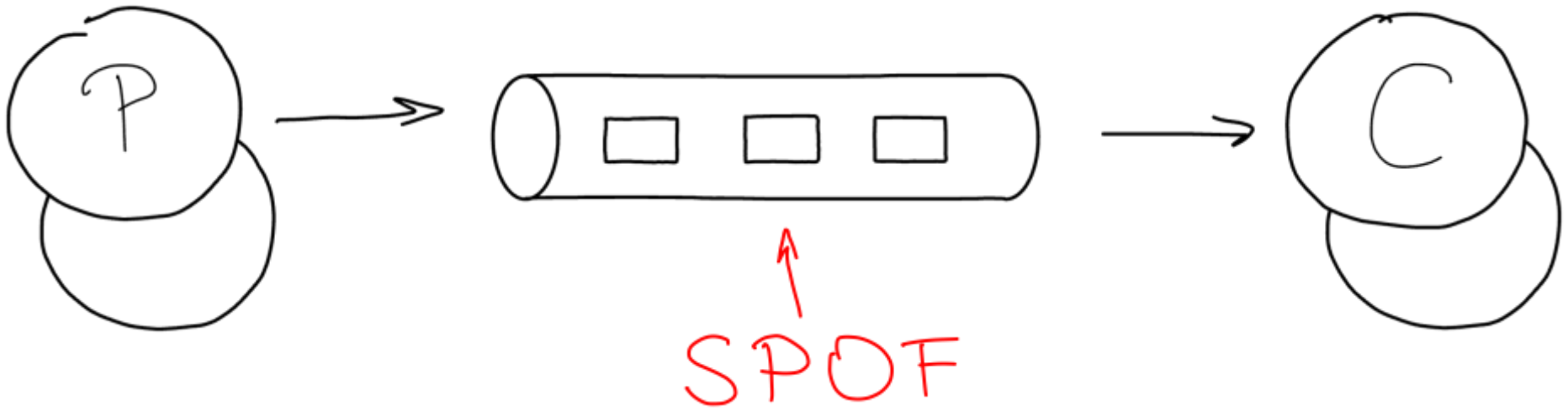
Topology: single instance



Scalability: no
Guarantee: X ≤ 1, X ≥ 1

Availability: low
Durability: low

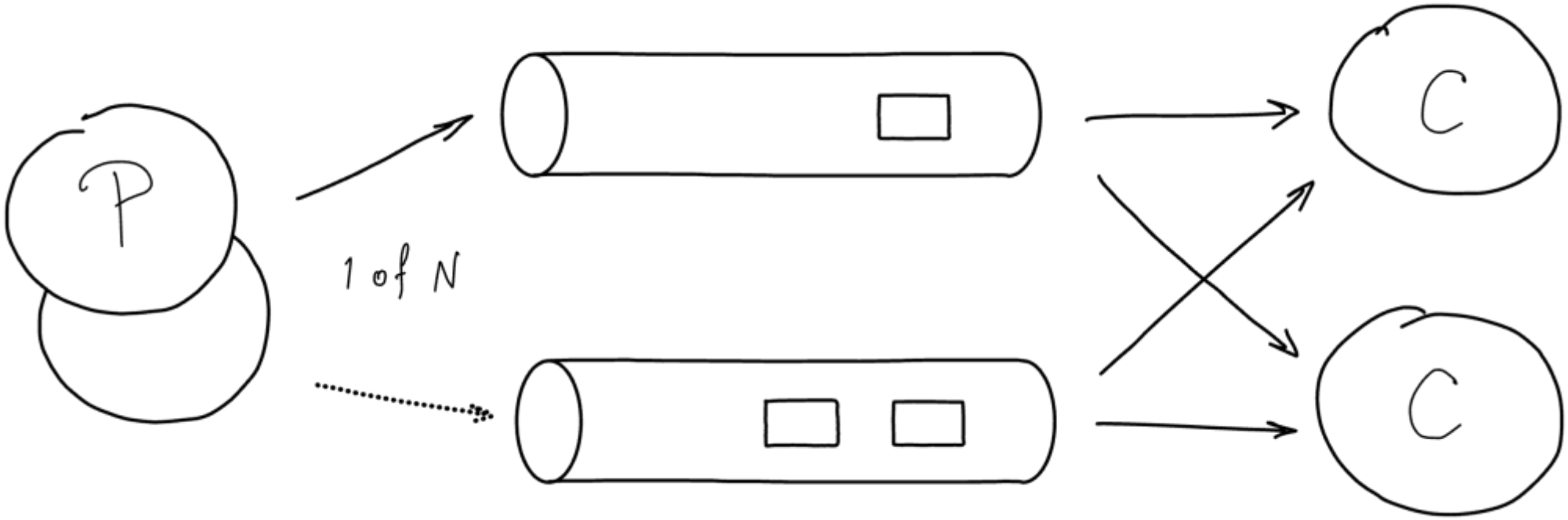
Topology: single instance



Scalability: no
Guarantee: X ≤ 1, X ≥ 1

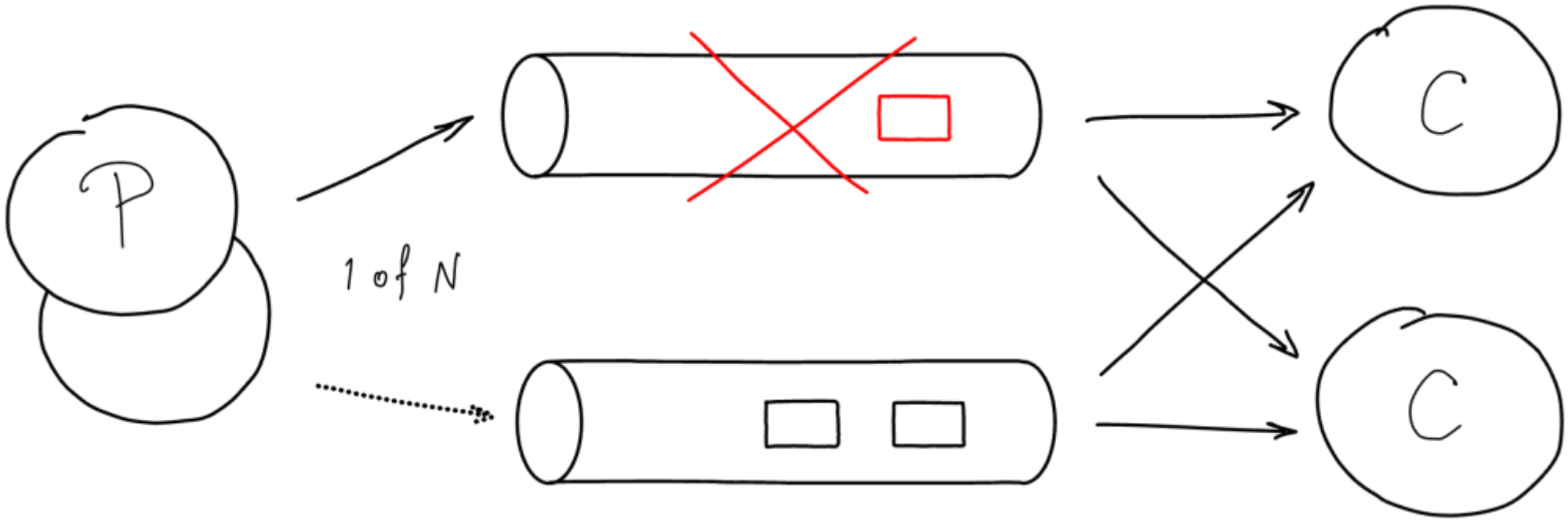
Availability: low
Durability: low

Topology: multi-instance



Scalability: yes

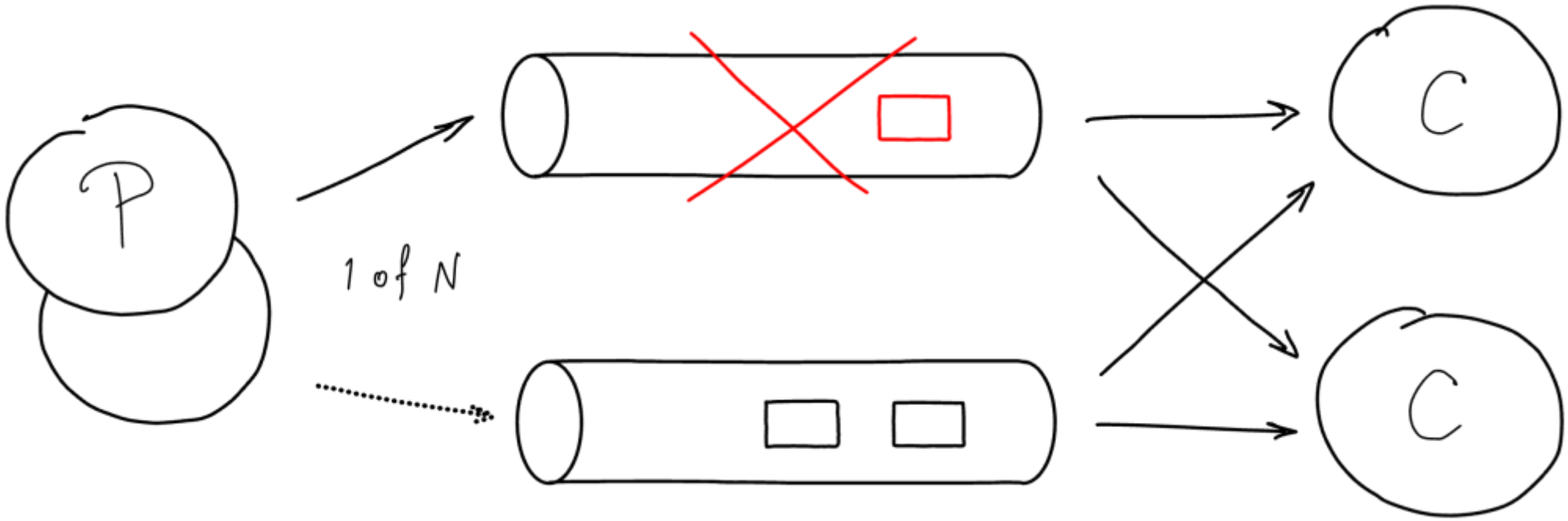
Multiple queues, put to 1



Scalability: yes

Availability: high

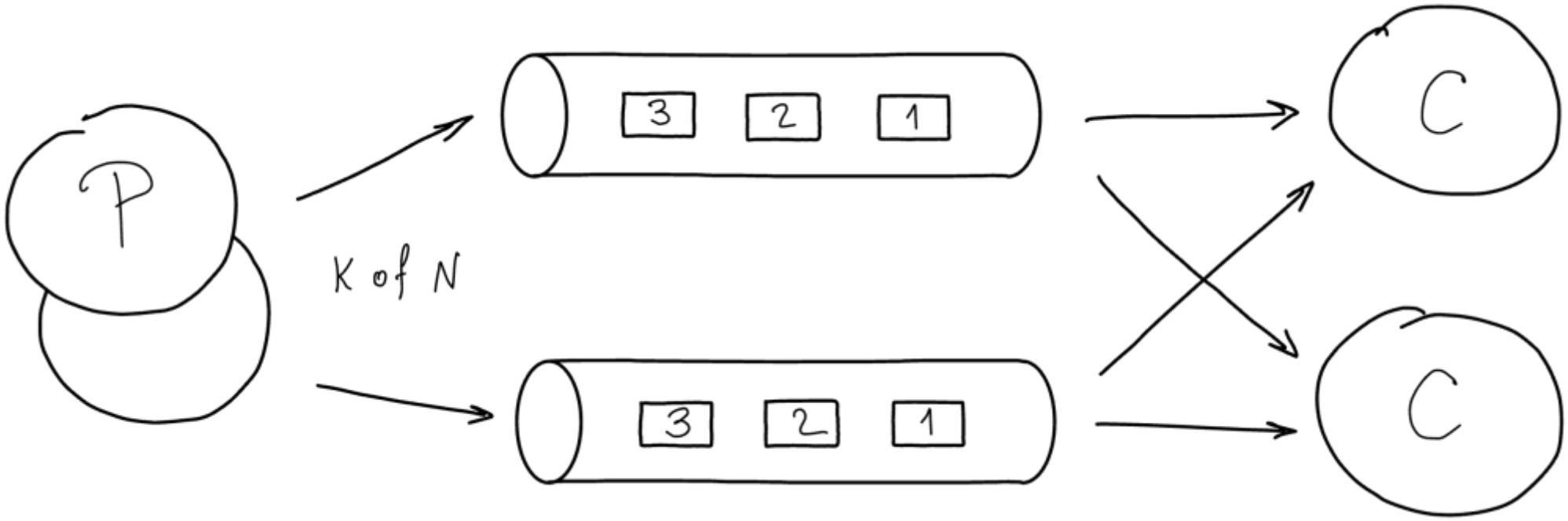
Multiple queues, put to 1



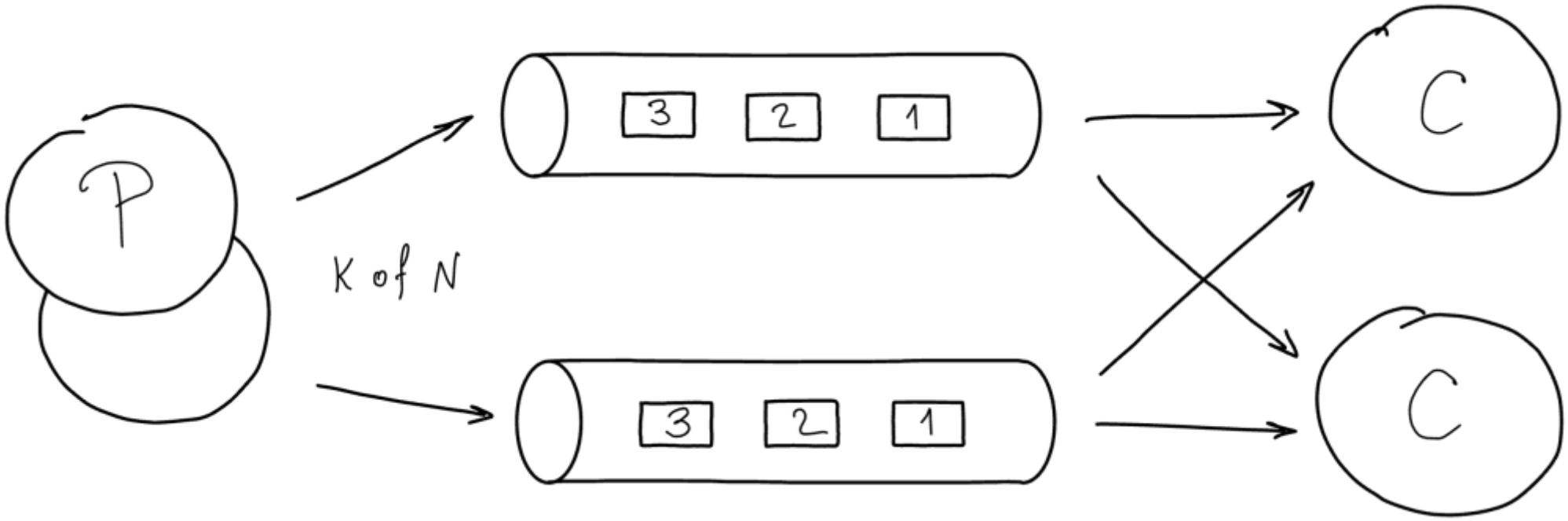
Scalability: yes
Guarantee: X ≤ 1, X ≥ 1

Availability: high
Durability: medium

Multiple queues, put to K/N

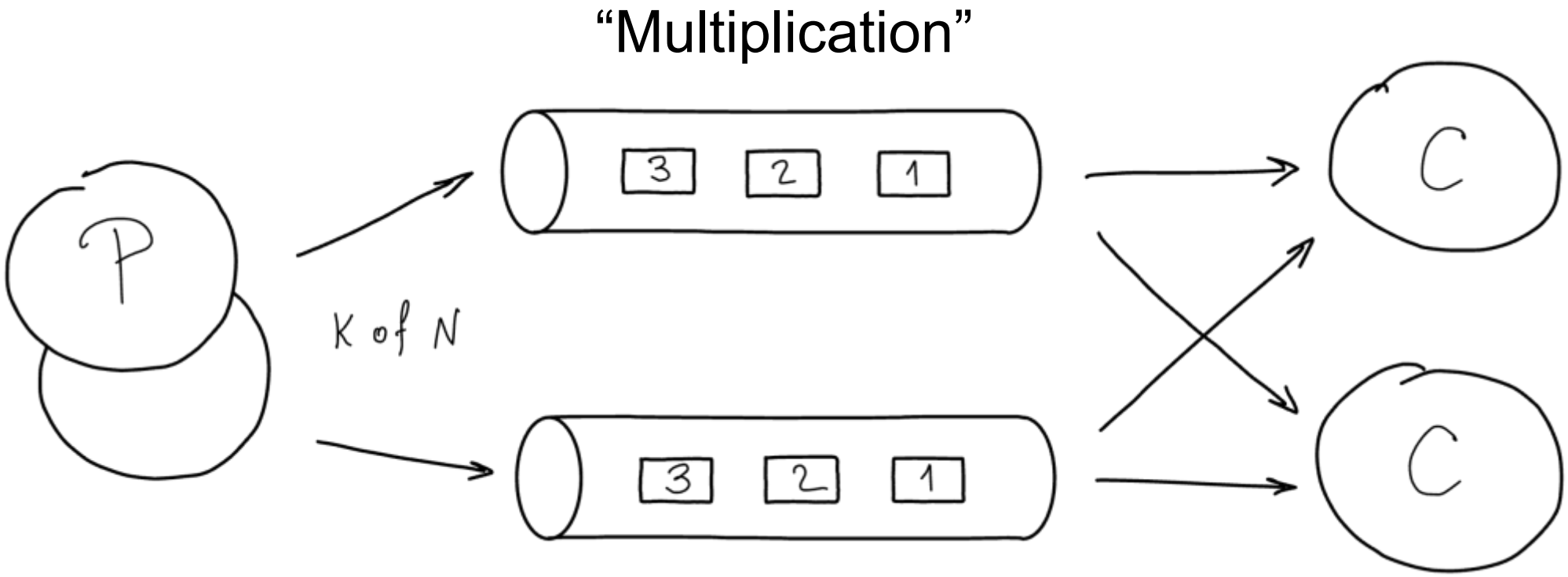


Multiple queues, put to K/N



Availability: high
Durability: high

Multiple queues, put to K/N



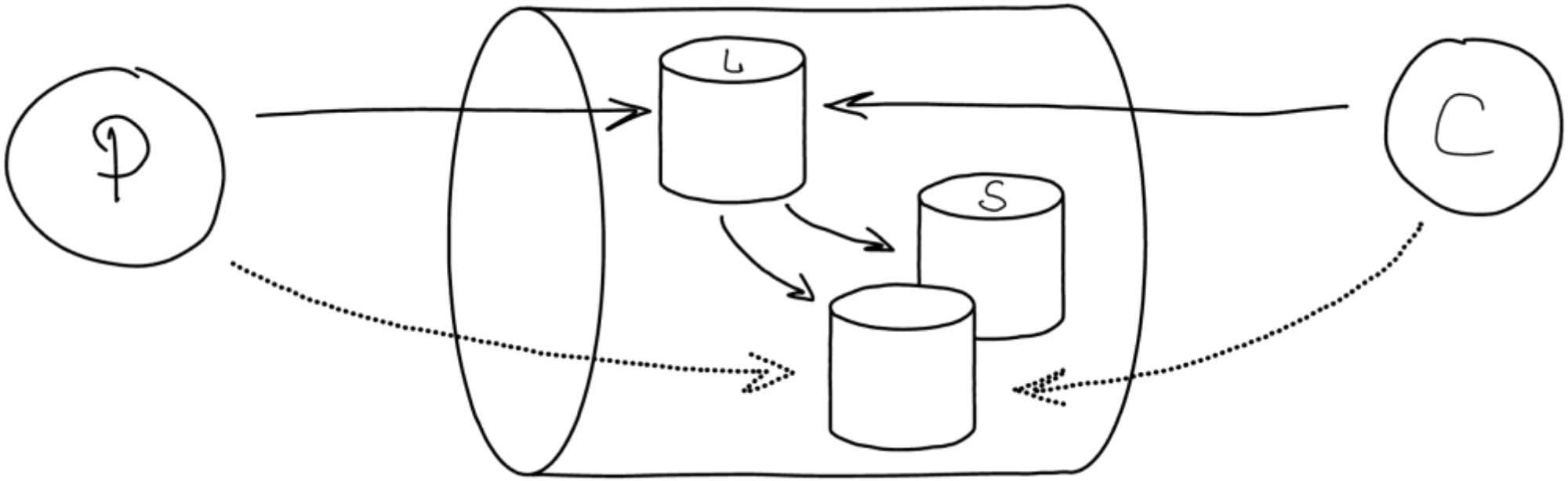
Scalability: yes

Guarantee: X ≤ K, X ≥ K, X > 1

Availability: high

Durability: high

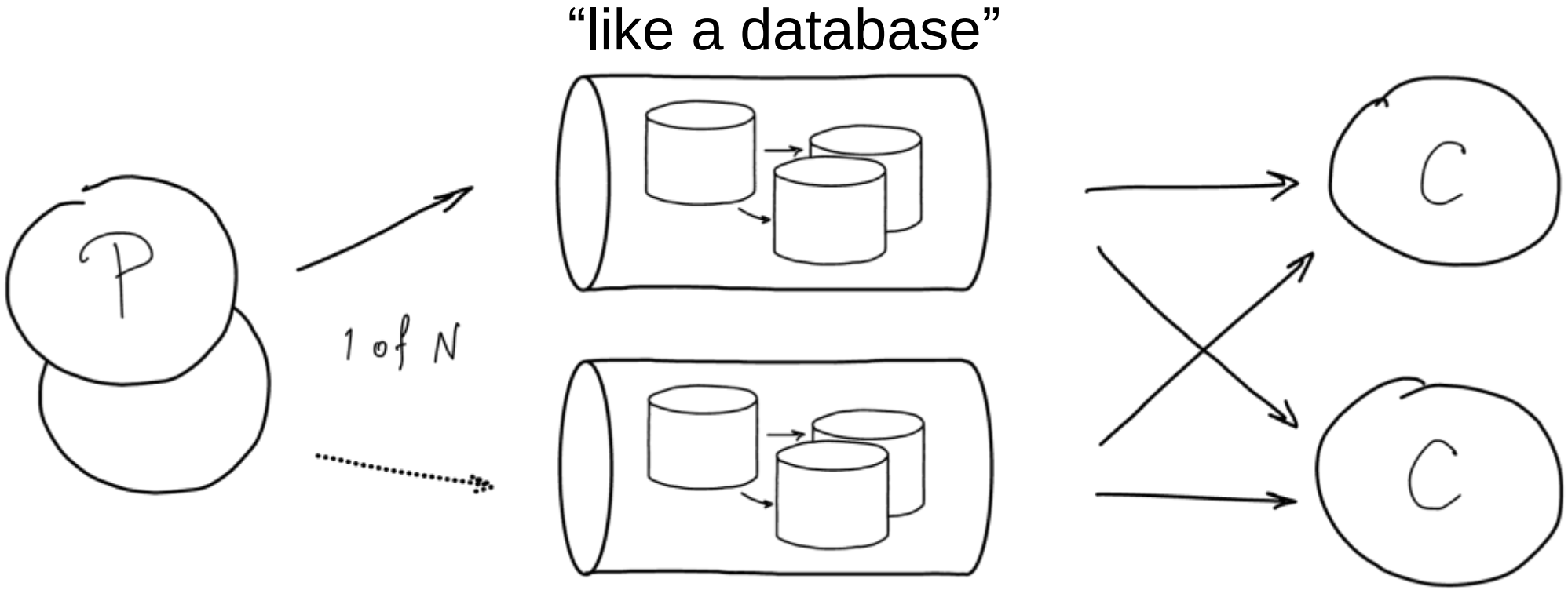
Replication



Interaction
with a leader

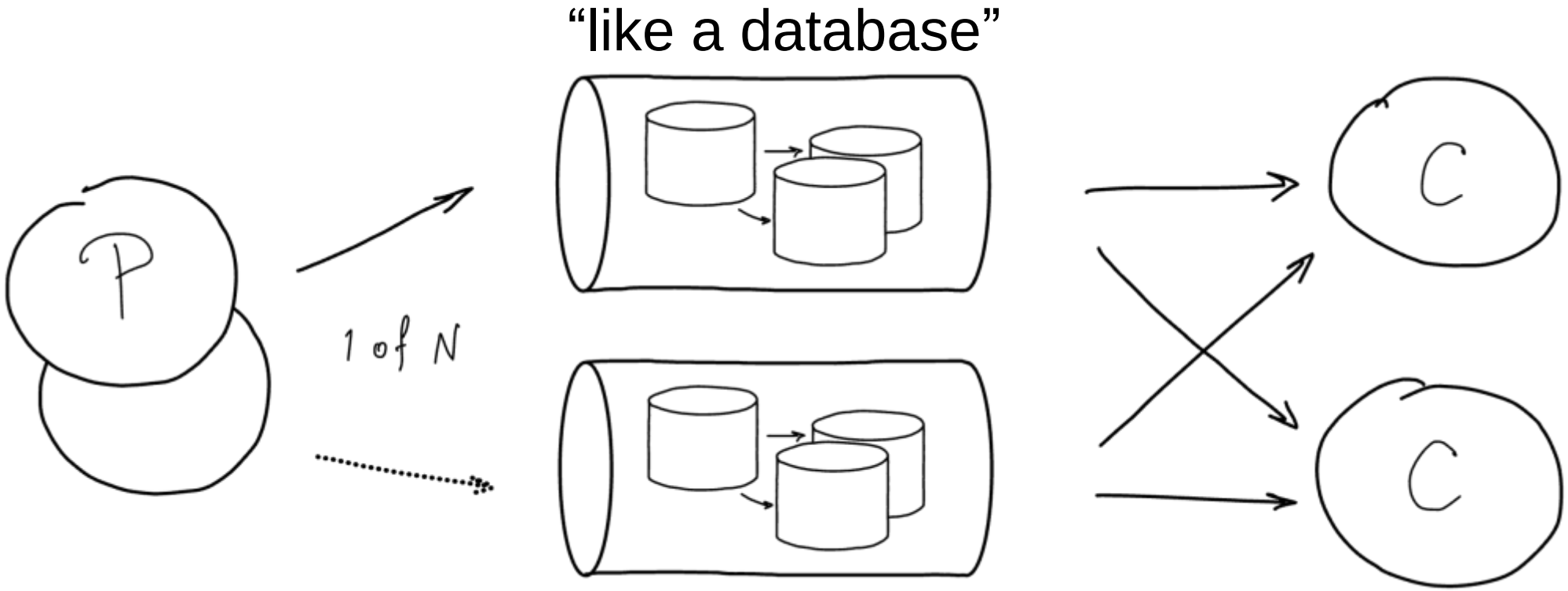
Replicas
are on standby

Replicated queues, 1/N



Availability: high
Durability: high

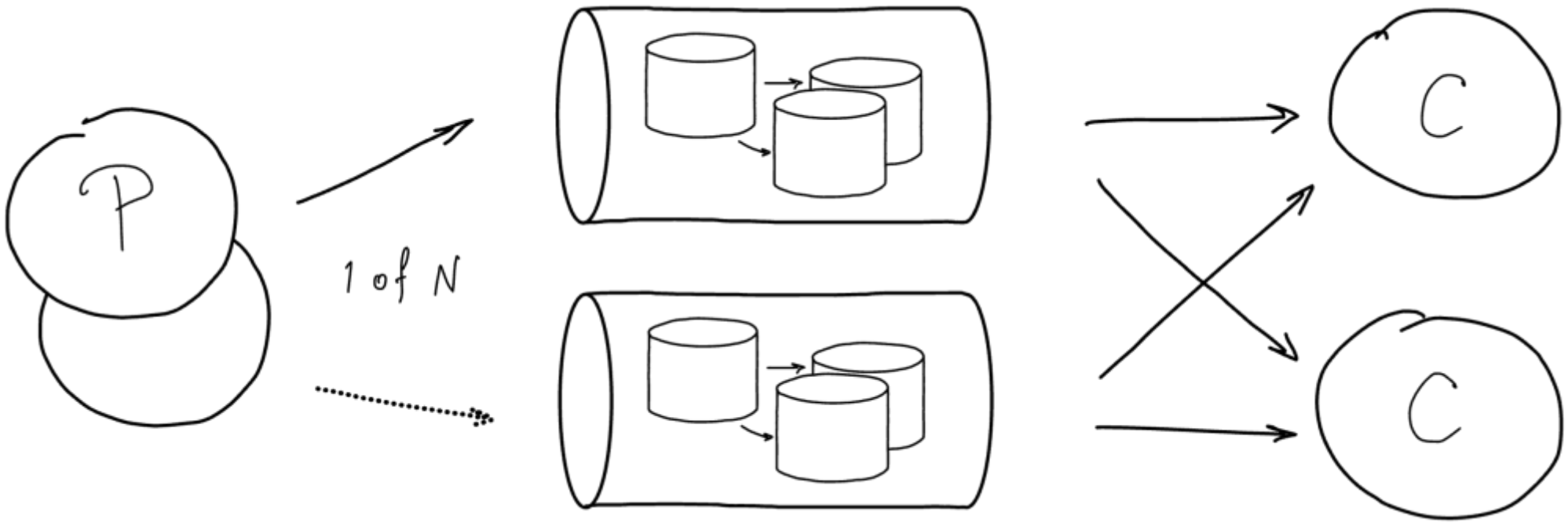
Replicated queues, 1/N



Scalability: yes
Guarantee: X ≈ 1 (X ≥ 1)

Availability: high
Durability: high

Replicated queues, 1/N



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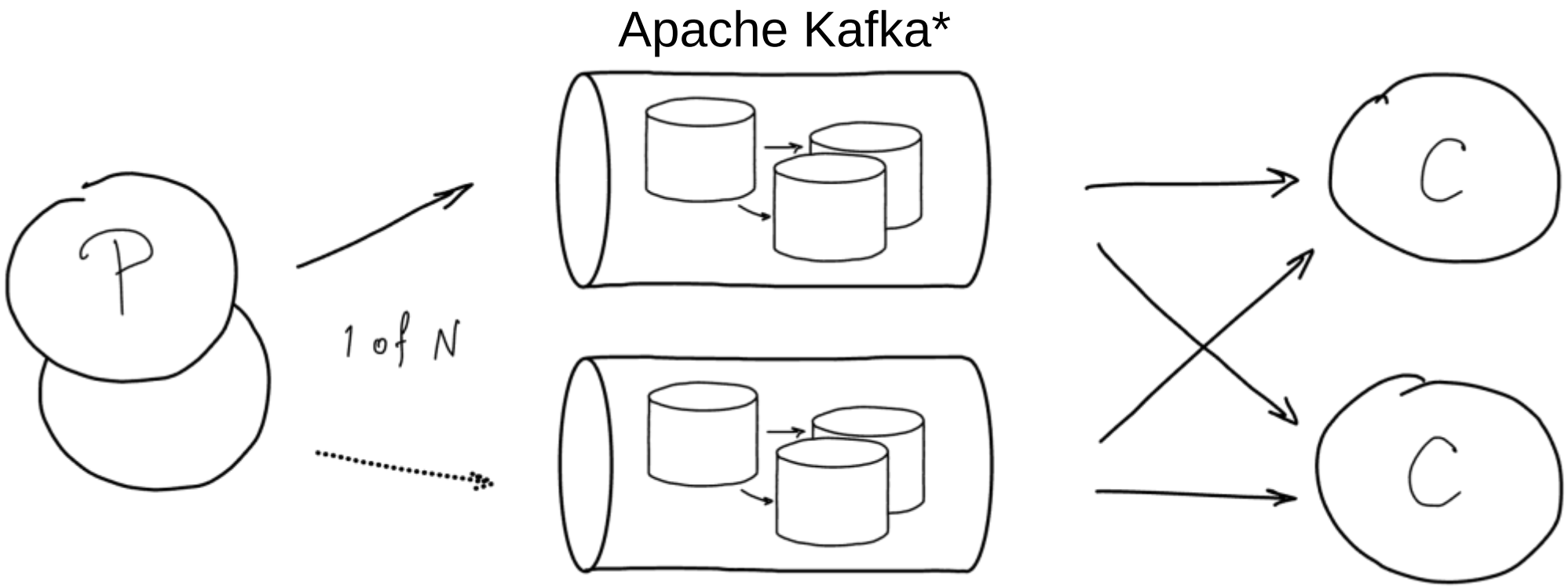
Replicated queues, 1/N



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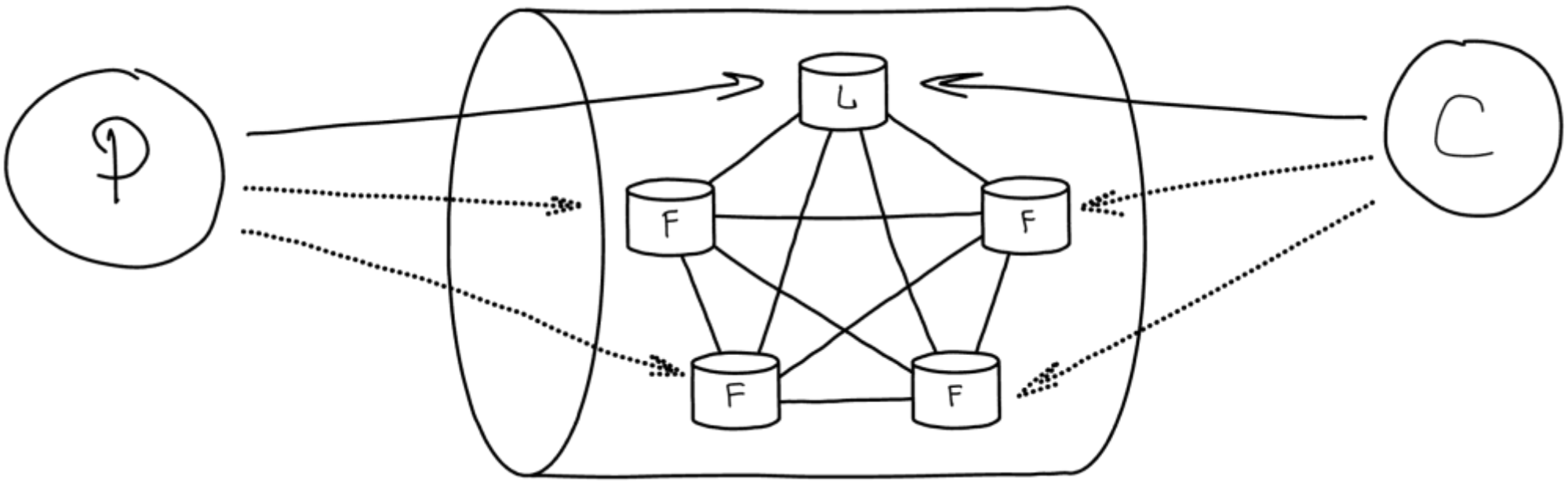
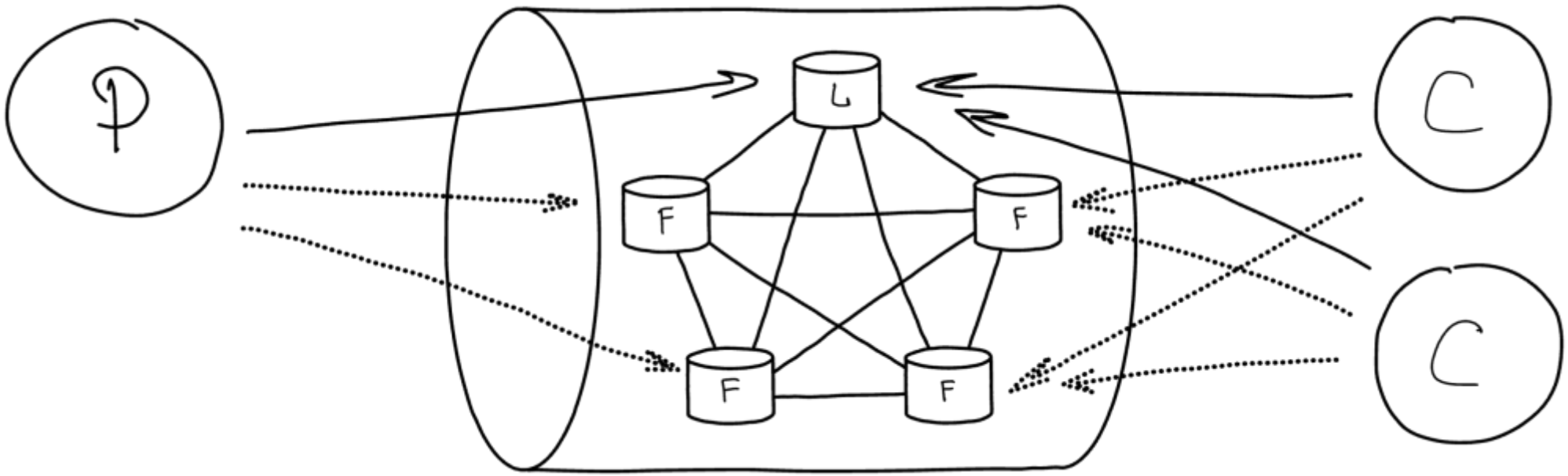
“Like a database”: quorum



Quorum writes give protection from data loss
Quorum guarantees consistency, X → 1 (X ≥ 1)
Most reliable. But slow.

Quorum queue cluster



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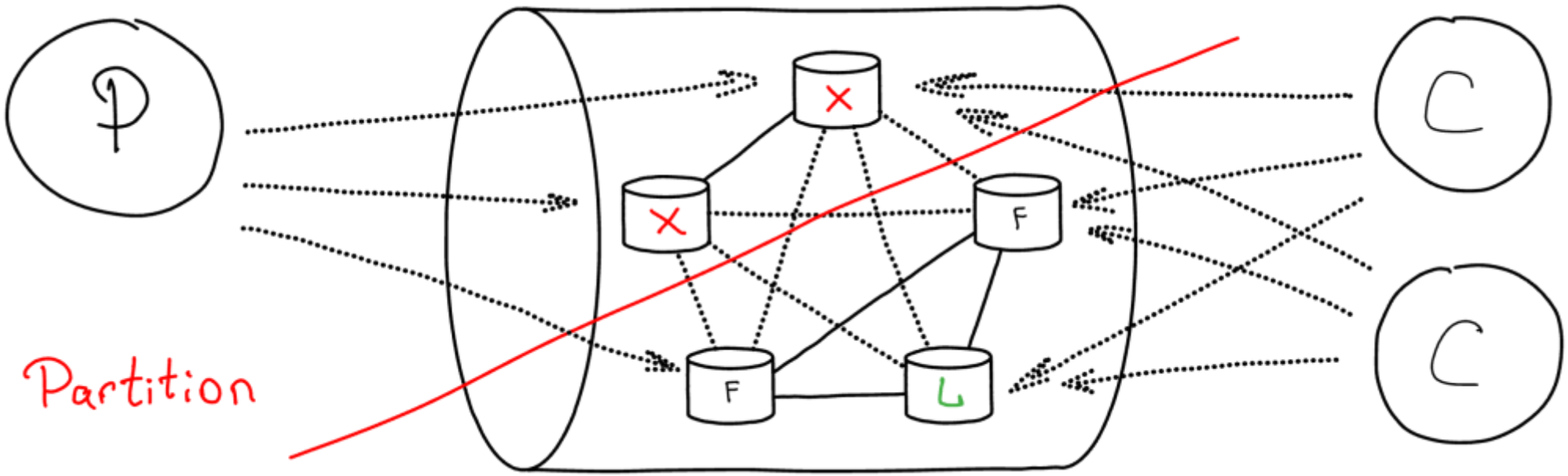
Quorum queue cluster

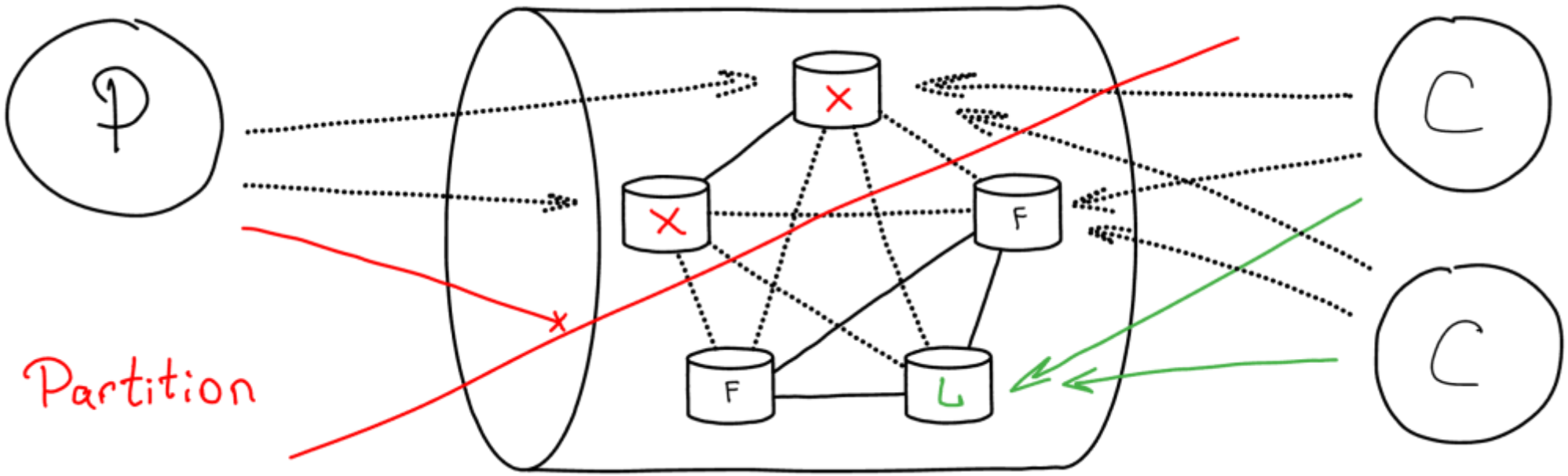


Guarantee: X ≈ 1 (X ≥ 1)

Availability: limited

Durability: high

Quorum queue cluster



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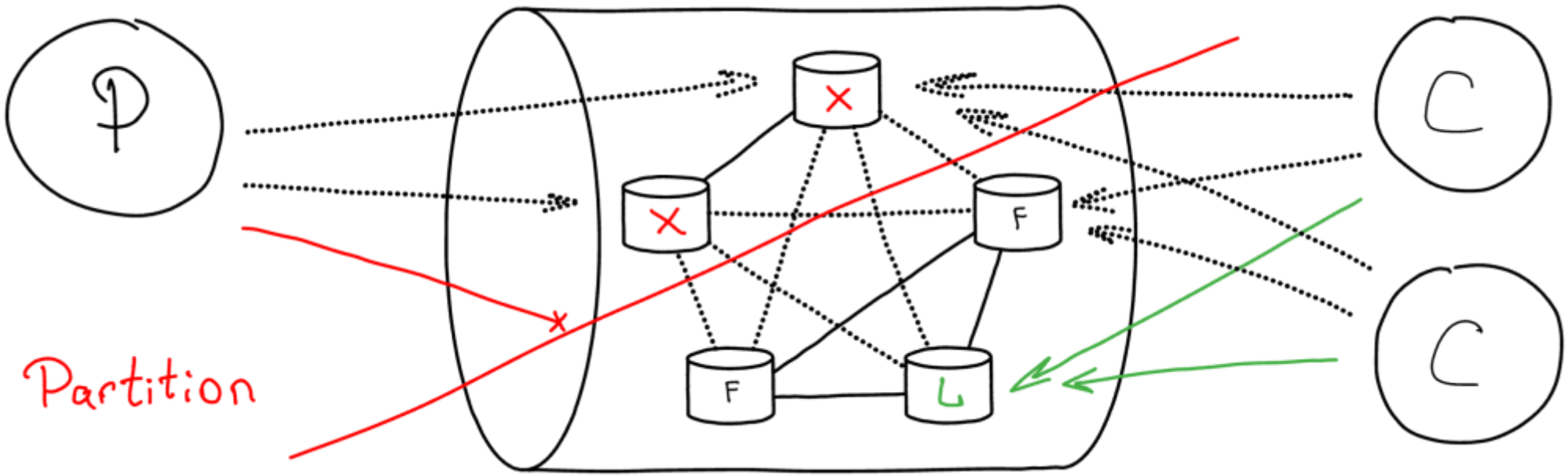

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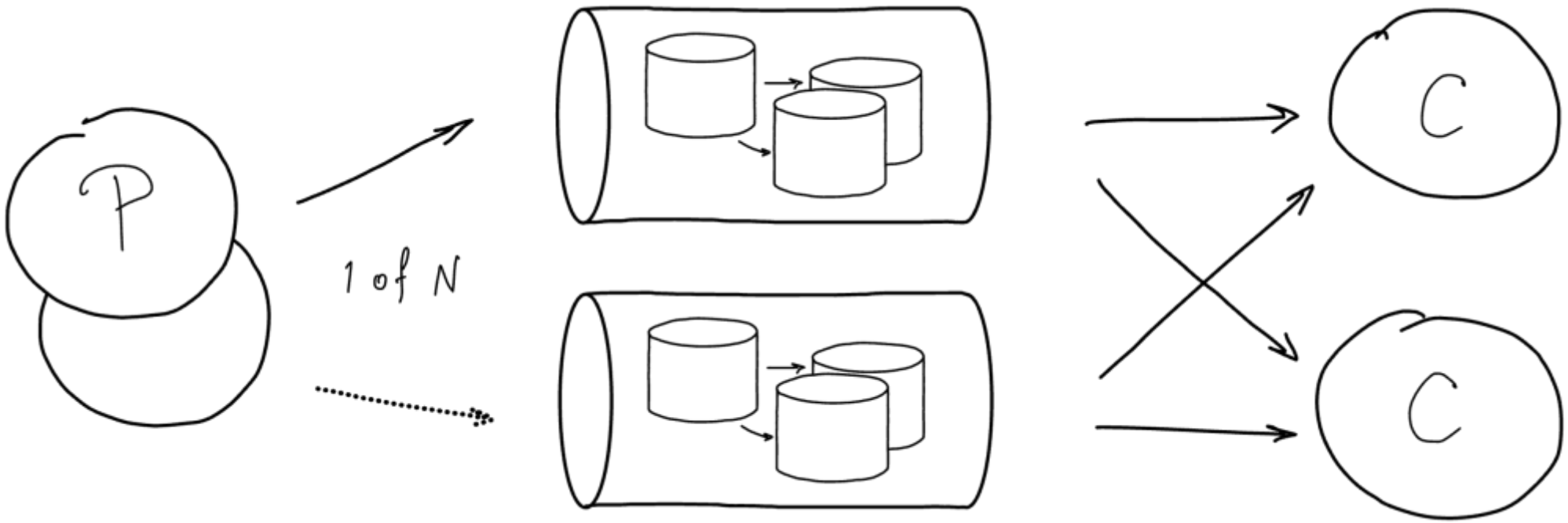
Replicated queue, 1/N



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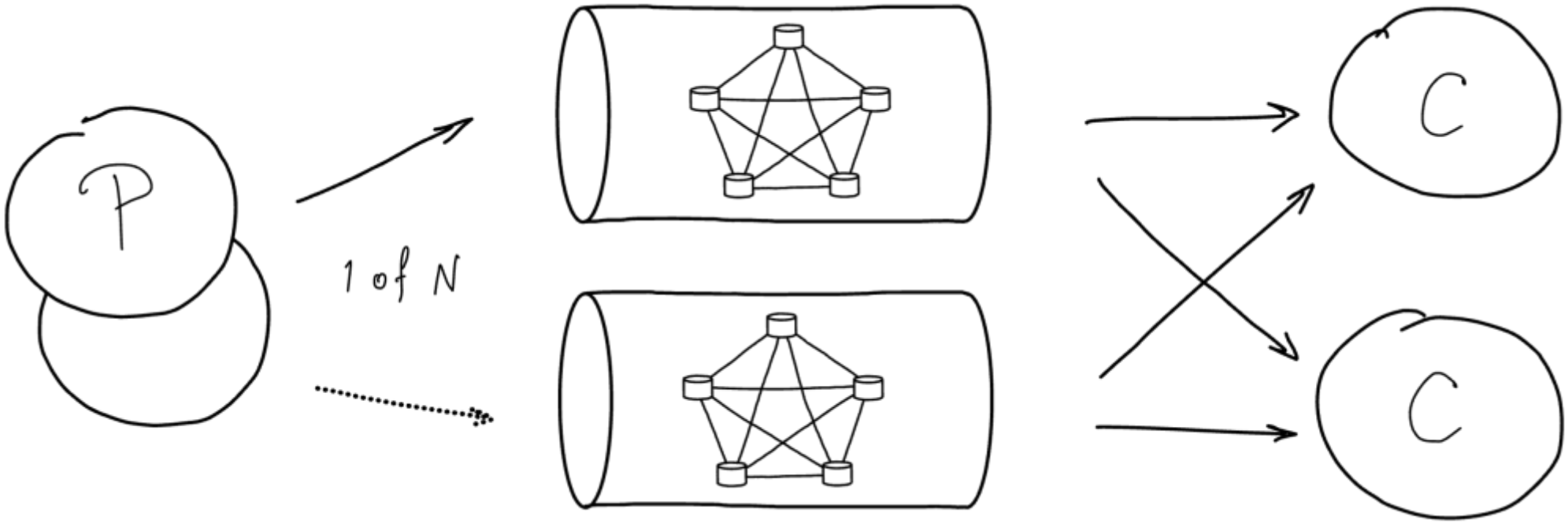

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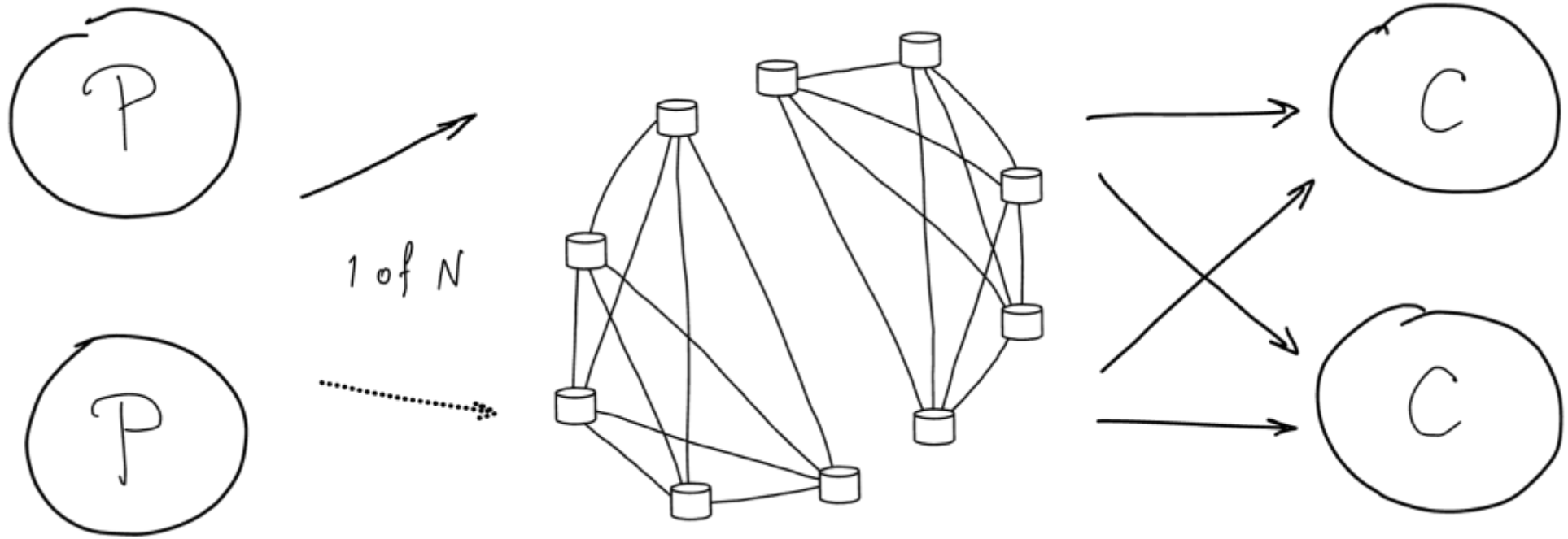

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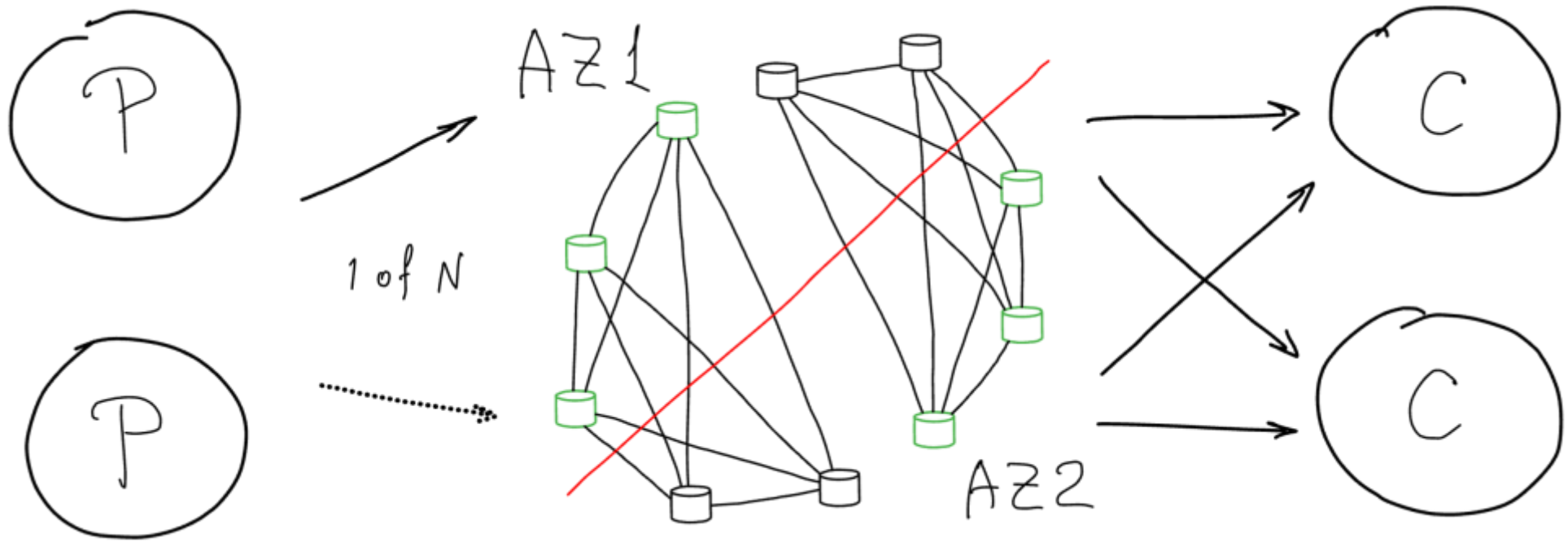

Scalability: yes
Guarantee: X ≈ 1 (X ≥ 1)

Availability: high
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What else to know?

- Protocols & limitations
- Monitoring & maintenance
- Best choices

Protocols & limitations

Message state
is bound to connection

- Low latency
- Immediate requeue

- Hard to scale
- Task lifecycle

Stateless
(HTTP/REST/SQS)

- Scaling
- HTTP-balancing

- Autorelease is a must

Monitoring & maintenance

- Queue capacity and consumption
  - There is always a limit.

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  - Full event cycle (QoS)
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- Duplicate your messages to logs!

Maintenance: plan a failure

- Set up failure policies

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  - Stop accepting new messages
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Maintenance: plan a failure

- Set up failure policies
  - Stop accepting new messages
  - Discard/drop old messages
  - Save the survivors
- Have a plan for a fall down
  - To use it to get up

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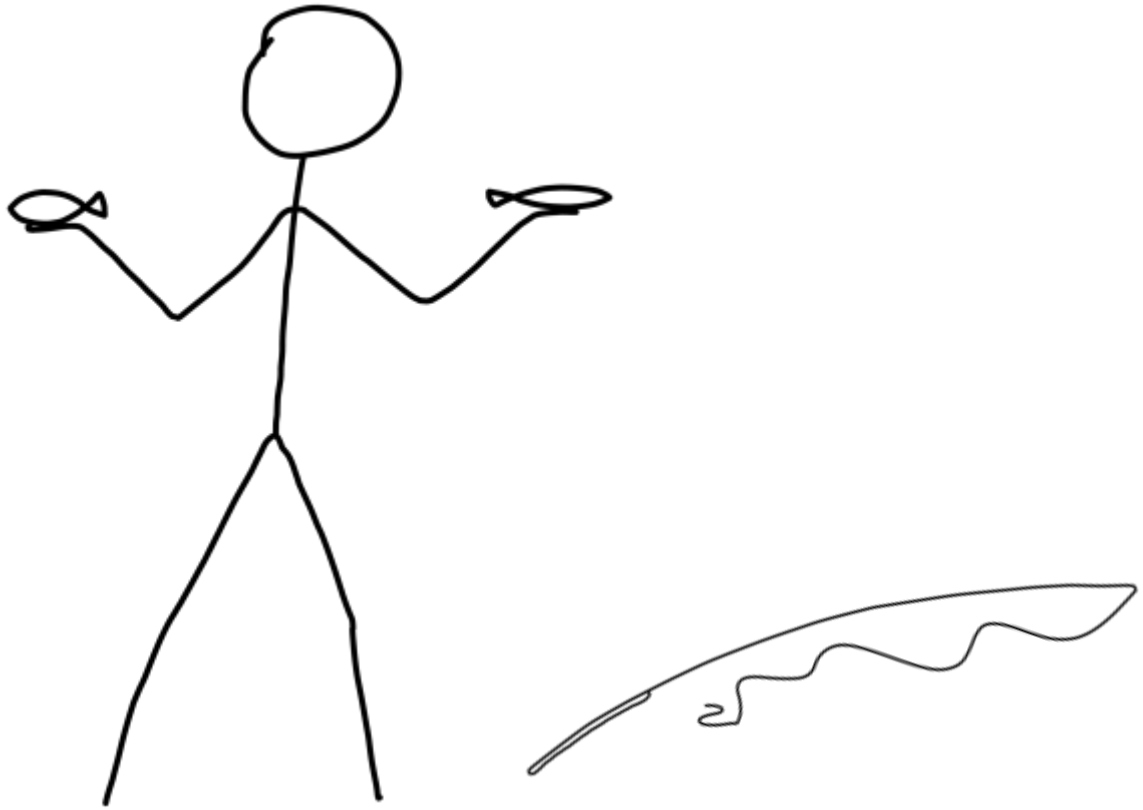
What if & how to?



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- Event loss tolerance
- Simple message delivery
- High throughput, scalability

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- NATS
- NSQ
- ZeroMQ

What if & how to?

- To give it a try

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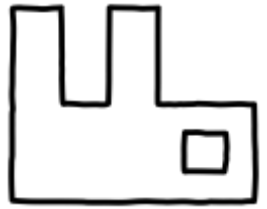


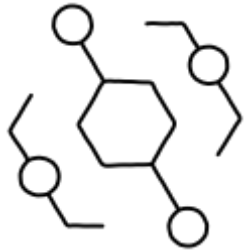
- To give it a try

- SQS (Simple Queue Service)
  - Amazon, GCP, …
- CloudAMQP
- Simple brokers: RabbitMQ, Redis, NATS
  (watch out for durability and availability)

What if & how to?

- For cloud applications
- For microservices
- For serverless architecture

What if & how to?



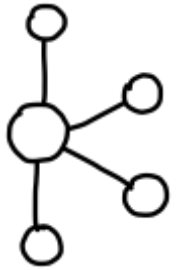
- For cloud applications
- For microservices
- For serverless architecture

- SQS (Simple Queue Service)
  - Amazon, GCP, …
- Amazon EventBridge

What if & how to?

- Set up a streaming architecture
- High requirements for durability
- Strict FIFO

What if & how to?



- Set up a streaming architecture
- High requirements for durability
- Strict FIFO

- Apache Kafka
- NATS JetStream
- Tarantool

What if & how to?

- Complex processing scenarios and chains
- Delayed processing, rescheduling
- Arbitrary topologies
- Dependent events

What if & how to?

- Complex processing scenarios and chains
- Delayed processing, rescheduling
- Arbitrary topologies
- Dependent events

- RabbitMQ
- Tarantool

What’s next? Apache Kafka!

- Architecture of Kafka and why it’s so popular
- The principles behind and main properties
- Stream processing and EventSourcing with Kafka Streams
- Deployment topologies, Mirroring
- Cluster parameters tuning
- Working with Kafka from Python and Go

To be continued…