Lecture 14: ZooKeeper

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Course content

- Introduction
- Data streams 1 & 2
- The MapReduce paradigm
- Looking behind the scenes of MapReduce: HDFS & Scheduling
- Algorithm design for MapReduce
- A high-level language for MapReduce: Pig Latin 1 & 2
- MapReduce is not a database, but HBase nearly is
- Lets iterate a bit: Graph algorithms & Giraph
- **Coordination in distributed systems**

Learning objectives

- Place ZooKeeper in the Hadoop ecosystem
- **Explain** and discuss the advantages of using ZooKeeper compared to a distributed system not using it
- **Explain** ZooKeeper’s data model
- **Derive** protocols to implement configuration tasks

Introduction

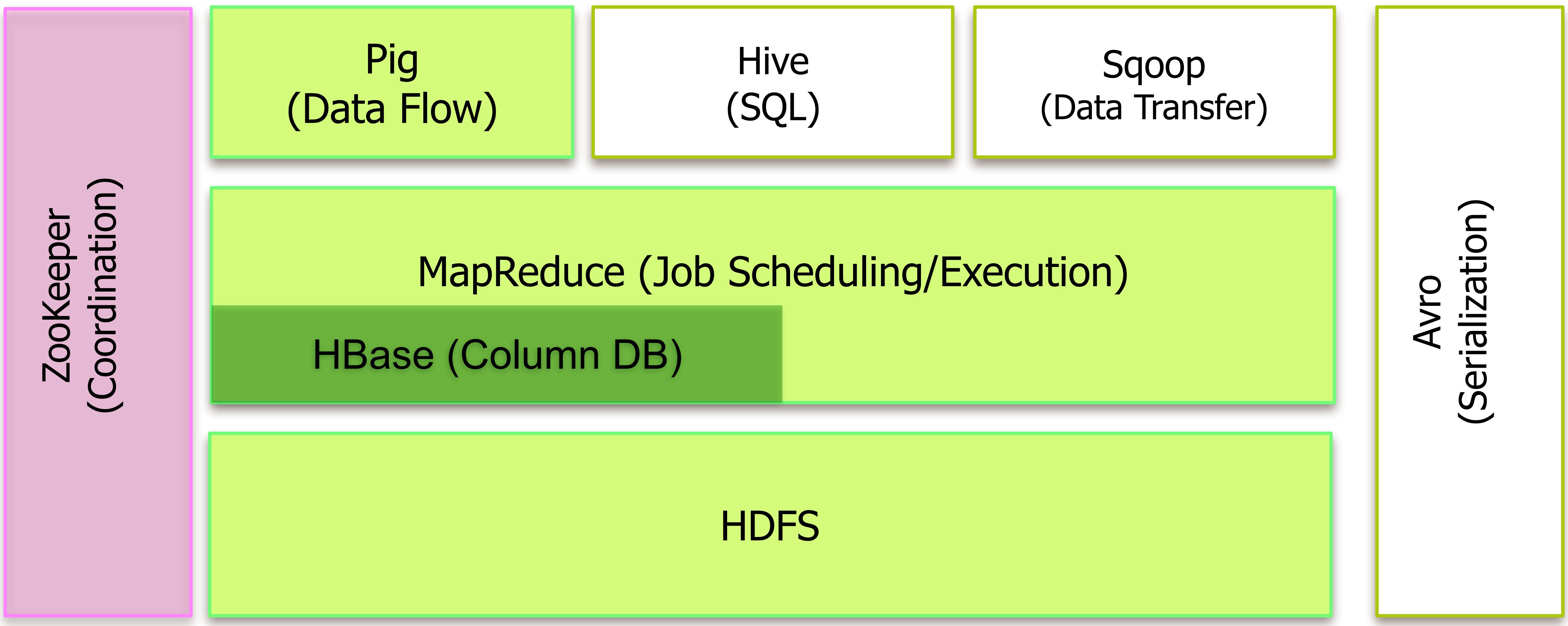
ZooKeeper

A highly-available service for coordinating processes of distributed applications.

- Developed at Yahoo! Research
- Started as sub-project of Hadoop, now a top-level Apache project
- Development is driven by application needs

http://zookeeper.apache.org/

ZooKeeper in the Hadoop ecosystem



Coordination

Proper coordination is not easy.

Fallacies of distributed computing

- The network is reliable
- There is no latency
- The topology does not change
- The network is homogeneous
- The bandwidth is infinite
- …

Motivation

- In the past: a **single** program running on a **single** computer with a **single** CPU
- Today: applications consist of **independent** programs running on a **changing** set of computers
- Difficulty: **coordination** of those independent programs
- Developers have to deal with **coordination logic** and **application logic** at the same time

ZooKeeper: **designed** to relieve developers from writing coordination logic code.

Lets think ….

Question: how do you elect the leader?

application logic

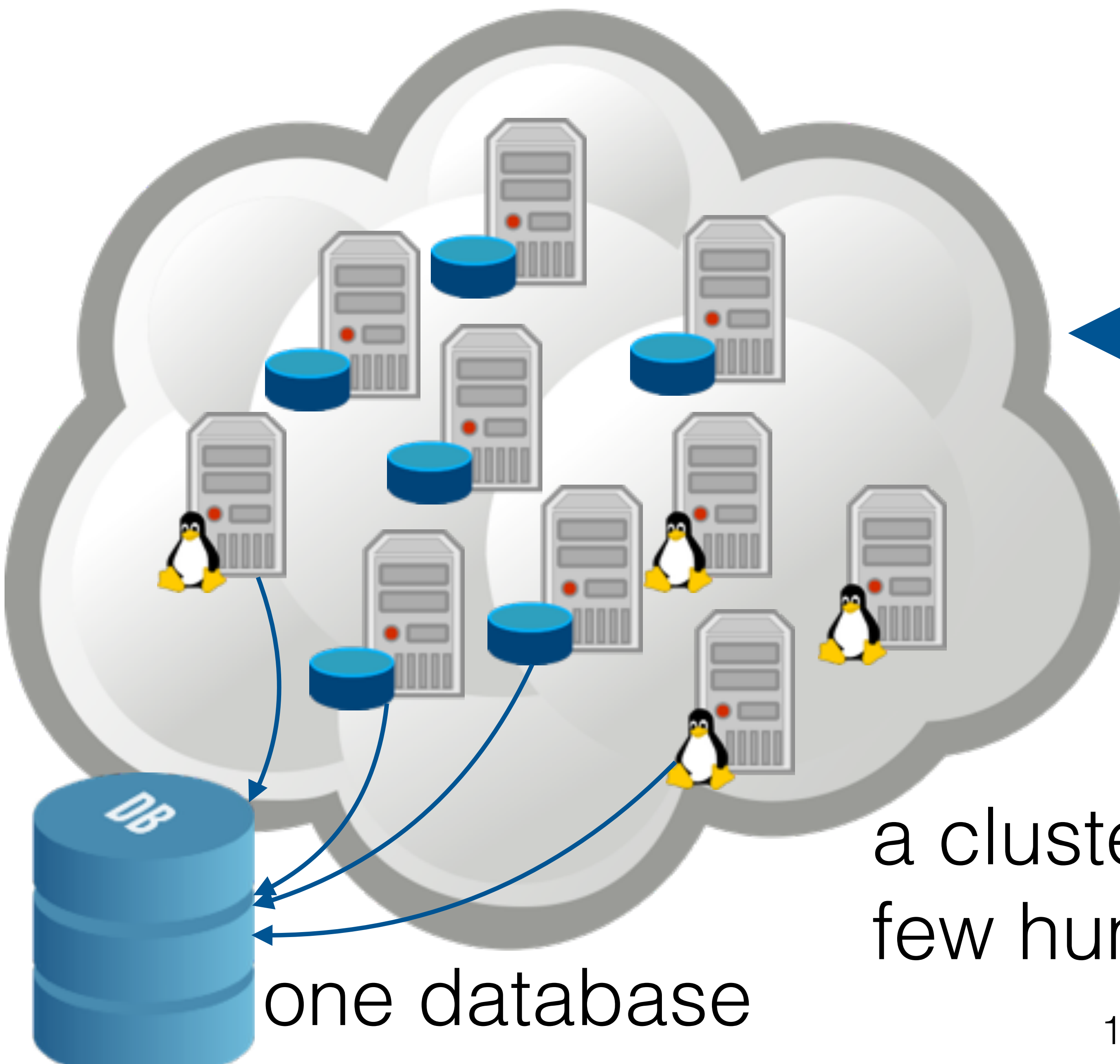
A program that crawls the Web

one machine (the leader) should coordinate the effort

coordination logic

a cluster with a few hundred machines

Question: how do you lock a service?



one database

a cluster with a few hundred machines

A program that crawls the Web

application logic

The progress of the crawl is stored in a DB: who accesses what & when?

coordination logic

Question: how can the configuration be distributed?

configuration file

application logic

A program that crawls the Web

Every worker should start with the same configuration

coordination logic

a cluster with a few hundred machines

Introduction contd.

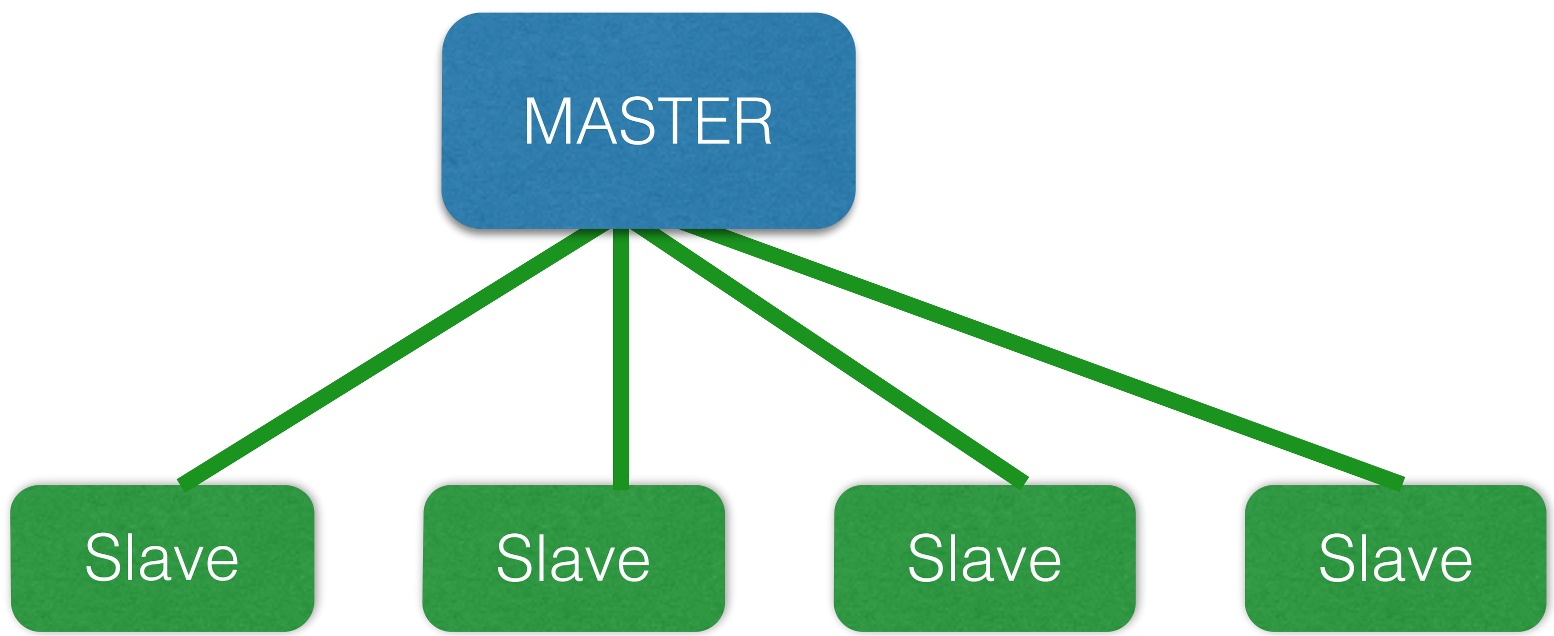
Solution approaches

- Be **specific**: develop a particular service for each coordination task
  - Locking service
  - Leader election
  - etc.

- Be **general**: provide an API to make many services possible

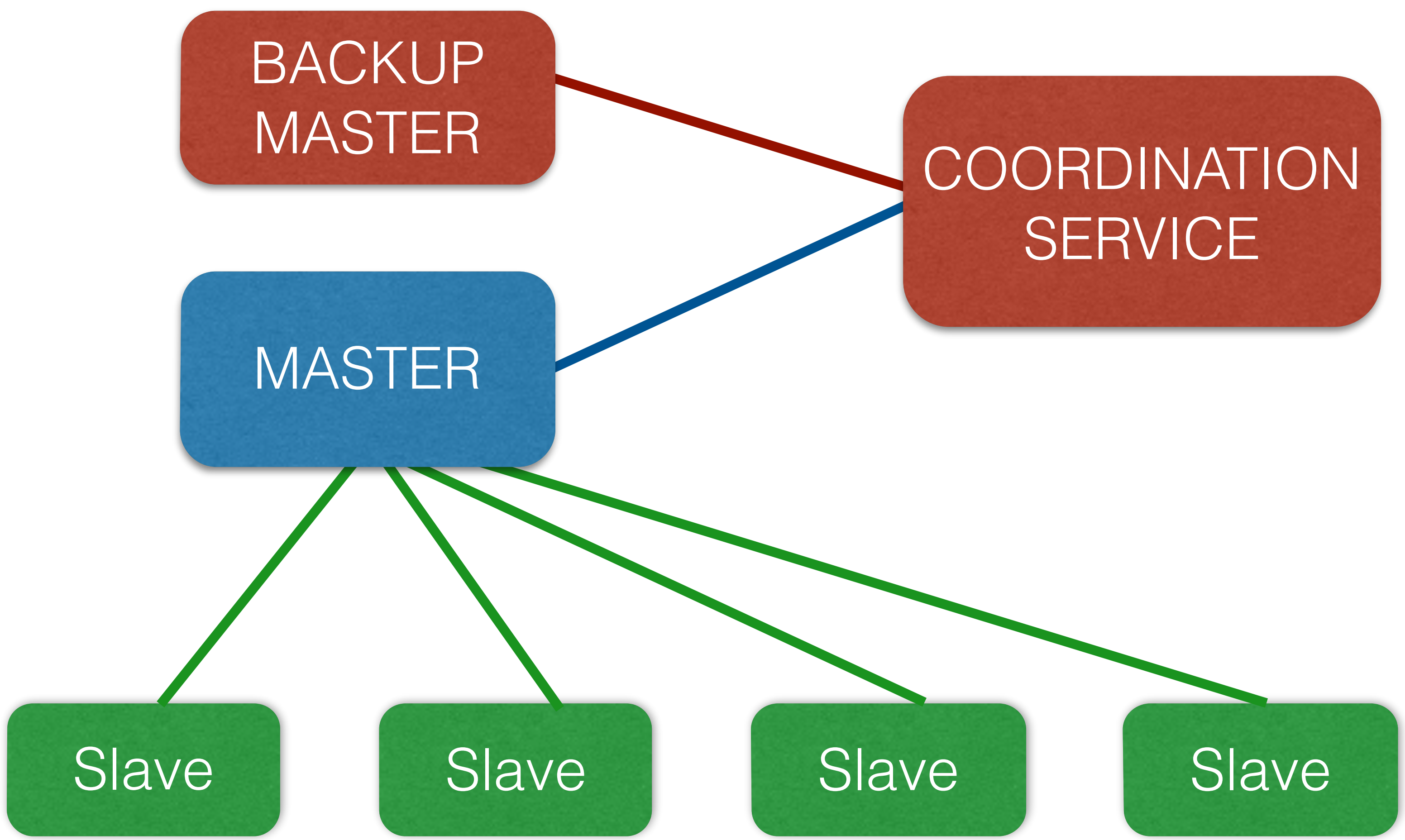
ZooKeeper	The Rest
API that enables application developers to **implement their own primitives easily**	specific primitives are implemented on the server side

How can a distributed system look like?



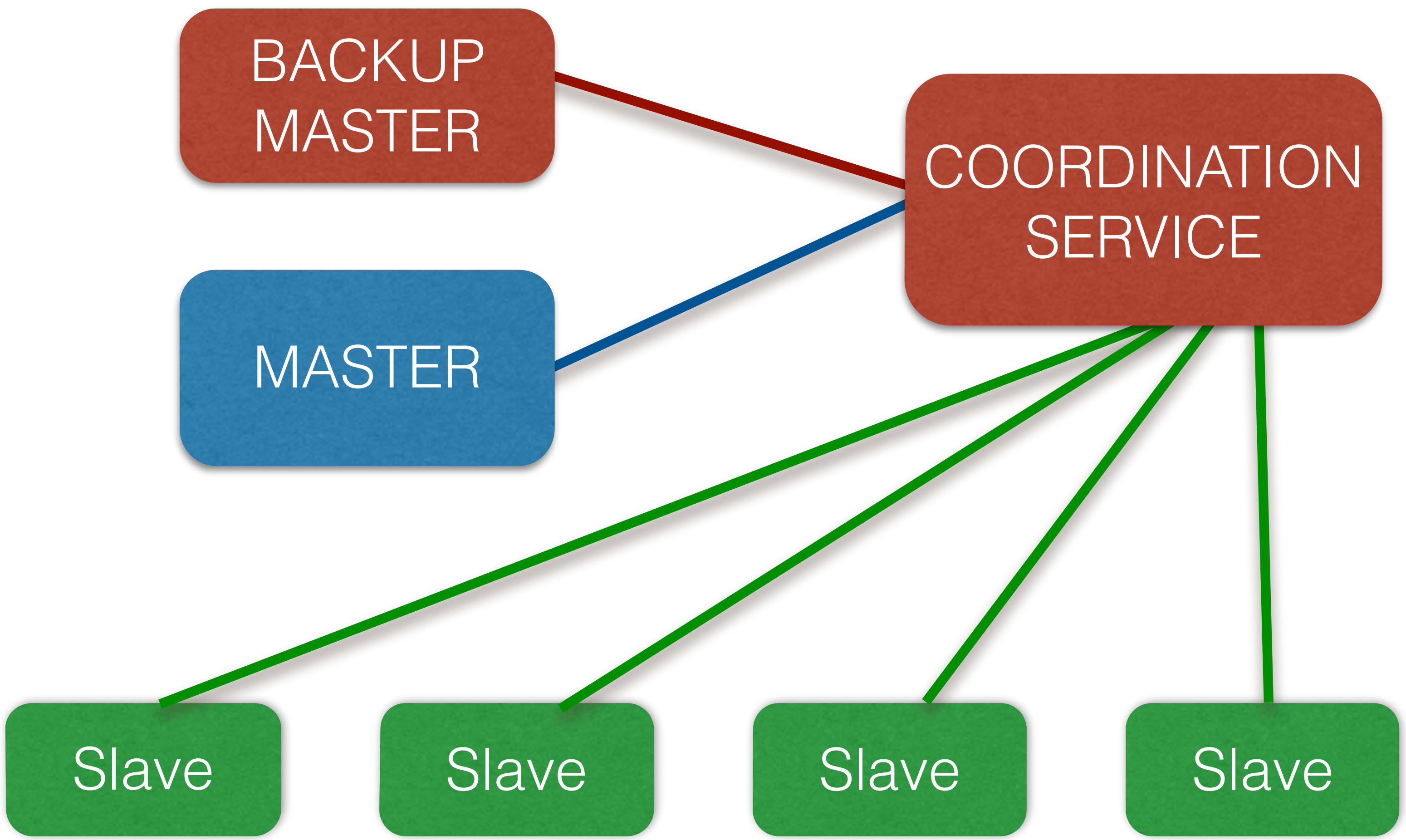
- \+ **simple**
- \- **coordination performed by the master**
- \- **single point of failure**
- \- **scalability**

How can a distributed system look like?



+ **not a single point of failure anymore**
- **scalability is still an issue**

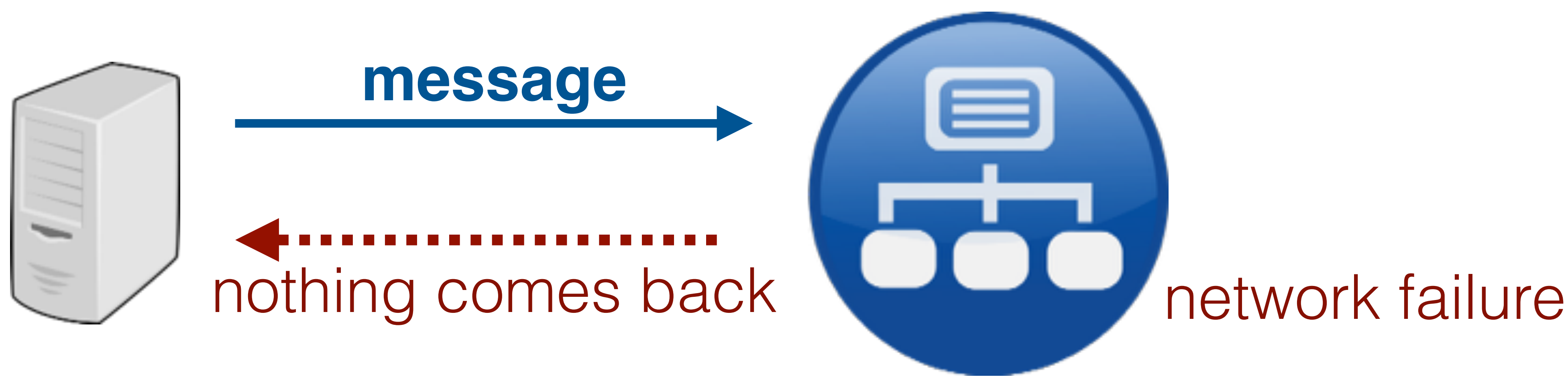
How can a distributed system look like?



+ scalability

What makes distributed system coordination difficult?

Partial failures make application writing difficult



Sender does not know:

- whether the message was received
- whether the receiver's process died before/after processing the message

Typical coordination problems in distributed systems

- **Static configuration**: a list of operational parameters for the system processes
- **Dynamic configuration**: parameter changes on the fly
- **Group membership**: who is alive?
- **Leader election**: who is in charge who is a backup?
- **Mutually exclusive access** to critical resources (locks)
- **Barriers** (supersteps in Giraph for instance)

The ZooKeeper API allows us to implement all these coordination tasks easily.

ZooKeeper principles

ZooKeeper’s design principles

Remember the dining philosophers, forks & deadlocks.

- API is wait-free
  - No blocking primitives in ZooKeeper
  - Blocking can be implemented by a client
  - No deadlocks
- Guarantees
  - Client requests are processed in FIFO order
  - Writes to ZooKeeper are linearisable
- Clients receive notifications of changes before the changed data becomes visible

ZooKeeper's strategy to be fast and reliable

- ZooKeeper service is an ensemble of servers that use replication (high availability)
- Data is cached on the client side:

Example: a client caches the ID of the current **leader** instead of probing ZooKeeper every time.

- What if a new **leader** is elected?
  - Potential solution: polling (not optimal)
  - **Watch mechanism**: clients can watch for an update of a given data object

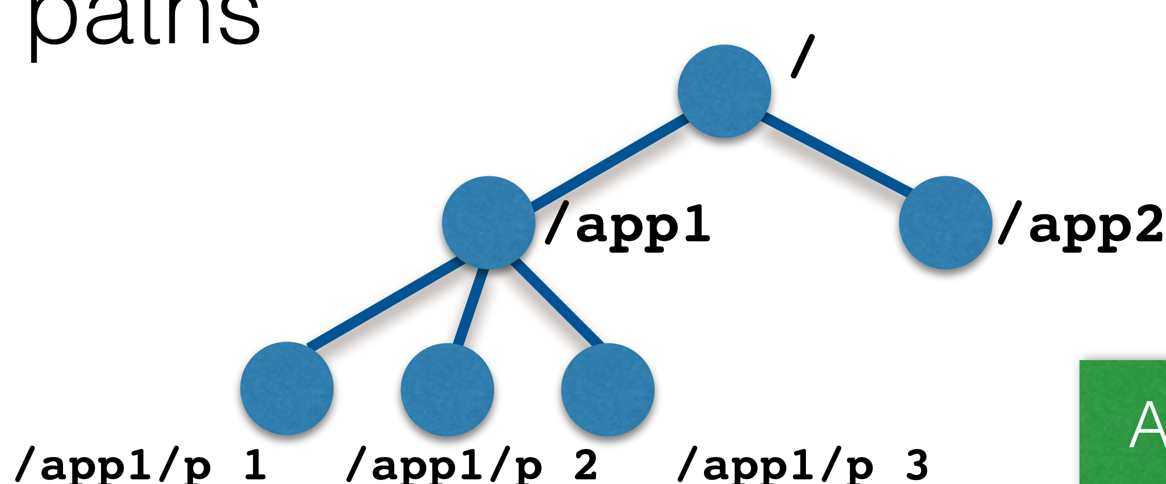
ZooKeeper is optimised for read-dominant operations!

ZooKeeper terminology

- **Client**: user of the ZooKeeper service
- **Server**: process providing the ZooKeeper service
- **znode**: **in-memory** data node in ZooKeeper, organised in a hierarchical namespace (the data tree)
- **Update/write**: any operation which modifies the state of the data tree
- Clients establish a **session** when connecting to ZooKeeper

ZooKeeper's data model: filesystem

- znodes are organised in a hierarchical namespace
- znodes can be manipulated by clients through the ZooKeeper API
- znodes are referred to by UNIX style file system paths



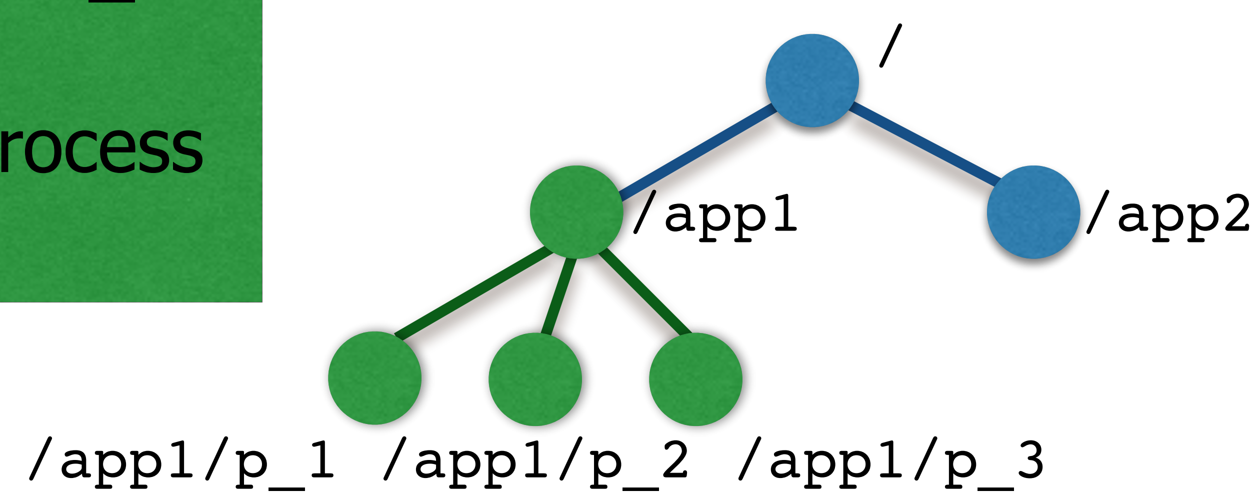
All znodes store **data (file like)** & can have **children (directory like)**.

znodes

- znodes are not designed for general data storage (usually require storage in the order of kilobytes)

- znodes map to abstractions of the client application

Group membership protocol:
Client process `pi` creates znode `p_i` under `/app1`.
`/app1` persists as long as the process is running.



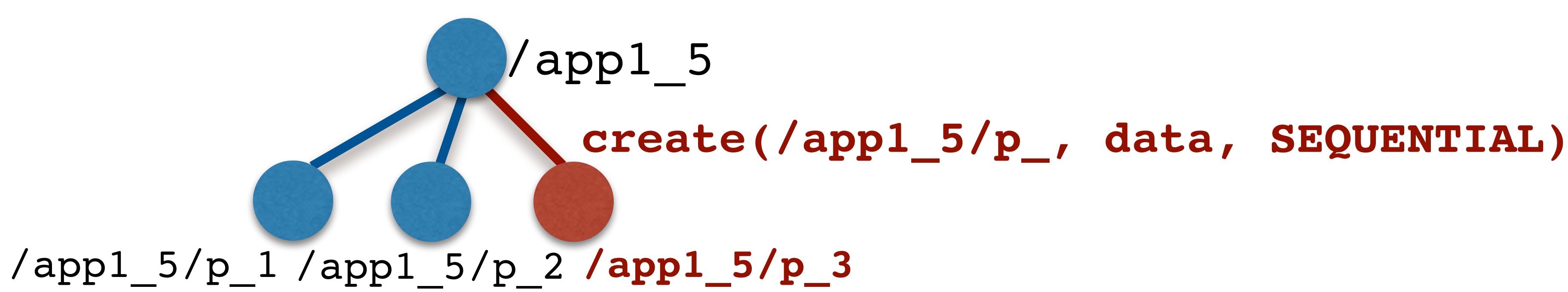
znode flags

- Clients manipulate znodes by creating and deleting them

ephemeral (Greek): passing, short-lived

- **EPHEMERAL** flag: clients create znodes which are deleted at the end of the client's session

- **SEQUENTIAL** flag: monotonically increasing counter appended to a znode's path;
  counter value of a new znode under a parent is always larger than value of existing children



znodes & watch flag

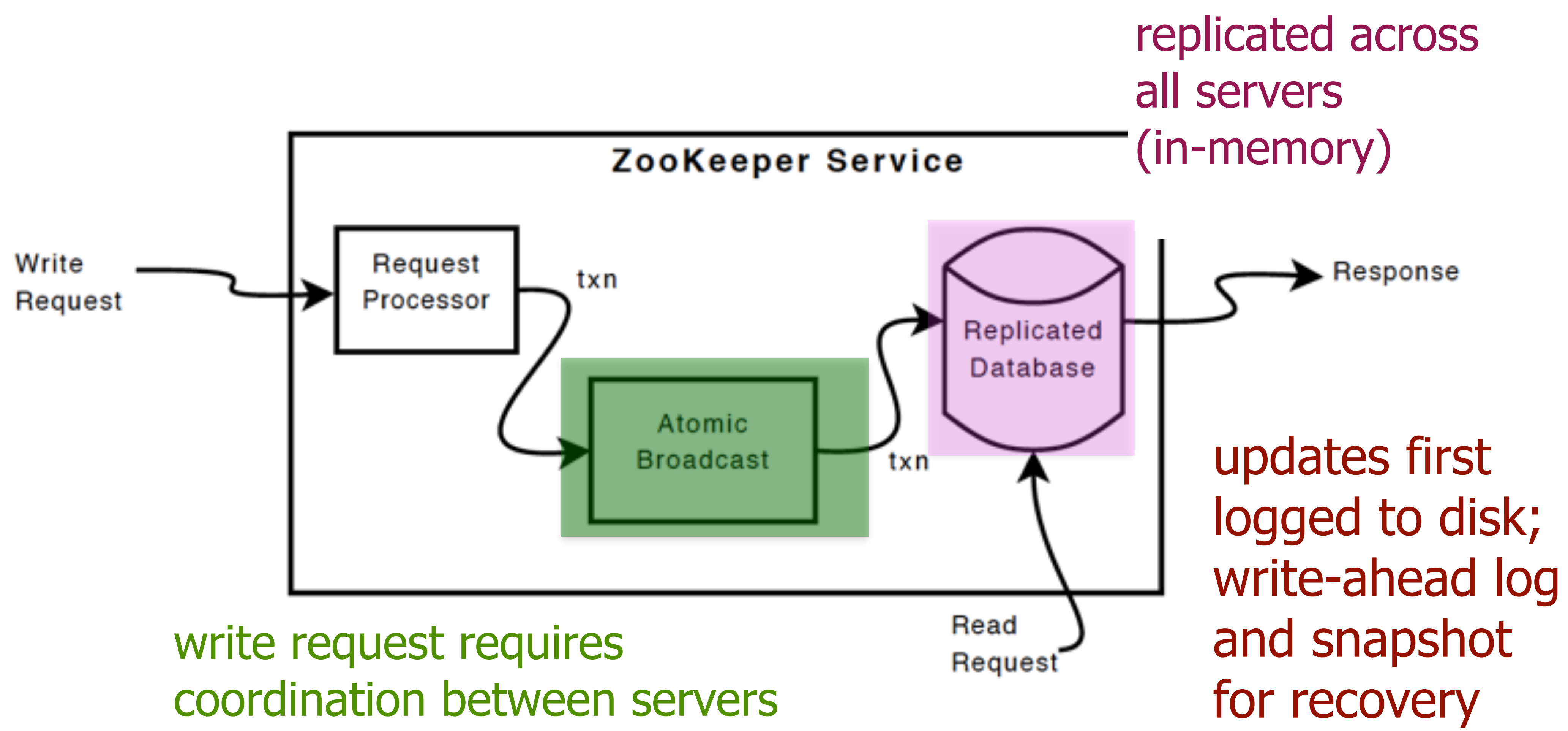
- Clients can issue read operations on znodes with a watch flag
- Server **notifies** the client when the information on the znode has changed
- Watches are **one-time** triggers associated with a session (unregistered once triggered or session closes)
- Watch notifications indicate the change, not the new data

Sessions

- A client connects to ZooKeeper and initiates a session
- Sessions have an associated **timeout**
- ZooKeeper considers a client faulty if it does not receive anything from its session for more than that timeout
- Session ends: faulty client or explicitly ended by client

A few implementation details

ZooKeeper data is replicated on each server that composes the service



Source: http://bit.ly/13VFohW

A few implementation details

- ZooKeeper server services clients
- Clients connect to exactly one server to submit requests
    - read requests served from the local replica
    - write requests are processed by an agreement protocol (an elected server leader initiates processing of the write request)

Lets work through
some examples

No partial read/writes (no **`open`**, **`seek`** or **`close`** methods).

ZooKeeper API

- `String create(path, data, flags)`
  - creates a znode with path name path, stores data in it and sets flags (ephemeral, sequential)
- `void delete(path, version)`
  - deletes the anode if it is at the expected version
- `Stat exists(path, watch)`
  - watch flag enables the client to set a watch on the znode
- `(data, Stat) getData(path, watch)`
  - returns the data and meta-data of the znode
- `Stat setData(path, data, version)`
  - writes data if the version number is the current version of the znode
- `String[] getChildren(path, watch)`

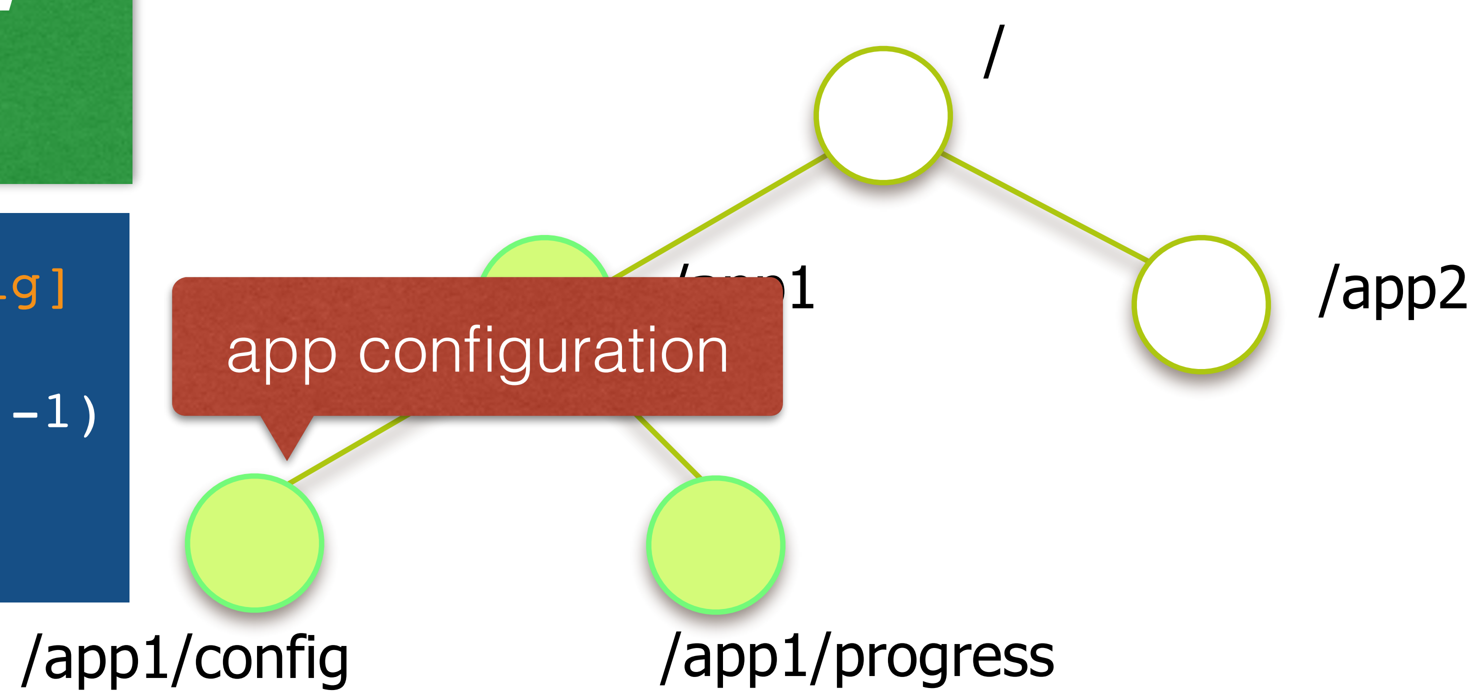
Note: no `createLock()` or similar methods.

Example: configuration

- `String create(path, data, flags)`
- `void delete(path, version)`
- `Stat exists(path, watch)`
- `(data, Stat) getData(path, watch)`
- `Stat setData(path, data, version)`
- `String[] getChildren(path, watch)`

Questions:
1. How does a **new** worker query ZK for a configuration?
2. How does an administrator **change** the configuration **on the fly**?
3. How do the workers read the **new** configuration?

```
[configuration stored in /app1/config]
1. getData(/app1/config,true)
2. setData(/app1/config/config_data,-1)
[notify watching clients]
3. getData(/app1/config,true)
```

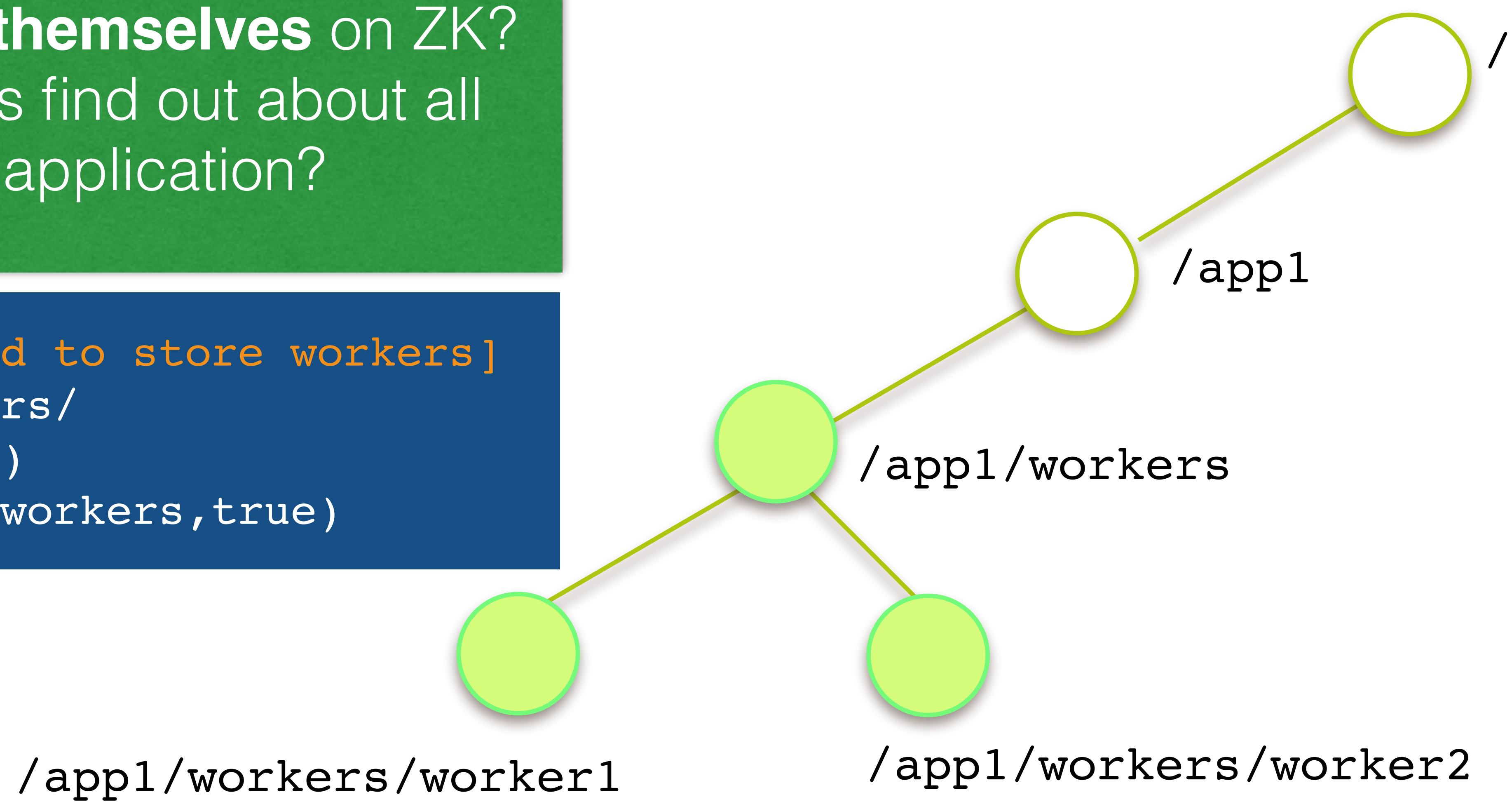


Example: group membership

- `String create(path, data, flags)`
- `void delete(path, version)`
- `Stat exists(path, watch)`
- `(data, Stat) getData(path, watch)`
- `Stat setData(path, data, version)`
- `String[] getChildren(path, watch)`

Questions:
1. How can all workers (slaves) of an application **register themselves** on ZK?
2. How can a process find out about all **active** workers of an application?

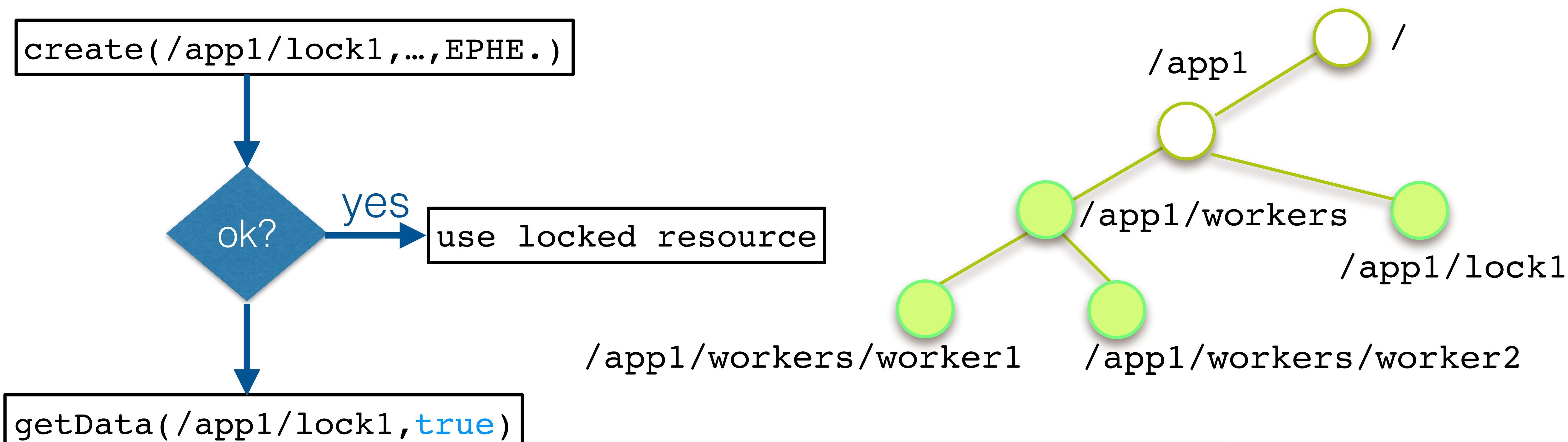
```
[a znode is designated to store workers]
1. create(/app1/workers/
worker,data,EPHEMERAL)
2. getChildren(/app1/workers,true)
```



Example: simple locks

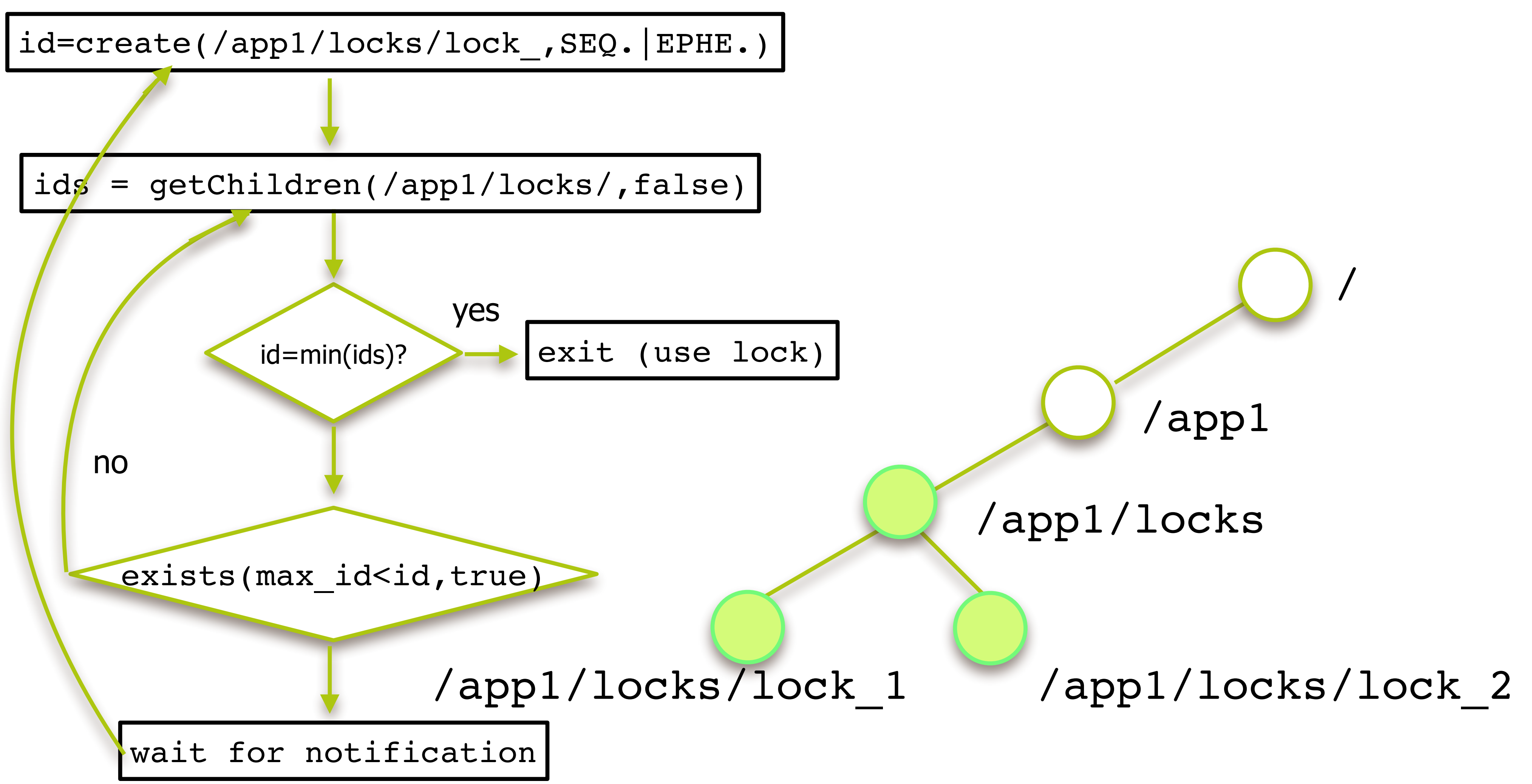
- `String create(path, data, flags)`
- `void delete(path, version)`
- `Stat exists(path, watch)`
- `(data, Stat) getData(path, watch)`
- `Stat setData(path, data, version)`
- `String[] getChildren(path, watch)`

Question:
1. How can all workers of an application use a single resource through a lock?



all processes compete at all times for the lock

Example:
locking without herd effect

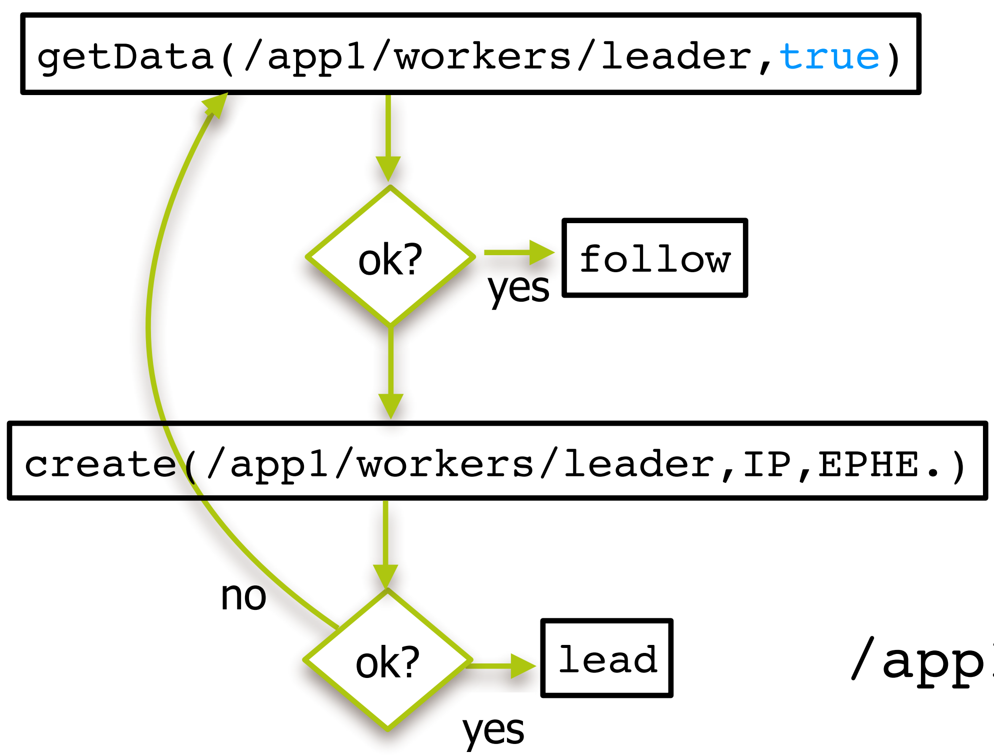


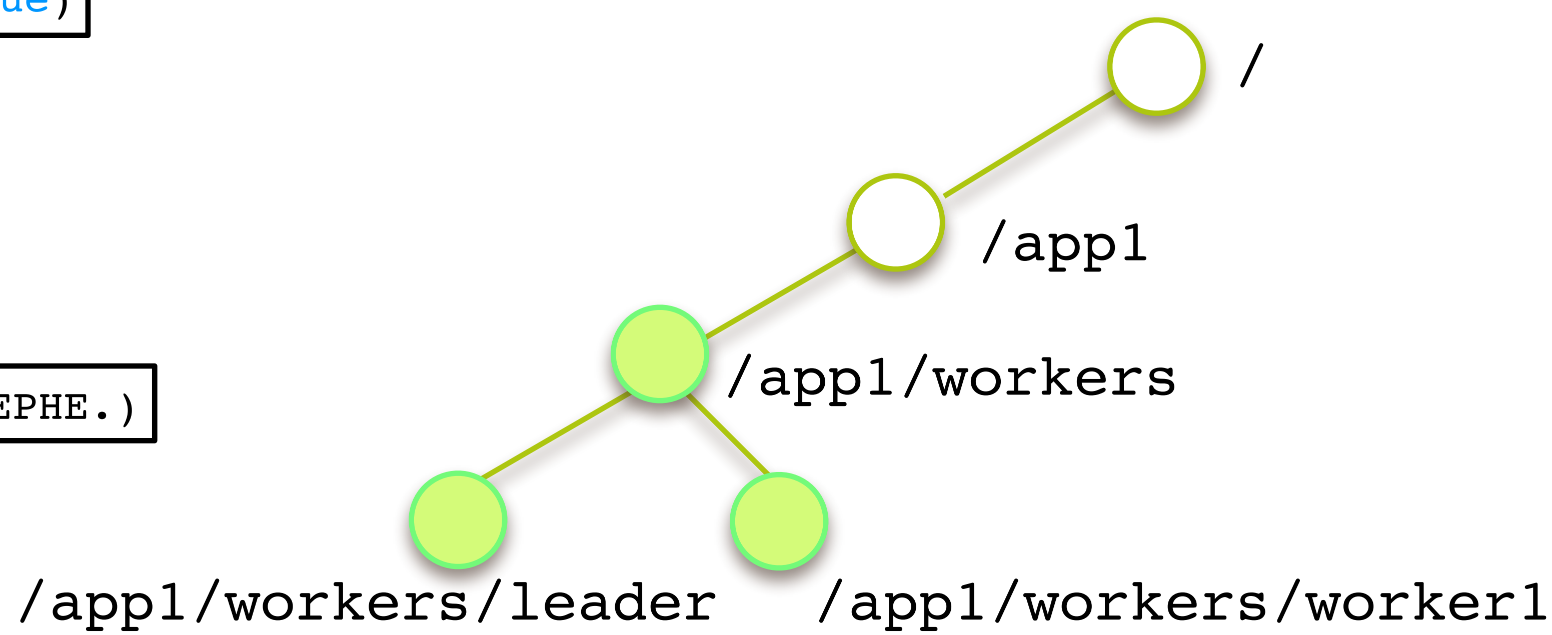
Question:
1. How can all workers of an application use a single resource through a lock?

Example: leader election

- `String create(path, data, flags)`
- `void delete(path, version)`
- `Stat exists(path, watch)`
- `(data, Stat) getData(path, watch)`
- `Stat setData(path, data, version)`
- `String[] getChildren(path, watch)`

Question:
1. How can all workers of an application elect a leader among themselves?





if the leader dies, elect again ("herd effect")

ZooKeeper applications

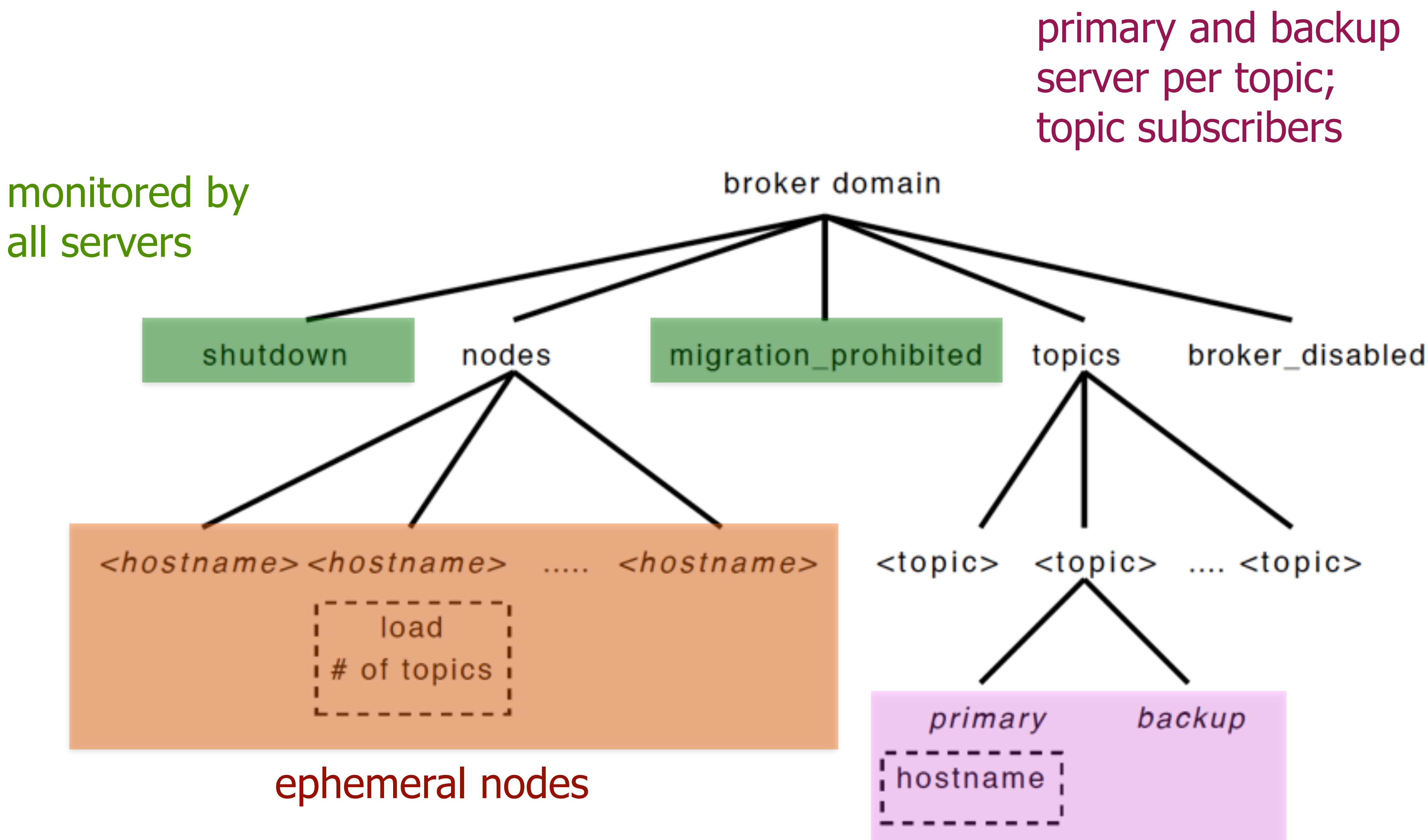
The Yahoo! fetching service

- Fetching Service is part of Yahoo!'s crawler infrastructure
- Setup: master commands page-fetching processes
  - Master provides the fetchers with configuration
  - Fetchers write back information of their status and health
- Main advantage of ZooKeeper:
  - Recovery from master failures
  - Guaranteed availability despite failures
- Used primitives of ZK: configuration metadata, leader election

Yahoo! message broker

- A distributed publish-subscribe system
- The system manages thousands of topics that clients can publish messages to and receive messages from
- The topics are distributed among a set of servers to provide scalability
- Used primitives of ZK: configuration metadata (to distribute topics), failure detection and group membership

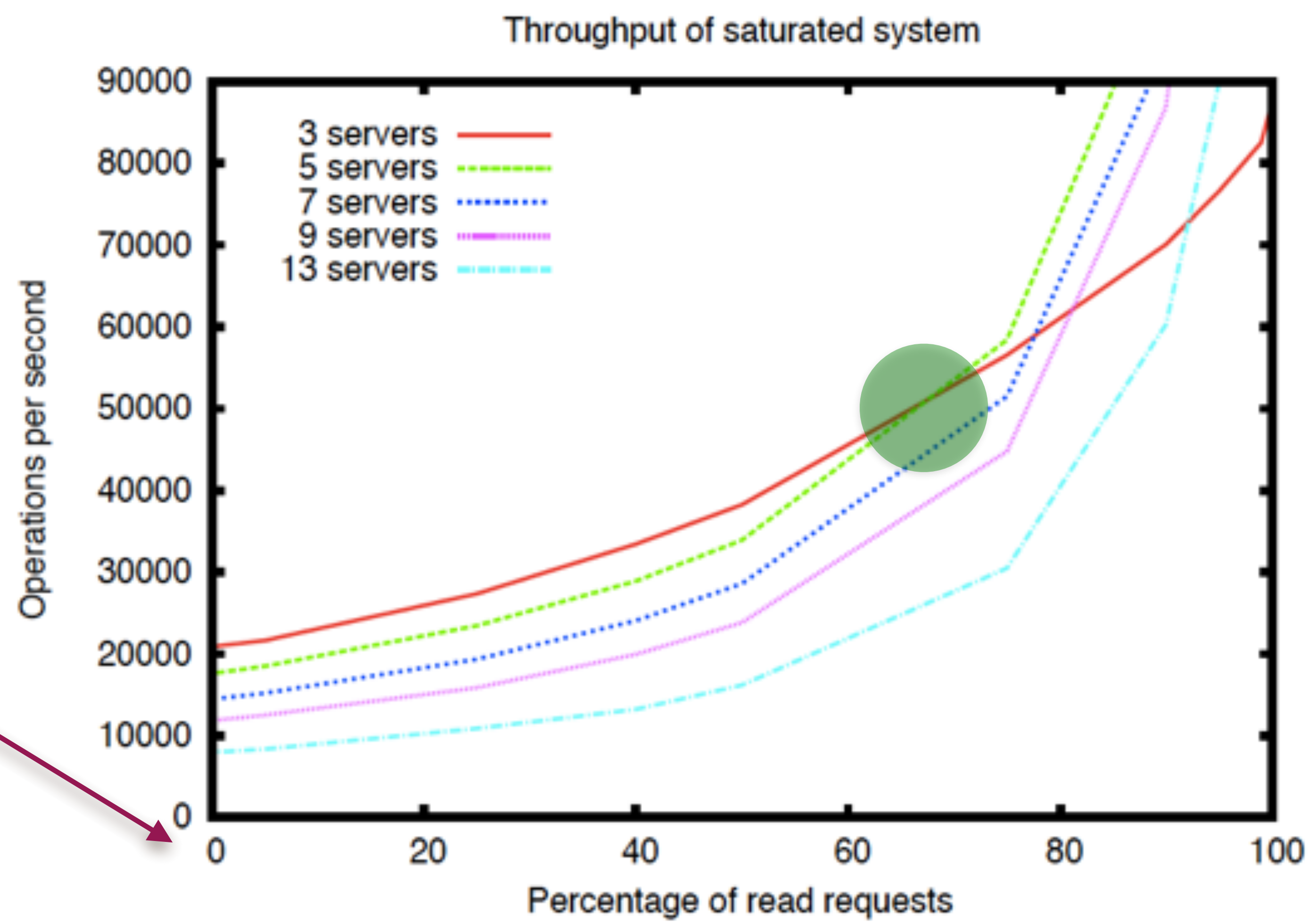
Yahoo! message broker



Source: http://bit.ly/13VFohW

Throughput

Setup: 250 clients, each client has at least 100 outstanding requests (read/write of 1K data)



crossing eventually always happens

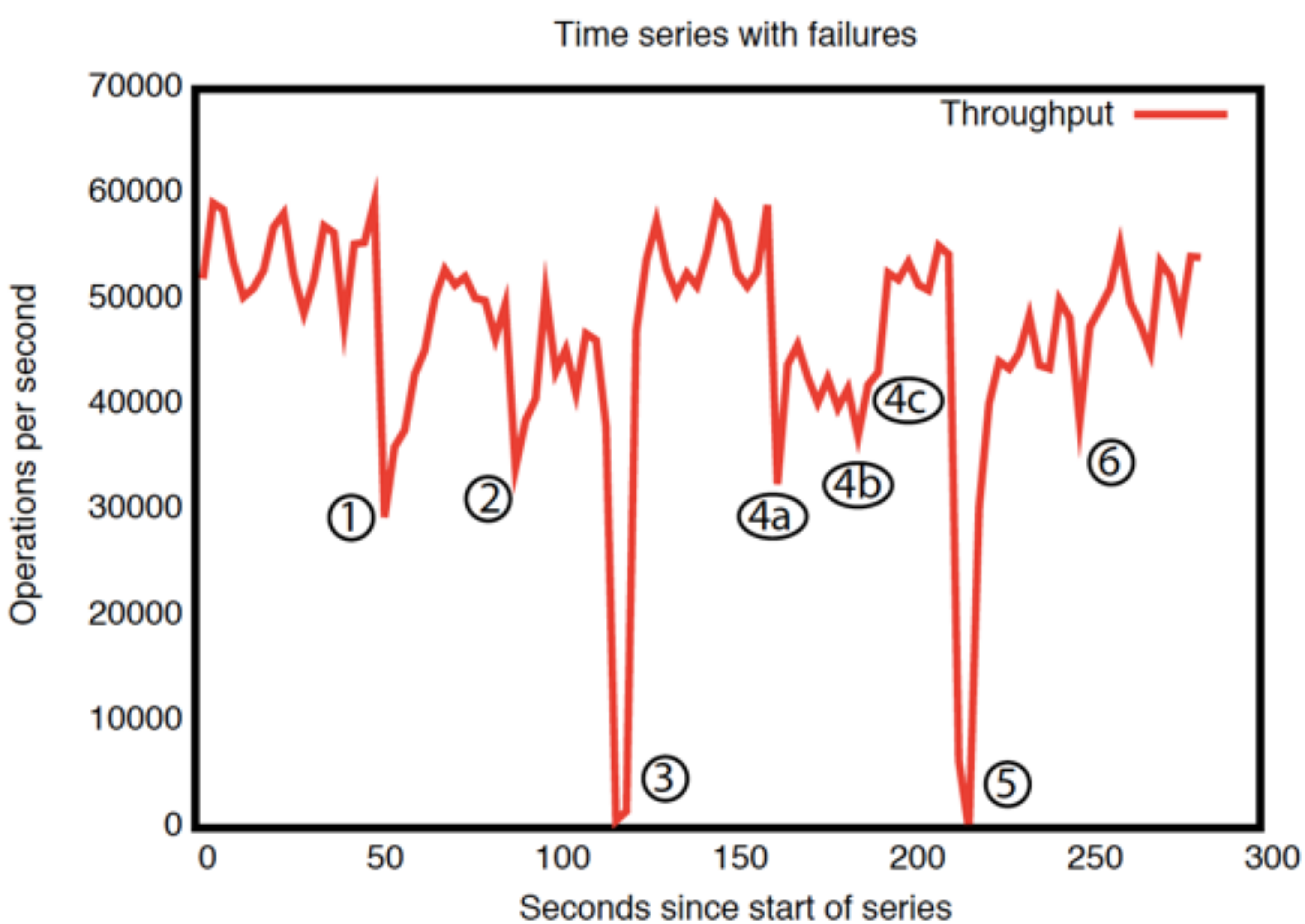
only write requests

only read requests

Source: http://bit.ly/13VFohW

Recovery from failure

Setup: 250 clients, each client has at least 100 outstanding requests (read/write of 1K data); 5 ZK machines (1 leader, 4 followers), 30% writes



(1) failure & recovery of a follower
(2) failure & recovery of a different follower
(3) failure of the leader
(4) failure of followers (a,b), recovery at (c)
(5) failure of the leader
(6) recovery of the leader

Source: http://bit.ly/13VFohW

References

- [book] *ZooKeeper* by Junqueira & Reed, 2013 (available on the TUD campus network)

- [paper] *ZooKeeper: Wait-free coordination for Internet-scale systems* by Hunt et al., 2010; http://bit.ly/13VFohW

Summary

- Whirlwind tour through ZooKeeper
- Why do we need it?
- Data model of ZooKeeper: znodes
- Example implementations of different coordination tasks

That’s it!

In 7 weeks we covered …

- Data streaming
- MapReduce
- Pig
- HBase
- Giraph
- ZooKeeper

All major “big data” technologies in use today.

These technologies are still continuously changing.

New ones appear all the time, e.g. Dremel

What about the exam?

- Multiple choice & open questions
- Take a hint from the assignments, the quizzes and the in-lecture Q&A sessions
- Take a look at last year's exam and resit
- Nobody asked for a Dutch exam, answers are expected in English!

THE END