Lecture 11: Zookeeper – A Distributed Coordination Paradigm

CSCI4180

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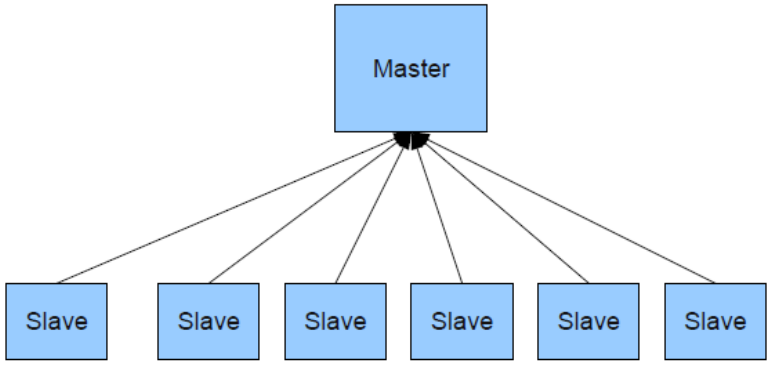
Outline

- Why Zookeeper?
- Zookeeper data model
- Zookeeper programming basics
- Zookeeper applications
  - Distributed lock service
  - Distributed barrier
  - Distributed producer-consumer queue
  - Distributed leader election

Classic Distributed Systems

- Work assignment
  - Master assigns work
  - Workers execute tasks assigned by master



- What happens if master crashes?
  - Single point of failure
  - No work is assigned → a new master is needed
- What happens if one worker crashes?
  - Okay… but fails if dependencies exist
  - Need to detect crashed workers

HBase: Recap

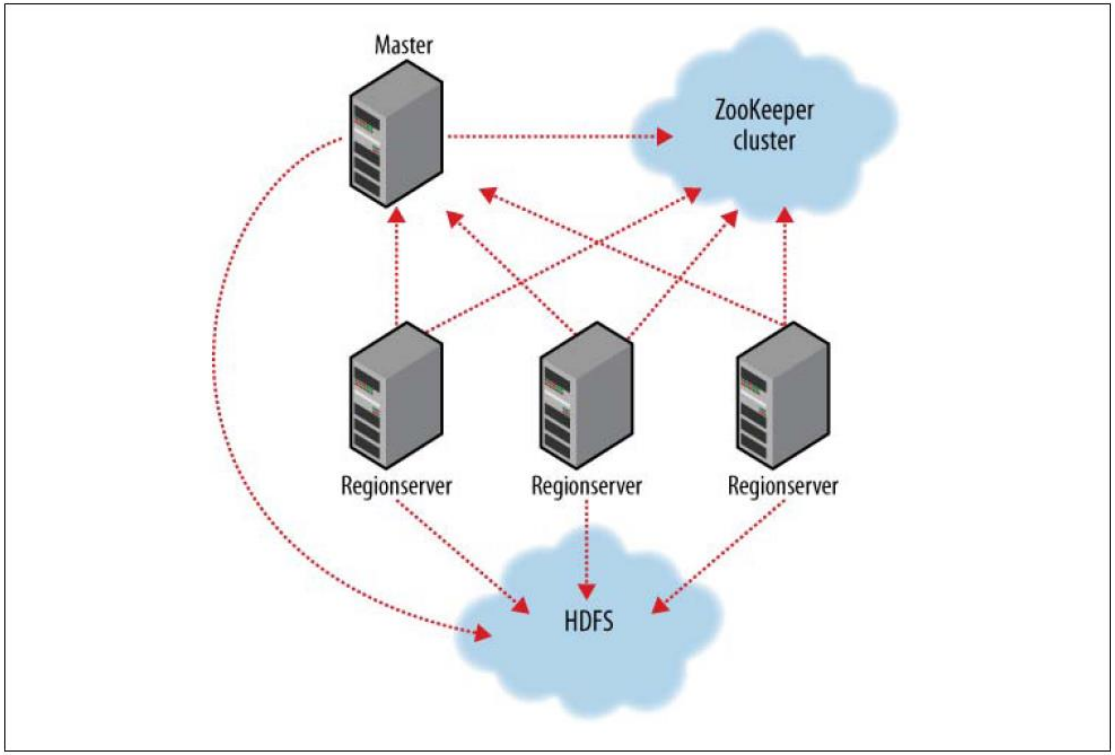


Figure 13-1. HBase cluster members

- HBase depends on **ZooKeeper** and by default it manages a ZooKeeper instance as the authority on cluster state.

HBase: Recap

- How Zookeeper helps HBase?
  - **Crash recovery**: assignment of regions is mediated via ZooKeeper in case participating servers crash mid-assignment.
  - **Location management**: HBase clients navigate the ZooKeeper hierarchy to learn cluster attributes such as server locations

What is Zookeeper?

- **Zookeeper** is a highly-available, high-performance coordination service:
  - *Key features*: scalable, distributed, configuration, consensus, group membership, leader election, naming
- It is much more than just a distributed lock server!!

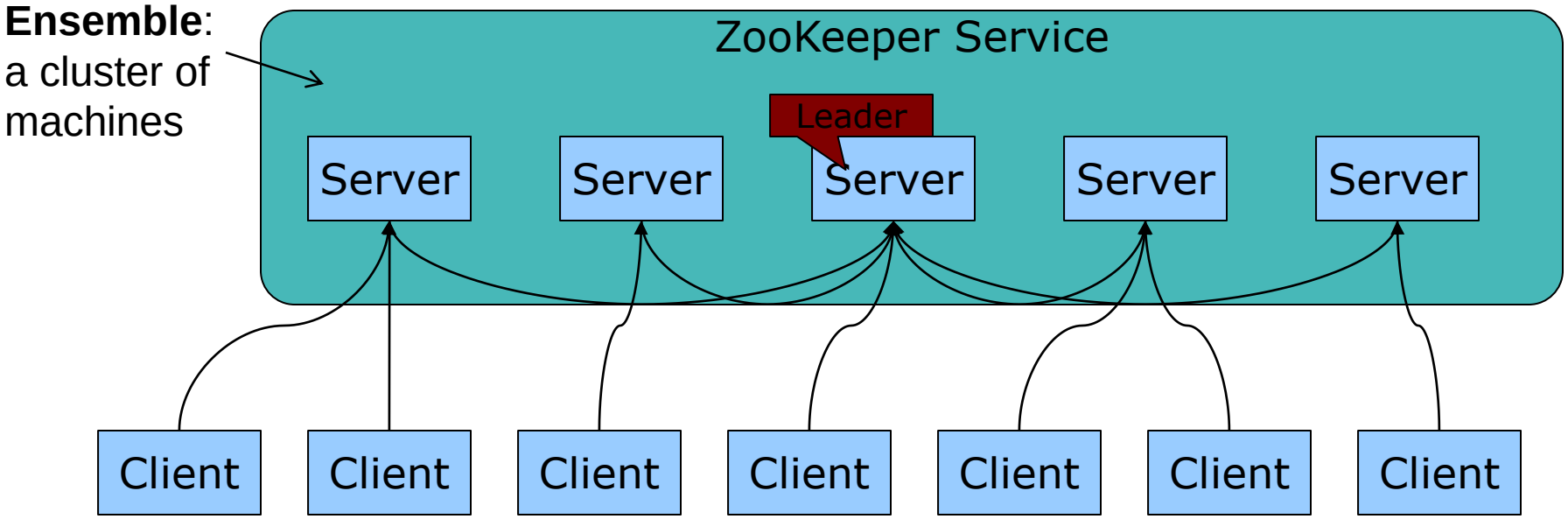
What is Zookeeper?

- File API without partial reads/writes
- No renames
- Ordered updates and strong persistence guarantees
- Conditional updates (version)
- Watches for data changes
- Ephemeral nodes
- Generated file names

Zookeeper Guarantees

- Clients will never detect old data.
- Clients will get notified of a change to data they are watching within a bounded period of time.
- All requests from a client will be processed in order.
- All results received by a client will be consistent with results received by all other clients.

Zookeeper Overview



- All servers store a copy of the data (in memory)
- A leader is elected at startup
- Followers service clients, all updates go through leader
- Update responses are sent when a majority of servers have persisted the change

Zookeeper Overview

- ZooKeeper uses a protocol called **Zab** that runs in two phases
  - Leader election:
    - Select a member called the *leader*, and have other machines be *followers*. This phase is finished once a majority (or *quorum*) of followers have synchronized their state with the leader.
  - Atomic broadcast:
    - All write requests are forwarded to the leader, which broadcasts the update to the followers. The leader commits the update if a majority agree
    - Consensus is designed to be **atomic**, so a change either succeeds or fails.

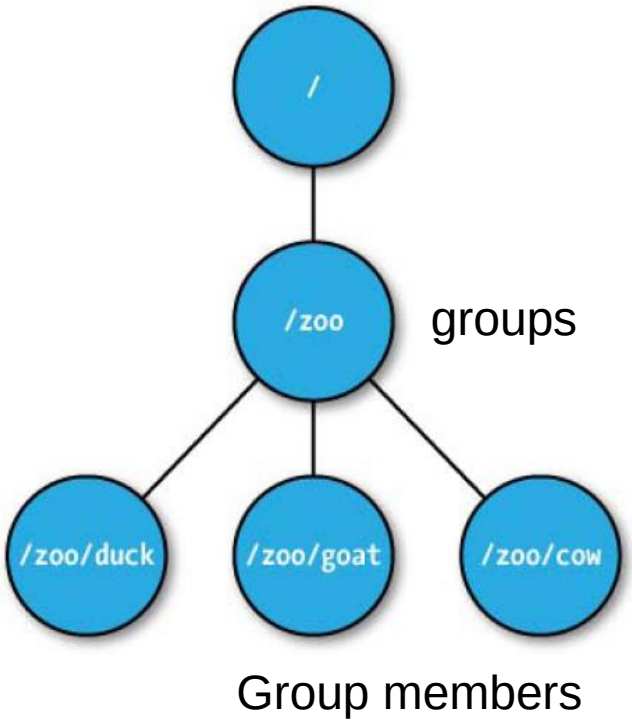
Zookeeper Overview

- Advanced notes:
  - Zookeeper's Zab is different from Paxos, which is a group coordination service
  - Zookeeper is different from Google Chubby Lock's service, as it is more lightweight

- Details: see Hunt's paper

Data Model

- A client can create a **znode**, read and write data to **znode** inside Zookeeper.
- Znodes are organized in a directory-like structure.
  - Call the intermediate nodes groups.
  - Call the leaf nodes group members.
  - Of course, it is not restricted to 3 levels (in the figure).



Data Model

- Think of Zookeeper as a “file system”
  - Hierarchical namespace: easy for management
- Znodes are not designed for general data storage. Instead, znodes map to abstractions of the client application, e.g., metadata
- However, znodes can store data
  - A maximum of 1MB by default

Data Model

- Zookeeper doesn't use handles to access znodes
  - Use absolute paths (e.g., /zoo/cow) directly
  - Saves overhead of calling open() or close()
- Data access is **atomic**
  - A client reading the data stored at a znode will never receive only some of the data; either the data will be delivered in its entirety, or the read will fail.

Data Model: Types of znodes

- **Persistent (or regular) znodes**
  - Clients manipulate persistent znodes by creating and deleting them explicitly
  - Usually represent groups, or intermediate nodes
- **Ephemeral znodes**
  - Clients create such znodes, and they either delete them explicitly, or let the system remove them automatically when the session that creates them terminates (deliberately or due to a failure).
  - Sessions have an associated timeout. Zookeeper considers a client faulty if it does not receive anything from its session for more than that timeout.
  - Usually represent the existence of an client, i.e., leaf node

Data Model: Watches

- **Watches** allow clients to get notifications when a znode changes
  - A client may wait on the creation of a znode. If the znode is created, the watch is triggered
- Watchers are triggered **only once**
  - Clients need to reregister the watch to receive multiple notifications

Data Model: znode creation

- **PERSISTENT & EPHEMERAL**
  - The naming of such znodes has to be **specific** and **unique**.
  - If a client with a duplicated pathname is joining a group, it will be rejected.
- **PERSISTENT_SEQUENTIAL & EPHEMERAL_SEQUENTIAL**
  - The naming of such znodes contains a client-defined prefix and the ***monotonic increasing, numerical postfix***: generated by the Zookeeper service.
  - E.g., creating a sequential znode using the name "**/zoo/fubar**", the resulting name will be: "**/zoo/fubar001**"
  - Another client using the **same name** "**/zoo/fubar**" to create a sequential znode **will not be rejected**, and the resulting name will be "**/zoo/fubar002**".

Client APIs

- **create(path, data, flags)**:
  - Creates a znode with pathname; flag specifies the type of znode
- **delete(path, version)**:
  - Deletes the znode path if that znode is at the expected version
- **exists(path, watch)**:
  - Returns true if the znode with pathname exists
- **getData(path, watch) / setData(path, data, version)**
  - Reads/writes data in the znode
- **getChildren(path, watch)**:
  - Returns the set of names of the children of a znode
- **sync()**:
  - Waits for all updates pending at the start of the operation to propagate to the server that the client is connected to

Installing Zookeeper

- Install zookeeper-3.4.3
  - Set the path to “/usr/local/zookeeper-3.4.3/bin”
  - Create zoo.cfg in “/usr/local/zookeeper-3.4.3/conf”

```
tickTime=2000
dataDir=/app/zookeeper
clientPort=2181
```

- Start the Zookeeper service

```
[hduser@localhost zookeeper-hduser]$ zkServer.sh start
JMX enabled by default
Using config: /usr/local/zookeeper-3.4.3/bin/../conf/zoo.cfg
Starting zookeeper ... STARTED
[hduser@localhost zookeeper-hduser]$ echo ruok | nc localhost 2181
imok[hduser@localhost zookeeper-hduser]$
```

Compiling Zookeeper Programs

- Compiling

```
export CLASSPATH=/usr/local/zookeeper-3.4.3/lib/*:/usr/local/zookeeper-
3.4.3/*:.
javac [Program Name]
```

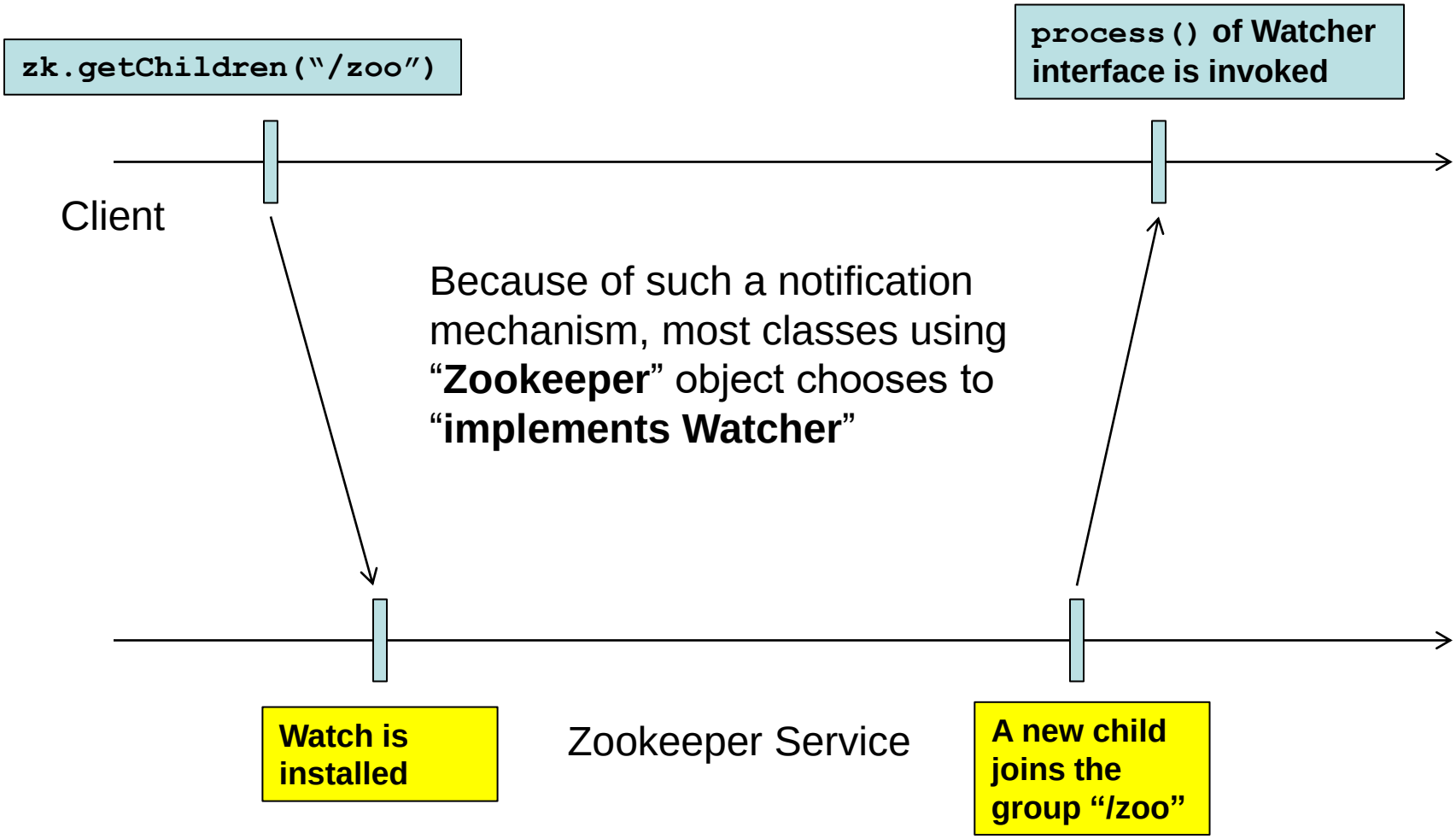
- Run

```
export CLASSPATH=/usr/local/zookeeper-3.4.3/lib/*:/usr/local/zookeeper-
3.4.3/*:.
java [Class name] [Args]
```

Zookeeper Programming

- **Zookeeper object**:
  - The main object controlling every aspect of Zookeeper
  - Instantiate this object when connecting to Zookeeper.
  - Using the object methods, you can:
    - create/delete znodes
    - get and set znode data
    - query a znode's child list
- **Watcher interface**:
  - It is the Zookeeper-specific event. It calls back when:
    - the concerned node is created/deleted.
    - the concerned node has its list of children changed.
- See demos: CreateGroup.java, DeleteGroup.java, JoinGroup.java, WatchGroup.java

Watcher Interface



Watcher Interface

- Watch creation
  - There are 3 methods that install watches
    - **`Zookeeper.exists()`**
    - **`Zookeeper.getChildren()`**
    - **`Zookeeper.getData()`**
  - All functions are non-blocking calls, meaning that they return the answers immediately
    - A separate thread will listen to the watcher and be triggered to execute process().
- Recall that the watch is installed and is triggered once only
  - Need repetitive calls to one of the above 3 methods to install the watch again

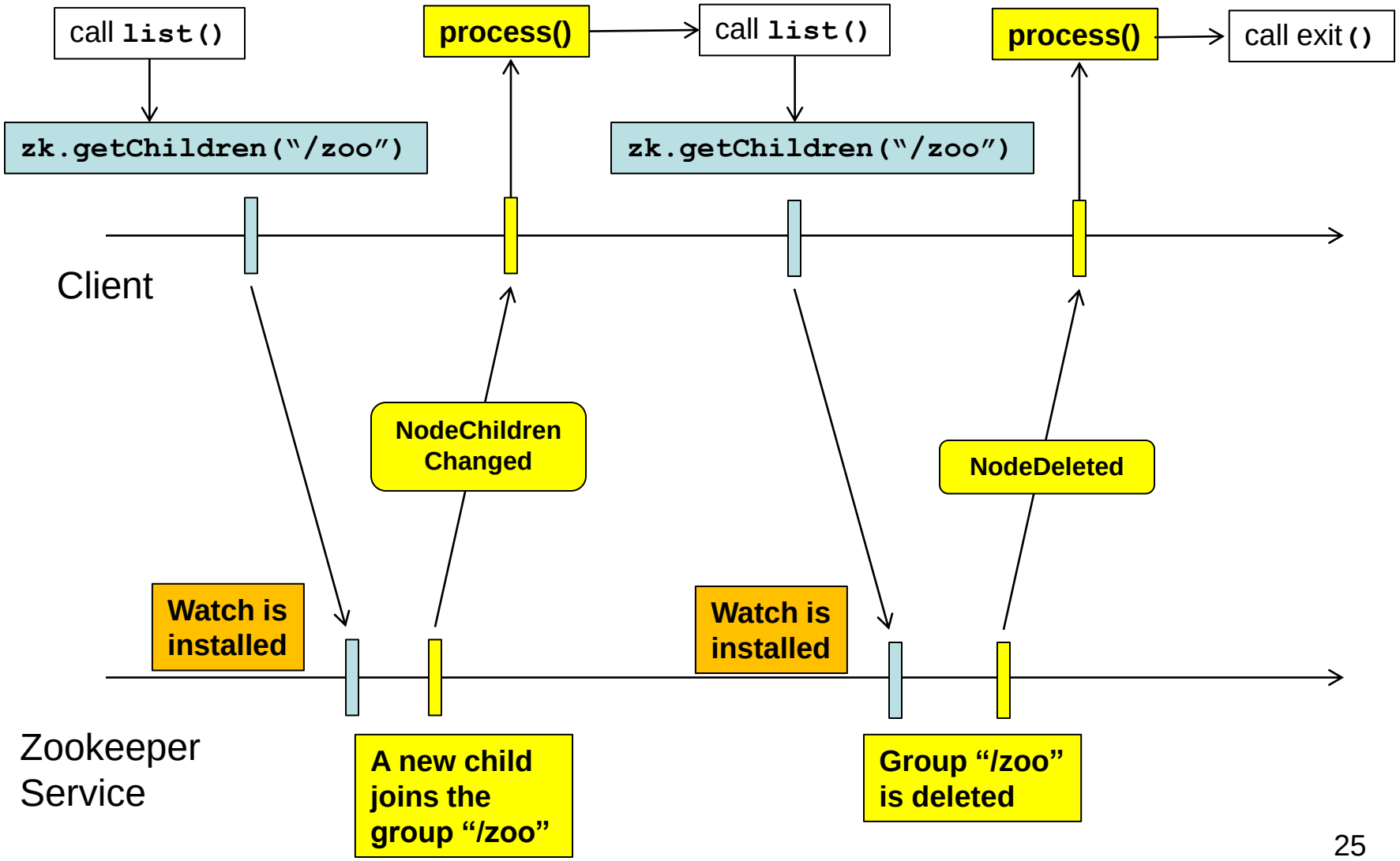
Watch Triggers

Table 14-2. Watch creation operations and their corresponding triggers

Watch creation	Watch trigger				
	create		delete		setData
	znode	child	znode	child	
exists	NodeCreated		NodeDeleted		NodeDataChanged
getData			NodeDeleted		NodeDataChanged
getChildren		NodeChildrenChanged	NodeDeleted	NodeChildrenChanged	

- See WatchGroup.java

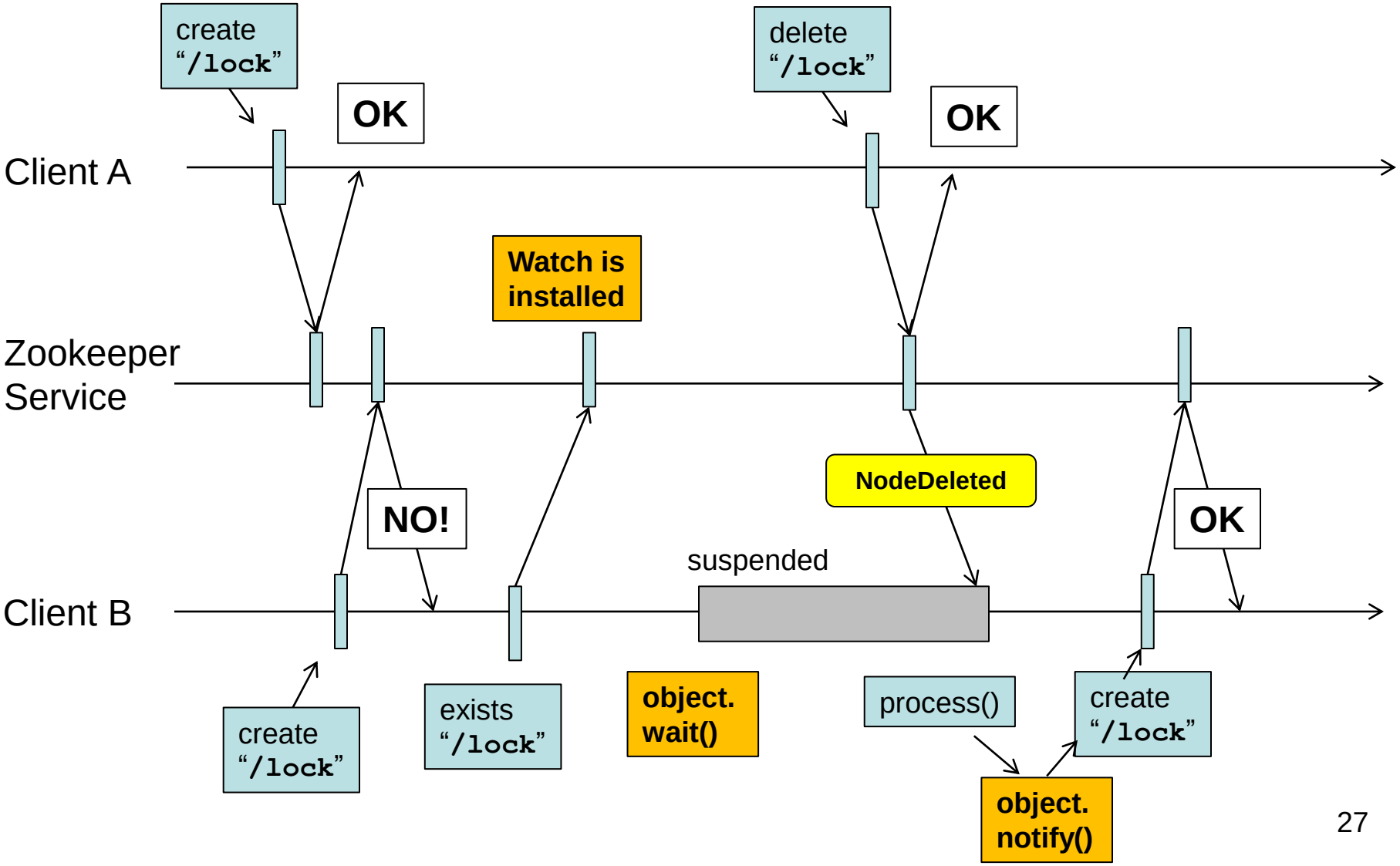
Watch Triggers



Distributed Lock Service

- Lock and critical section:
  - When I'm the first one who takes the lock, others should wait until I leave.
  - Others will then race in order to get the lock.
- Mapping to Zookeeper:
  - When a client is the first one who creates **an EPHEMERAL znode**, that means "***client takes the lock***".
  - Other clients would fail to create such a znode. They **attach a Watch to the created znode**.
  - When the first client dies, all waiting clients will be triggered (**EventType.NodeDeleted**).
  - They can race for the lock by creating the same **EPHEMERAL znode.**
- See DistLock.java

Distributed Lock Service



Distributed Lock Service

- **Herd effect**: what if there are hundreds of clients waiting for the lock?
  - Many notifications are sent.
  - Many clients awake and rush for the lock together.
  - Only one of them gets the lock.
  - The situation happens again and again…
- How to avoid?
  - Using a set of "**EPHEMERAL_SEQUENTIAL**" clients!

Distributed Lock Service

- We give up the property that a released lock will be randomly held by another client.
  - New property: the client with the (numerically) **smallest pathname** will hold the lock.

- Using **`exists()`**, a client will only watch the deletion of the client that is just smaller than its pathname.

Distributed Lock Service

- Pseudo-code of simple lock without herd effect:
  - Lock()

```
1   n = create(l + “/lock-”, EPHEMERAL|SEQUENTIAL)
2   C = getChildren(l, false)
3   if n is lowest znode in C, exit
4   p = znode in C ordered just before n
5   if exists(p, true) wait for watch event
6   goto 2
```

  - Unlock()

```
1   delete(n)
```

Distributed Lock Service

- Pseudo-code of read/write lock:
  - Write lock

```
1  n = create(l + "/write-", EPHEMERAL|SEQUENTIAL)
2  C = getChildren(l, false)
3  if n is lowest znode in C, exit
4  p = znode in C ordered just before n
5  if exists(p, true) wait for event
6  goto 2
```

  - Read lock

```
1  n = create(l + "/read-", EPHEMERAL|SEQUENTIAL)
2  C = getChildren(l, false)
3  if no write znodes lower than n in C, exit
4  p = write znode in C ordered just before n
5  if exists(p, true) wait for event
6  goto 2
```

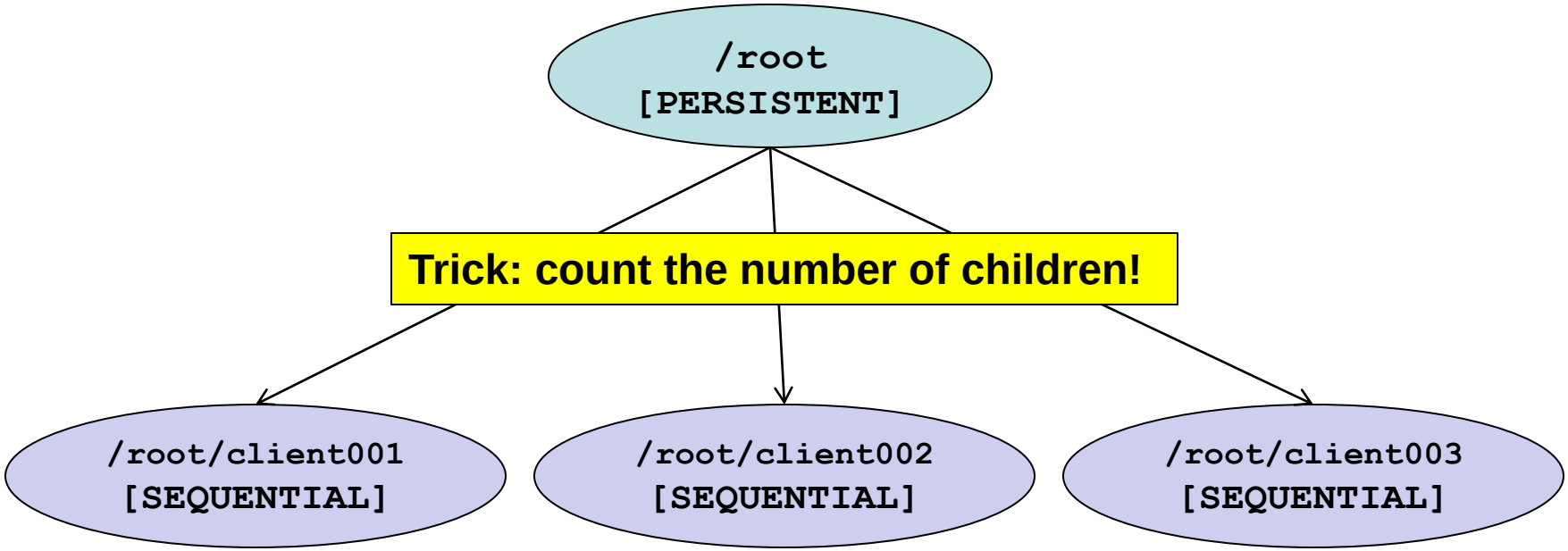
Any herd effect?

Distributed Barrier

- **Barrier** is a common programming construct in **multi-threading** programming.
- It aims to **synchronize progress** among threads.
- A barrier API usually asks for the number of threads that should wait, e.g., 3 in the example.
- For 3 threads have invoked the barrier call, they will be unblocked and progress together.

Distributed Barrier

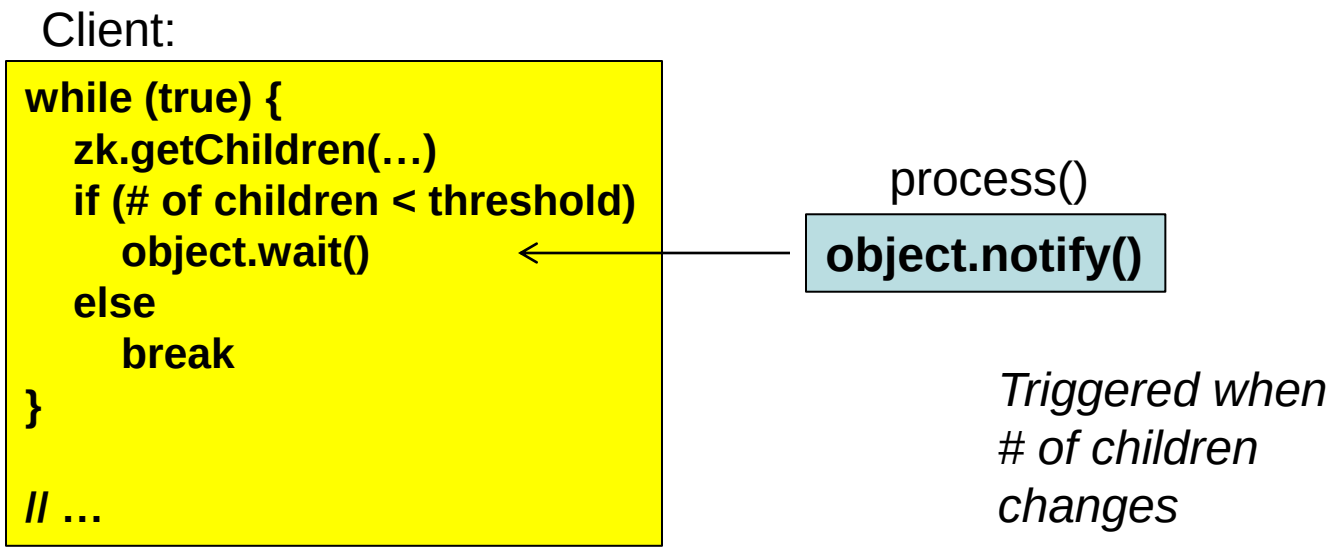
- How to realize using Zookeeper?
  - Use "**EPHEMERAL_SEQUENTIAL**" clients



Source: http://zookeeper.apache.org/doc/r3.4.3/zookeeperTutorial.html

Distributed Barrier

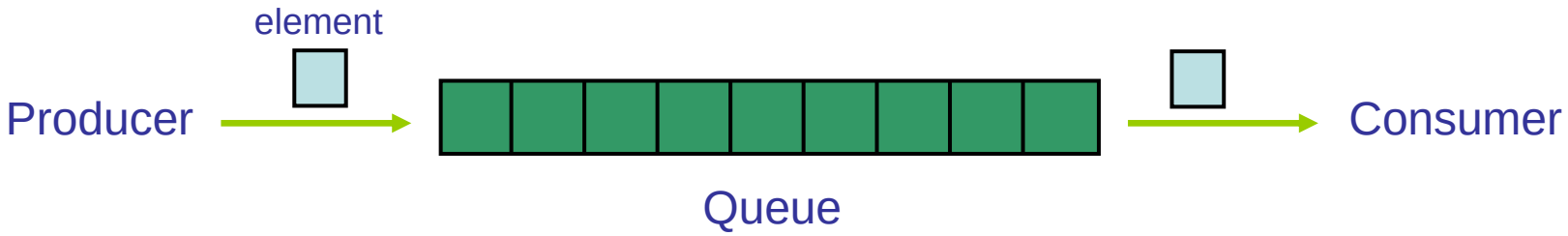
- How to realize using Zookeeper?
  - Use "**EPHEMERAL_SEQUENTIAL**" clients



Source: http://zookeeper.apache.org/doc/r3.4.3/zookeeperTutorial.html

Distributed Producer-Consumer Queue

- Requirements of a producer-consumer queue
  - Producer inserts elements when buffer is not full
  - Consumer extracts elements when buffer is not empty
  - First-in-first-out (FIFO): inserted elements and extracted elements in the same order



- Here, we consider an **unbounded** queue
  - Queue is never full

Distributed Producer-Consumer Queue

- Unbounded producer-consumer queue:

Producer:

```
while (true) {
    Create a "SEQUENTIAL" client;
    Data is stored in the client;
}
```

Consumer:

```
while (true) {
    zk.getChidren(...) // watch set
    if( # of children == 0 )
        object.wait();
    else {
        find the child with the smallest seq. num;
        getData() from that child;
        delete() that child;
     }
}
```

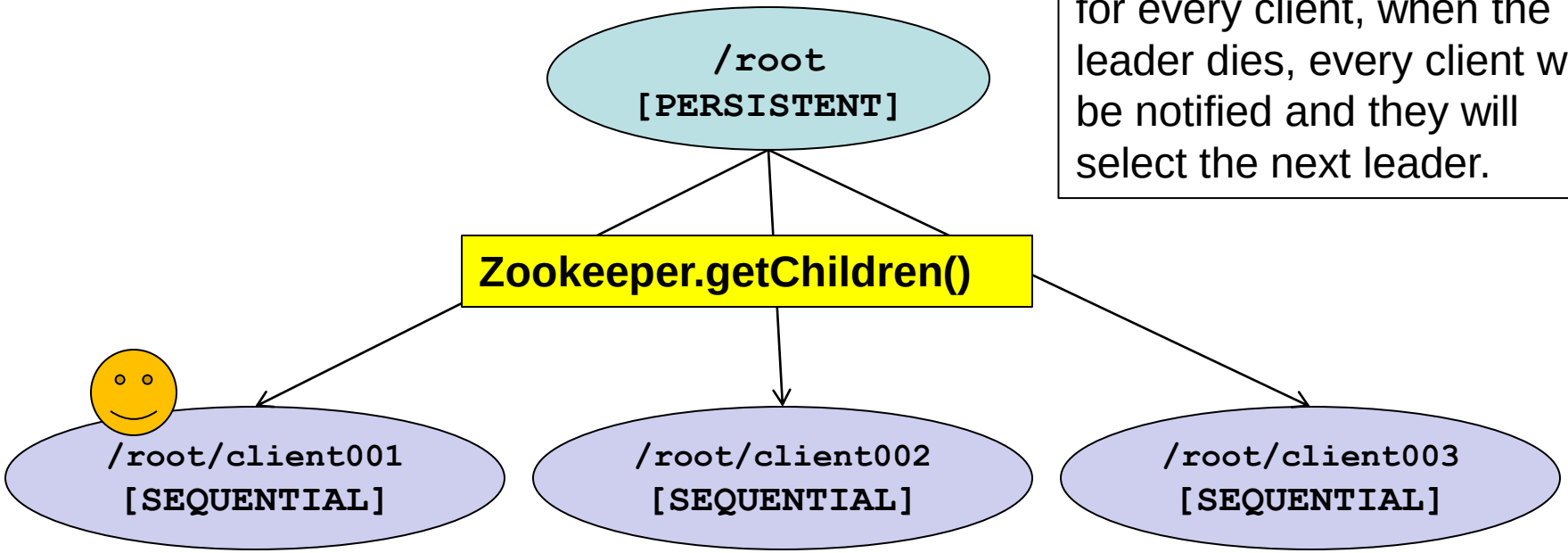
process()

```
object.notify()
```

Source: http://zookeeper.apache.org/doc/r3.4.3/zookeeperTutorial.html

Distributed Leader Election

- We pick the client with the smallest sequential number to be the leader



Since a watch is installed for every client, when the leader dies, every client will be notified and they will select the next leader.

Subtlties: Configuration Service

- Goal: a highly-available service that stores key-value pairs.
  - Treat this as a highly-available, robust file system.

- •API calls:
  - Zookeeper object:
    - getData(path, watcher);
    - setData(path, byte_array, -1);

Use Cases in Yahoo!

- Fetching service
  - Master coordinates page fetching process
  - Master provides fetchers with configuration
  - Fetchers inform master their health and status
  - Zookeeper is used to manage configuration and elect masters
- Katta
  - Distributed indexer
  - Zookeeper is used to track group membership, elect master, and manages configuration
- Yahoo! Message Broker
  - A distributed publish-subscribe service that manages different topics of messages
  - Zookeeper is used to manage distribution of topics, dealing with failures of machines, and control system operations

Use Cases in Yahoo!

- Summary:
  - Leader Election
  - Group Membership
  - Work Queues
  - Configuration Management
  - Cluster Management
  - Load Balancing
  - Sharding (database partitioning)

Conclusions

- Zookeeper is a generic platform for distributed computation
  - You can view it as a programming model like MapReduce
- Zookeeper is easy to learn and has a great potential!