Scalability, Availability & Stability Patterns

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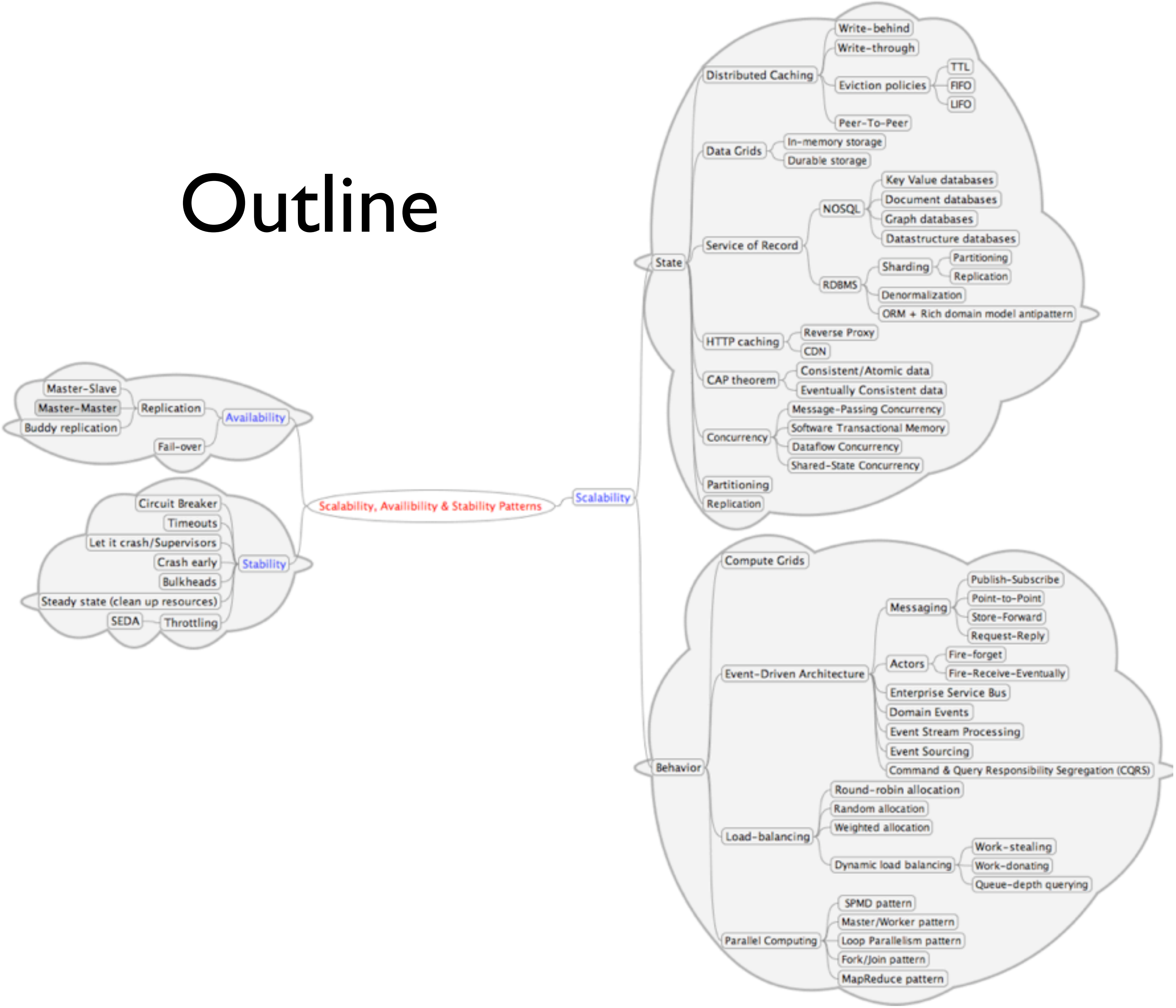
Outline


Scalability, Availibility & Stability Patterns
Availability
Replication
Master-Slave
Master-Master
Buddy replication
Fail-over
Stability
Circuit Breaker
Timeouts
Let it crash/Supervisors
Crash early
Bulkheads
Steady state (clean up resources)
SEDA
Throttling
Scalability
State
Distributed Caching
Write-behind
Write-through
Eviction policies
TTL
FIFO
LIFO
Peer-To-Peer
Data Grids
In-memory storage
Durable storage
Service of Record
NOSQL
Key Value databases
Document databases
Graph databases
Datastructure databases
RDBMS
Sharding
Partitioning
Replication
Denormalization
ORM + Rich domain model antipattern
HTTP caching
Reverse Proxy
CDN
CAP theorem
Consistent/Atomic data
Eventually Consistent data
Concurrency
Message-Passing Concurrency
Software Transactional Memory
Dataflow Concurrency
Shared-State Concurrency
Partitioning
Replication
Behavior
Compute Grids
Event-Driven Architecture
Messaging
Publish-Subscribe
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Store-Forward
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Actors
Fire-forget
Fire-Receive-Eventually
Enterprise Service Bus
Domain Events
Event Stream Processing
Event Sourcing
Command & Query Responsibility Segregation (CQRS)
Load-balancing
Round-robin allocation
Random allocation
Weighted allocation
Dynamic load balancing
Work-stealing
Work-donating
Queue-depth querying
Parallel Computing
SPMD pattern
Master/Worker pattern
Loop Parallelism pattern
Fork/Join pattern
MapReduce pattern

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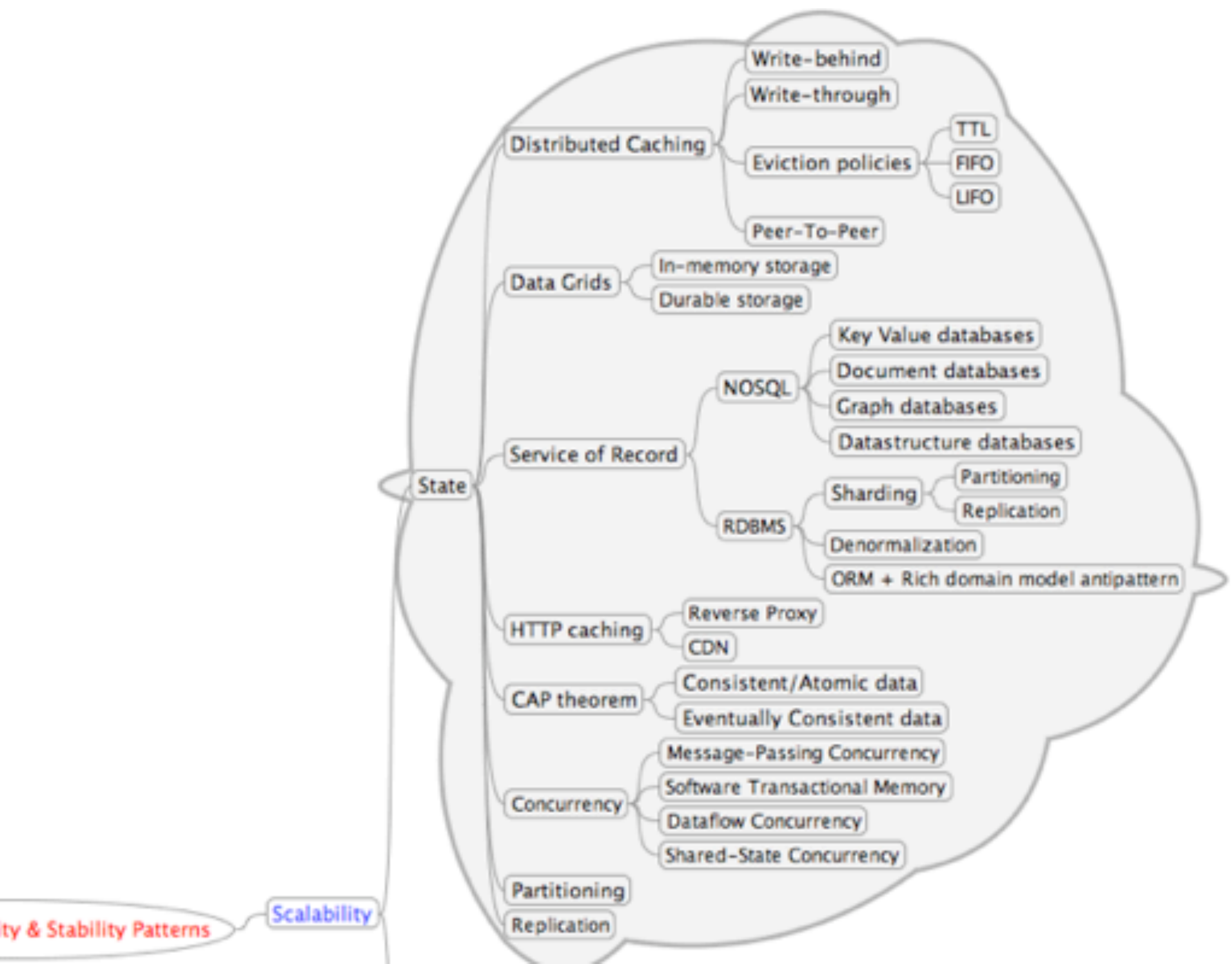

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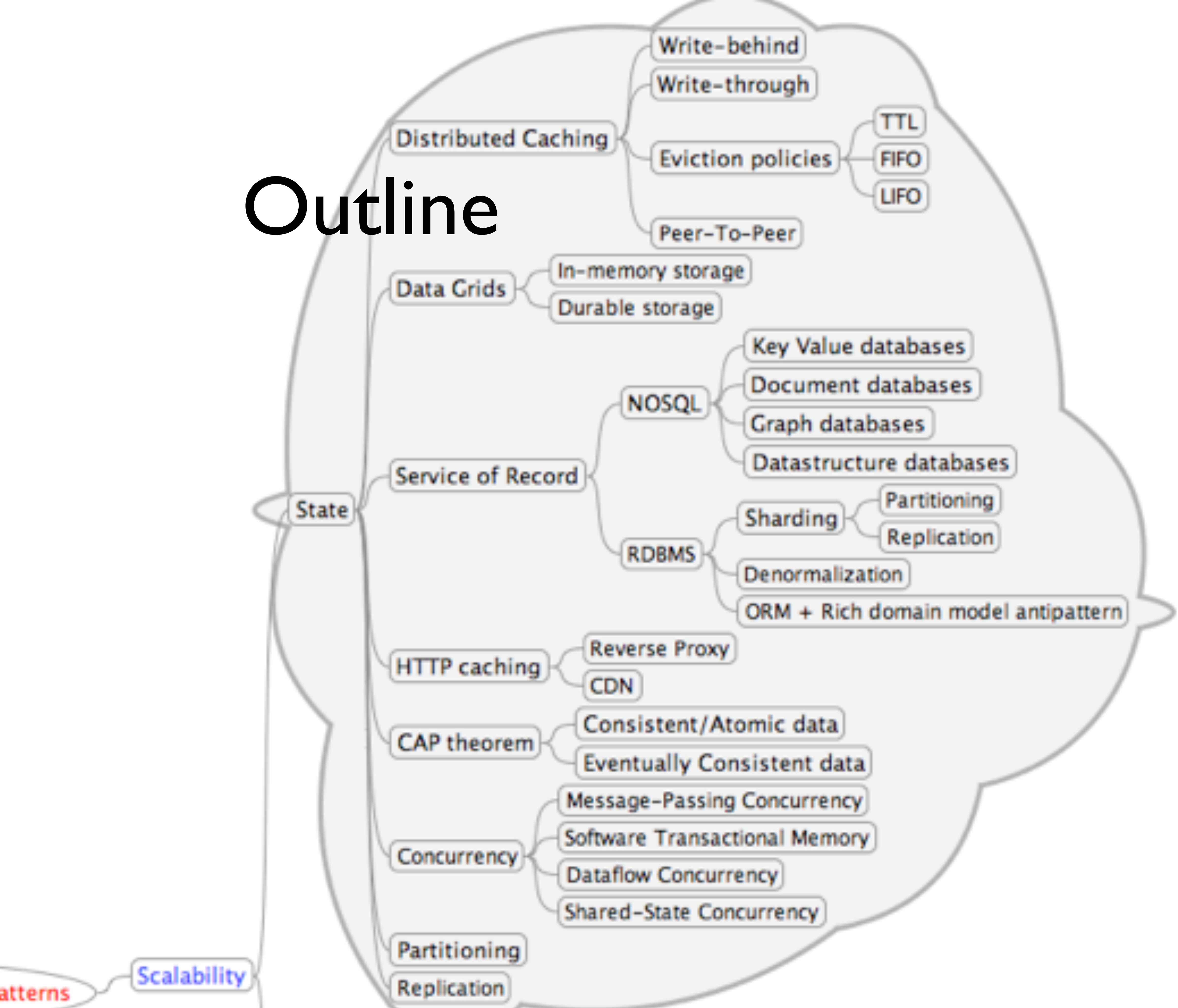
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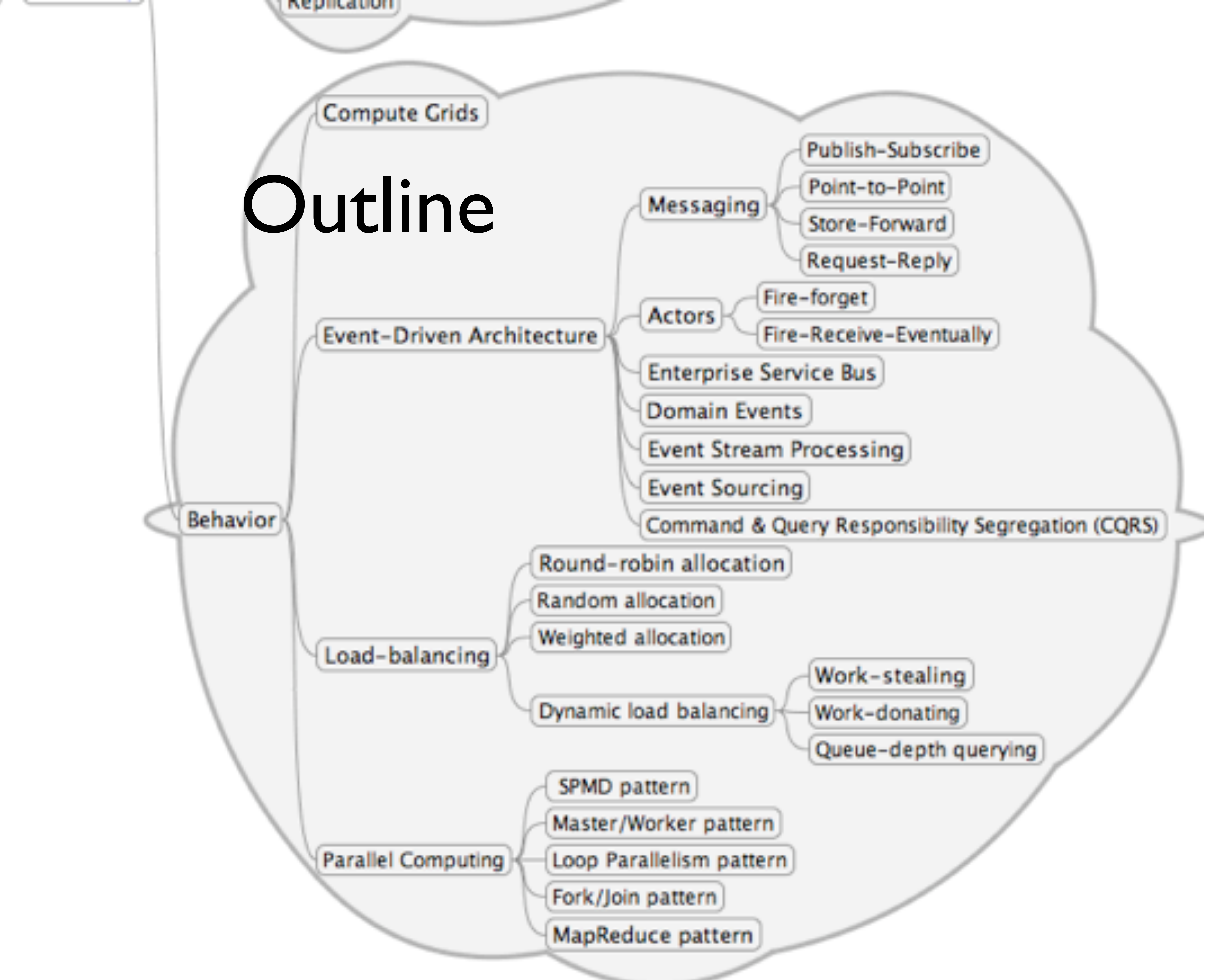

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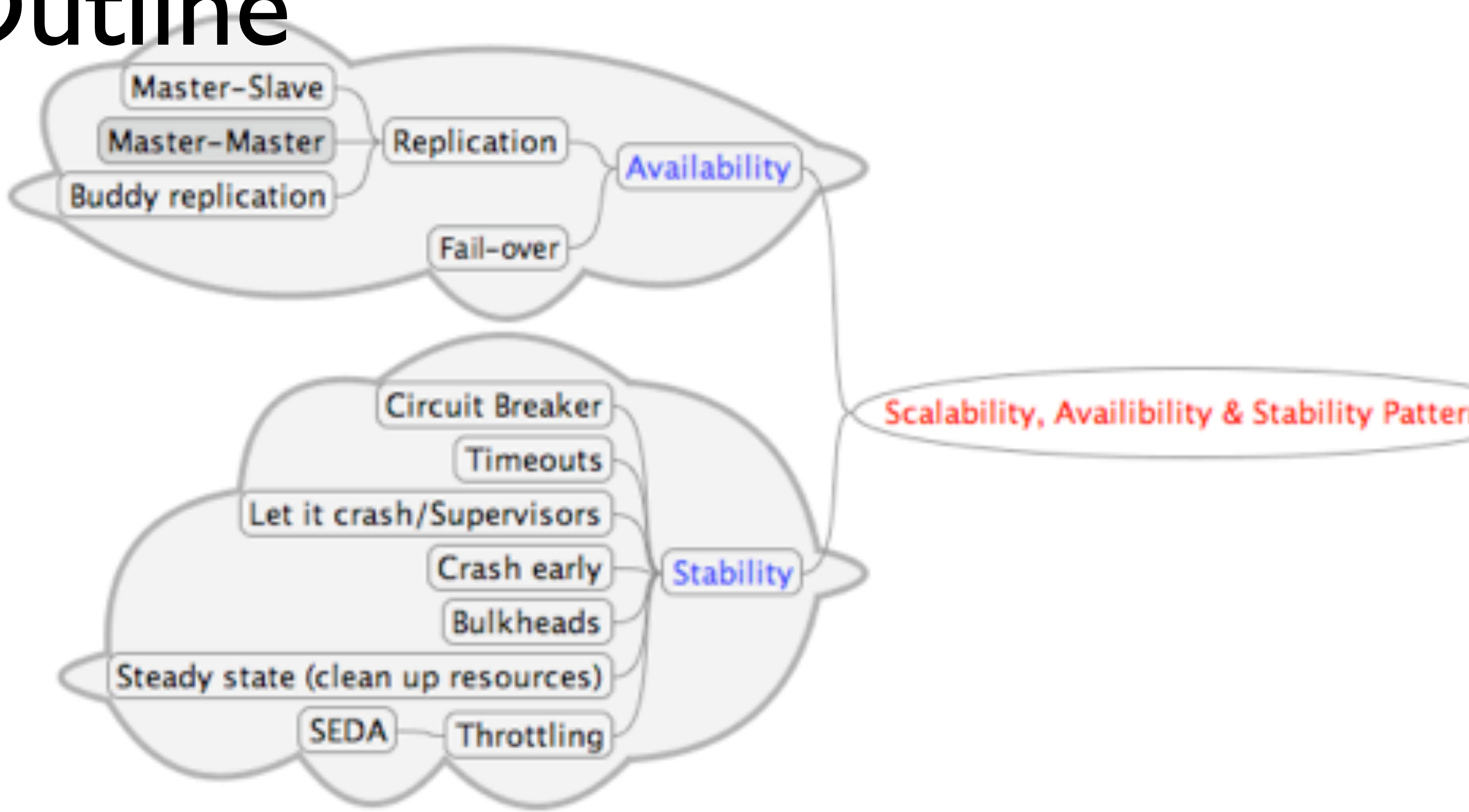

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Scalability, Availibility & Stability Patter

Introduction

Scalability Patterns

Managing Overload

Scale up vs Scale out?

General recommendations

- Immutability as the default
- Referential Transparency (FP)
- Laziness
- Think about your data:
  - Different data need different guarantees

Scalability Trade-offs


There is no
Free Lunch.

Trade-offs

- Performance vs Scalability
- Latency vs Throughput
- Availability vs Consistency

Performance

vs

Scalability

How do I know if I have a performance problem?

How do I know if I have a performance problem?

If your system is
slow for a single user

How do I know if I have a scalability problem?

How do I know if I have a scalability problem?

If your system is
fast for a single user
but slow under heavy load

Latency
vs
Throughput

You should strive for

maximal throughput

with

acceptable latency

Availability

vs

Consistency

Brewer's

CAP

theorem

You can only pick 2

Consistency

Availability

Partition tolerance

At a given point in time

Centralized system

- In a centralized system (RDBMS etc.) we don't have network partitions, e.g. P in CAP
- So you get both:
  - Availability
  - Consistency

Atomic

Consistent

Isolated

Durable

Distributed system

- In a distributed system we (will) have network partitions, e.g. P in CAP
- So you get to only pick one:
  - Availability
  - Consistency

CAP in practice:

- ...there are only two types of systems:
    1. CP
    2. AP
- ...there is only one choice to make. In case of a network partition, what do you sacrifice?
    1. C: Consistency
    2. A: Availability

Basically **A**vailable

Soft state

Eventually consistent

Eventual Consistency

...is an interesting trade-off

Eventual Consistency

...is an interesting trade-off

But let's get back to that later

Availability Patterns

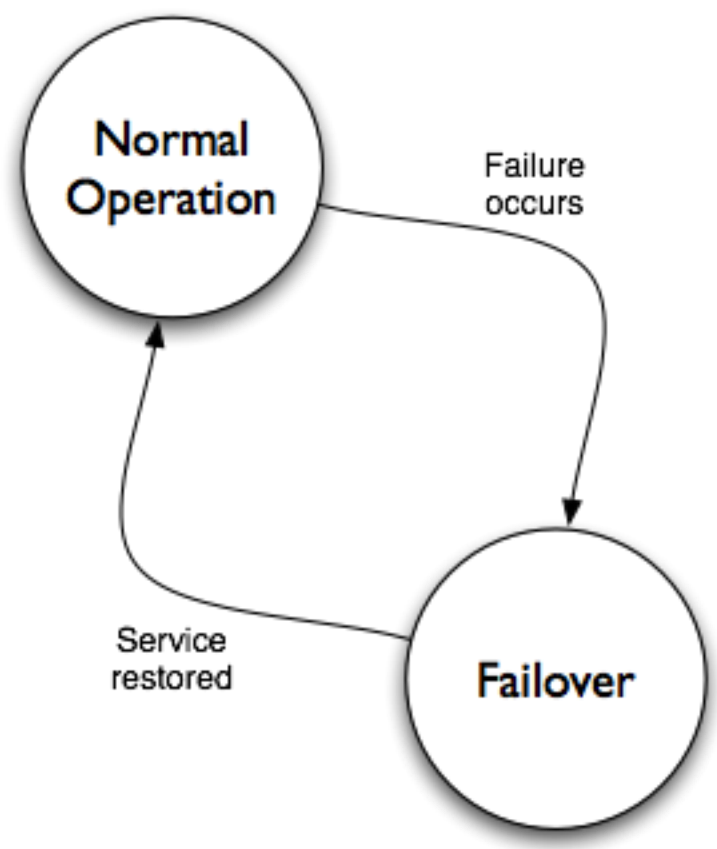
Availability Patterns

- Fail-over
- Replication
  - Master-Slave
  - Tree replication
  - Master-Master
  - Buddy Replication

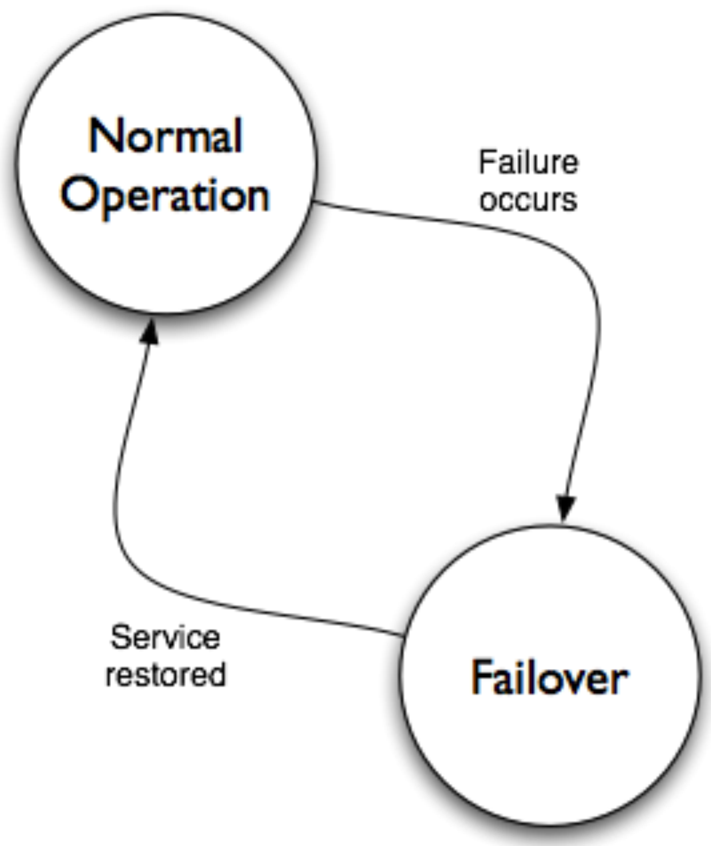
What do we mean with Availability?

Fail-over

Fail-over

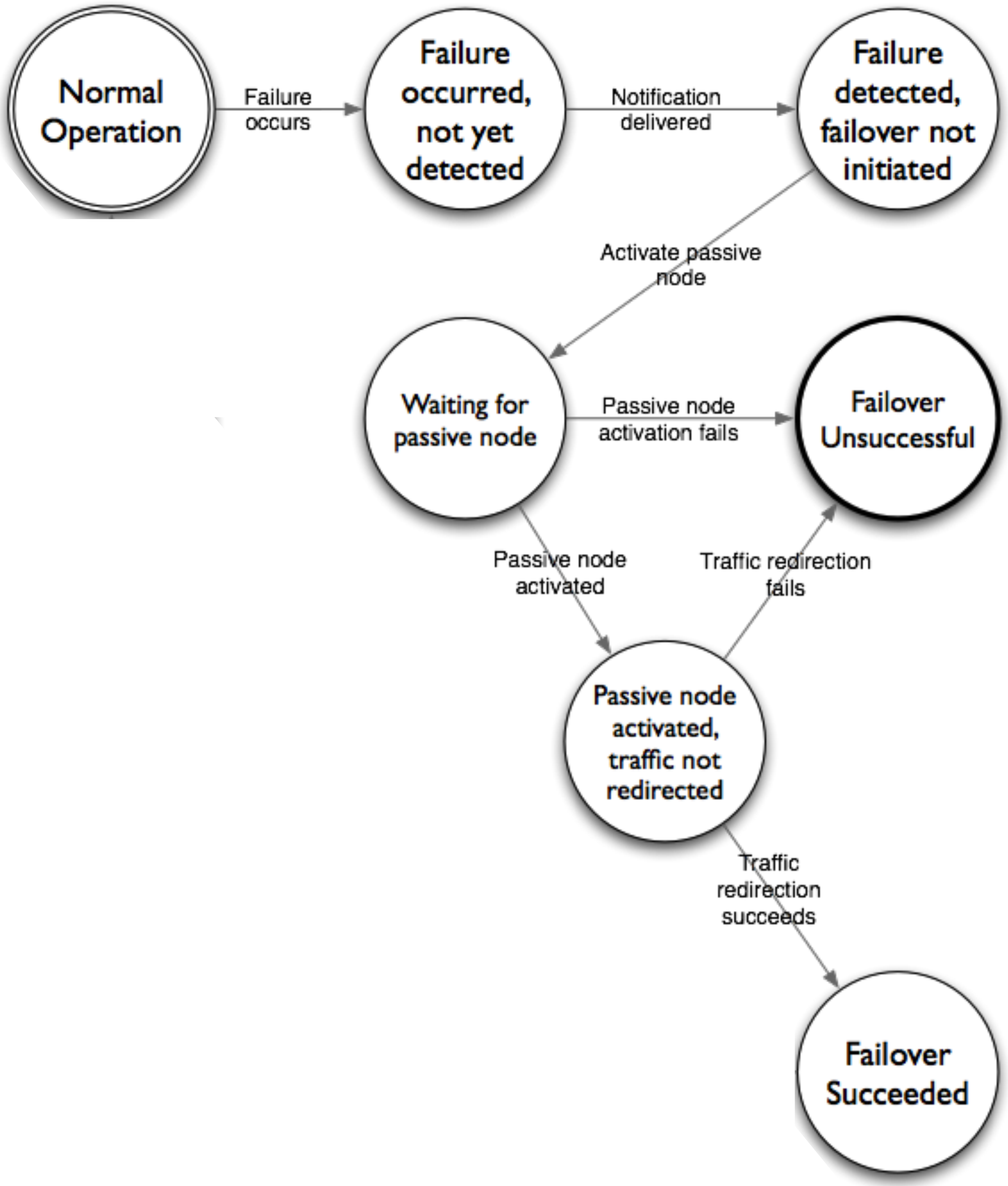

Normal Operation
Failure occurs
Failover
Service restored

Fail-over



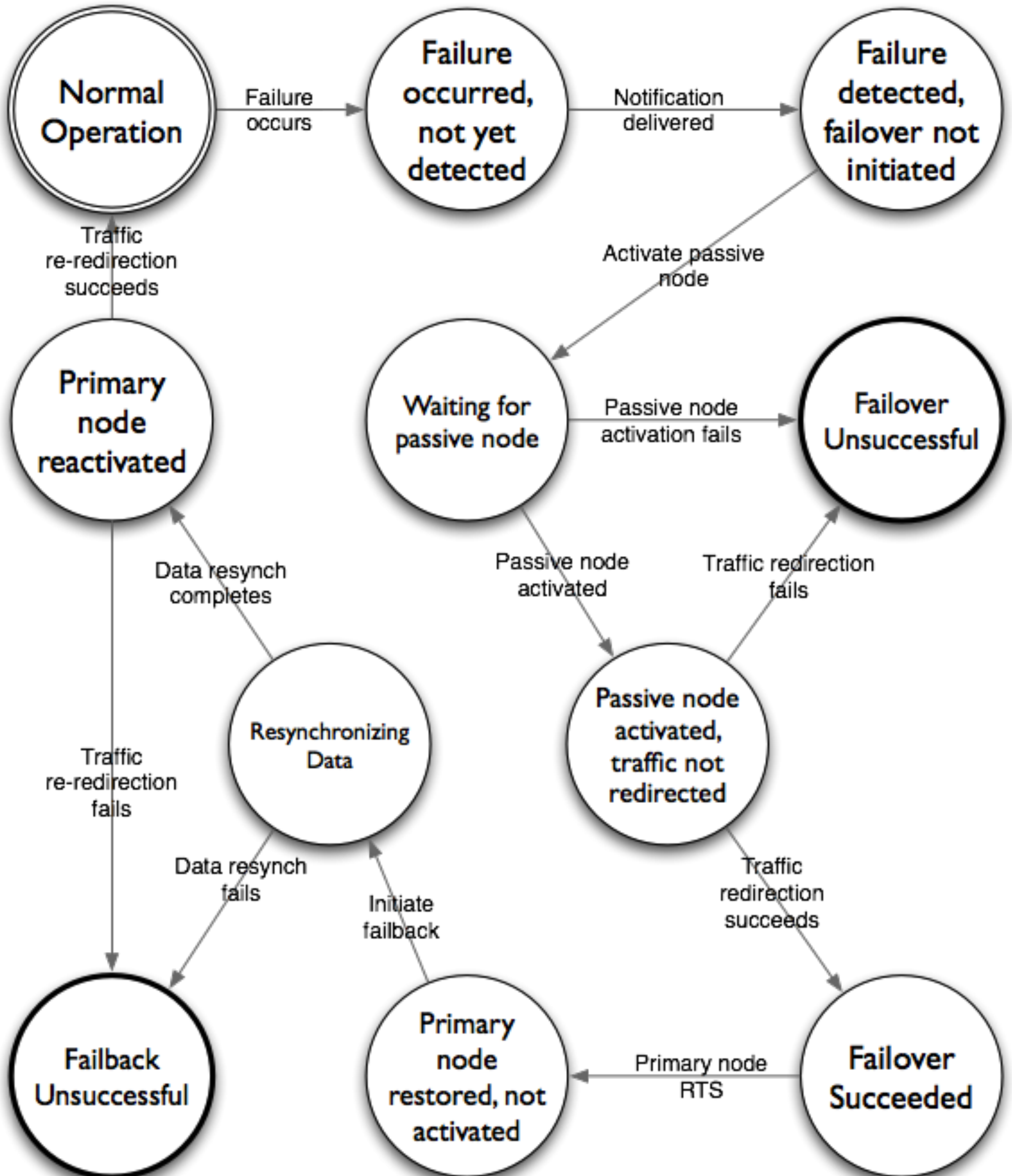
But fail-over is not always this simple

Fail-over



Normal Operation
Failure occurs
Failure occurred, not yet detected
Notification delivered
Failure detected, failover not initiated
Activate passive node
Waiting for passive node
Passive node activation fails
Failover Unsuccessful
Passive node activated
Traffic redirection fails
Passive node activated, traffic not redirected
Traffic redirection succeeds
Failover Succeeded

Fail-back



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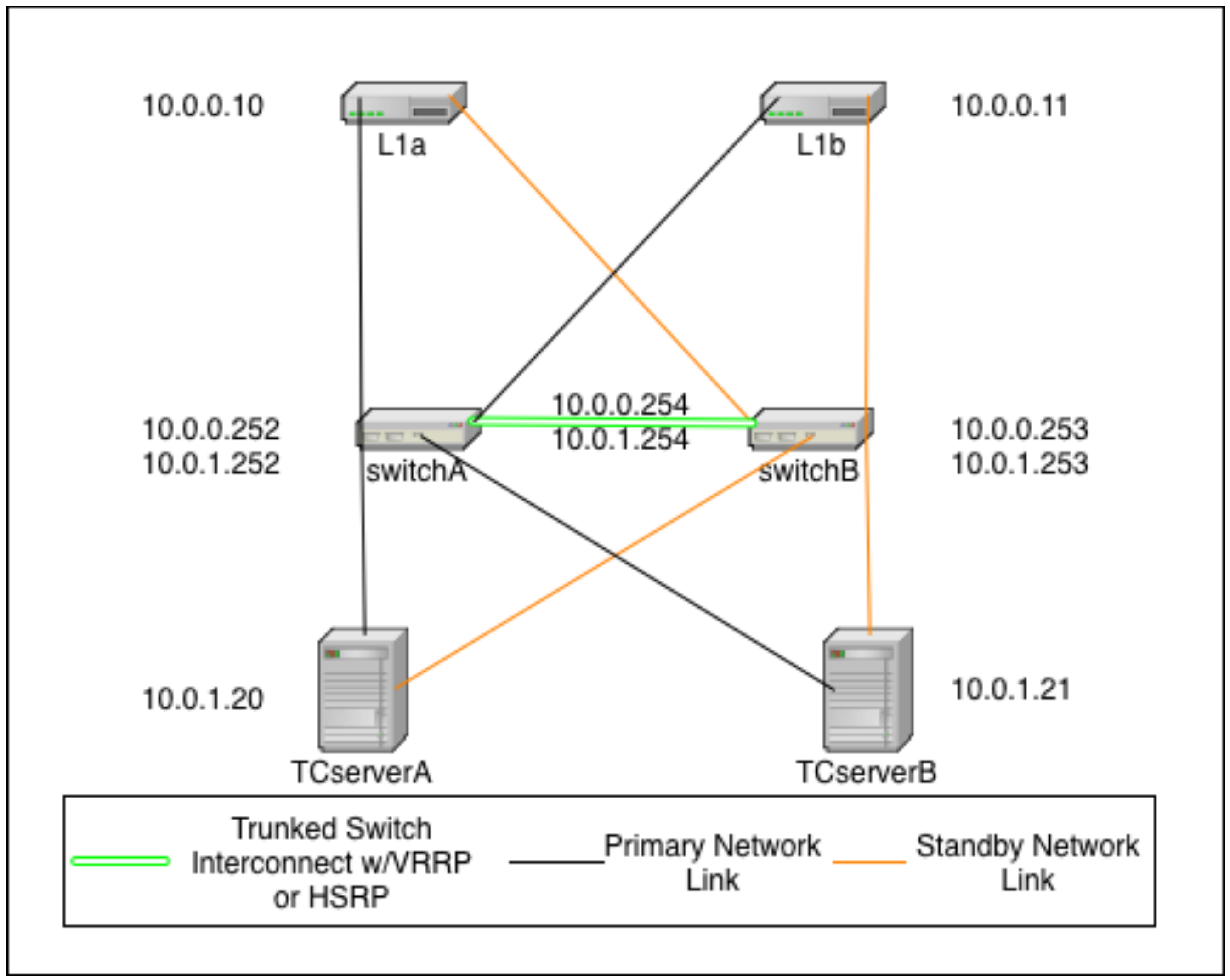
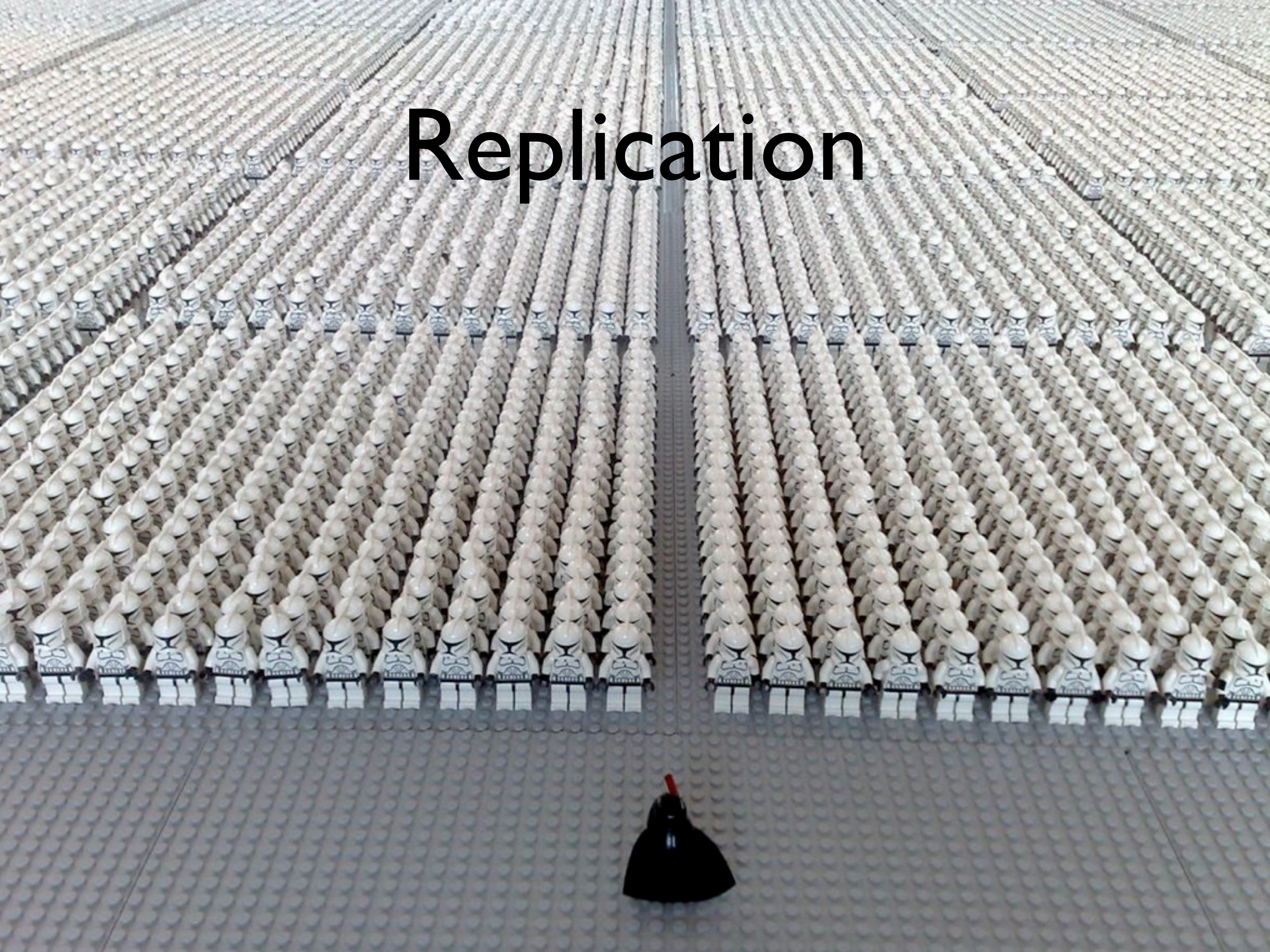
Passive node activated, traffic not redirected
Traffic redirection succeeds
Failover Succeeded
Primary node RTS
Primary node restored, not activated
Initiate failback
Resynchronizing Data
Data resynch completes
Data resynch fails
Primary node reactivated
Traffic re-redirection succeeds
Traffic re-redirection fails
Failback Unsuccessful

Network fail-over



Replication



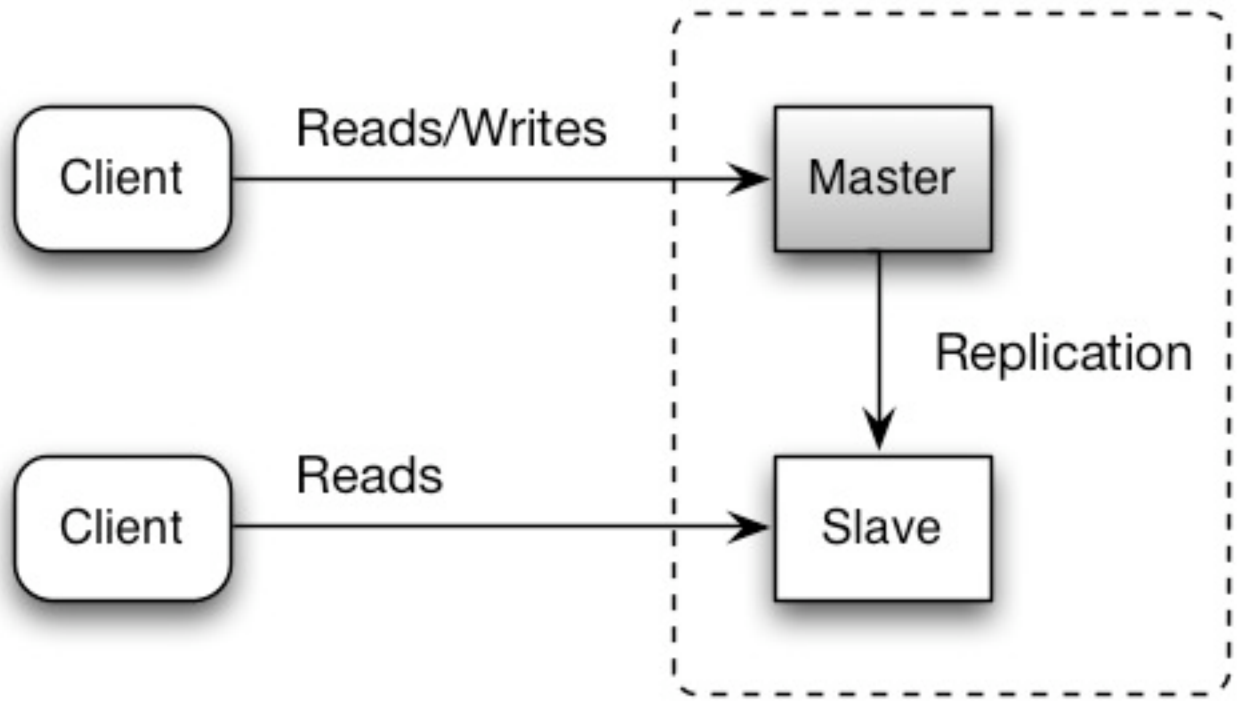
Replication

- Active replication - Push
- Passive replication - Pull
  - Data not available, read from peer, then store it locally
  - Works well with timeout-based caches

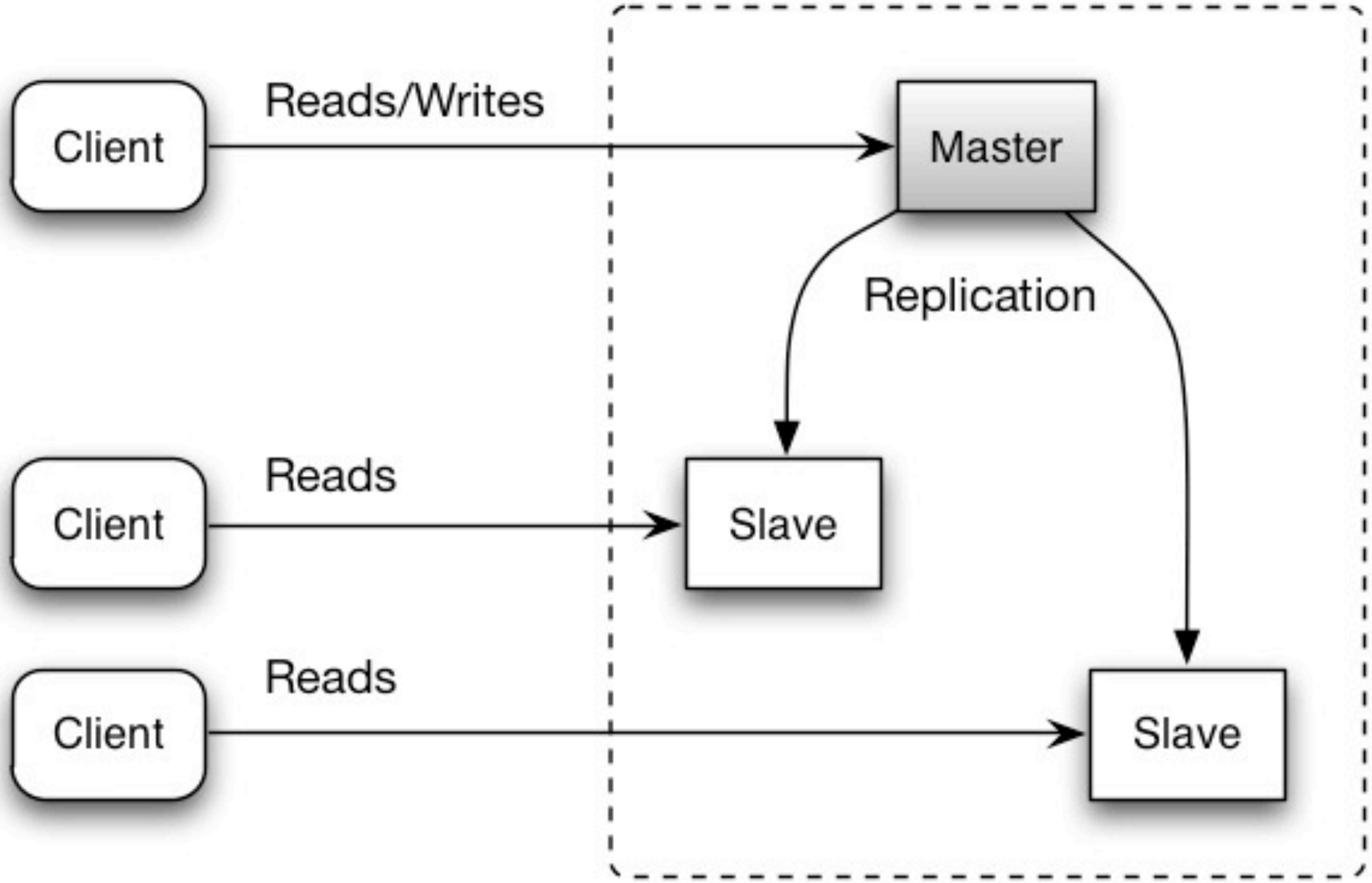
Replication

- Master-Slave replication
- Tree Replication
- Master-Master replication
- Buddy replication

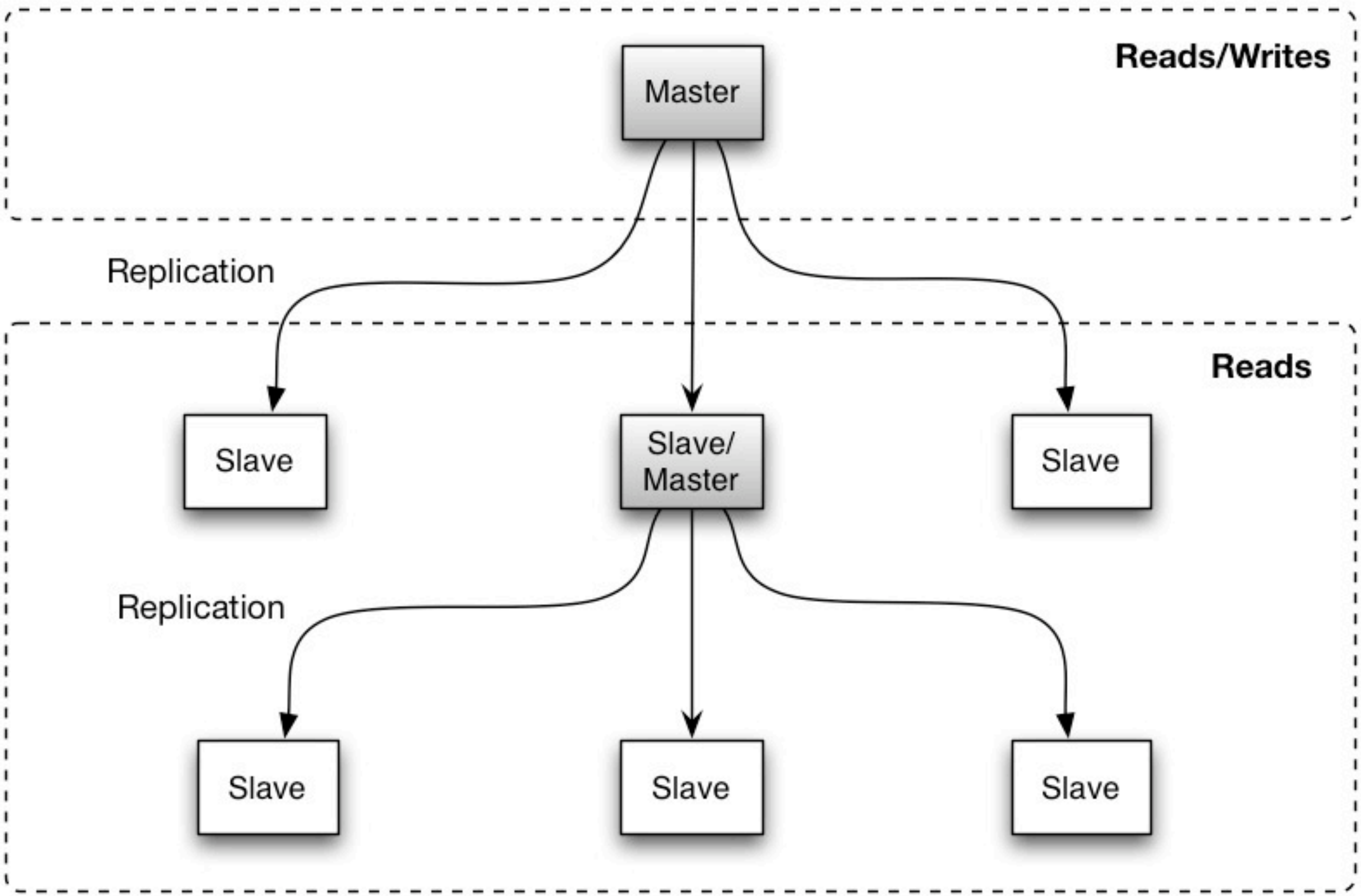
Master-Slave Replication



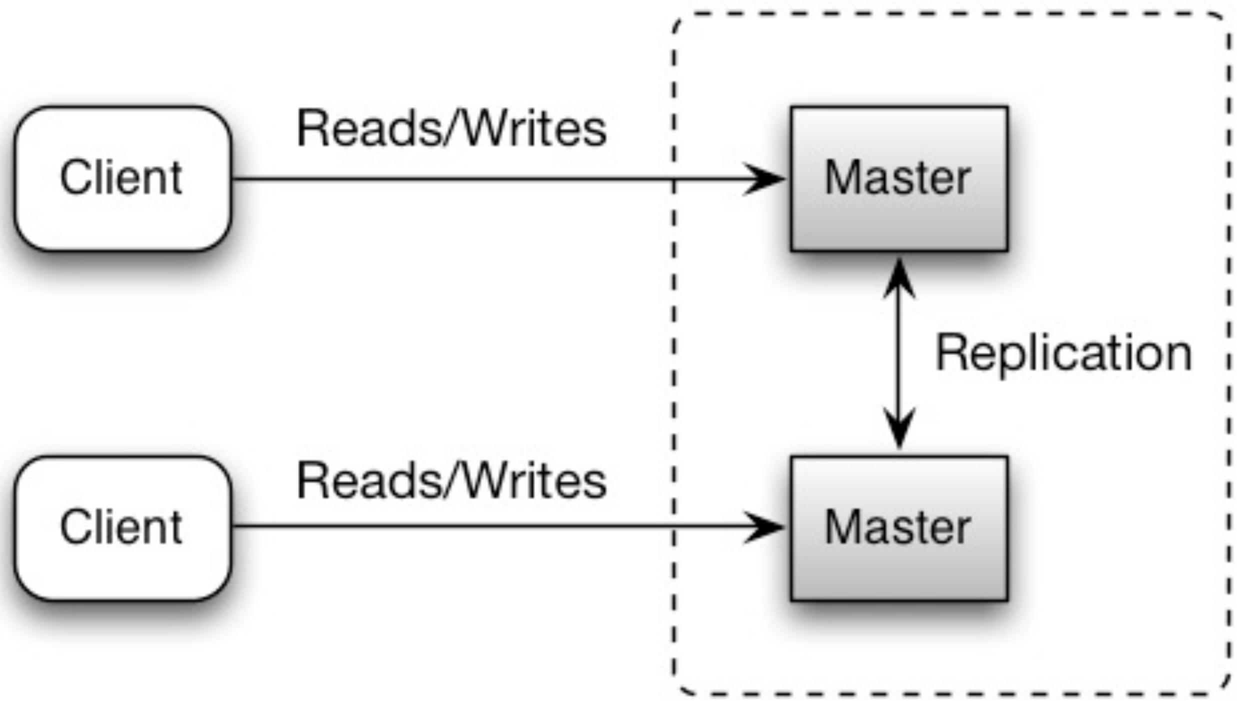
Master-Slave Replication



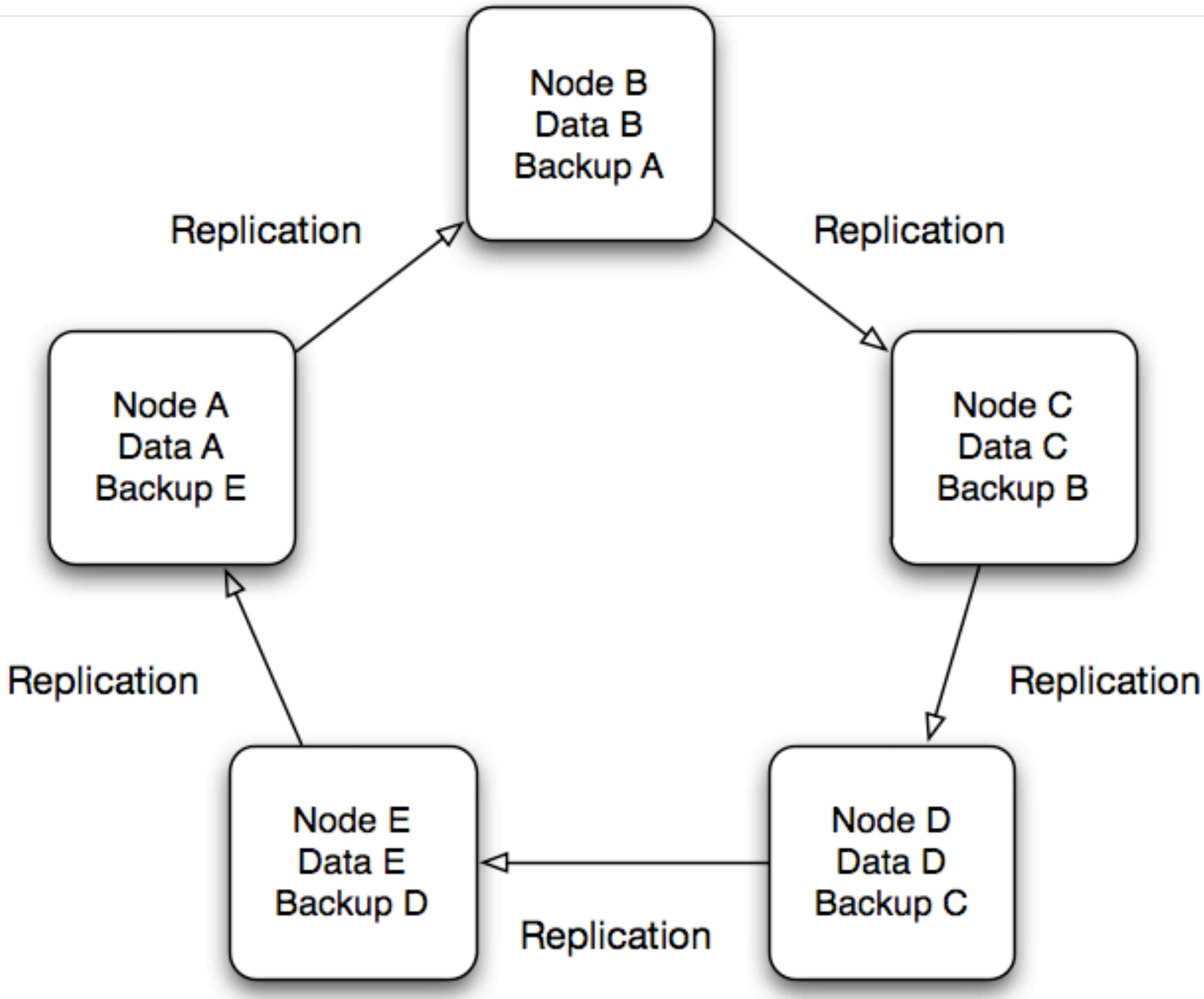
Tree Replication



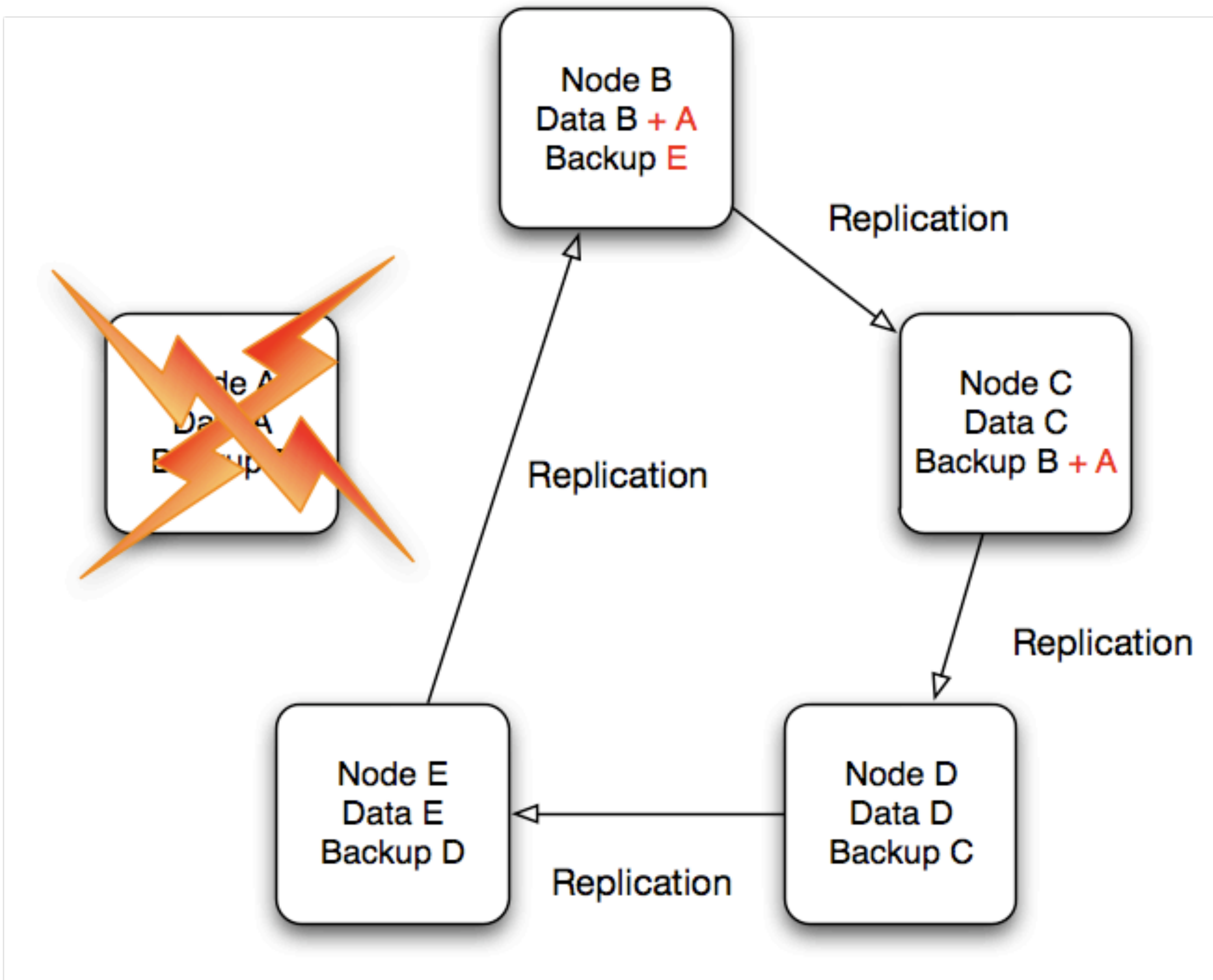
Master-Master Replication



Buddy Replication



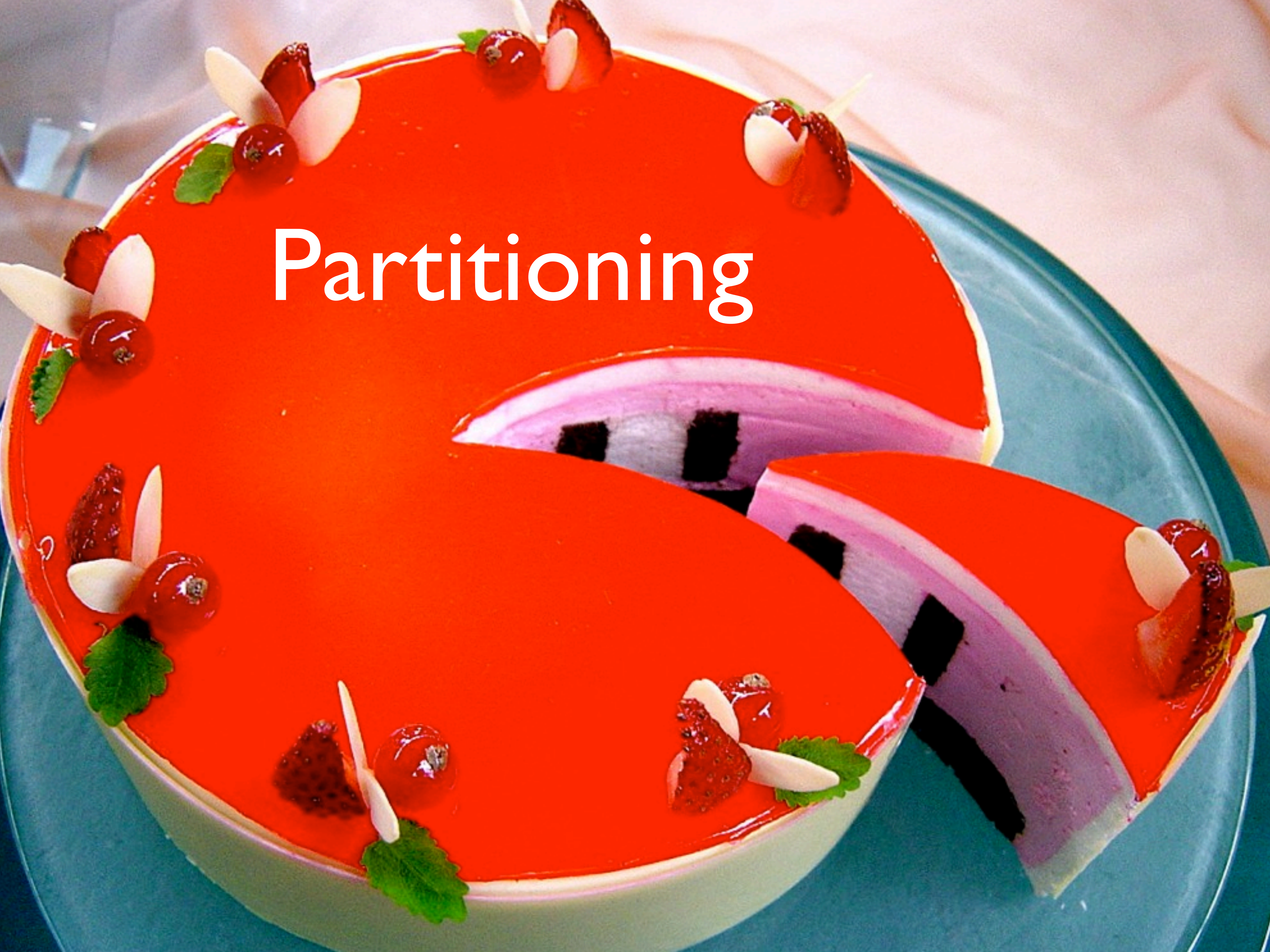
Buddy Replication



Scalability Patterns:
State

Scalability Patterns: State

- Partitioning
- HTTP Caching
- RDBMS Sharding
- NOSQL
- Distributed Caching
- Data Grids
- Concurrency


Partitioning

HTTP Caching

Reverse Proxy

- Varnish
- Squid
- rack-cache
- Pound
- Nginx
- Apache mod_proxy
- Traffic Server

HTTP Caching

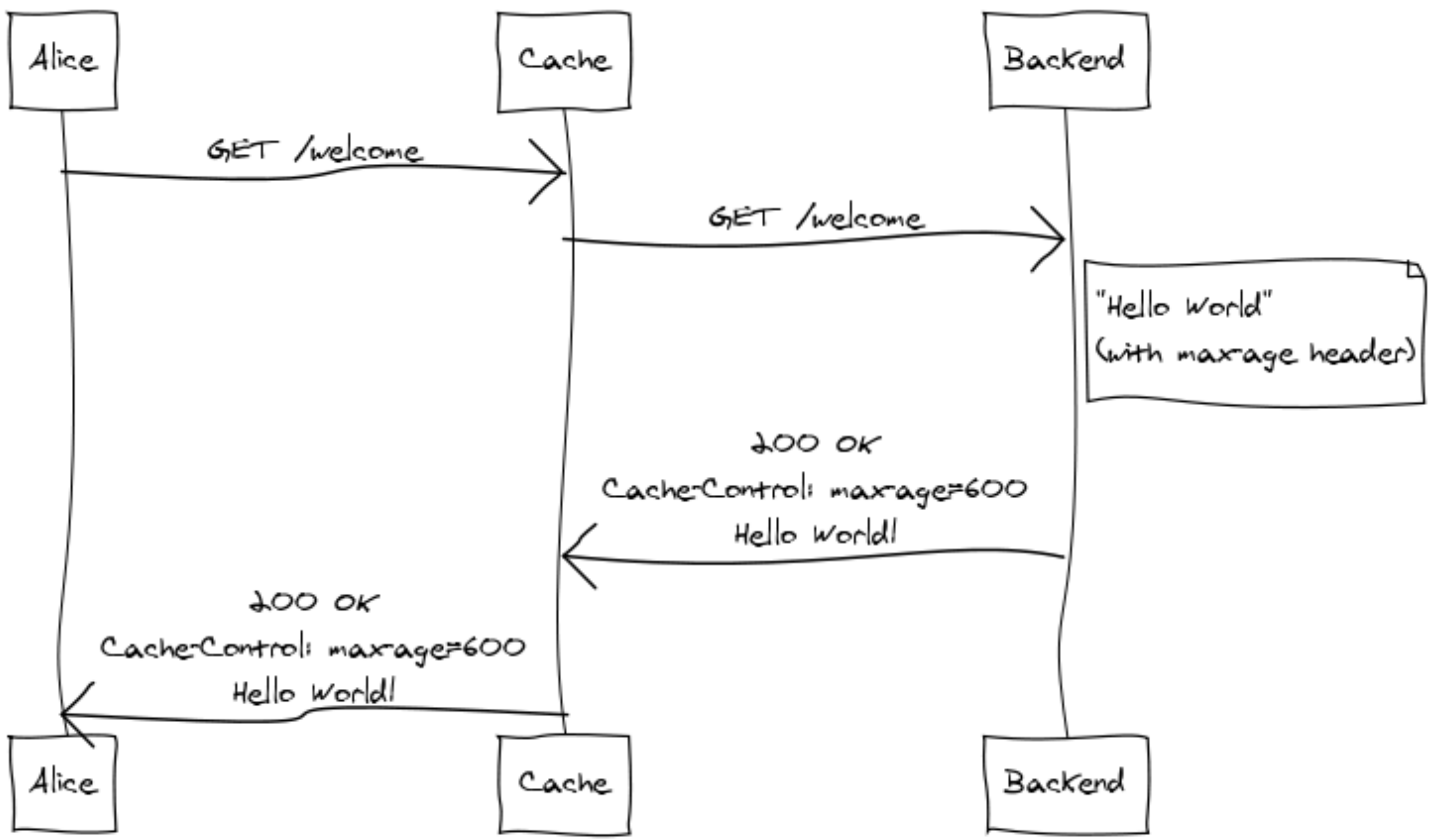
CDN, Akamai

Generate Static Content

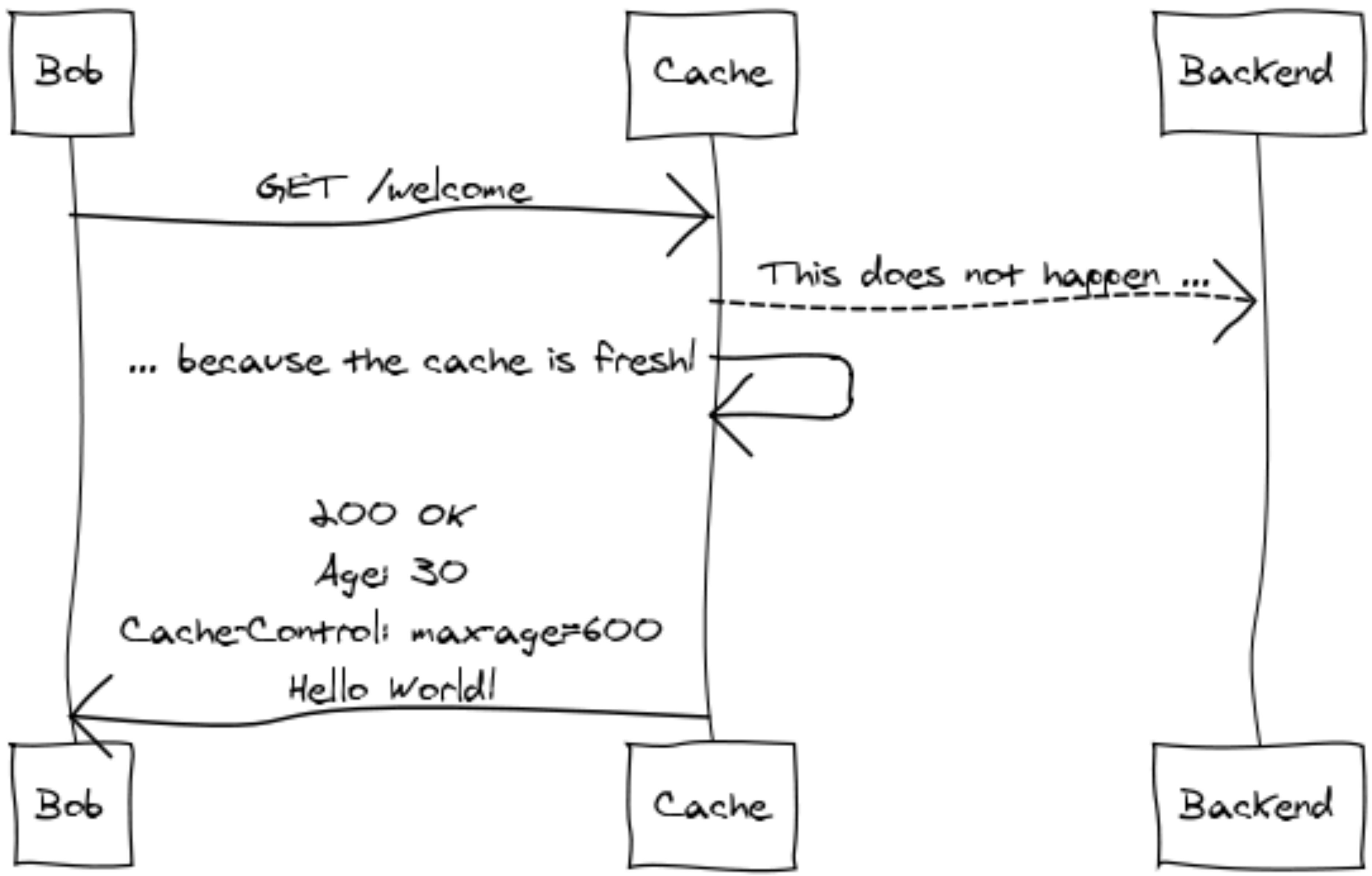
Precompute content

- Homegrown + cron or Quartz
- Spring Batch
- Gearman
- Hadoop
- Google Data Protocol
- Amazon Elastic MapReduce

HTTP Caching
First request



HTTP Caching
Subsequent request



Service of Record

SoR

Service of Record

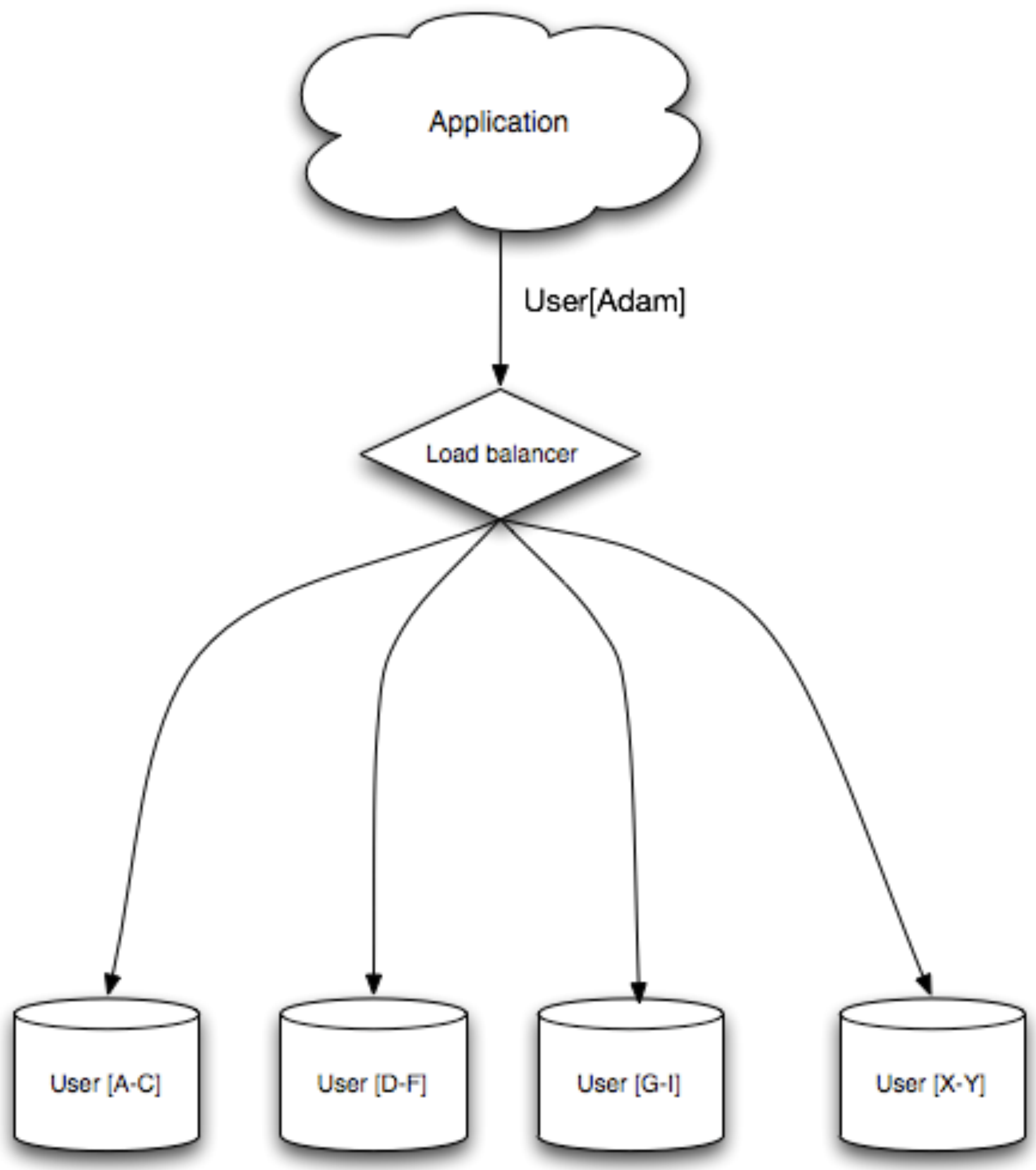
- Relational Databases (RDBMS)
- NOSQL Databases

How to scale out RDBMS?

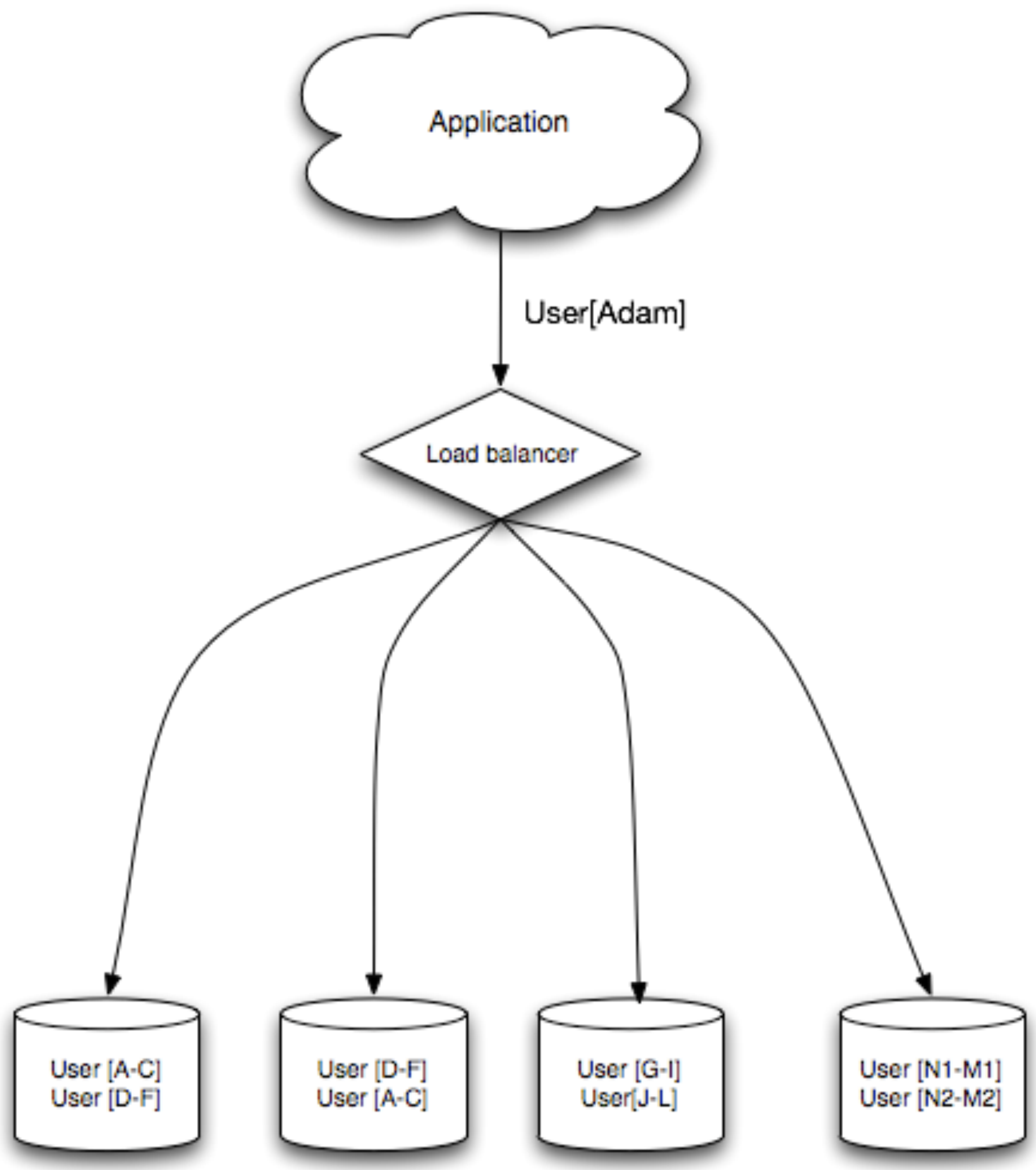
Sharding

- Partitioning
- Replication

Sharding: Partitioning



Sharding: Replication



ORM + rich domain model anti-pattern

- Attempt:
  - Read an object from DB
- Result:
  - You sit with your whole database in your lap

Think about your data

Think again

- When do you need ACID?
- When is Eventually Consistent a better fit?
- Different kinds of data has different needs

When is

a RDBMS

not

good enough?

Scaling reads
to a RDBMS
is hard

Scaling writes
to a RDBMS
is impossible

Do we really need a RDBMS?

Do we
really need
a RDBMS?

Sometimes...

Do we

really need

a RDBMS?

Do we
really need
a RDBMS?

But many times we don't

NOSQL
(Not Only SQL)

NOSQL

- Key-Value databases
- Column databases
- Document databases
- Graph databases
- Datastructure databases

Who's ACID?

- Relational DBs (MySQL, Oracle, Postgres)
- Object DBs (Gemstone, db4o)
- Clustering products (Coherence, Terracotta)
- Most caching products (ehcache)

Who's BASE?

Distributed databases

- Cassandra
- Riak
- Voldemort
- Dynomite,
- SimpleDB
- etc.

NOSQL in the wild

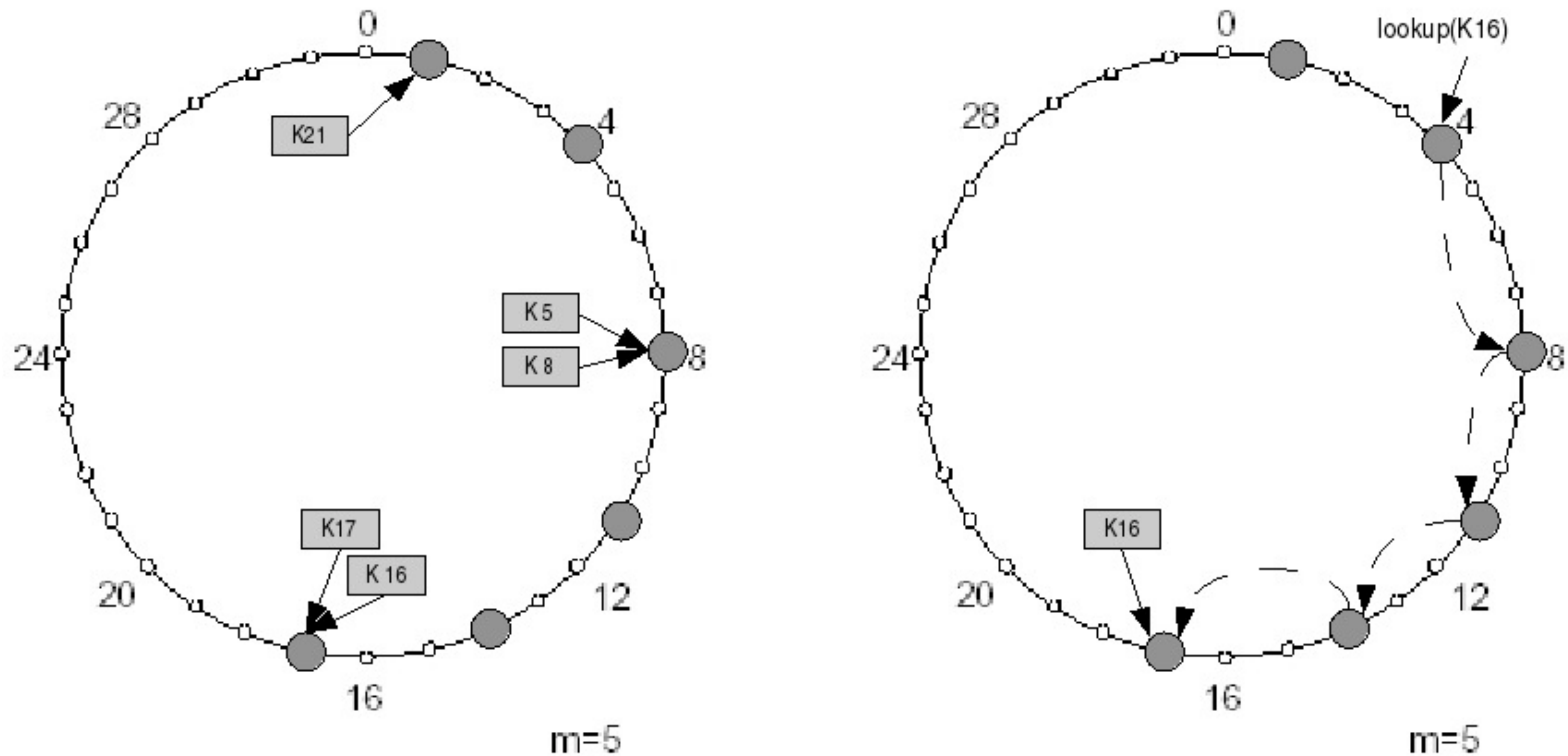
- Google: Bigtable
- Amazon: Dynamo
- Amazon: SimpleDB
- Yahoo: HBase
- Facebook: Cassandra
- LinkedIn: Voldemort

But first some background...

Chord & Pastry

- Distributed Hash Tables (DHT)
- Scalable
- Partitioned
- Fault-tolerant
- Decentralized
- Peer to peer
- Popularized
    - Node ring
    - Consistent Hashing

Node ring with Consistent Hashing



Find data in log(N) jumps

Bigtable

"How can we build a DB on top of Google File System?"

- Paper: Bigtable: A distributed storage system for structured data, 2006
- Rich data-model, structured storage
- Clones:

  HBase

  Hypertable

  Neptune

Dynamo

"How can we build a distributed hash table for the data center?"

- Paper: Dynamo: Amazon's highly available key-value store, 2007
- Focus: partitioning, replication and availability
- Eventually Consistent
- Clones:

  Voldemort

  Dynomite

Types of NOSQL stores

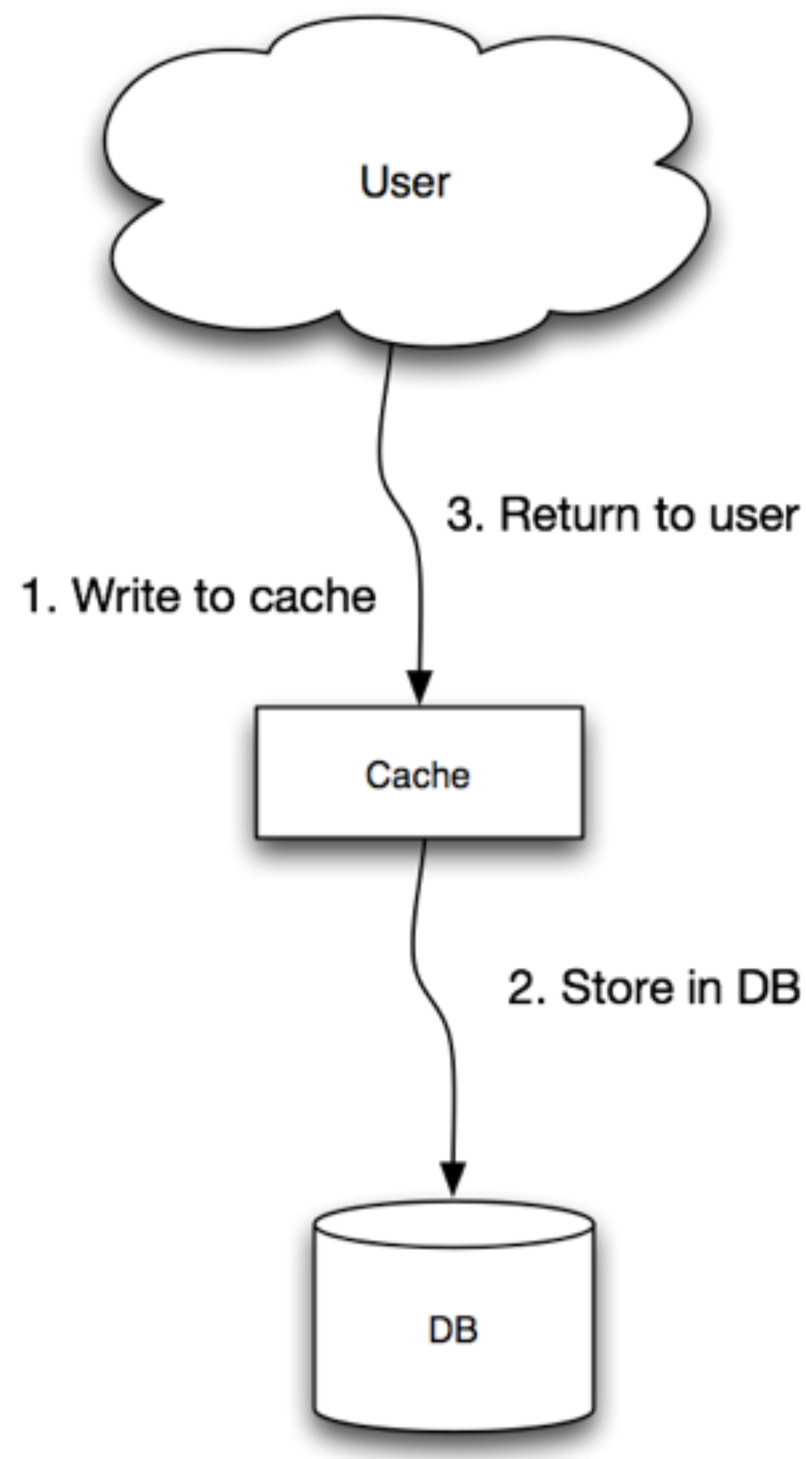
- Key-Value databases (Voldemort, Dynomite)
- Column databases (Cassandra, Vertica, Sybase IQ)
- Document databases (MongoDB, CouchDB)
- Graph databases (Neo4J, AllegroGraph)
- Datastructure databases (Redis, Hazelcast)

Distributed Caching

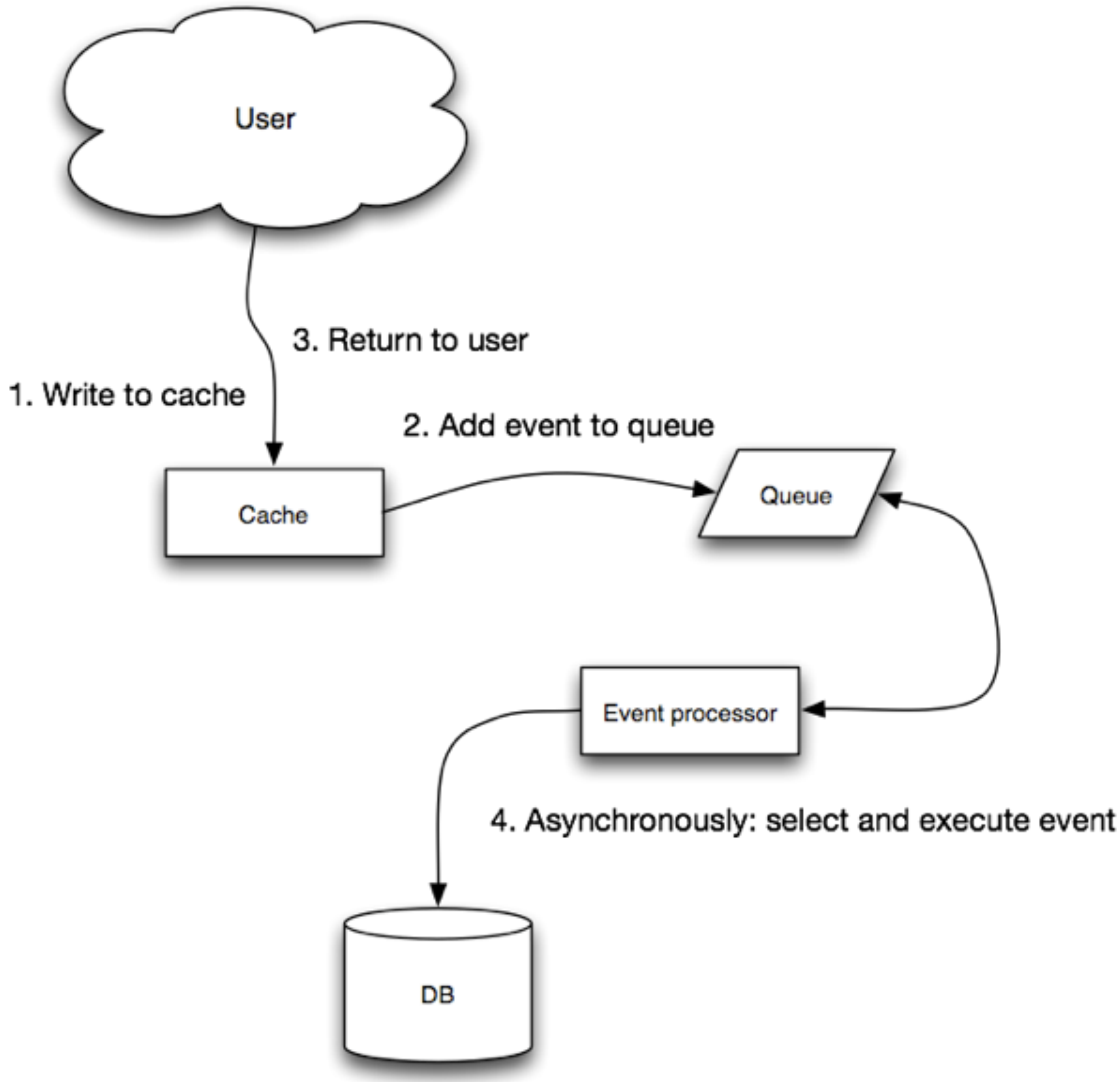
Distributed Caching

- Write-through
- Write-behind
- Eviction Policies
- Replication
- Peer-To-Peer (P2P)

Write-through



Write-behind



Eviction policies

- TTL (time to live)
- Bounded FIFO (first in first out)
- Bounded LIFO (last in first out)
- Explicit cache invalidation

Peer-To-Peer

- Decentralized
- No “special” or “blessed” nodes
- Nodes can join and leave as they please

Distributed Caching

Products

- EHCache
- JBoss Cache
- OSCache
- memcached

memcached

- Very fast
- Simple
- Key-Value (string -> binary)
- Clients for most languages
- Distributed
- Not replicated - so 1/N chance for local access in cluster

Data Grids / Clustering

Data Grids/Clustering

Parallel data storage

- Data replication
- Data partitioning
- Continuous availability
- Data invalidation
- Fail-over
- C + P in CAP

Data Grids/Clustering Products

- Coherence
- Terracotta
- GigaSpaces
- GemStone
- Tibco Active Matrix
- Hazelcast

Concurrency

Concurrency

- Shared-State Concurrency
- Message-Passing Concurrency
- Dataflow Concurrency
- Software Transactional Memory

Shared-State Concurrency

Shared-State Concurrency

- Everyone can access anything anytime
- Totally indeterministic
- Introduce determinism at well-defined places...
- ...using locks

Shared-State Concurrency

- Problems with locks:
  - Locks do not compose
  - Taking too few locks
  - Taking too many locks
  - Taking the wrong locks
  - Taking locks in the wrong order
  - Error recovery is hard

Shared-State Concurrency

Please use `java.util.concurrent.*`

- `ConcurrentHashMap`
- `BlockingQueue`
- `ConcurrentQueue`
- `ExecutorService`
- `ReentrantReadWriteLock`
- `CountDownLatch`
- `ParallelArray`
- `and much much more..`

Message-Passing Concurrency

Actors

- Originates in a 1973 paper by Carl Hewitt
- Implemented in Erlang, Occam, Oz
- Encapsulates state and behavior
- Closer to the definition of OO than classes

Actors

- Share NOTHING
- Isolated lightweight processes
- Communicates through messages
- Asynchronous and non-blocking
- No shared state

  … hence, nothing to synchronize.
- Each actor has a mailbox (message queue)

Actors

- Easier to reason about
- Raised abstraction level
- Easier to avoid
  - Race conditions
  - Deadlocks
  - Starvation
  - Live locks

Actor libs for the JVM

- Akka (Java/Scala)
- scalaz actors (Scala)
- Lift Actors (Scala)
- Scala Actors (Scala)
- Kilim (Java)
- Jetlang (Java)
- Actor's Guild (Java)
- Actorom (Java)
- FunctionalJava (Java)
- GPars (Groovy)

Dataflow Concurrency

Dataflow Concurrency

- Declarative
- No observable non-determinism
- Data-driven – threads block until data is available
- On-demand, lazy
- No difference between:
  - Concurrent &
  - Sequential code
- Limitations: can't have side-effects

STM:

Software Transactional Memory

STM: overview

- See the memory (heap and stack) as a transactional dataset
- Similar to a database
  - begin
  - commit
  - abort/rollback
- Transactions are retried automatically upon collision
- Rolls back the memory on abort

STM: overview

- Transactions can nest
- Transactions compose (yipee!!)

```
atomic {
    ...
    atomic {
        ...
    }
}
```

STM: restrictions

All operations in scope of a transaction:

- Need to be idempotent

STM libs for the JVM

- Akka (Java/Scala)
- Multiverse (Java)
- Clojure STM (Clojure)
- CCSTM (Scala)
- Deuce STM (Java)

Scalability Patterns:
Behavior

Scalability Patterns: Behavior

- Event-Driven Architecture
- Compute Grids
- Load-balancing
- Parallel Computing

Event-Driven Architecture

"Four years from now, 'mere mortals' will begin to adopt an event-driven architecture (EDA) for the sort of complex event processing that has been attempted only by software gurus [until now]"

--Roy Schulte (Gartner), 2003

Event-Driven Architecture

- Domain Events
- Event Sourcing
- Command and Query Responsibility Segregation (CQRS) pattern
- Event Stream Processing
- Messaging
- Enterprise Service Bus
- Actors
- Enterprise Integration Architecture (EIA)

Domain Events

“It's really become clear to me in the last couple of years that we need a new building block and that is the Domain Events”

-- Eric Evans, 2009

Domain Events

“Domain Events represent the state of entities at a given time when an important event occurred and decouple subsystems with event streams. Domain Events give us clearer, more expressive models in those cases.”

-- Eric Evans, 2009

Domain Events

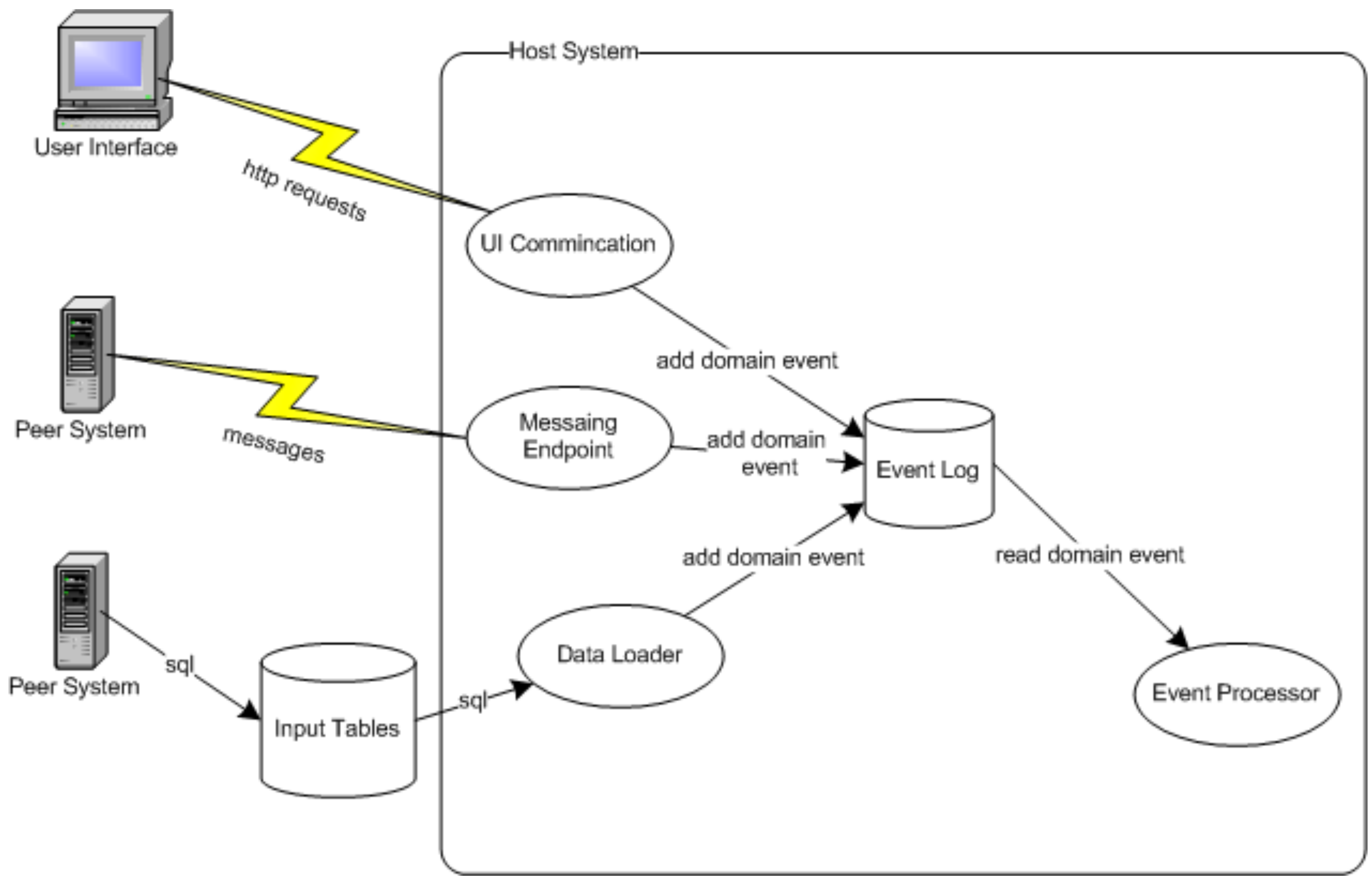
"State transitions are an important part of our problem space and should be modeled within our domain."

-- Greg Young, 2008

Event Sourcing

- Every state change is materialized in an Event
- All Events are sent to an EventProcessor
- EventProcessor stores all events in an Event Log
- System can be reset and Event Log replayed
- No need for ORM, just persist the Events
- Many different EventListeners can be added to EventProcessor (or listen directly on the Event log)

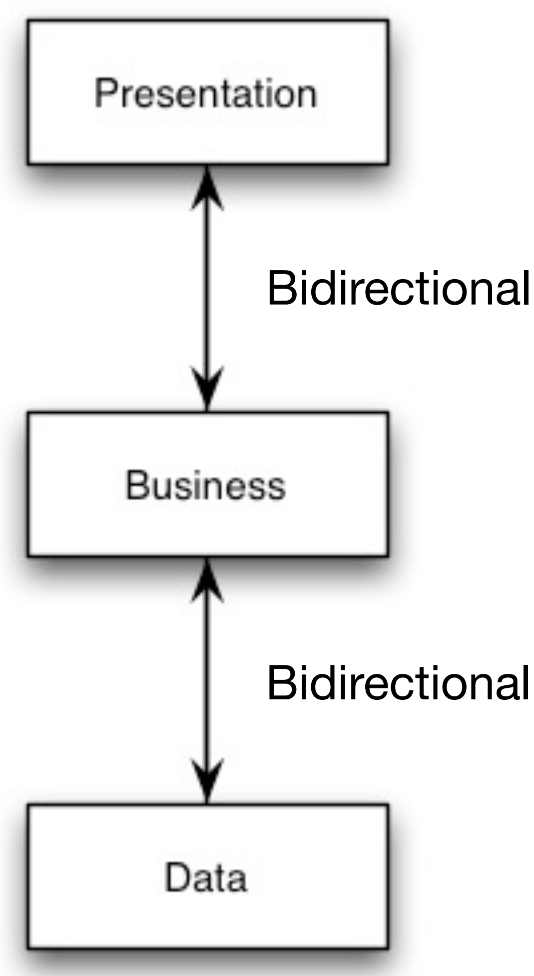
Event Sourcing

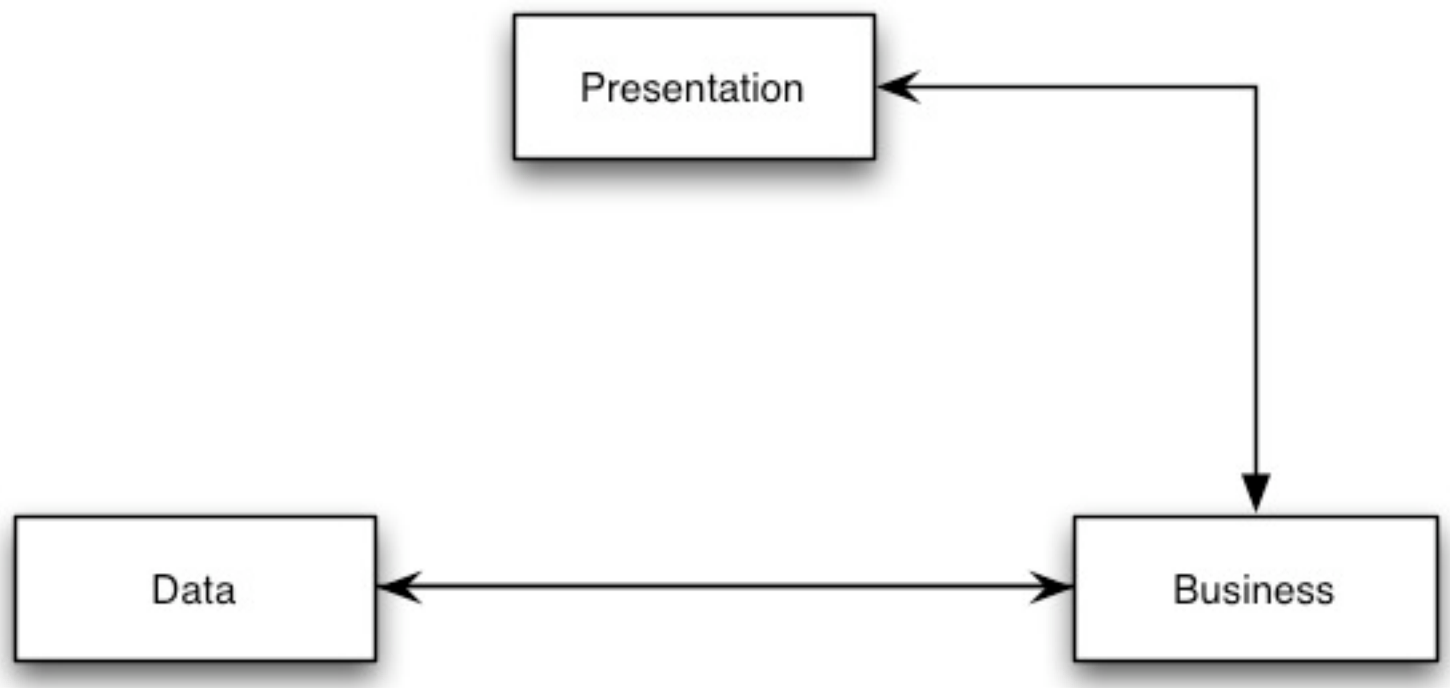


Command and Query Responsibility Segregation (CQRS) pattern

"A single model cannot be appropriate for reporting, searching and transactional behavior."

-- Greg Young, 2008


Presentation
Bidirectional
Business
Bidirectional
Data


Presentation
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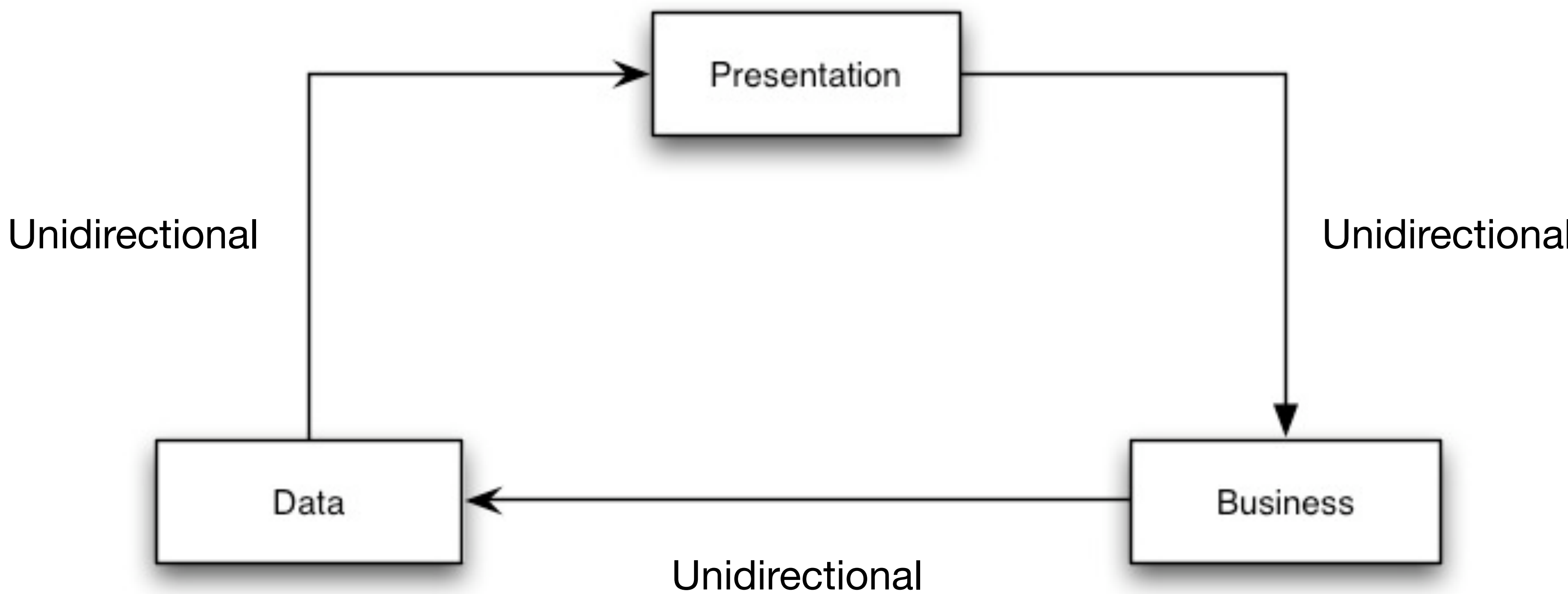
Presentation
Unidirectional
Unidirectional
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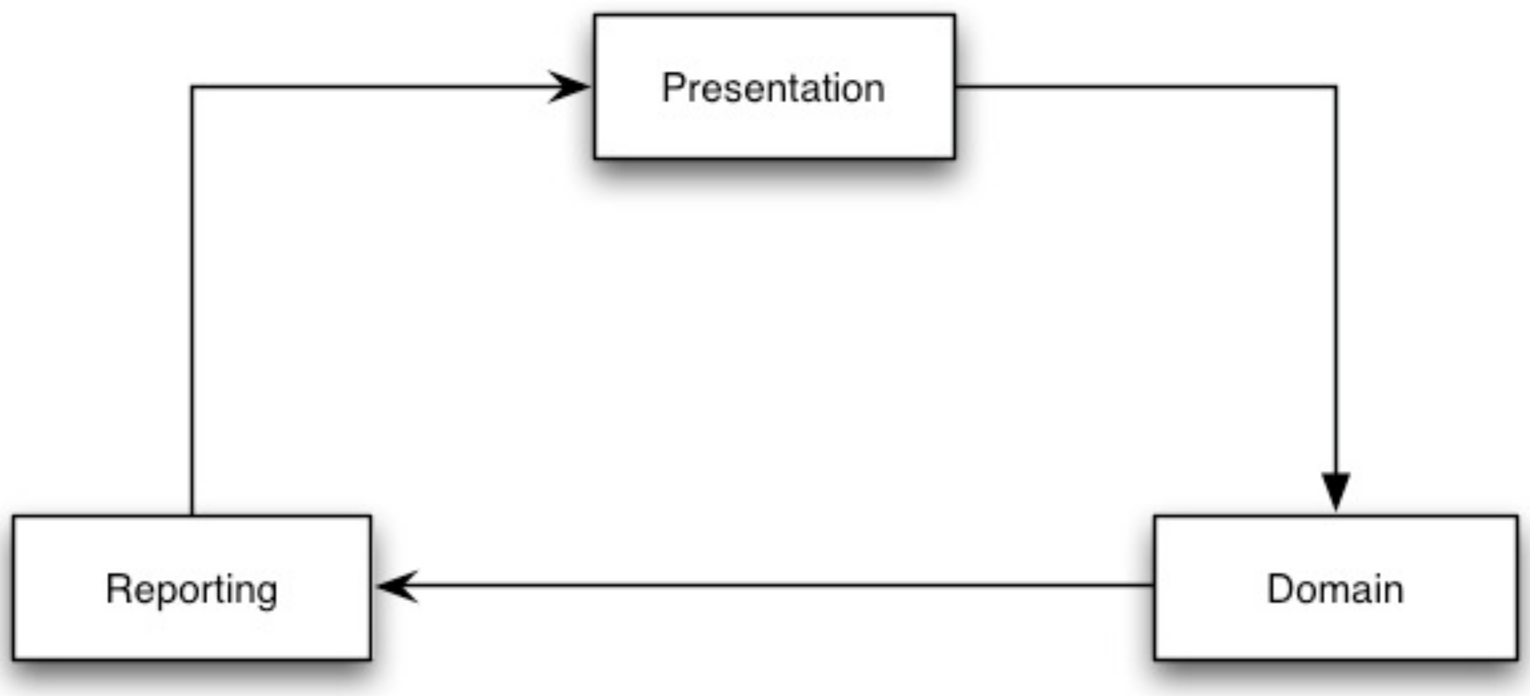
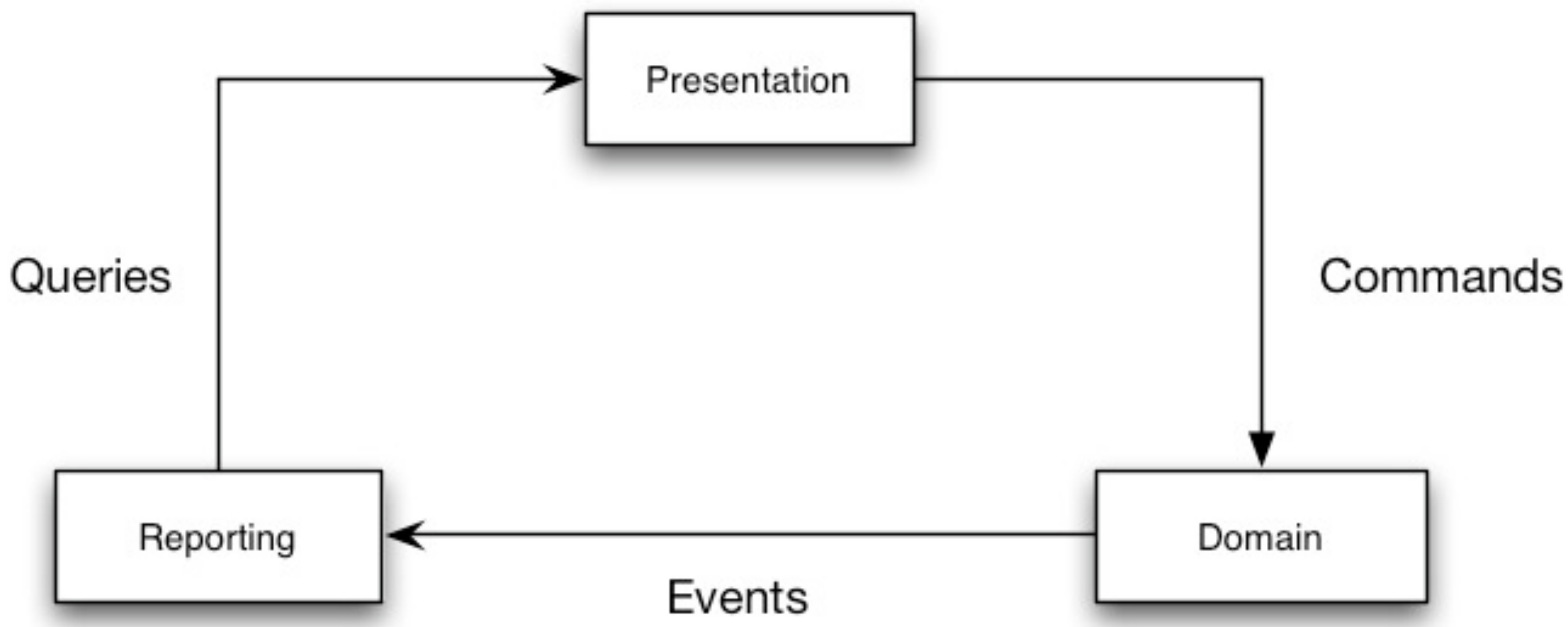
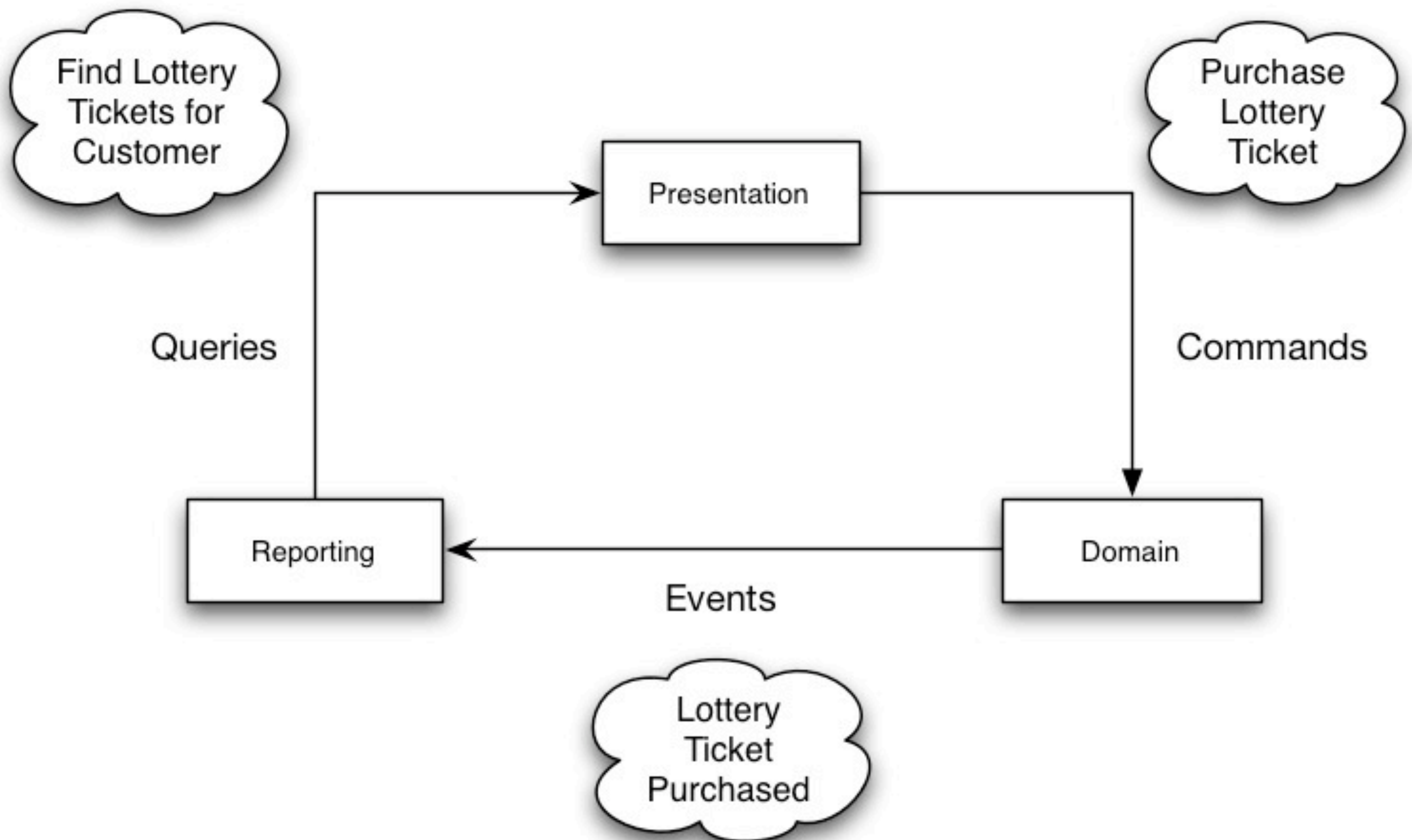
Business
Unidirectional


Presentation
Reporting
Domain

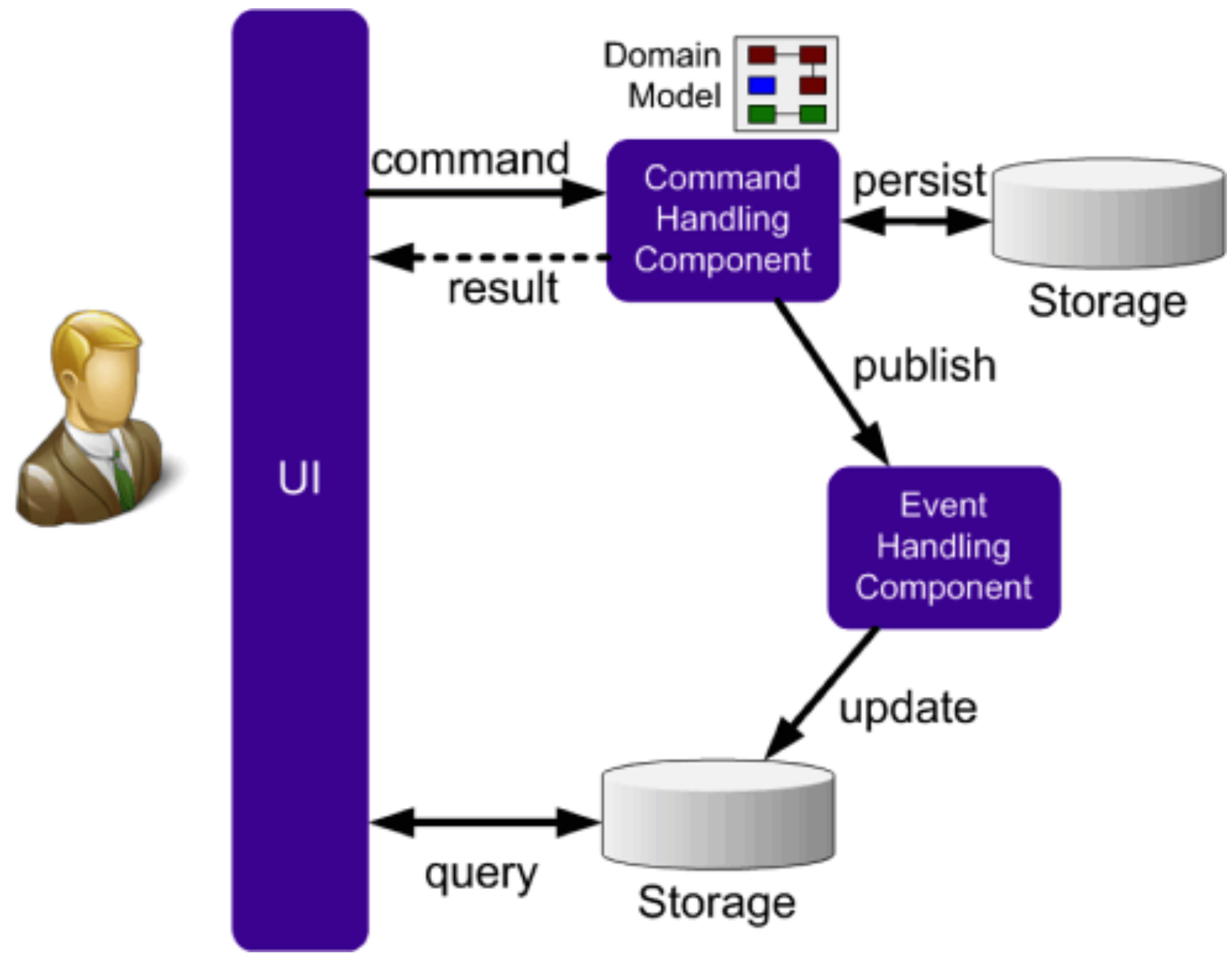

Presentation
Queries
Commands
Reporting
Domain
Events


Find Lottery Tickets for Customer
Purchase Lottery Ticket
Presentation
Queries
Commands
Reporting
Domain
Events
Lottery Ticket Purchased

CQRS
in a nutshell

- All state changes are represented by Domain Events
- Aggregate roots receive *Commands* and publish *Events*
- *Reporting* (query database) is updated as a result of the published *Events*
- All *Queries* from *Presentation* go directly to *Reporting* and the *Domain* is not involved

CQRS

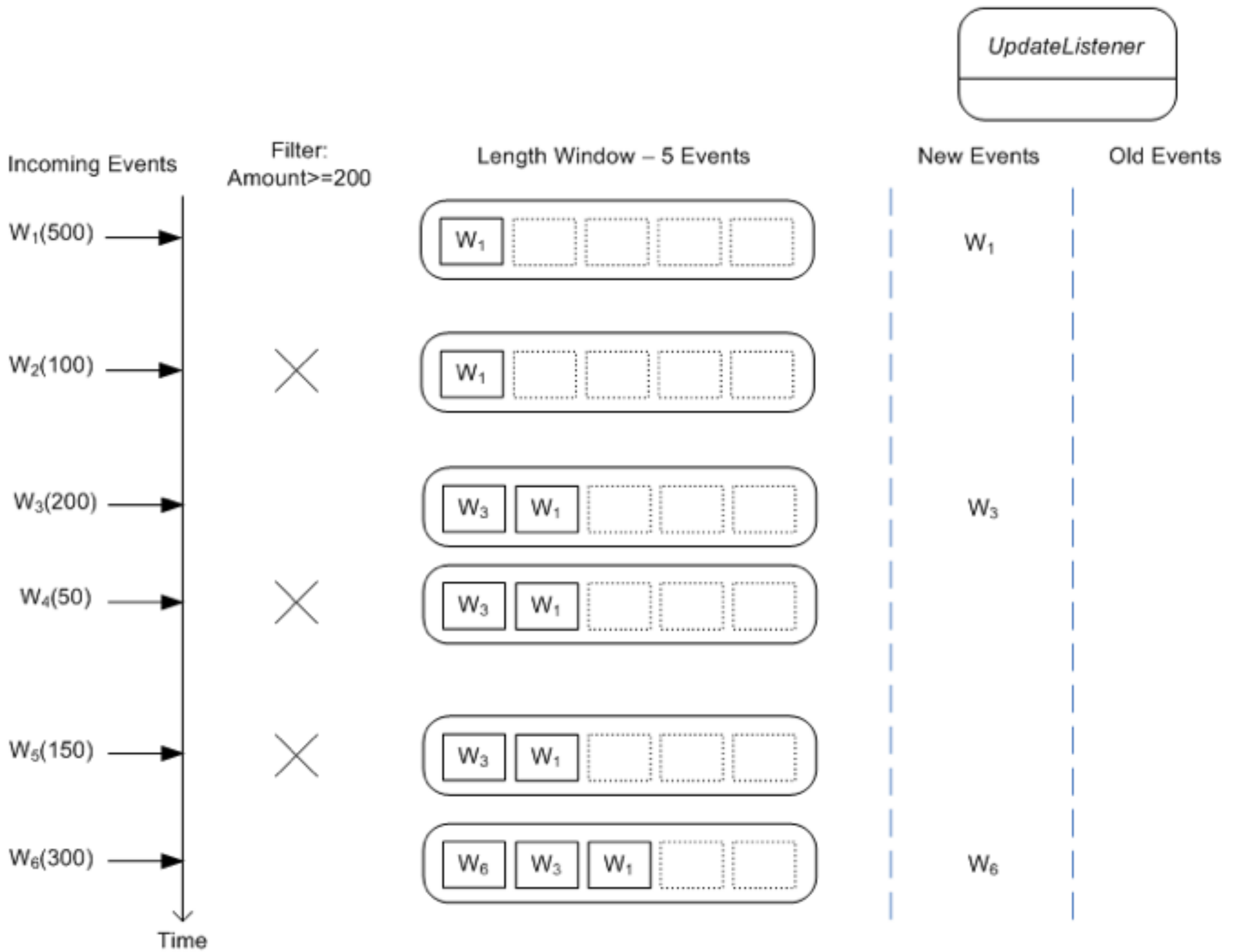


Copyright by Axis Framework

CQRS: Benefits

- Fully encapsulated domain that only exposes behavior
- Queries do not use the domain model
- No object-relational impedance mismatch
- Bullet-proof auditing and historical tracing
- Easy integration with external systems
- Performance and scalability

Event Stream Processing




```
select * from
Withdrawal(amount>=200).win:length(5)
```

Event Stream Processing

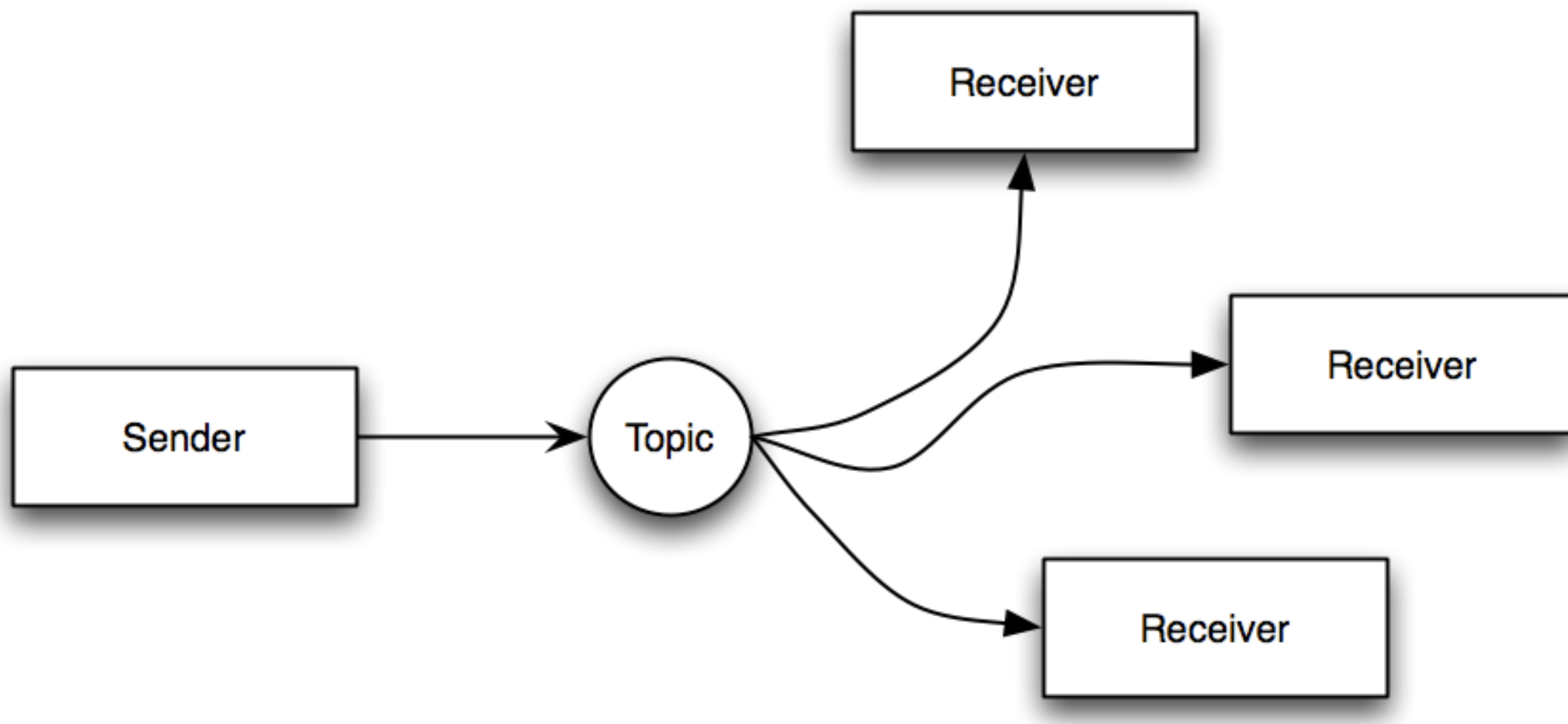
Products

- Esper (Open Source)
- StreamBase
- RuleCast

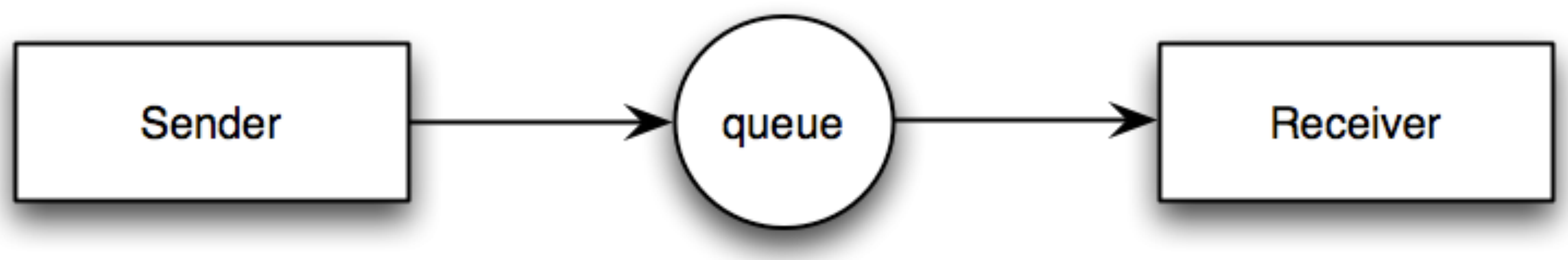
Messaging

- Publish-Subscribe
- Point-to-Point
- Store-forward
- Request-Reply

Publish-Subscribe

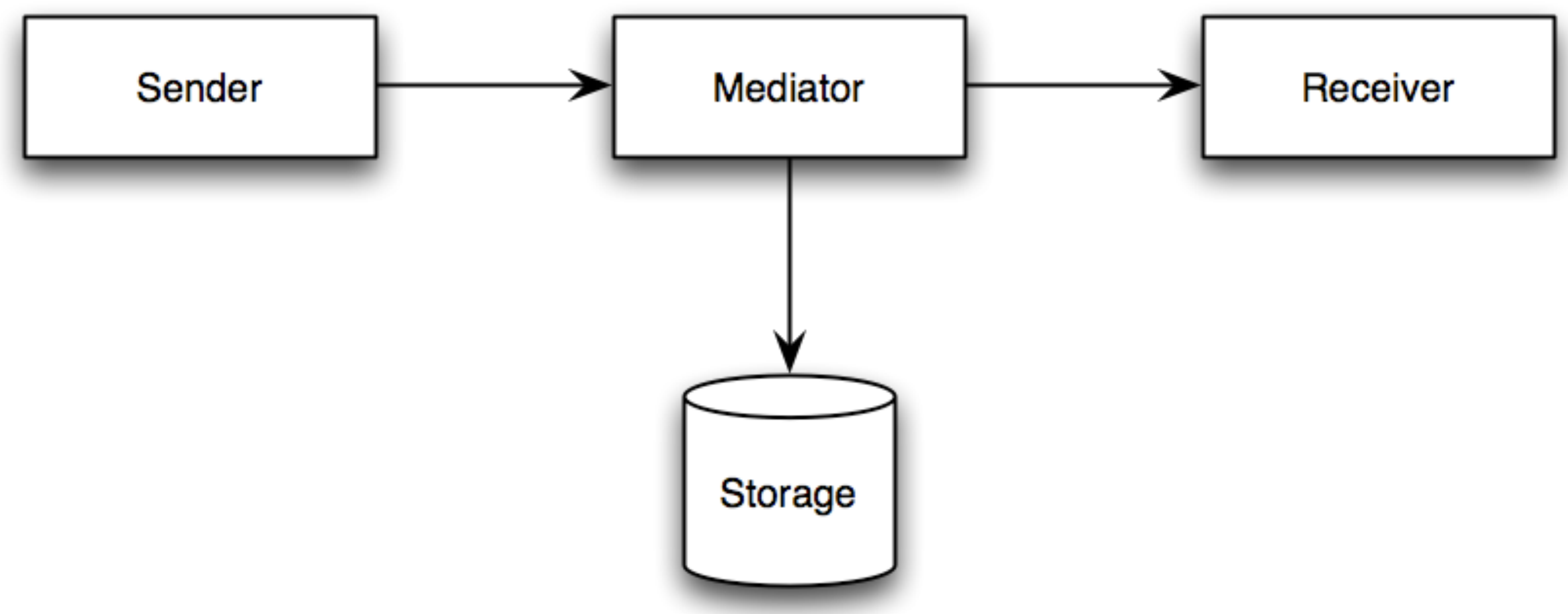


Point-to-Point



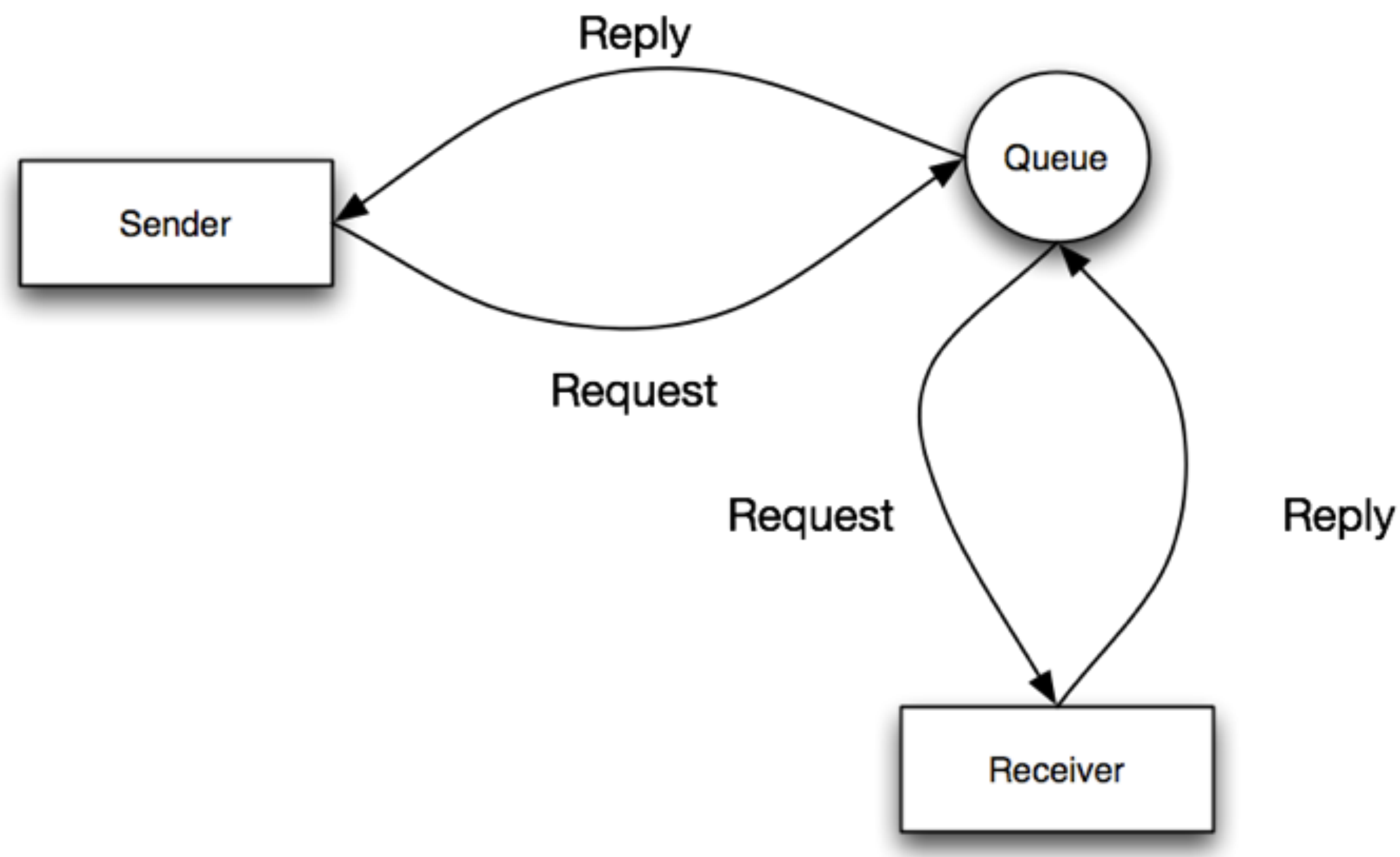
Store-Forward

Durability, event log, auditing etc.



Request-Reply

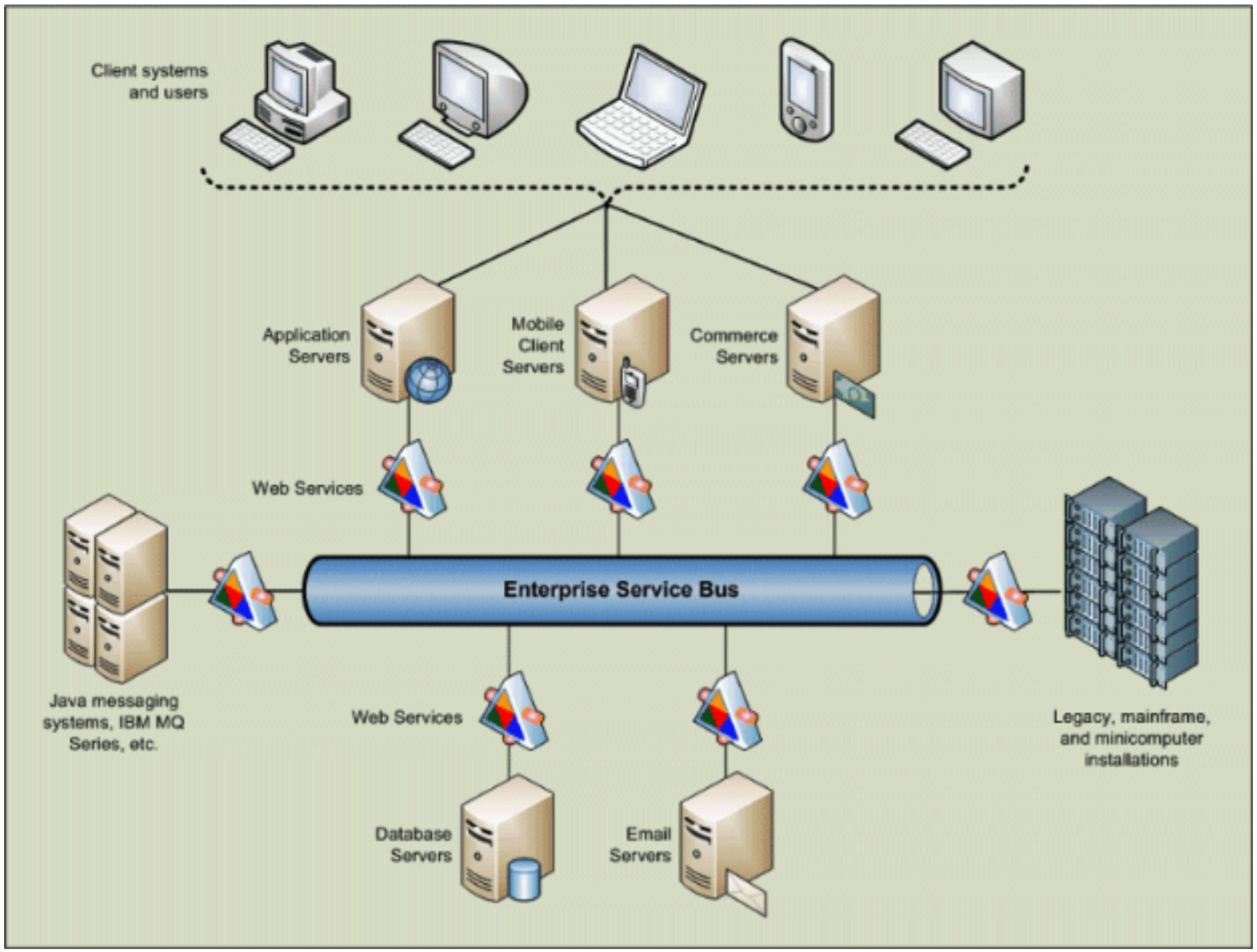
F.e. AMQP's '`replyTo`' header



Messaging

- Standards:
  - AMQP
  - JMS
- Products:
  - RabbitMQ (AMQP)
  - ActiveMQ (JMS)
  - Tibco
  - MQSeries
  - etc

ESB


Client systems
and users
Application
Servers
Mobile
Client
Servers
Commerce
Servers
Web Services
Enterprise Service Bus
Java messaging
systems, IBM MQ
Series, etc.
Web Services
Legacy, mainframe,
and minicomputer
installations
Database
Servers
Email
Servers

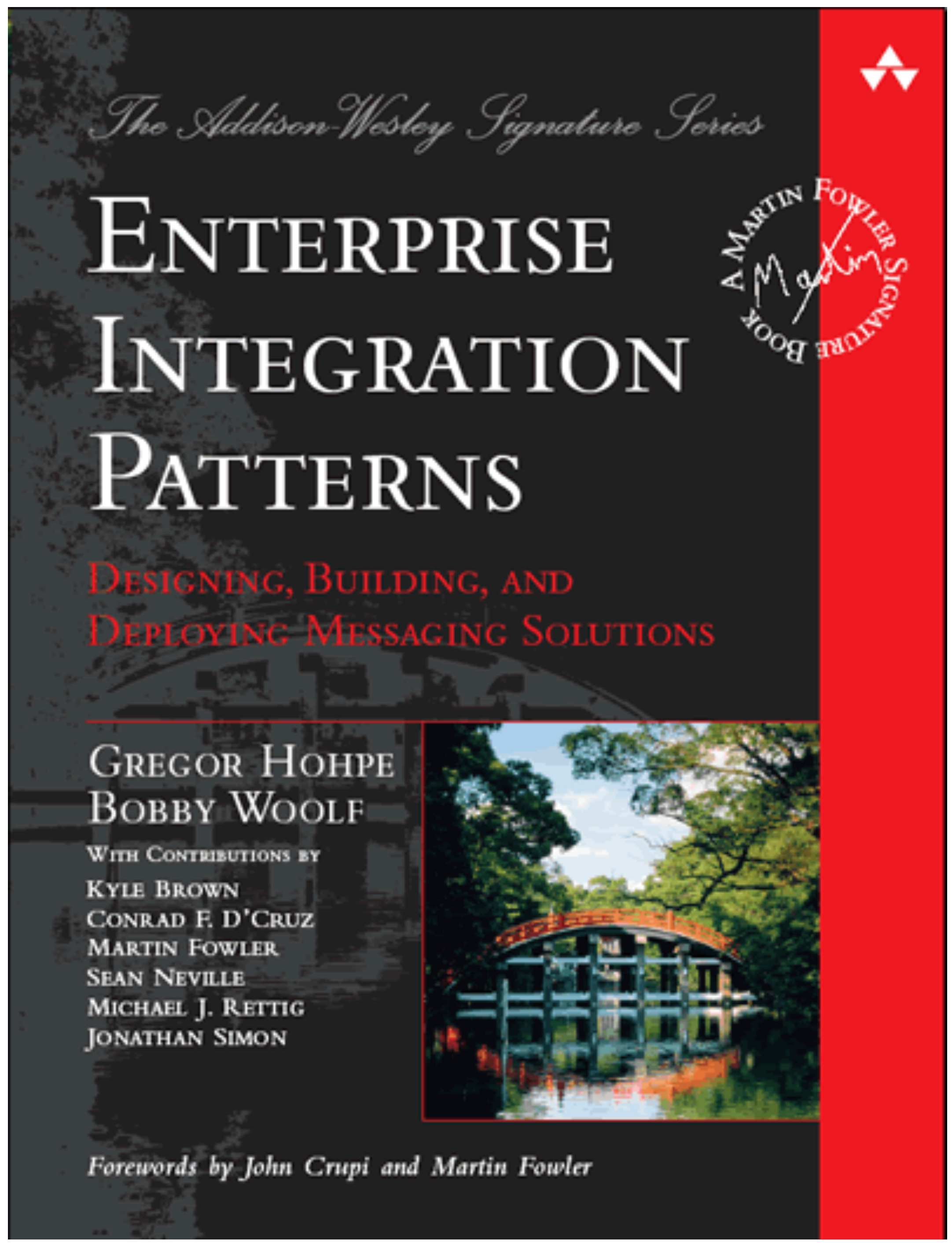
ESB products

- ServiceMix (Open Source)
- Mule (Open Source)
- Open ESB (Open Source)
- Sonic ESB
- WebSphere ESB
- Oracle ESB
- Tibco
- BizTalk Server

Actors

- Fire-forget
  - Async send
- Fire-And-Receive-Eventually
  - Async send + wait on Future for reply

Enterprise Integration Patterns



Enterprise Integration Patterns

Apache Camel

- More than 80 endpoints
- XML (Spring) DSL
- Scala DSL

Compute Grids

Compute Grids
Parallel execution

- Divide and conquer
  1. Split up job in independent tasks
  2. Execute tasks in parallel
  3. Aggregate and return result
- MapReduce - Master/Worker

Compute Grids
Parallel execution

- Automatic provisioning
- Load balancing
- Fail-over
- Topology resolution

Compute Grids

Products

- Platform
- DataSynapse
- Google MapReduce
- Hadoop
- GigaSpaces
- GridGain


Load balancing
© Bob Elsdale

Load balancing

- Random allocation
- Round robin allocation
- Weighted allocation
- Dynamic load balancing
  - Least connections
  - Least server CPU
  - etc.

Load balancing

- DNS Round Robin (simplest)
  - Ask DNS for IP for host
  - Get a new IP every time
- Reverse Proxy (better)
- Hardware Load Balancing

Load balancing products

- Reverse Proxies:
  - Apache mod_proxy (OSS)
  - HAProxy (OSS)
  - Squid (OSS)
  - Nginx (OSS)
- Hardware Load Balancers:
  - BIG-IP
  - Cisco

Parallel Computing

Parallel Computing

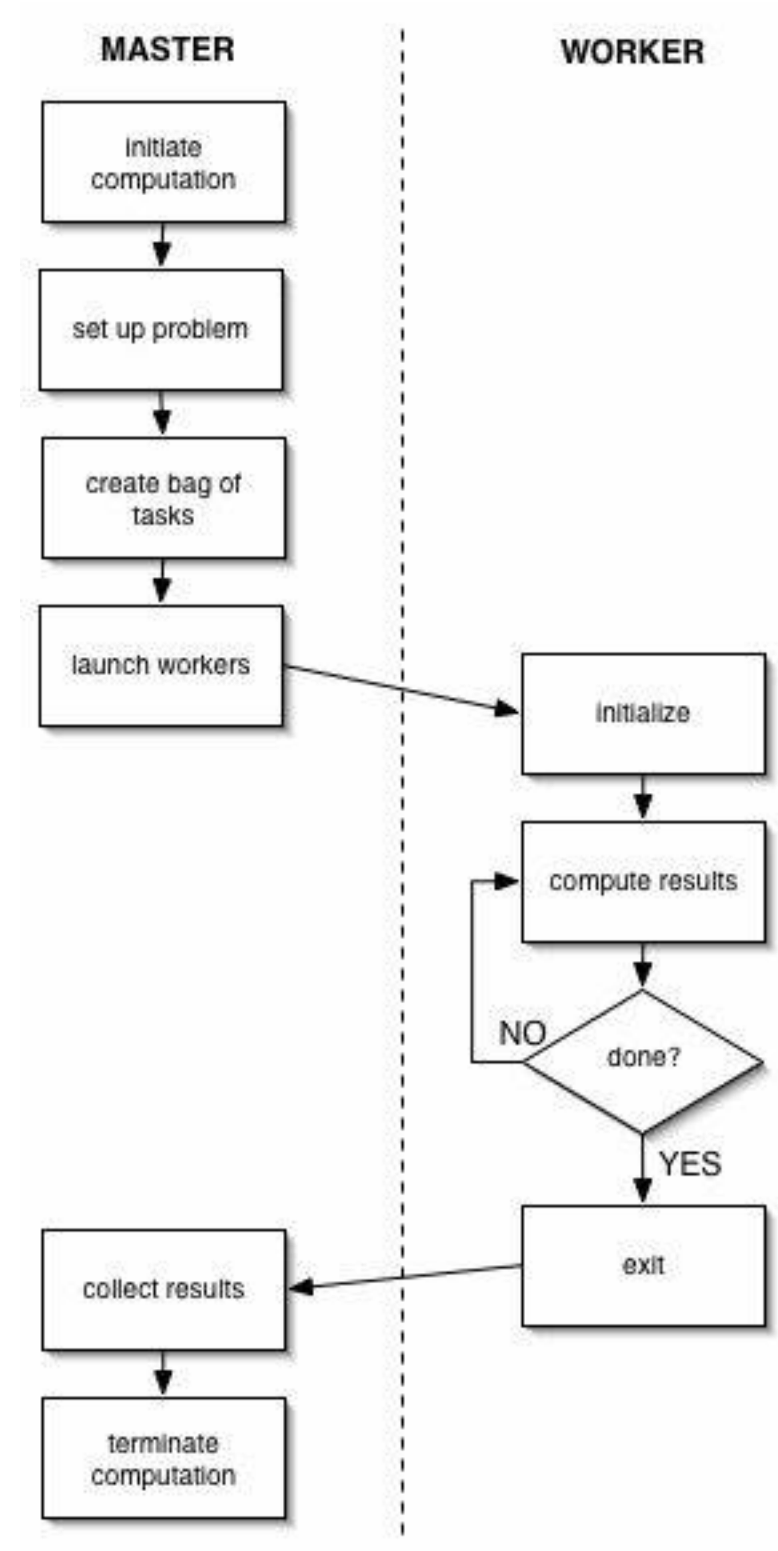
- SPMD Pattern
- Master/Worker Pattern
- Loop Parallelism Pattern
- Fork/Join Pattern
- MapReduce Pattern

- UE: Unit of Execution
    - Process
    - Thread
    - Coroutine
    - Actor

SPMD Pattern

- Single Program Multiple Data
- Very generic pattern, used in many other patterns
- Use a single program for all the UEs
- Use the UE's ID to select different pathways through the program. F.e:
    - Branching on ID
    - Use ID in loop index to split loops
- Keep interactions between UEs explicit

Master/Worker



Master/Worker

- Good scalability
- Automatic load-balancing
- How to detect termination?
  - Bag of tasks is empty
  - Poison pill
- If we bottleneck on single queue?
  - Use multiple work queues
  - Work stealing
- What about fault tolerance?
  - Use "in-progress" queue

Loop Parallelism

- Workflow
  1. Find the loops that are bottlenecks
  2. Eliminate coupling between loop iterations
  3. Parallelize the loop
- If too few iterations to pull its weight
  - Merge loops
  - Coalesce nested loops
- OpenMP
  - `omp parallel for`

What if task creation can’t be handled by:

- parallelizing loops (Loop Parallelism)
- putting them on work queues (Master/Worker)

What if task creation can’t be handled by:

- parallelizing loops (Loop Parallelism)
- putting them on work queues (Master/Worker)

Enter

Fork/Join

Fork/Join

- Use when relationship between tasks is simple
- Good for recursive data processing
- Can use work-stealing

1. Fork: Tasks are dynamically created
2. Join: Tasks are later terminated and data aggregated

Fork/Join

- Direct task/UE mapping
  - 1-1 mapping between Task/UE
  - Problem: Dynamic UE creation is expensive
- Indirect task/UE mapping
  - Pool the UE
  - Control (constrain) the resource allocation
  - Automatic load balancing

Fork/Join

Java 7 `ParallelArray` (Fork/Join DSL)

Fork/Join

Java 7 `ParallelArray` (Fork/Join DSL)

```
ParallelArray students =
  new ParallelArray(fjPool, data);

double bestGpa = students.withFilter(isSenior)
                         .withMapping(selectGpa)
                         .max();
```

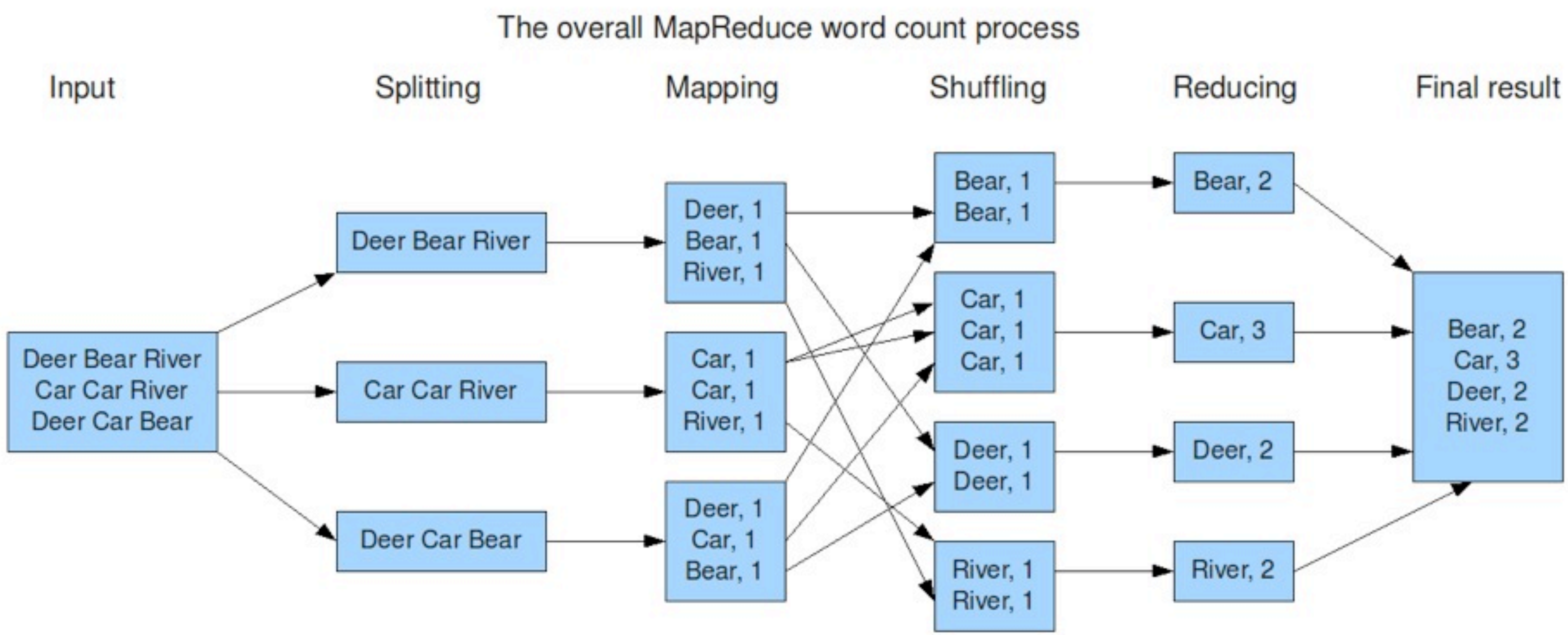
MapReduce

- Origin from Google paper 2004
- Used internally @ Google
- Variation of Fork/Join
- Work divided upfront not dynamically
- Usually distributed
- Normally used for massive data crunching

MapReduce
Products

- Hadoop (OSS), used @ Yahoo
- Amazon Elastic MapReduce
- Many NOSQL DBs utilizes it for searching/querying

MapReduce


The overall MapReduce word count process
Input
Splitting
Mapping
Shuffling
Reducing
Final result
Deer Bear River
Car Car River
Deer Car Bear
Deer Bear River
Car Car River
Deer Car Bear
Deer, 1
Bear, 1
River, 1
Car, 1
Car, 1
River, 1
Deer, 1
Car, 1
Bear, 1
Bear, 1
Bear, 1
Car, 1
Car, 1
Car, 1
Deer, 1
Deer, 1
River, 1
River, 1
Bear, 2
Car, 3
Deer, 2
River, 2
Bear, 2
Car, 3
Deer, 2
River, 2

Parallel Computing

products

- MPI
- OpenMP
- JSR166 Fork/Join
- java.util.concurrent
    - ExecutorService, BlockingQueue etc.
- ProActive Parallel Suite
- CommonJ WorkManager (JEE)

Stability Patterns

Stability Patterns

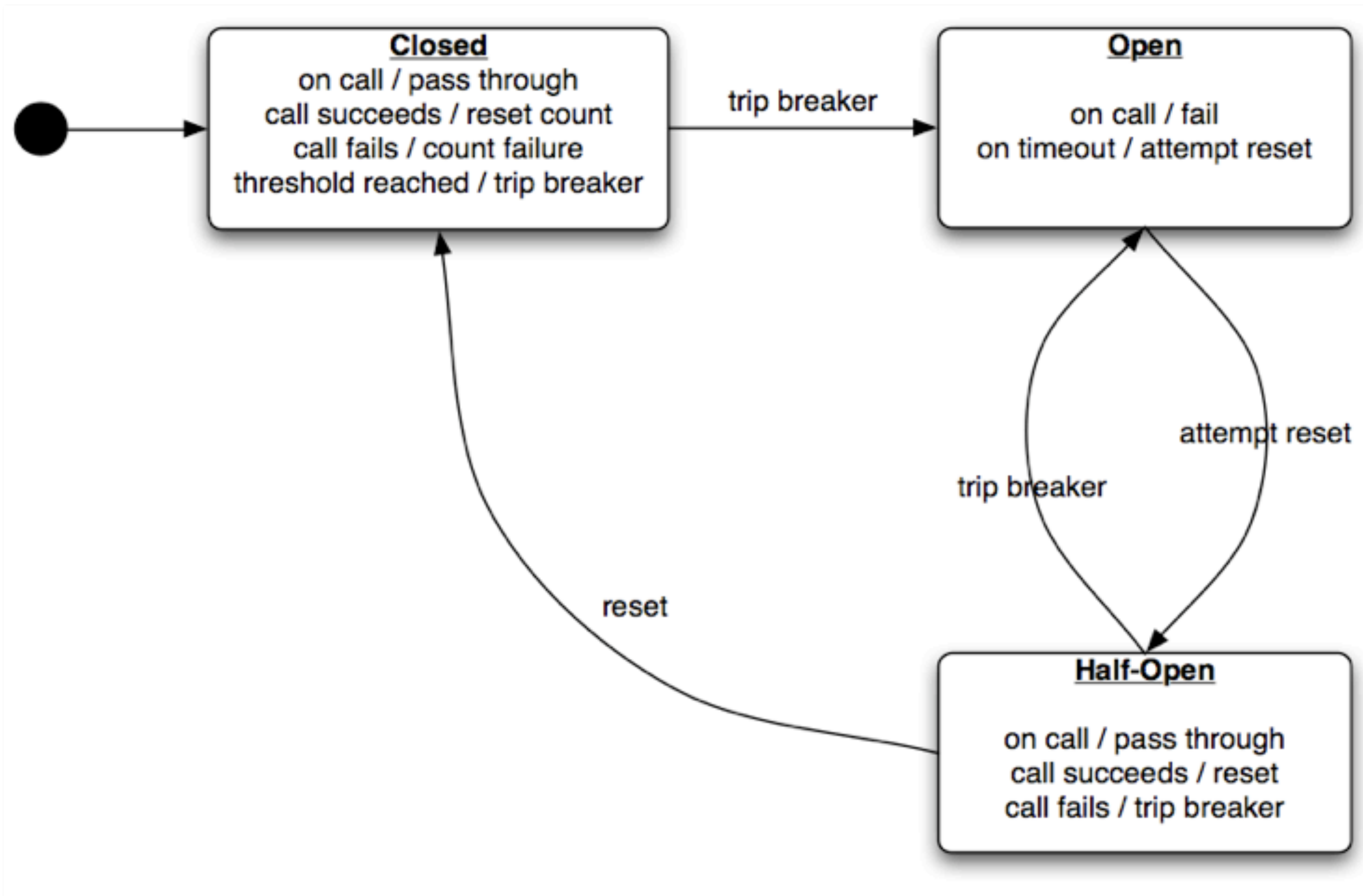
- Timeouts
- Circuit Breaker
- Let-it-crash
- Fail fast
- Bulkheads
- Steady State
- Throttling

Timeouts

Always use timeouts (if possible):

- `Thread.wait(timeout)`
- `reentrantLock.tryLock`
- `blockingQueue.poll(timeout, timeUnit)/offer(..)`
- `futureTask.get(timeout, timeUnit)`
- `socket.setSoTimeOut(timeout)`
- etc.

Circuit Breaker

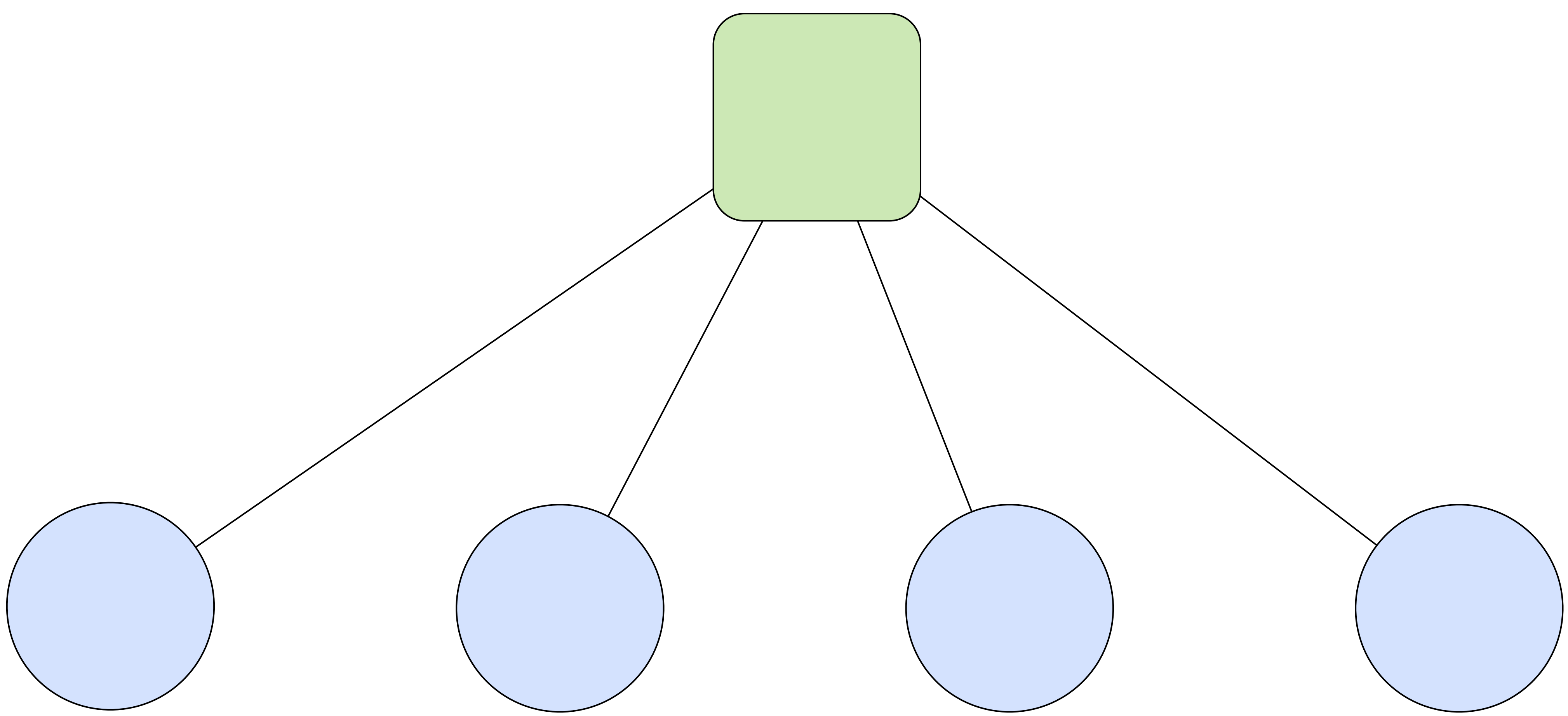


Let it crash

- Embrace failure as a natural state in the life-cycle of the application
- Instead of trying to prevent it; manage it
- Process supervision
- Supervisor hierarchies (from Erlang)

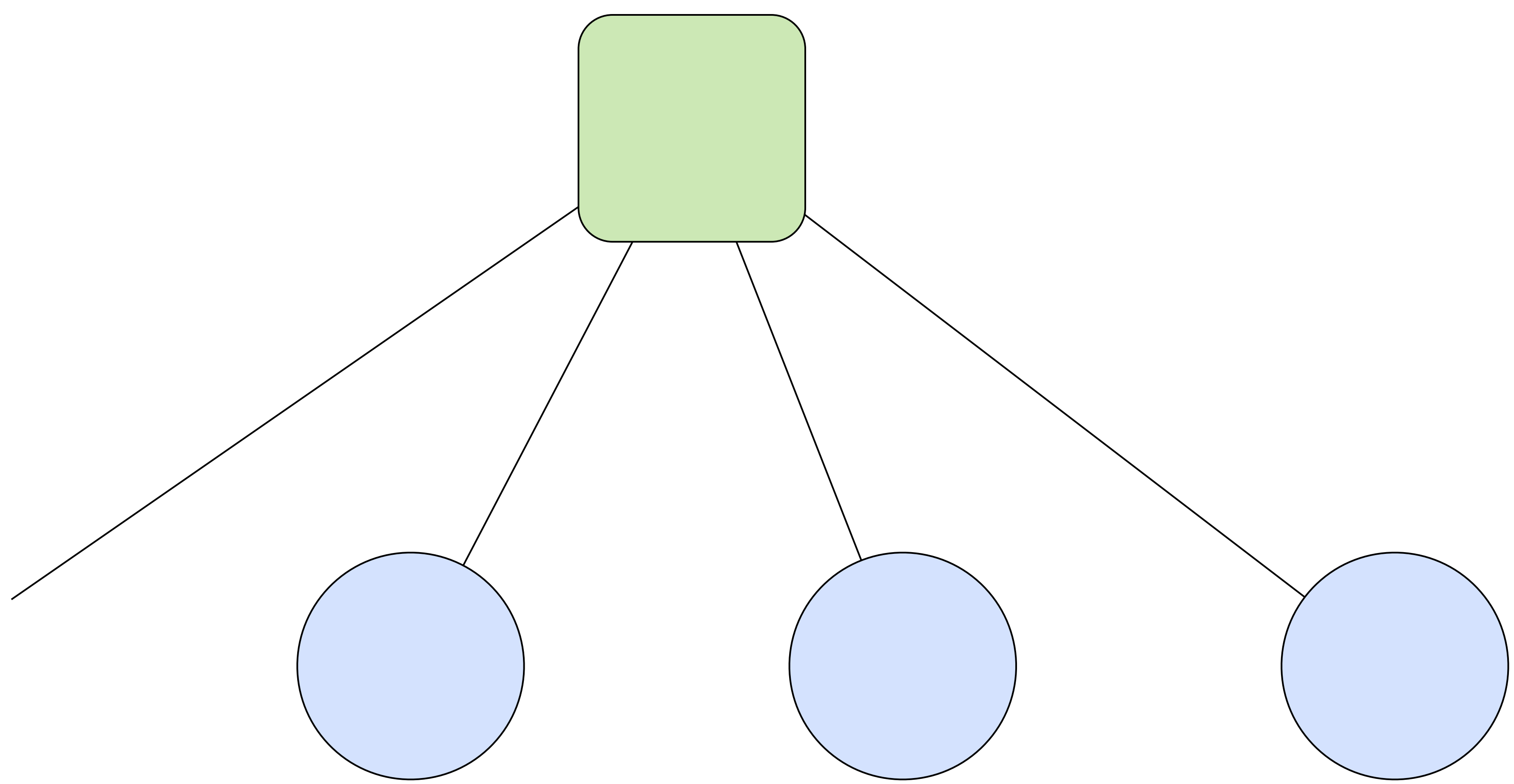
Restart Strategy

OneForOne



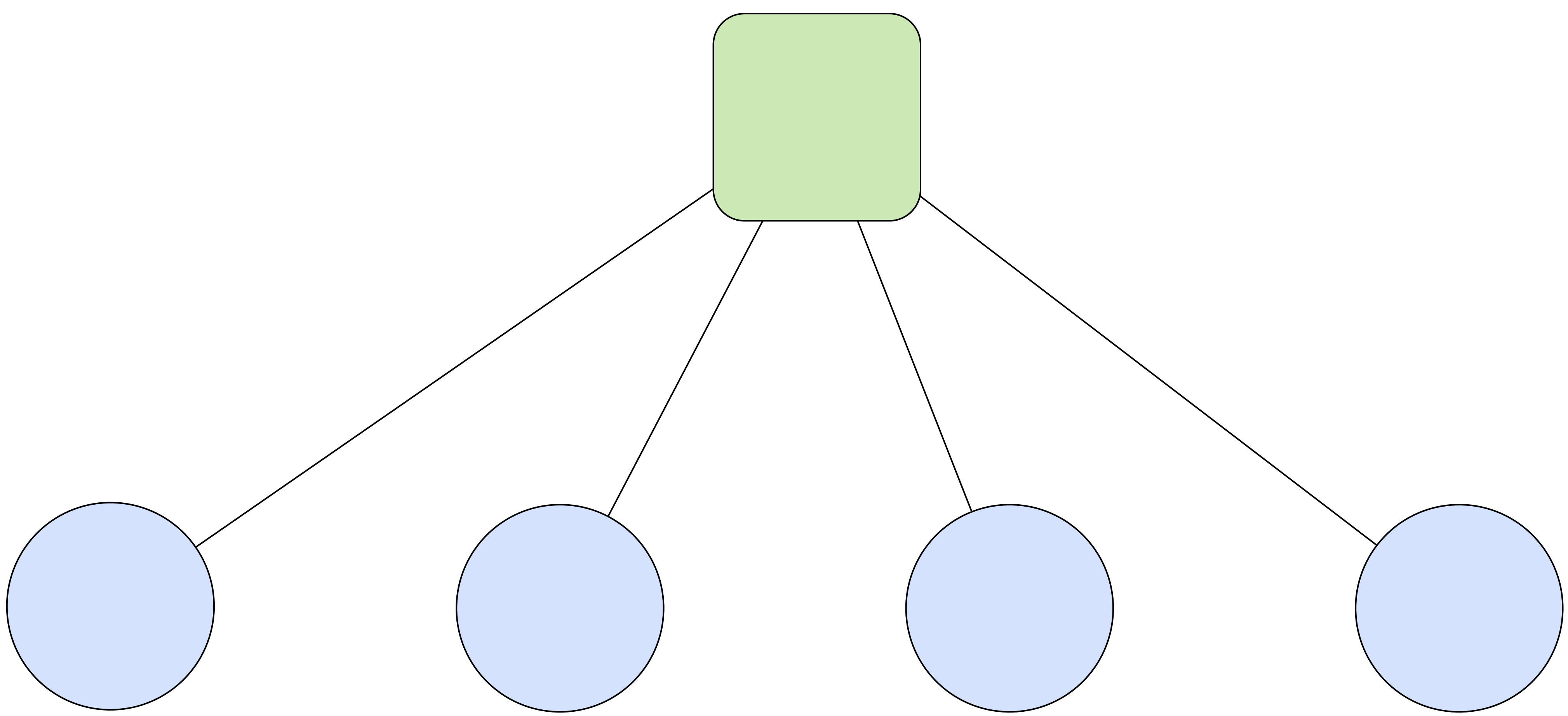
Restart Strategy

OneForOne



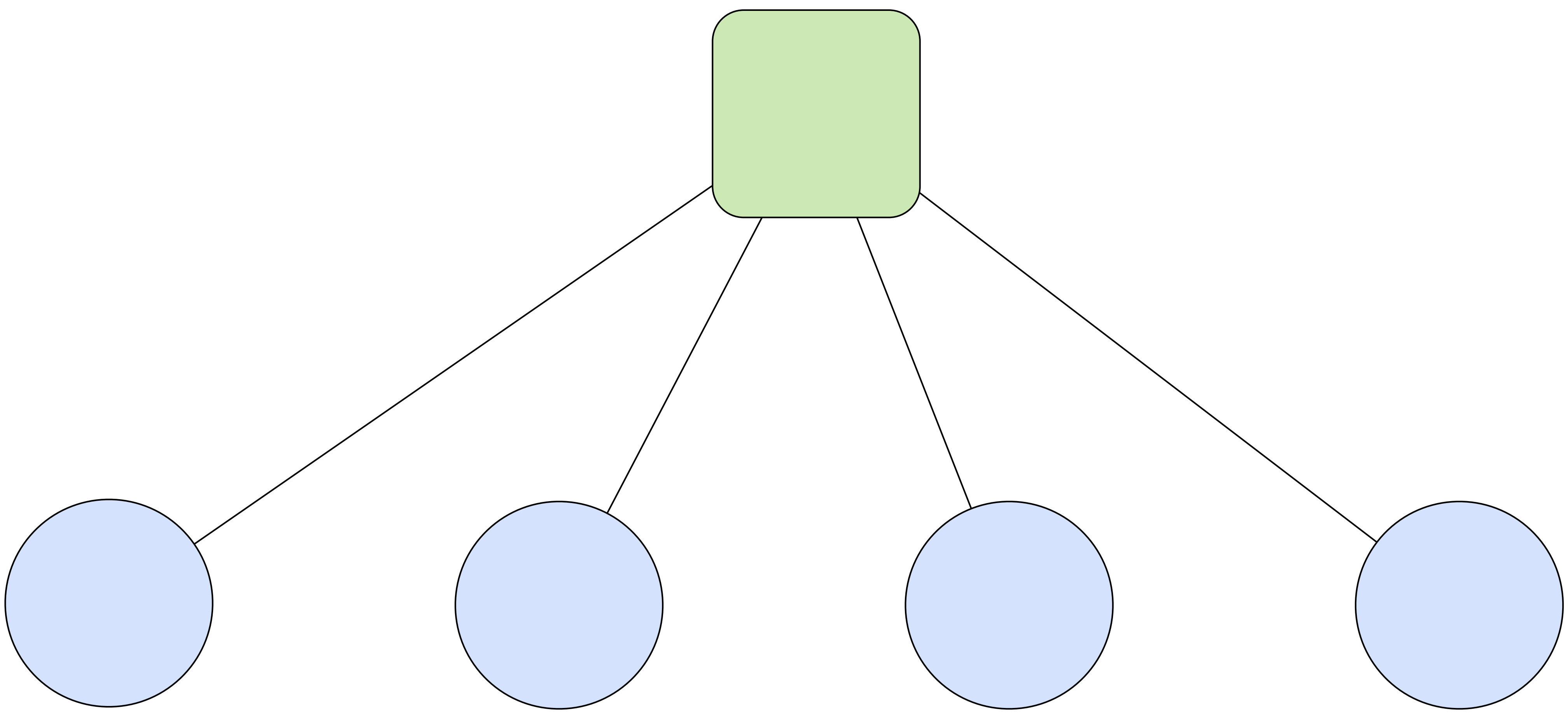
Restart Strategy

OneForOne



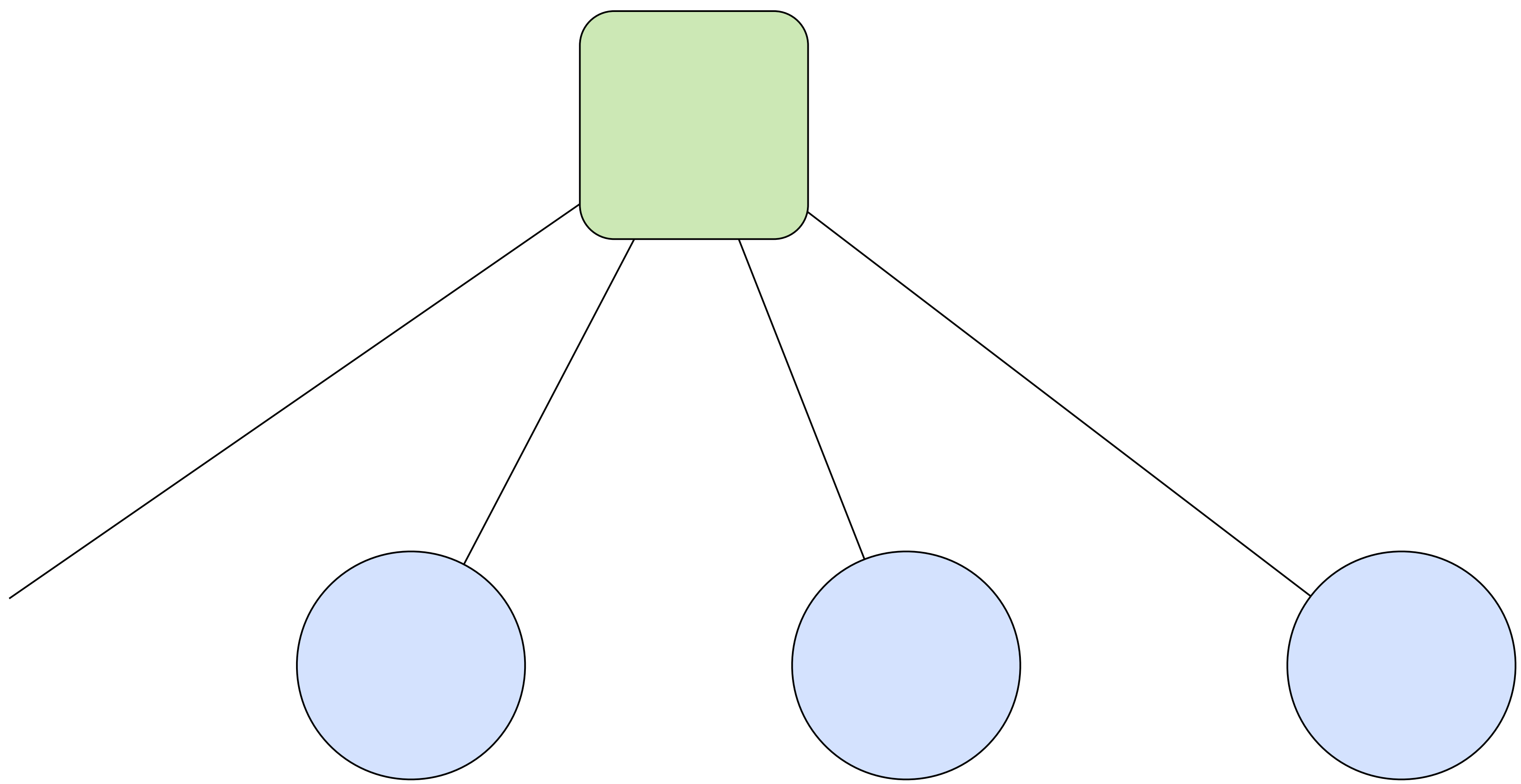
Restart Strategy

AllForOne



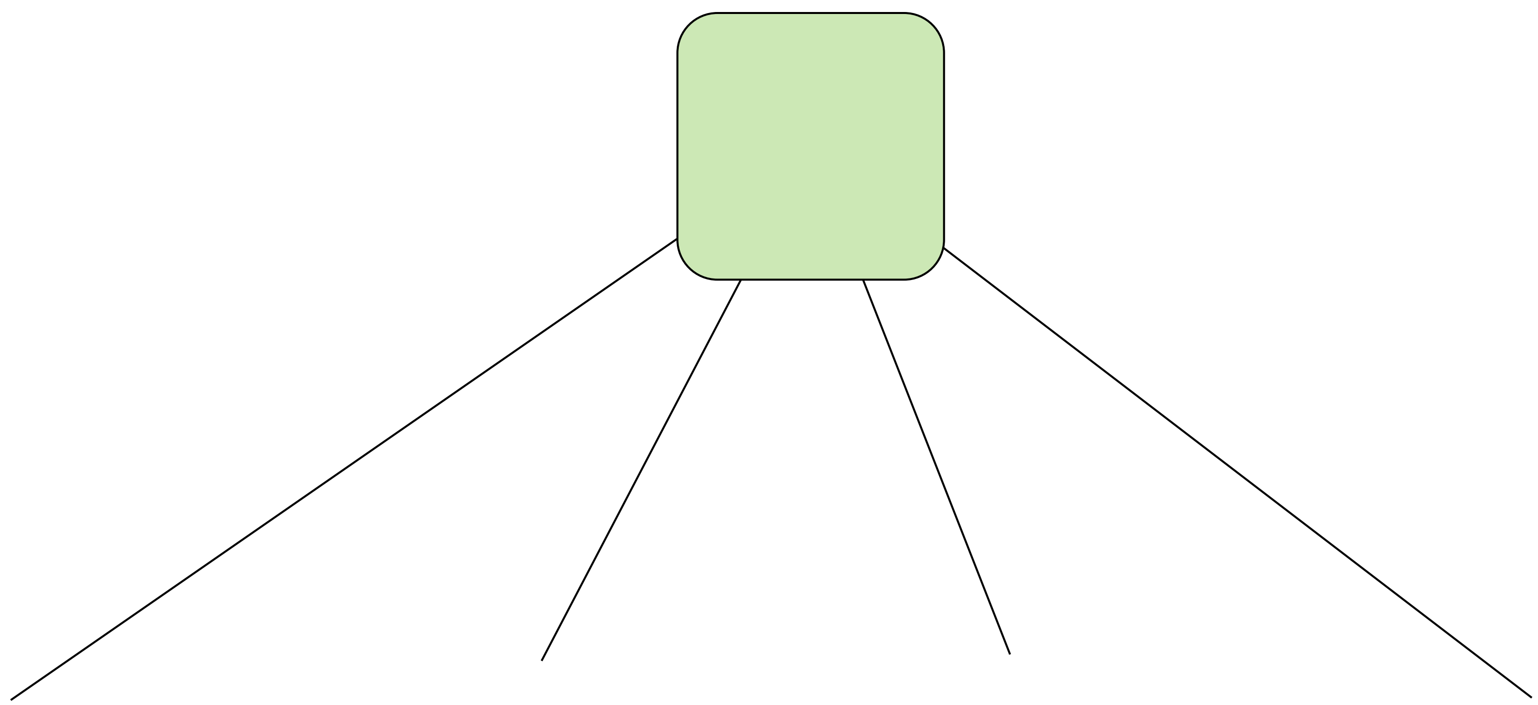
Restart Strategy

AllForOne



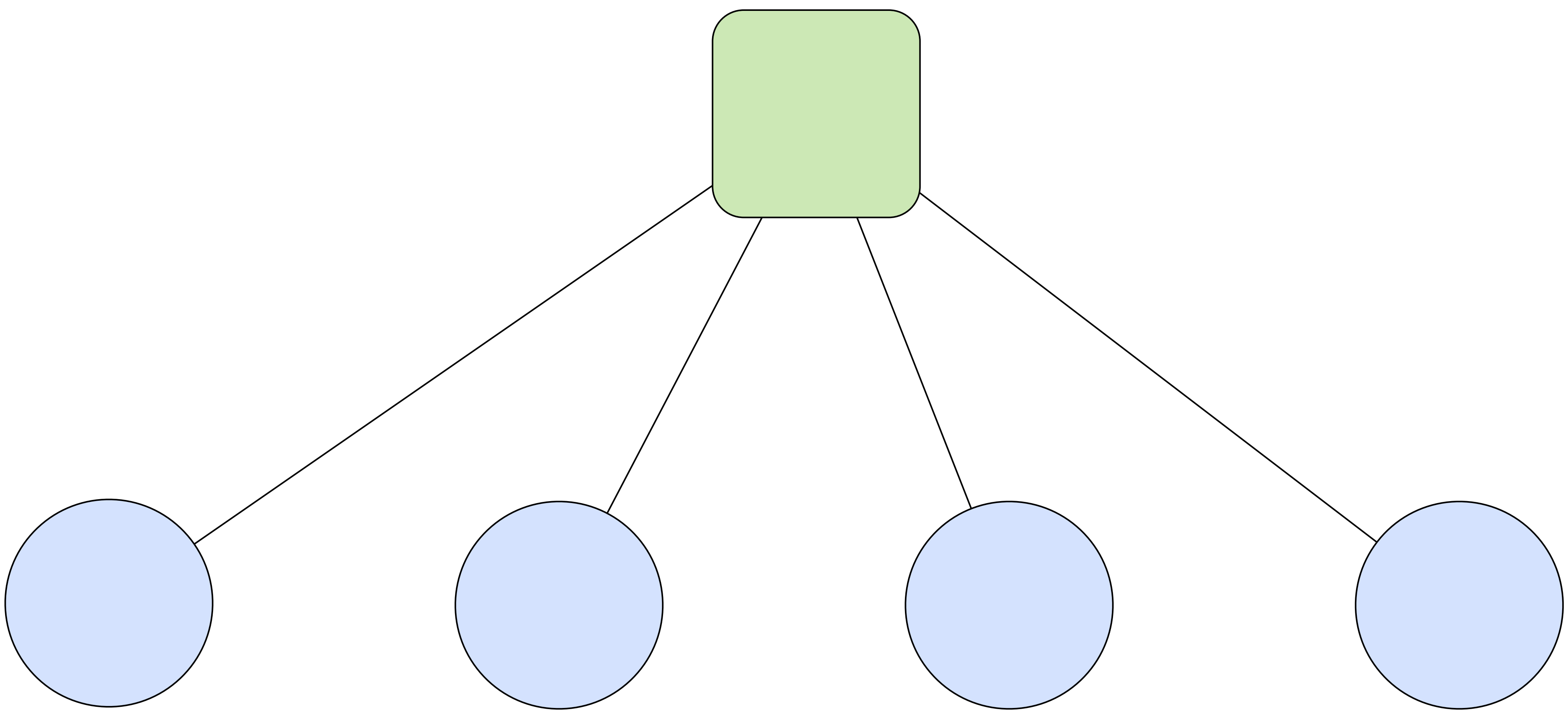
Restart Strategy

AllForOne

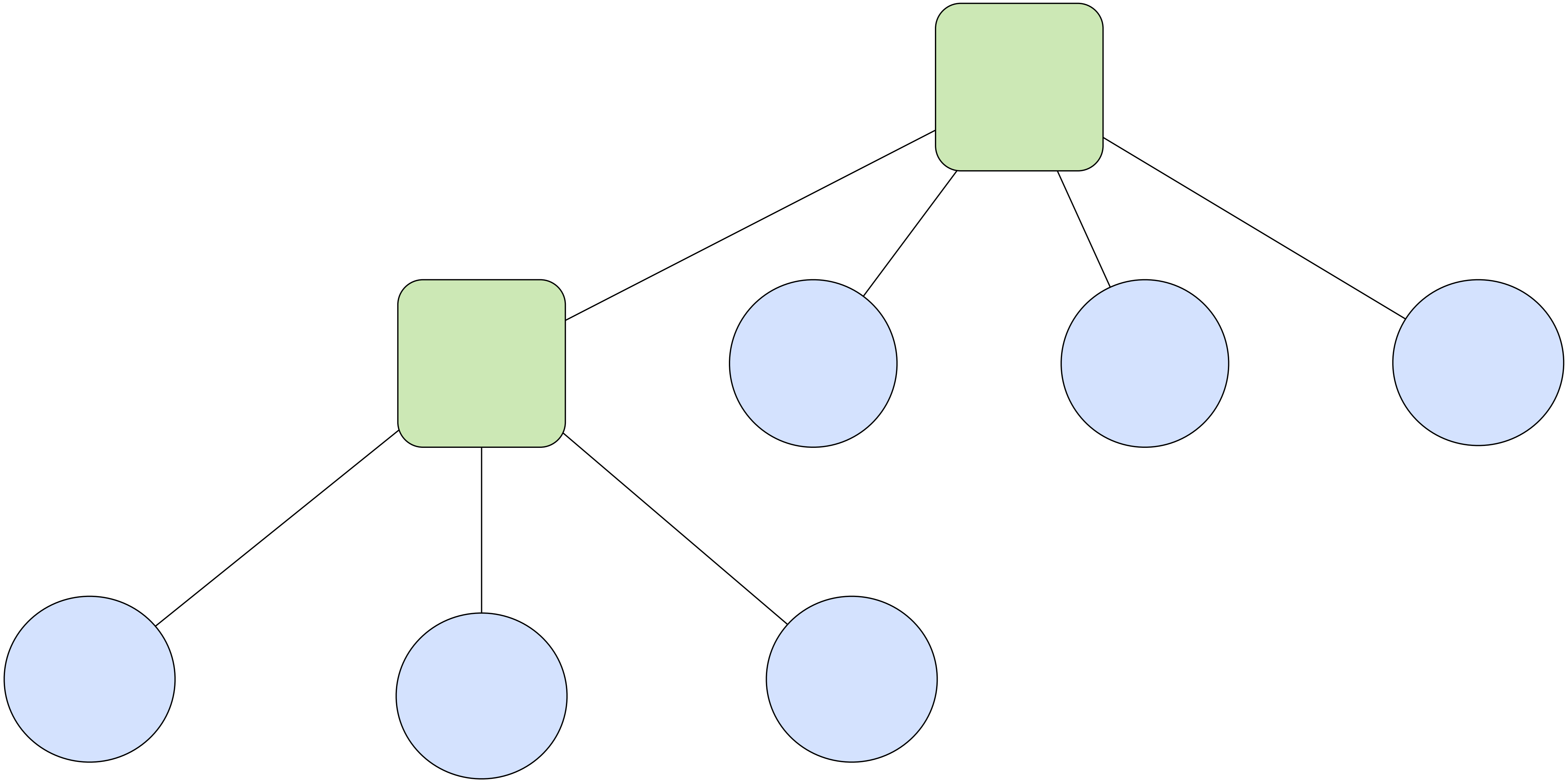


Restart Strategy

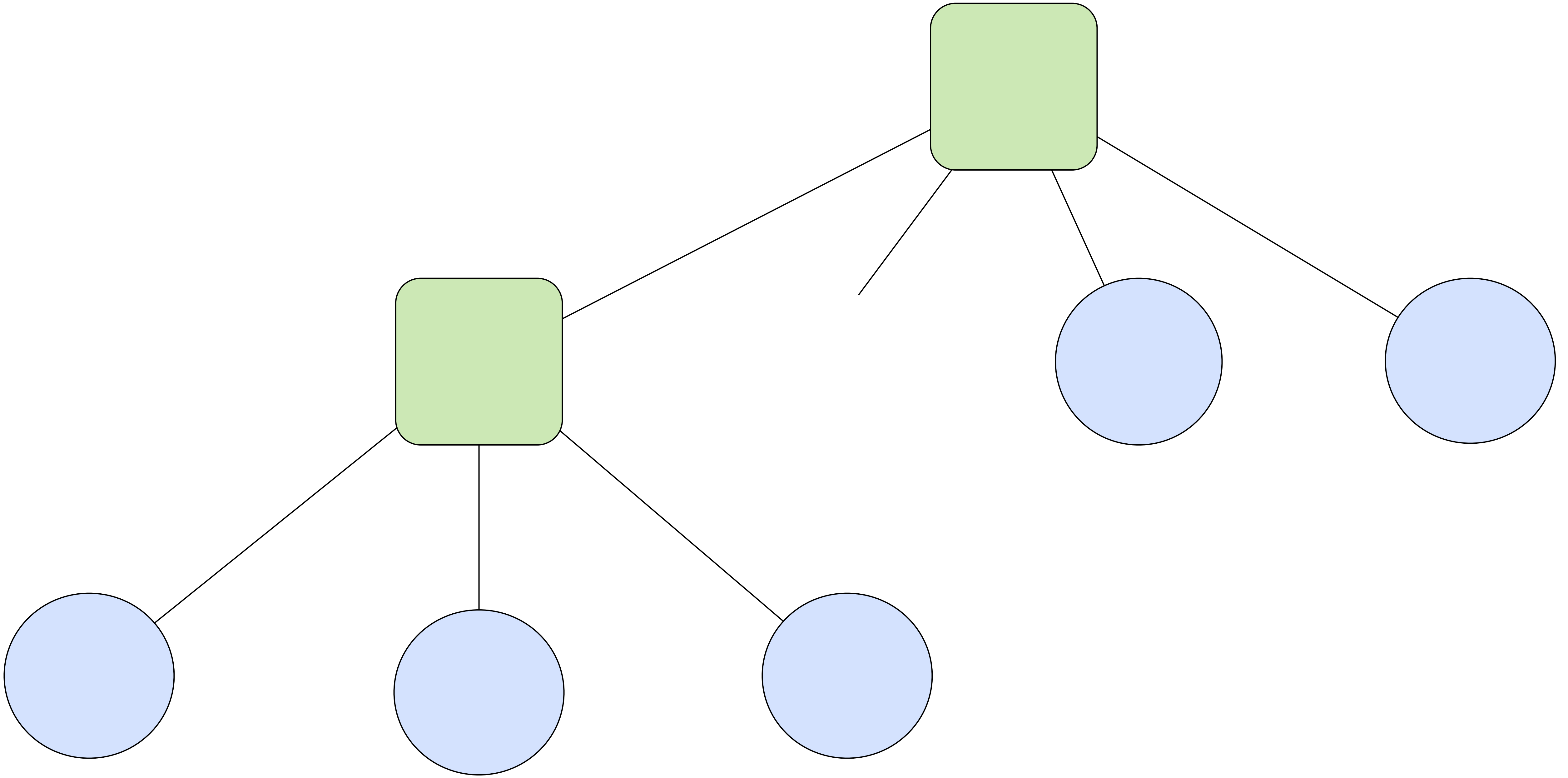
AllForOne



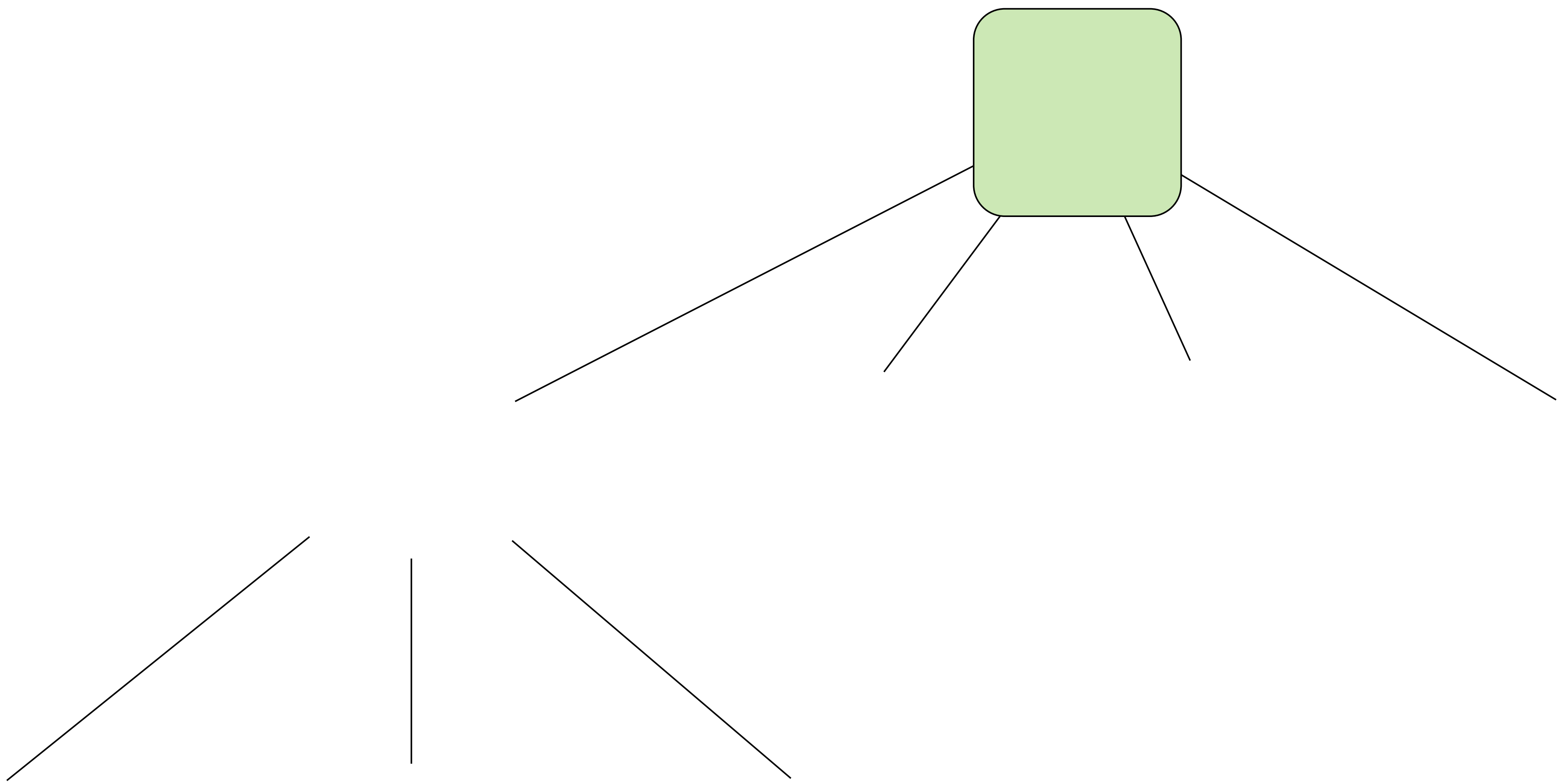
Supervisor Hierarchies



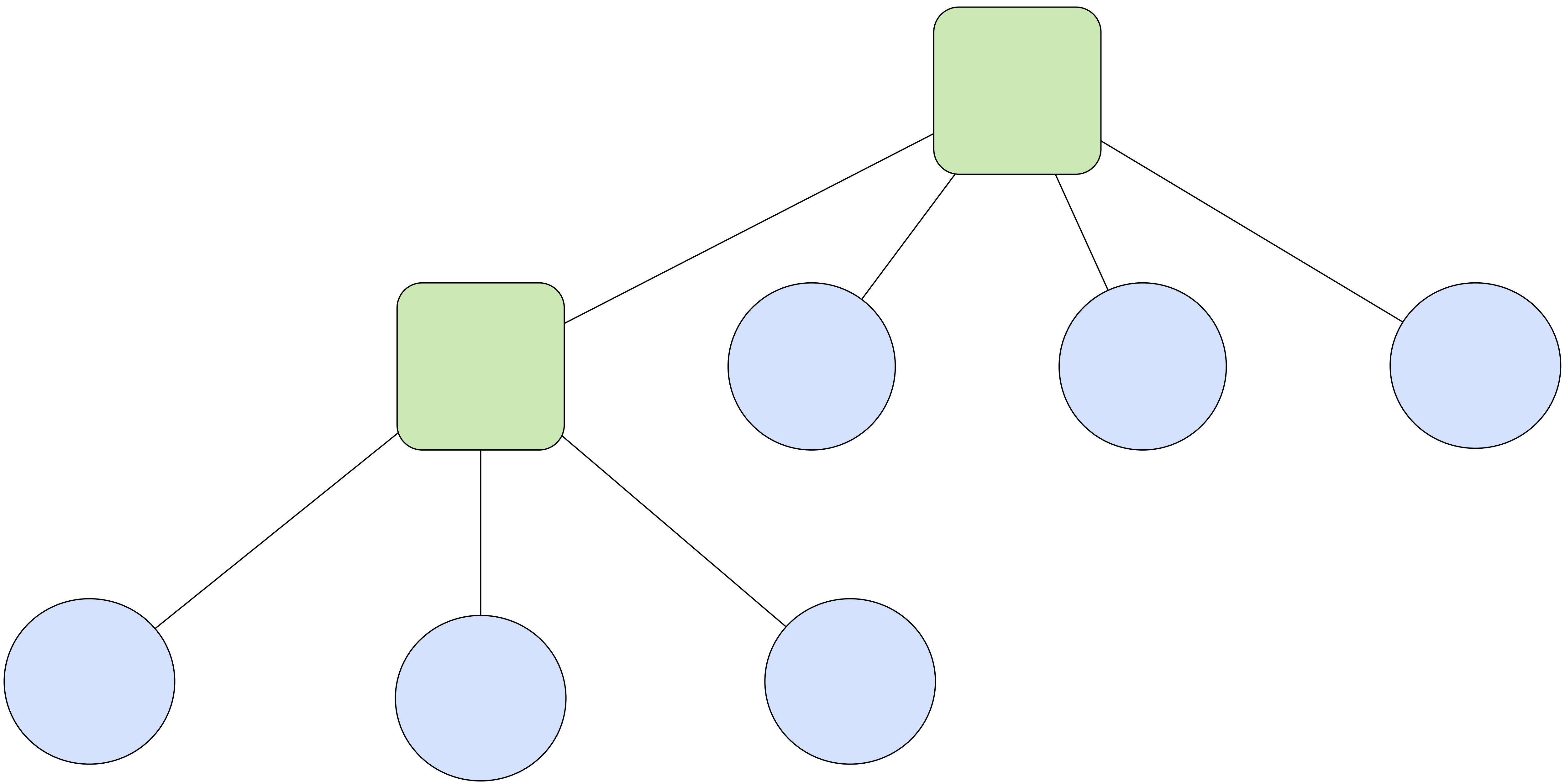
Supervisor Hierarchies



Supervisor Hierarchies



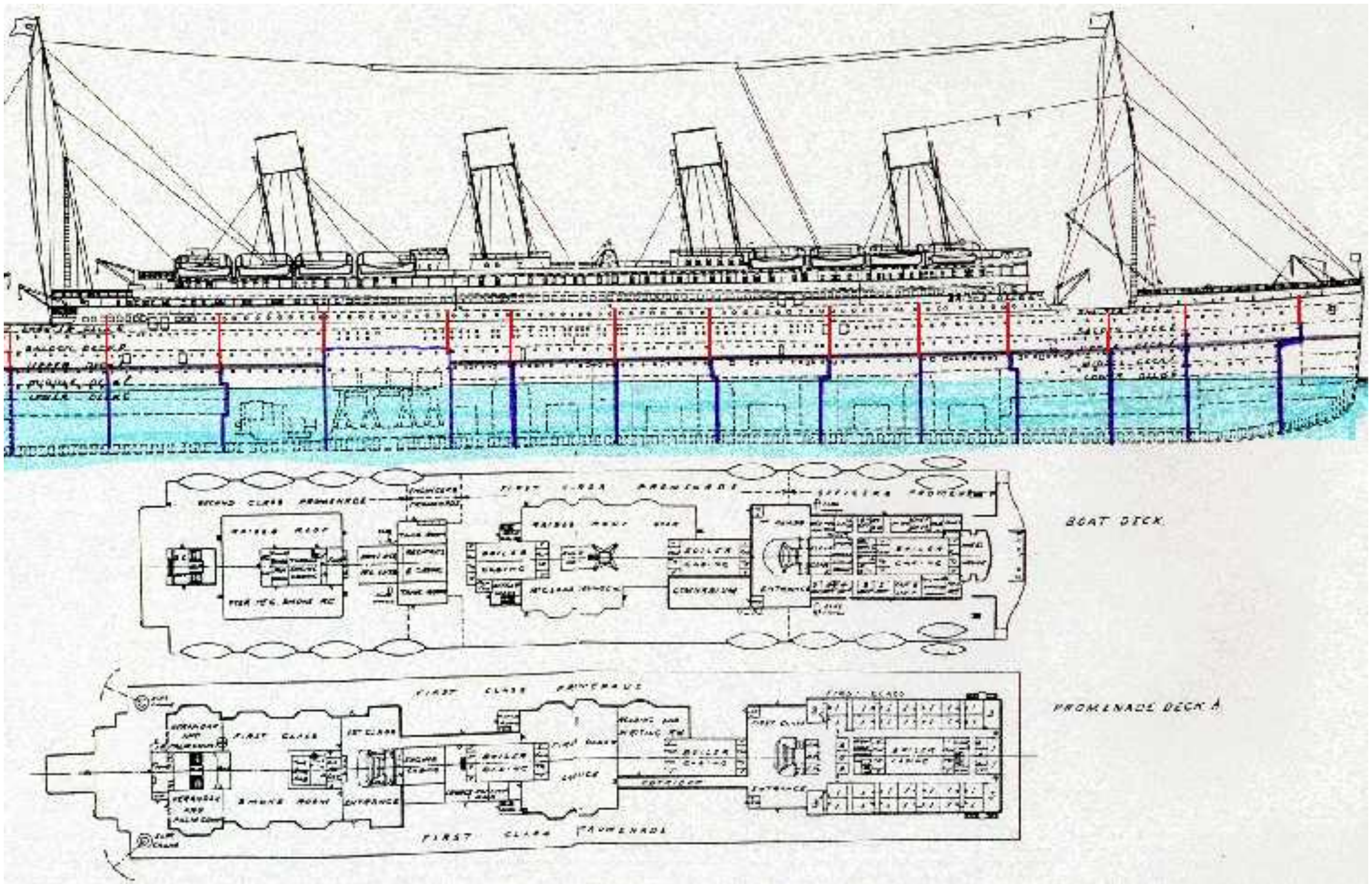
Supervisor Hierarchies



Fail fast

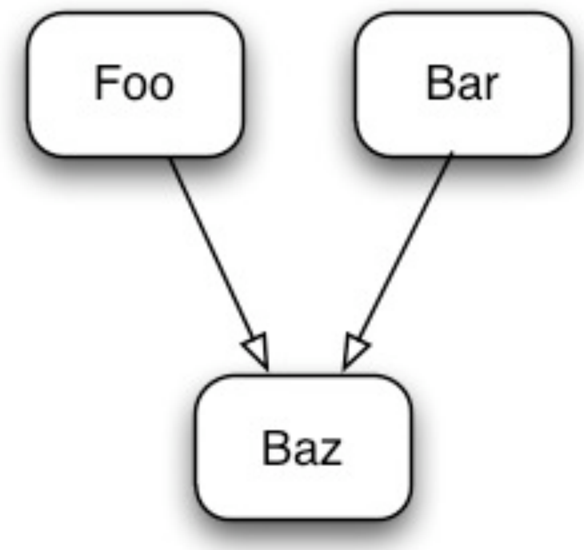
- Avoid "slow responses"
- Separate:
  - `SystemError` - resources not available
  - `ApplicationError` - bad user input etc
- Verify resource availability before starting expensive task
- Input validation immediately

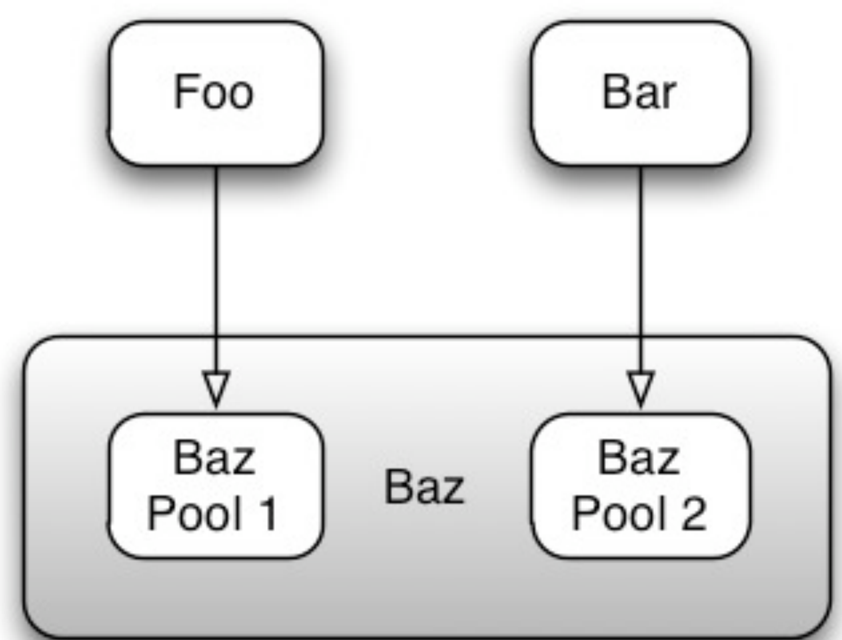
Bulkheads



Bulkheads

- Partition and tolerate failure in one part
- Redundancy
- Applies to threads as well:
  - One pool for admin tasks to be able to perform tasks even though all threads are blocked



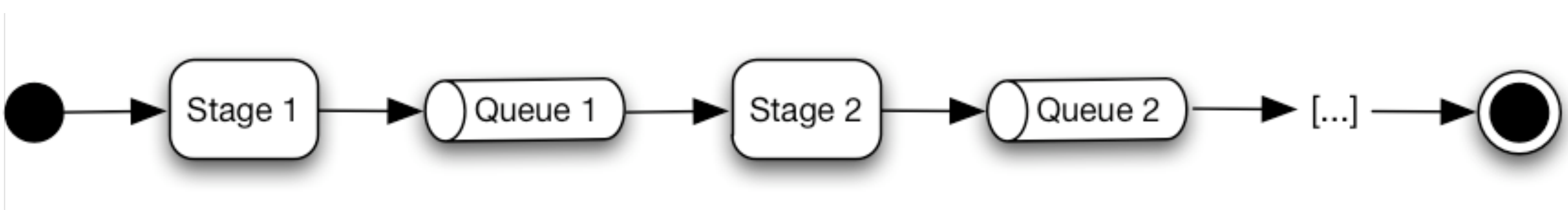


Steady State

- Clean up after you
- Logging:
  - RollingFileAppender (log4j)
  - logrotate (Unix)
  - Scribe - server for aggregating streaming log data
  - Always put logs on separate disk

Throttling

- Maintain a steady pace
- Count requests
  - If limit reached, back-off (drop, raise error)
- Queue requests
  - Used in for example *Staged Event-Driven Architecture (SEDA)*



thanks

for listening

Extra material

Client-side consistency

- Strong consistency
- Weak consistency
  - Eventually consistent
  - Never consistent

Client-side Eventual Consistency levels

- Casual consistency
- Read-your-writes consistency (important)
- Session consistency
- Monotonic read consistency (important)
- Monotonic write consistency

Server-side consistency

- N = the number of nodes that store replicas of the data
- W = the number of replicas that need to acknowledge the receipt of the update before the update completes
- R = the number of replicas that are contacted when a data object is accessed through a read operation

Server-side consistency

$W + R > N$ strong consistency

$W + R <= N$ eventual consistency