CREASON: Callable and Replicated Shared Objects over NoSQL*

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Building scalable Cloud applications

- Cloud applications handle large amounts of clients
  - Large amounts of data: need *scalable* data storage
  - Pay-as-you-go model requires *elastic* scaling
- Failures happen often and must not break service
  - Application data stored in database *persistently*
  - Multiple copies: *consistency* under concurrent operations
- Application design must be *simple* and *scalable*
  - Easy-to-learn programming model and database integration
  - Sharing of data between application instances with database

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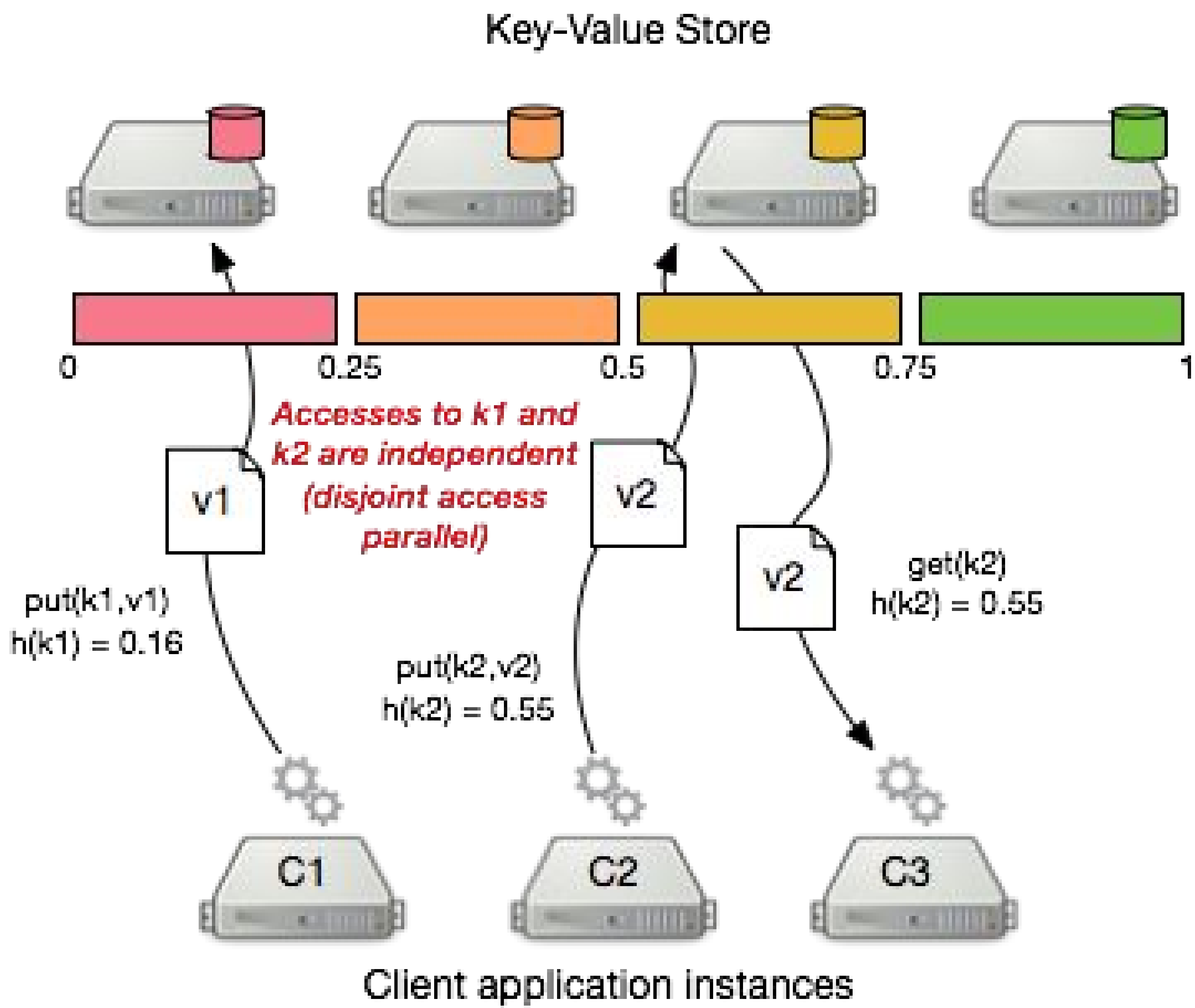
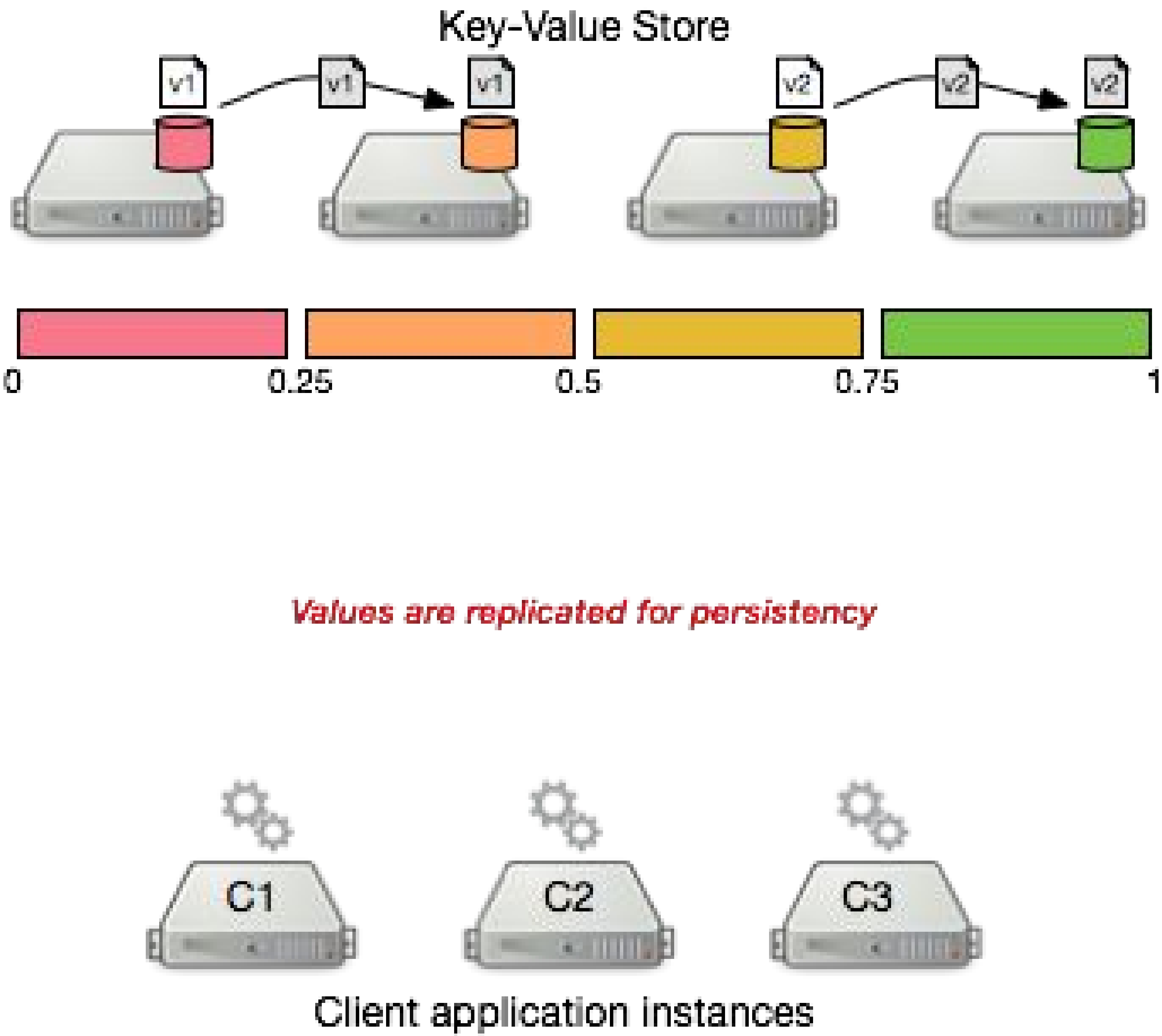
There is not only SQL

- Scaling "traditional" relational (SQL) databases
  - ☹ Limited horizontal scalability, poor support for elasticity
    - Sharding is complex and static, no cross-shard consistency
  - ☹ Fault tolerance with master/slave replication
- NoSQL databases to the rescue
  - ☹ Simpler data schema and querying
    - Only primary index: key/value store, no support for joins
  - ☹ Independent accesses to different keys
  - ☺ Excellent horizontal scalability and elasticity

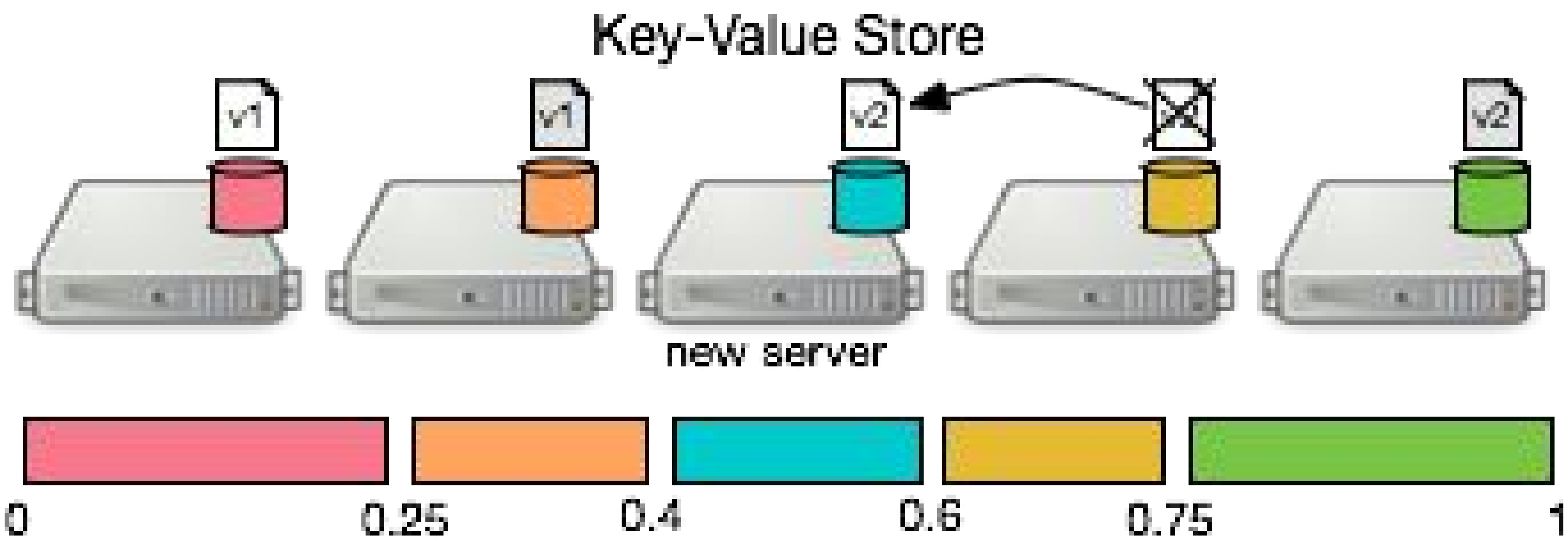
NoSQL for scalable applications



NoSQL for scalable applications

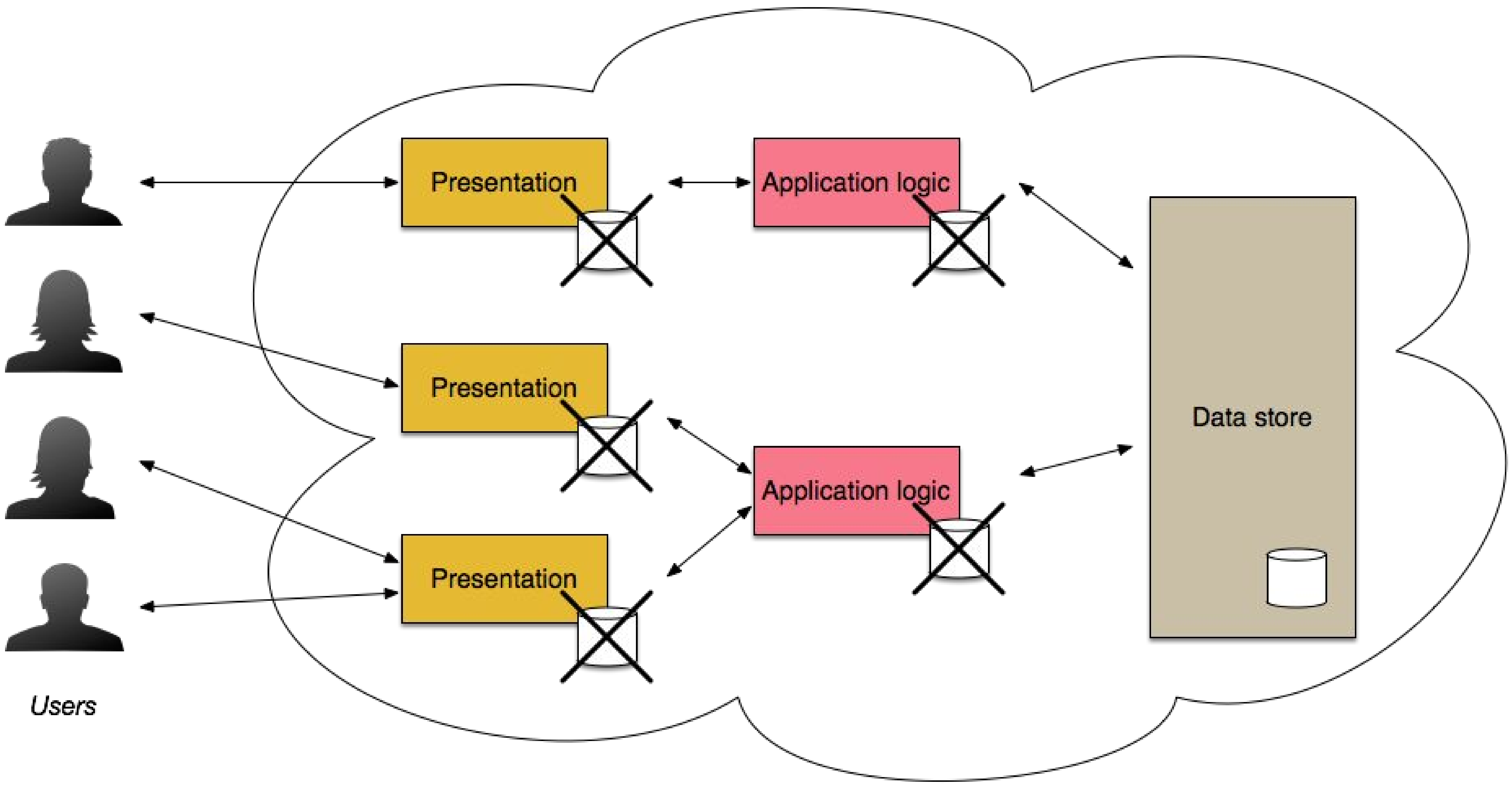


NoSQL for scalable applications



Adding a storage server without service interruption allows horizontal elastic scalability

Typical Cloud-based application



NoSQL databases

- Many flavours of NoSQL
  - General-purpose or {Document,Graph,Column}-oriented
- Interface = variation of a key/value store API
  - Some also support transactions, scans, etc.

NoSQL in an object-oriented application

- Object-oriented programming = prevalent model
- Data shared between application instances

  Objects survive termination of application instances
  & failure of NoSQL servers

- Database storage and in-memory objects use different representations

  But require a *mapping phase* between the two representations
  impedance mismatch

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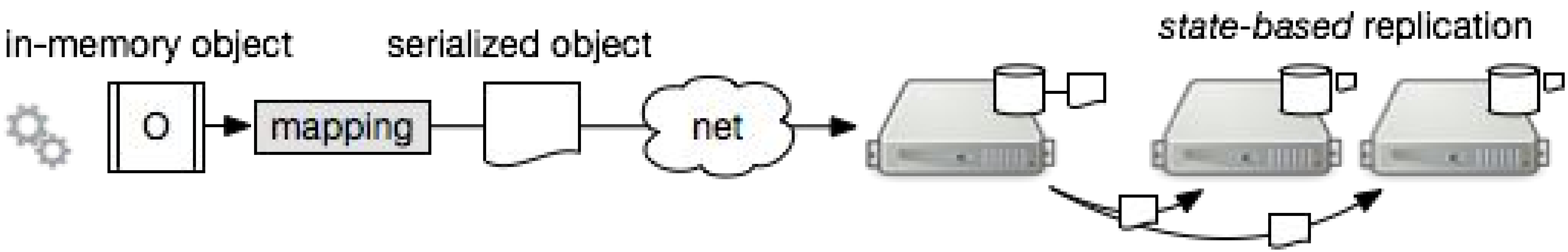
State-of-the-art: Object-DB mappers

- Object-Relational Mapper
  - Store application objects in relational database
  - Hibernate
  - Integration with OO langage (e.g., Java)

- Object-NoSQL Mapper
  - Maps and store application objects in NoSQL database
  - Hibernate OGM, MongoDB Morphia, Google's Objectify

Client-side Object-NoSQL mapping



- ☹ Access to object: fetch full serialized representation from DB
  - Objects instantiated locally and their methods also called locally
  - Some objects may grow very large
    - Methods may access only a small part of their content
  - Data structure (e.g. graph) traversal = multiple back-and-forth with DB
- ☹ Concurrent accesses to objects with no strong consistency
  - Objectify (part of Google App Engine) not thread-safe

CRESON: objectives

- Support callable objects over NoSQL
  - Application objects instantiated from the DB *at the server side*
    - No shipping of any serialized representation over the network
  - Method calls also performed at the server side

- Dependability and concurrent accesses to shared objects
  - Objects are replicated for persistence
  - Replication happens at the level of operations (method calls)
    - No shipping of full serialized state between replicas
    - Shared objects with *strong consistency* guarantees
    - Including for composed operations accessing multiple objects

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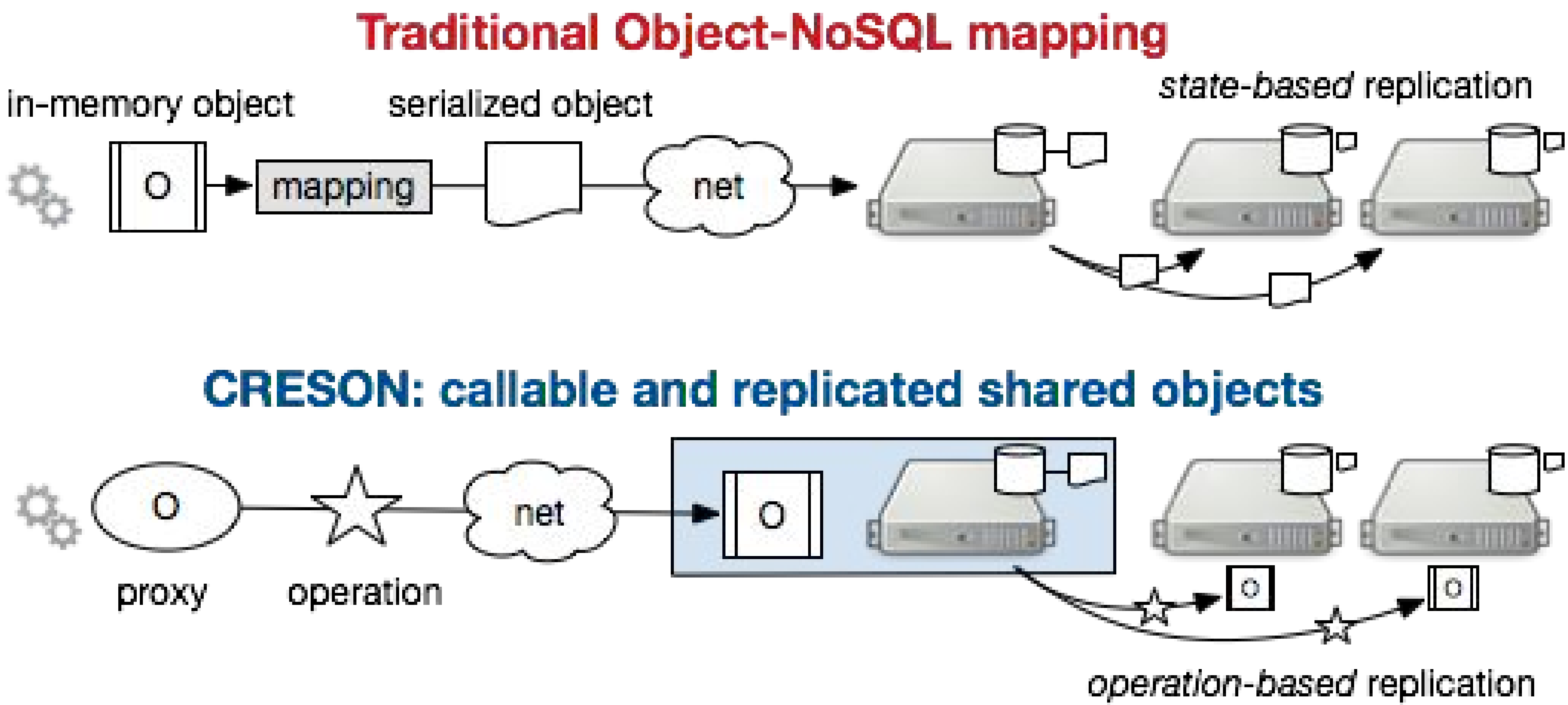
CRESON: server-side mapping



Outline

- Introduction and motivation
- Server-side Object-NoSQL mapping with CRESON
- CRESON design
  - LKVS abstraction
  - Object management components
  - State Machine Replication
  - Guarantees
- Portage of an existing application StackSync to CRESON

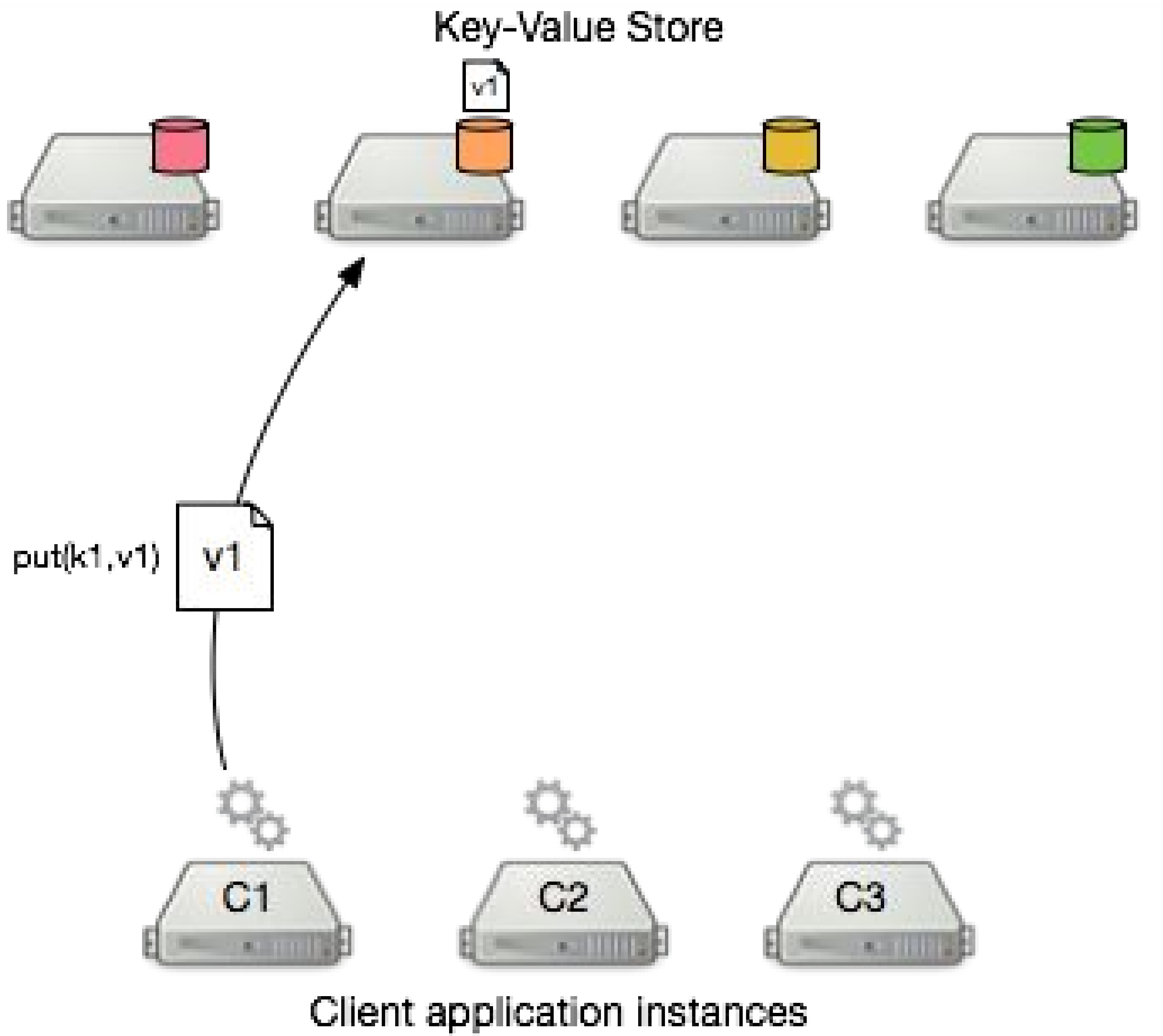
CRESON: components

- LKVS: novel NoSQL storage abstraction
  - ***Listenable*** Key-Value Store
  - Extends key-value API
- Object management logic atop the LKVS
  - Implemented as part of the listener handlers
  - Maintain multiple replicas of the object
  - Implement state-machine replication (operation-based)
- Client-side integration with the Java language
  - Using annotations (similar to JPA)

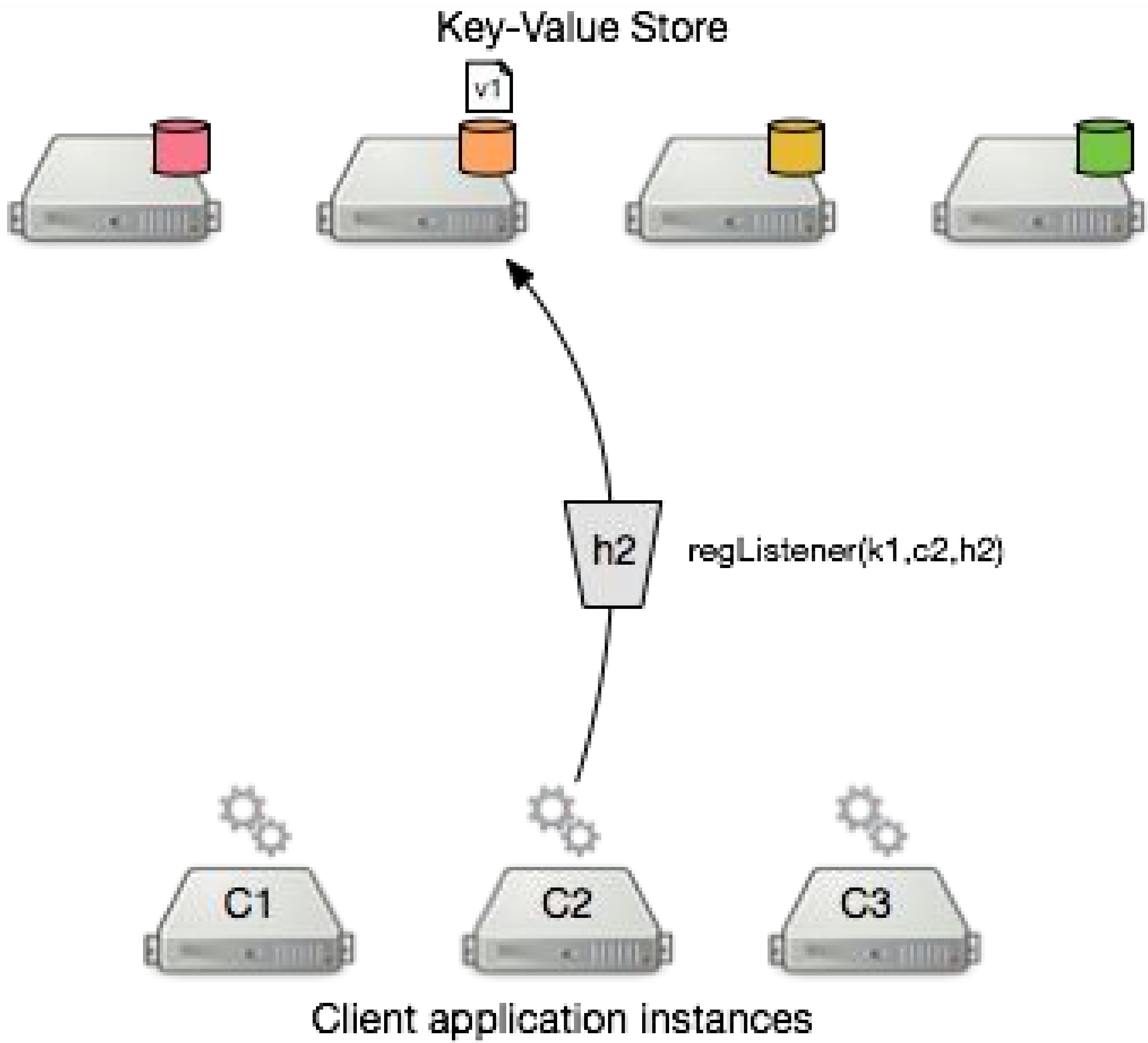
Listenable Key/Value Store

- Classical Key/Value API
  - `void put(K k, V v)`
  - `V get(K k)`
- Two new calls
  - `void regListener(K k, Handler h, Listener l)`
  - `void unregListener(K k, Listener l)`

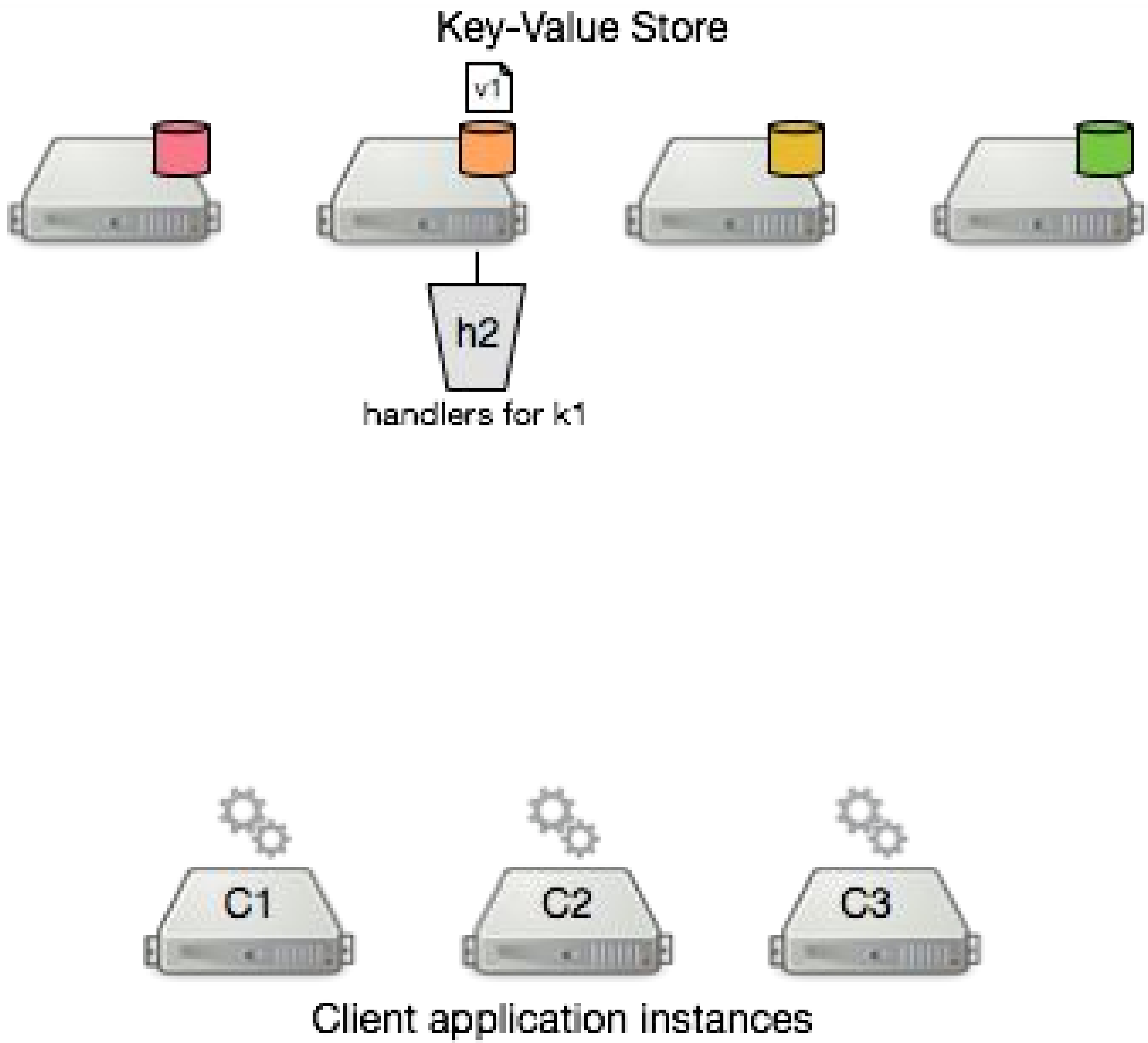
LKVS illustrated



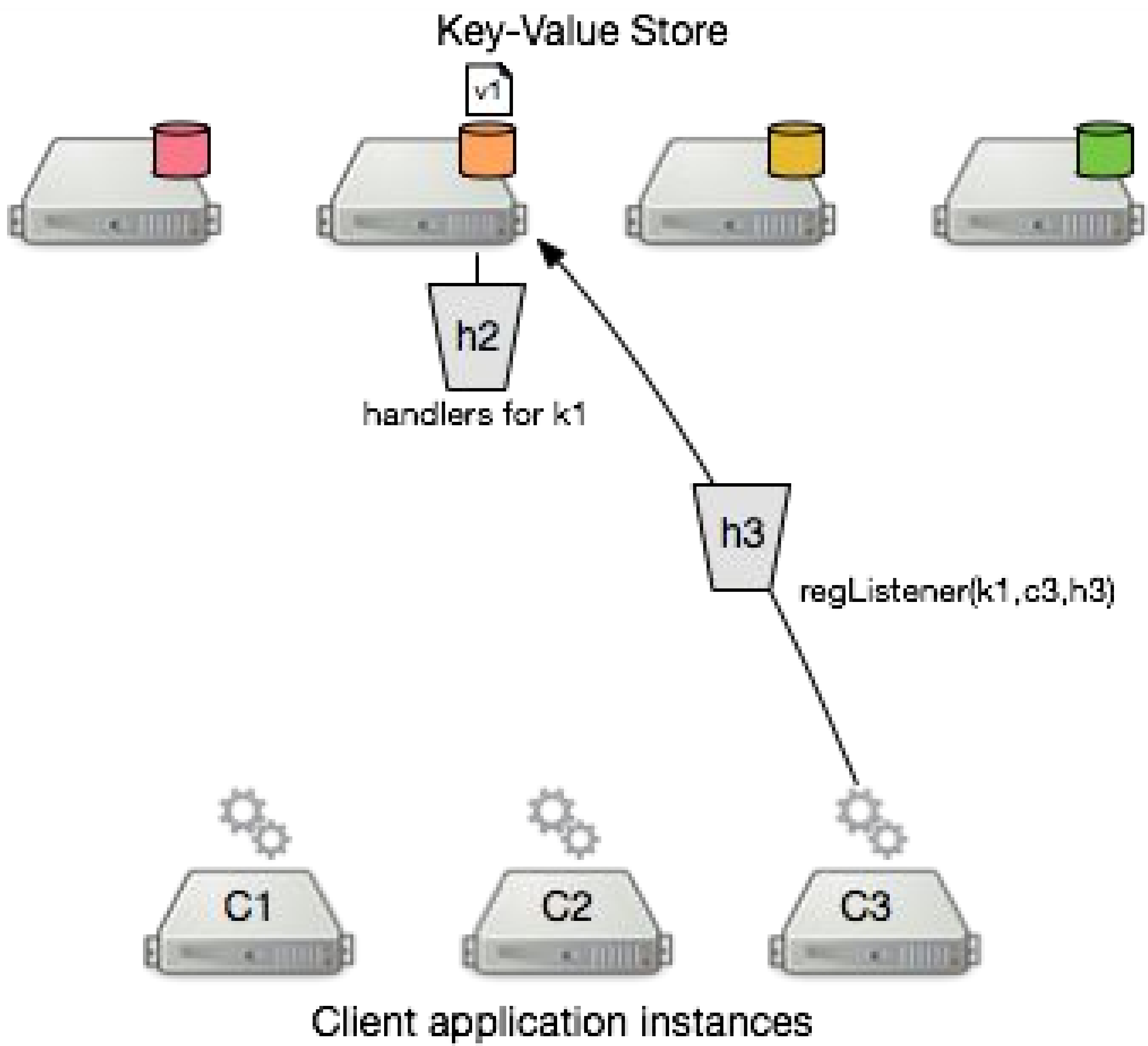
LKVS illustrated



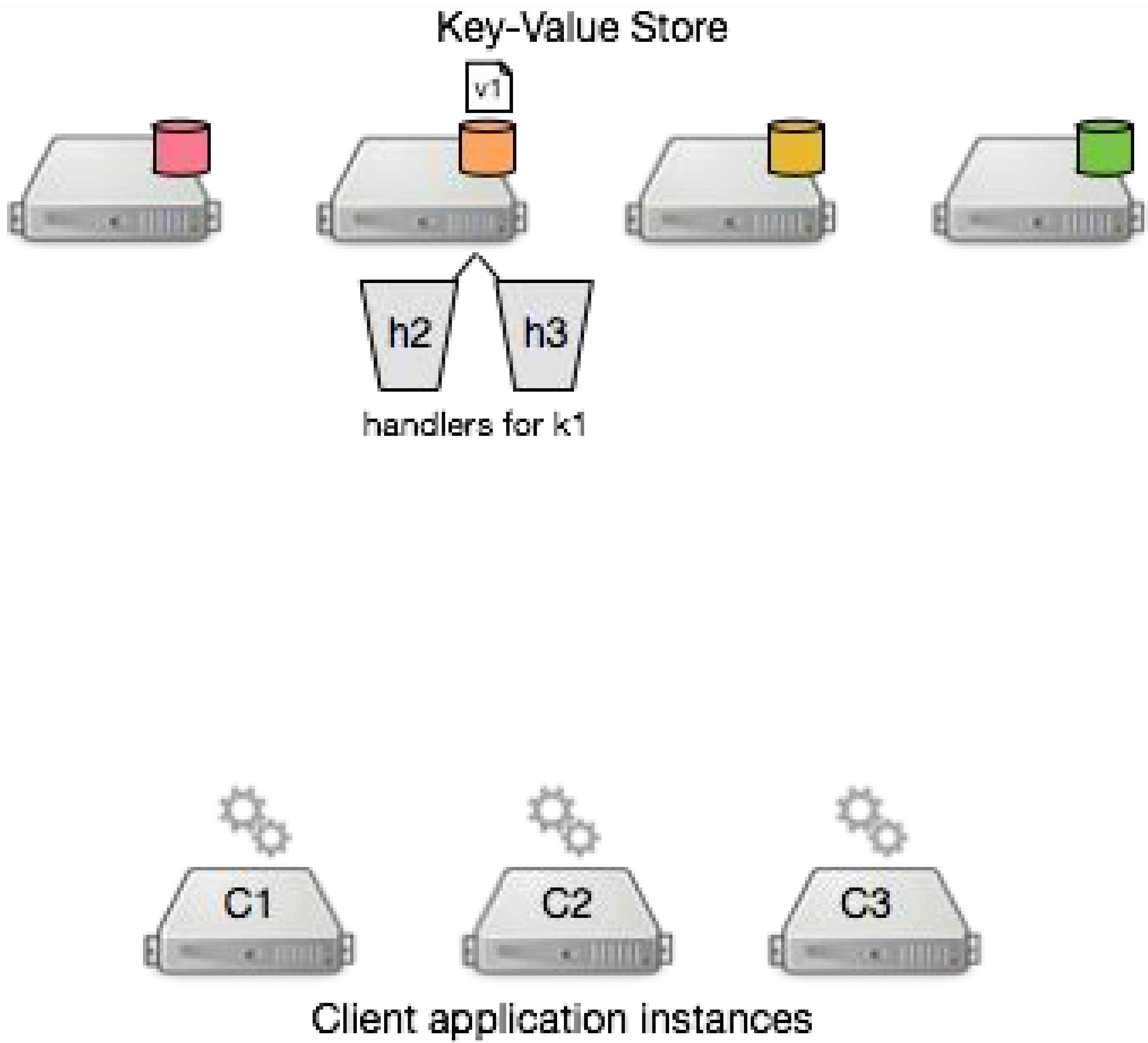
LKVS illustrated



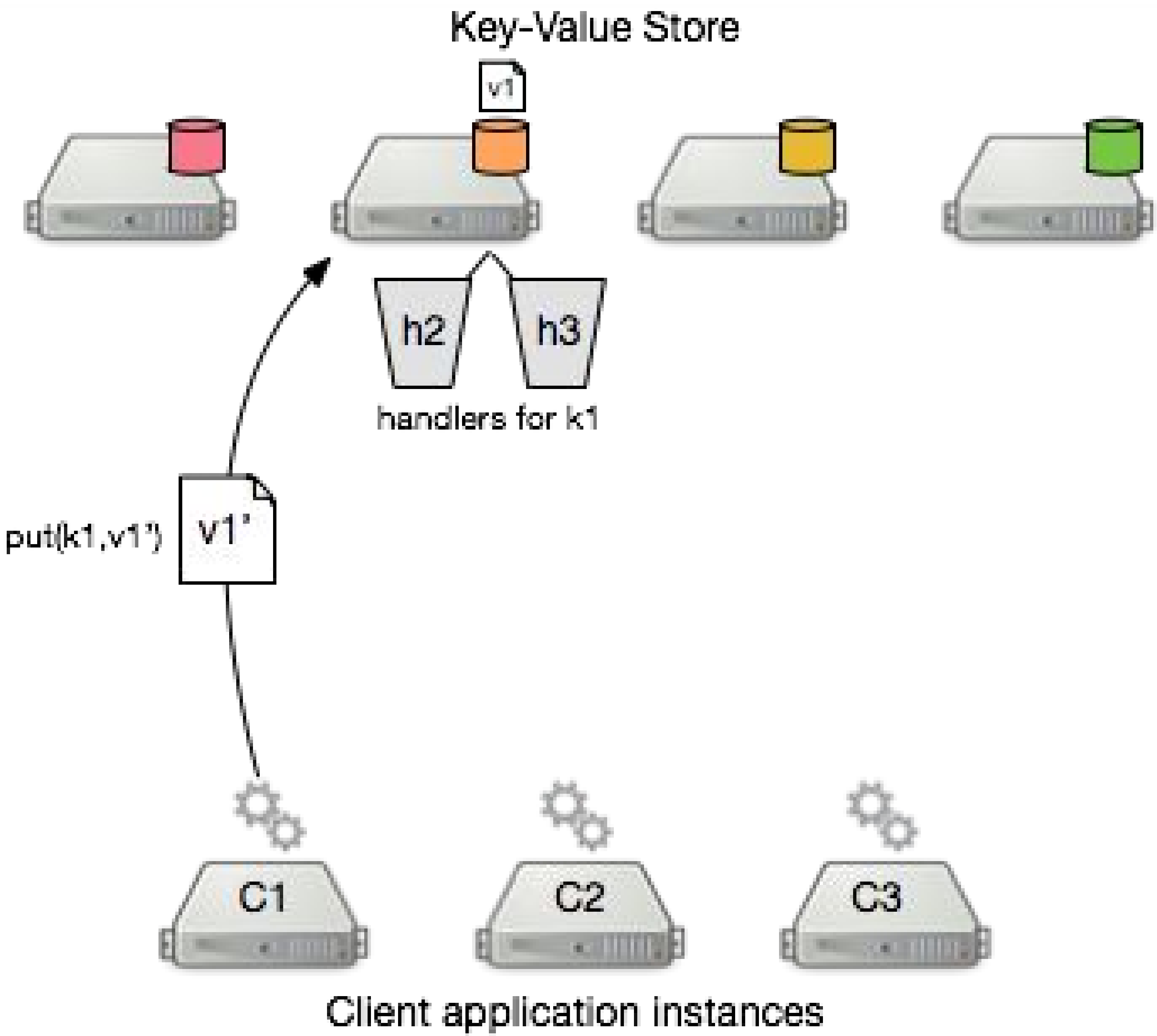
LKVS illustrated



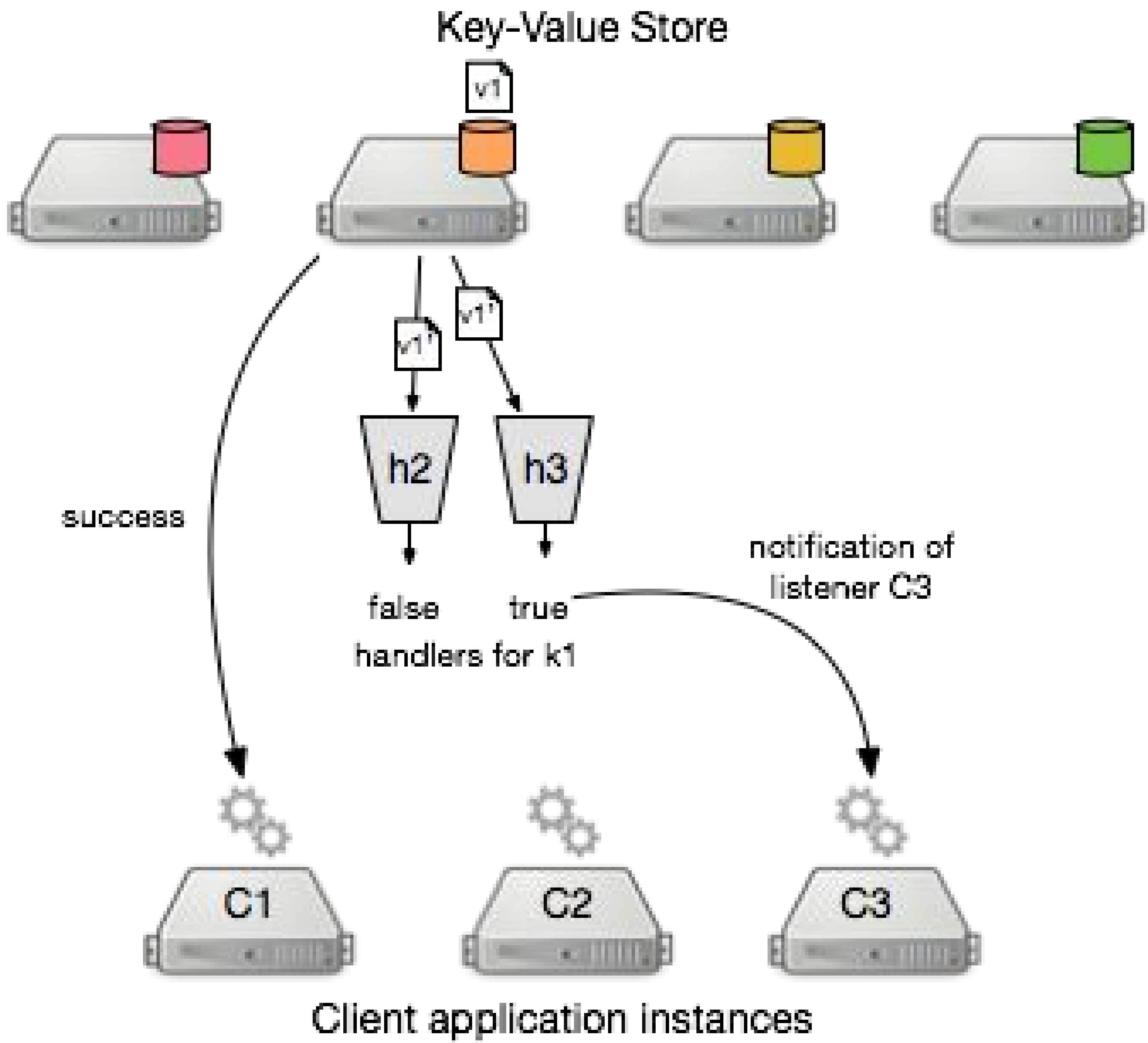
LKVS illustrated



LKVS illustrated

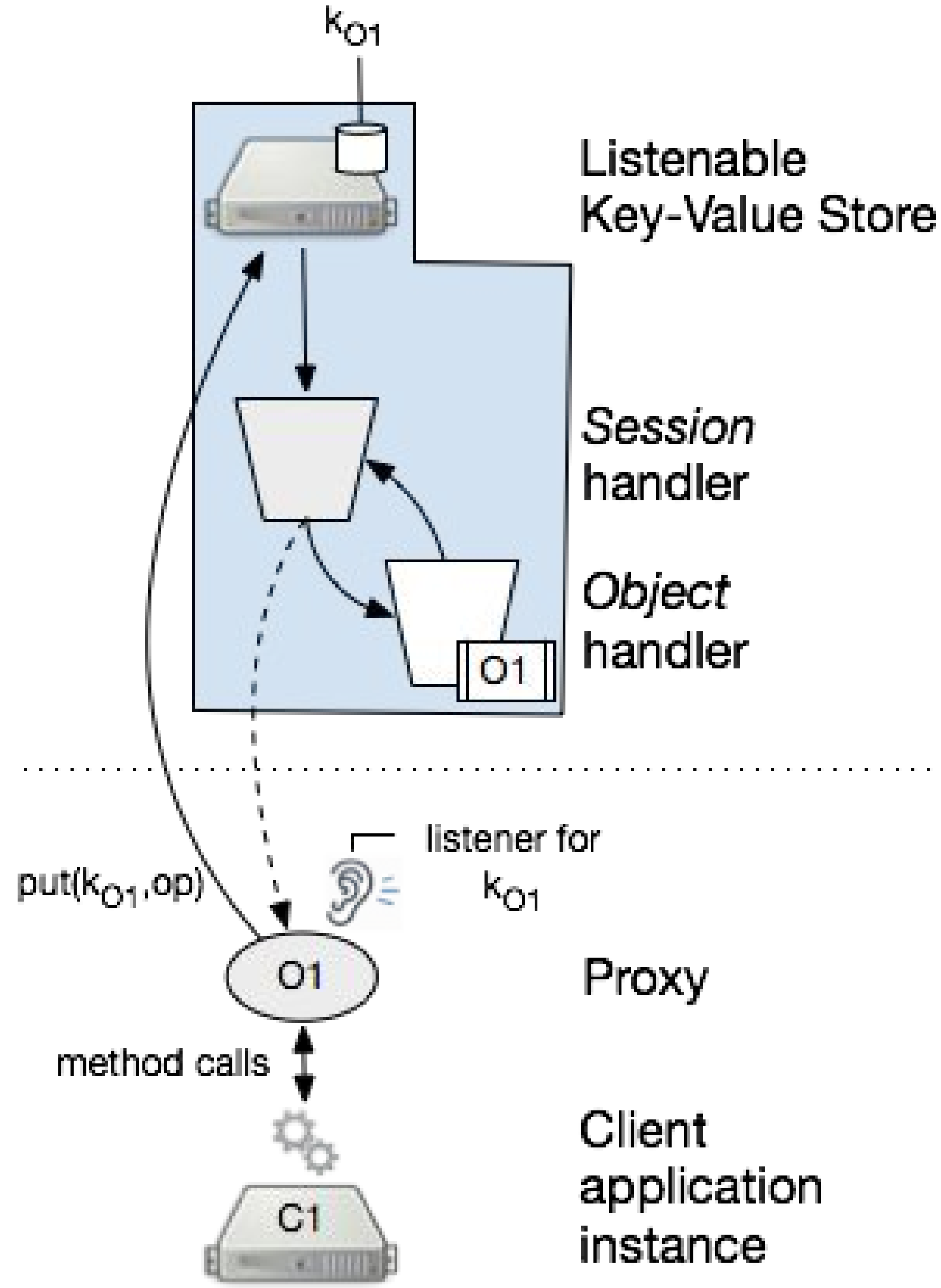


LKVS illustrated



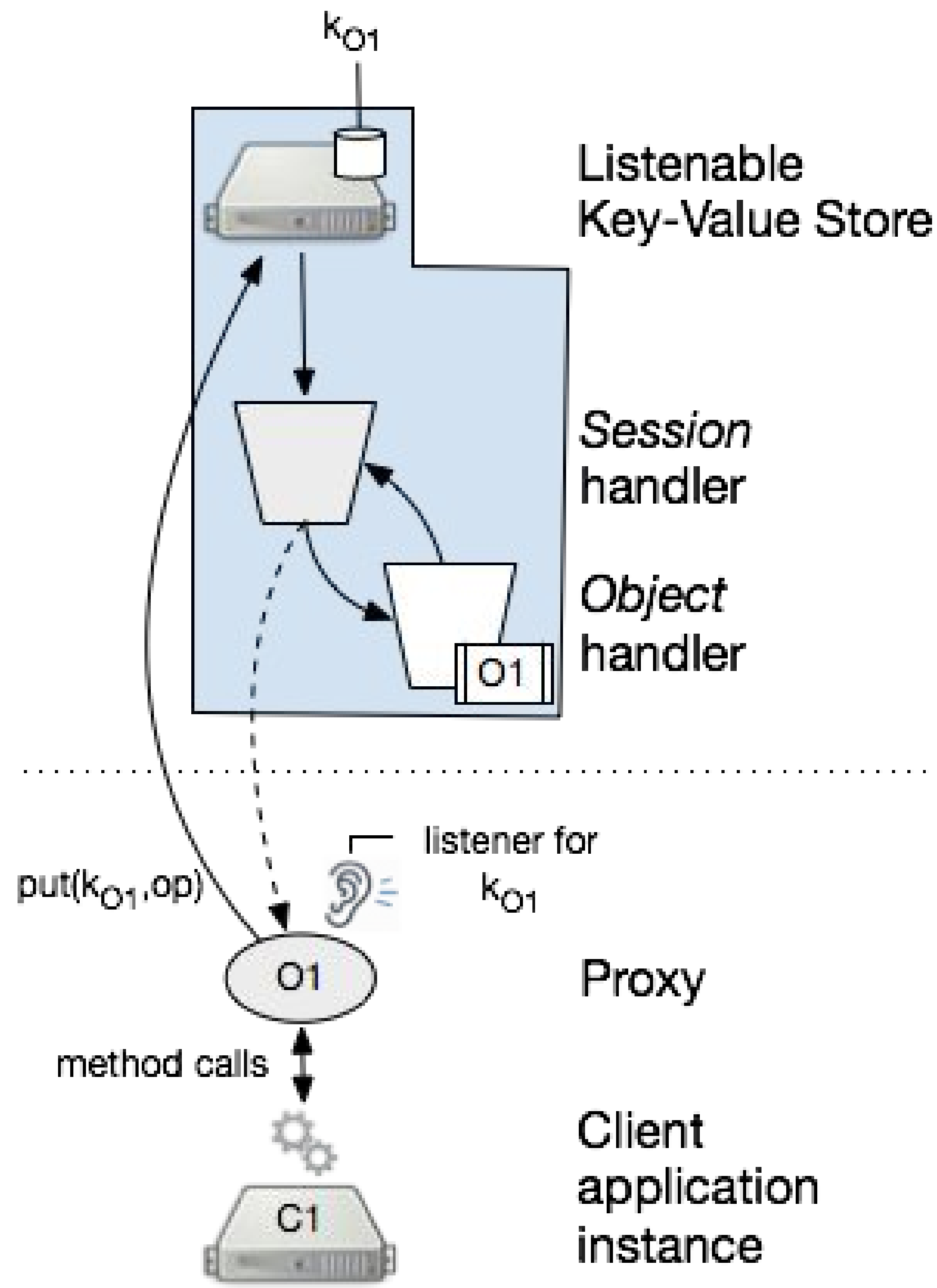
Object management in CRESON (1)

- Client-side *proxy*
- First opening of object for key `k` by a client
  - Not in DB: instantiate new object, server side
  - Serialized in DB: use mapping, server side
- Object closed by last client for key `k`
  - Object serialized, server side, stored in DB
- Method calls and object creation/closing are sent with `put()` calls for key `k`
  - Intercepted by handlers registered with key `k`
  - caller receives the result as a notification



Object management in CRESON (2)

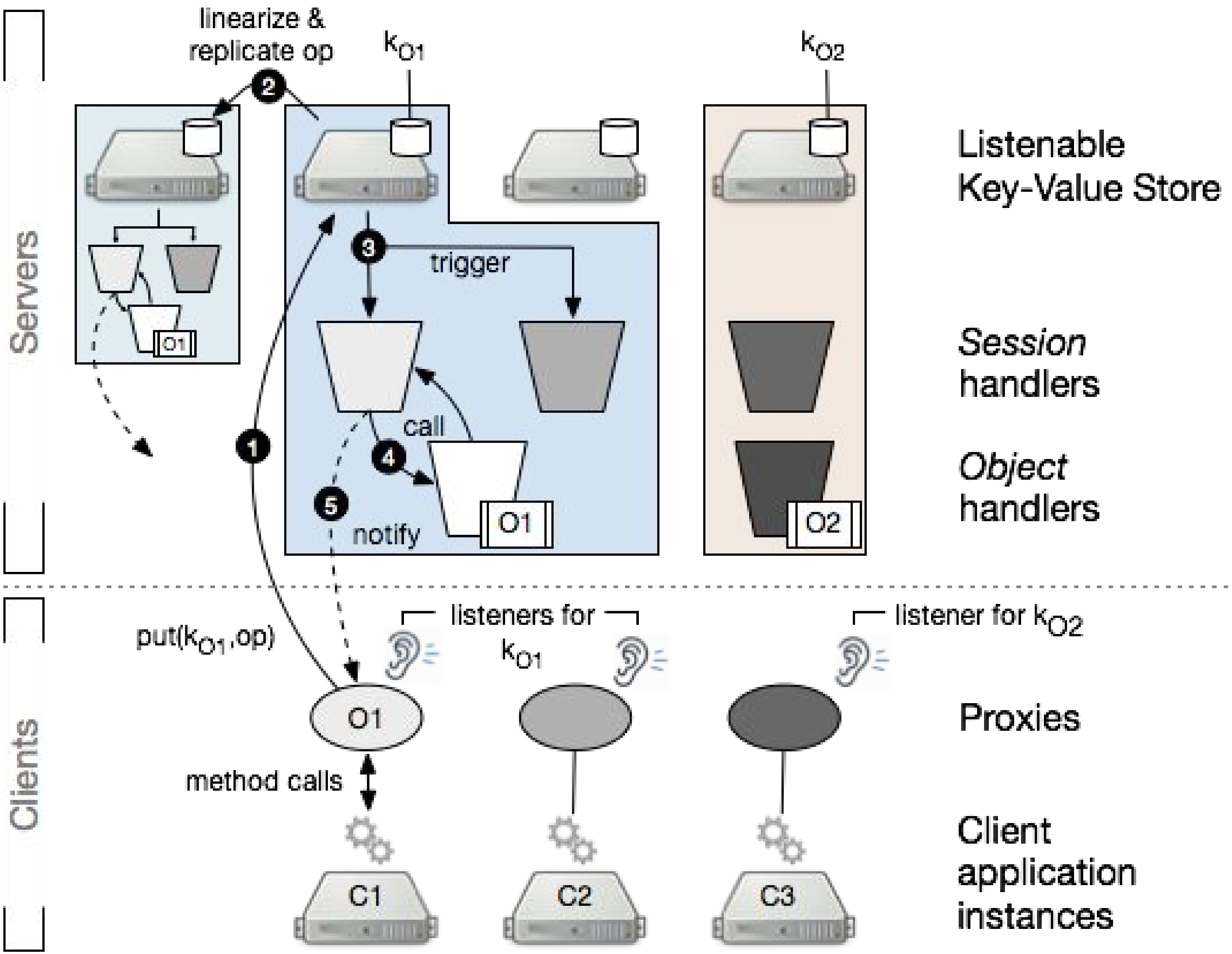
- Two types of handlers for each key
  - One *Session* handler per client
    - Associated with one listener client
    - Ignore operation if from another client
    - Forward to object handler otherwise
  - *Object* handler owns actual object
    - Issues method calls
    - Send return values to session handlers



State Machine Replication

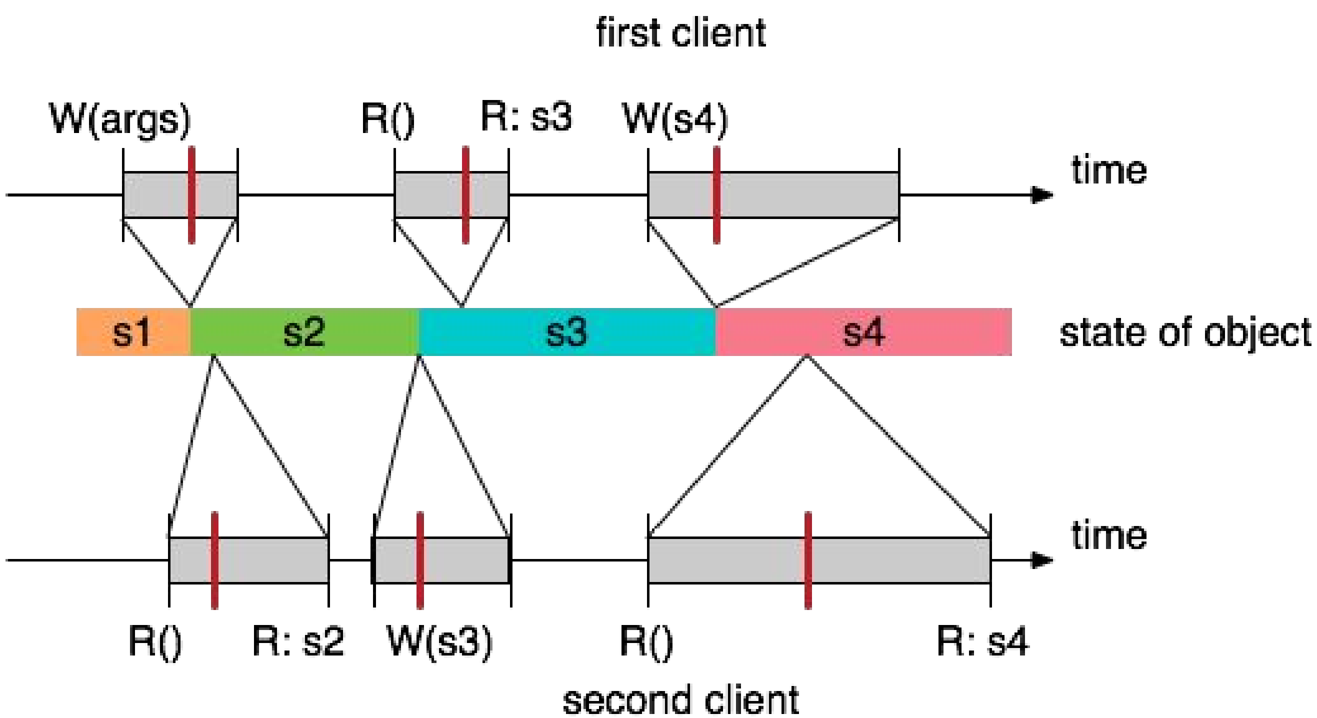
- To survive faults, objects are replicated at the LKVS side
  - Multiple copies of serialized objects
  - Multiple in-memory instances of the same live shared object
- Operation-based replication
  - replicas receive the same stream of operations
  - Order is total,
- Constraint: objects must be *deterministic*
  - Reach unique state from any possible (state, operation) pair
  - Easy to achieve if no use of independent pseudo-random numbers generator

Putting everything together



CRESON guarantees

- ✓ Strong consistency: *linearizability*
- ✓ Wait-freedom for shared objects
- ✓ Composition
  - A shared object can call other objects
  - Maintains linearizability
- ✓ Persistence
- ✓ Disjoint-access parallelism
  - Accesses to distinct objects use distinct LKVS components
- ✓ Elasticity

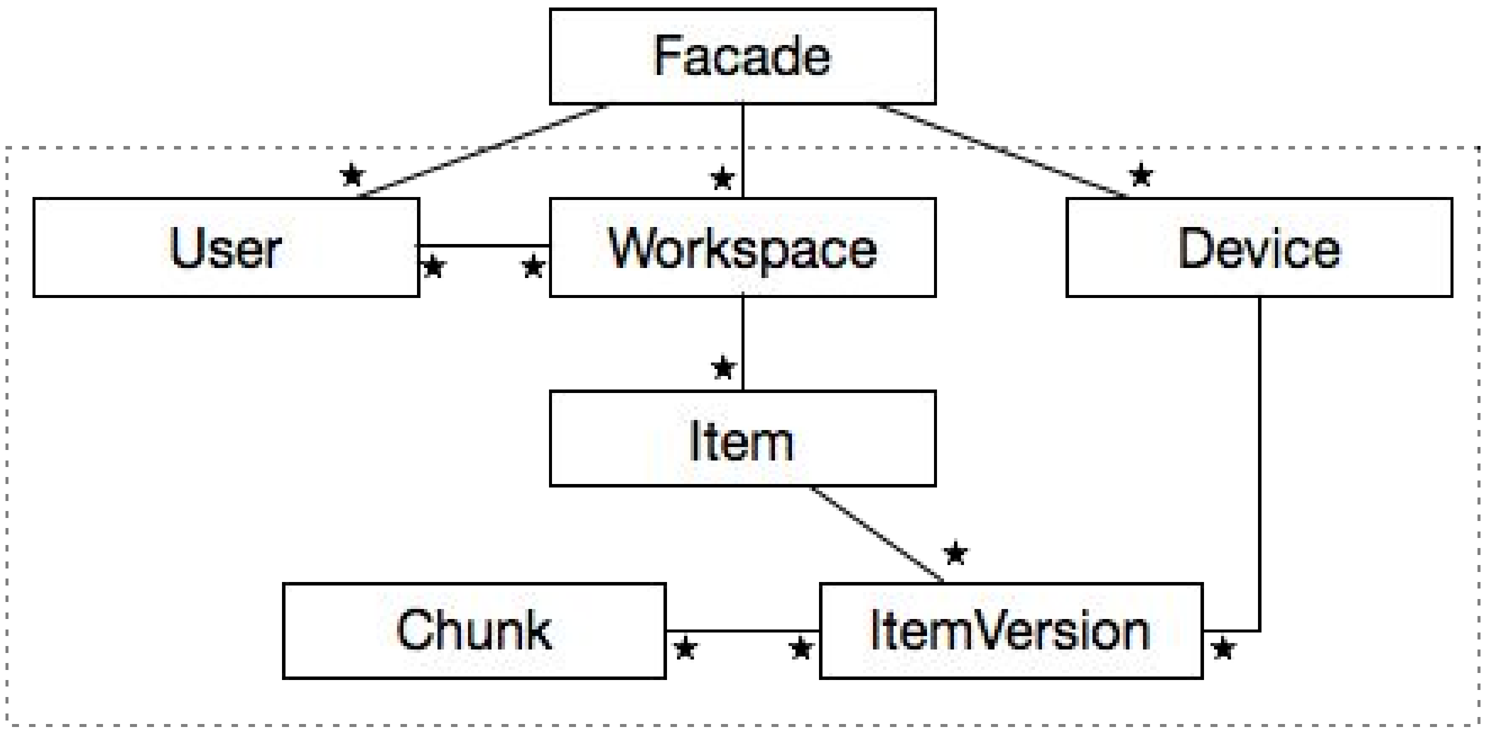


Use case and Interface

- Collaboration with EU project CloudSpaces
  - Open-source Dropbox-like application
  - Synchronization of user file system with cloud-stored file system
  - Sharing of folders and files between users spaces
- Trace collected from Ubuntu U1 personal cloud service
- Data stored in OpenStack Swift
- Metadata requires strongly consistent storage

Original Metadata Management

- PostgreSQL relational database
- Performance: use of stored procedures implementing app. logic at server side
- Scalability: sharded (partitioned) database using PL/Proxy
  - No support for elastic scaling
  - No consistency (ACID) guarantees across shards



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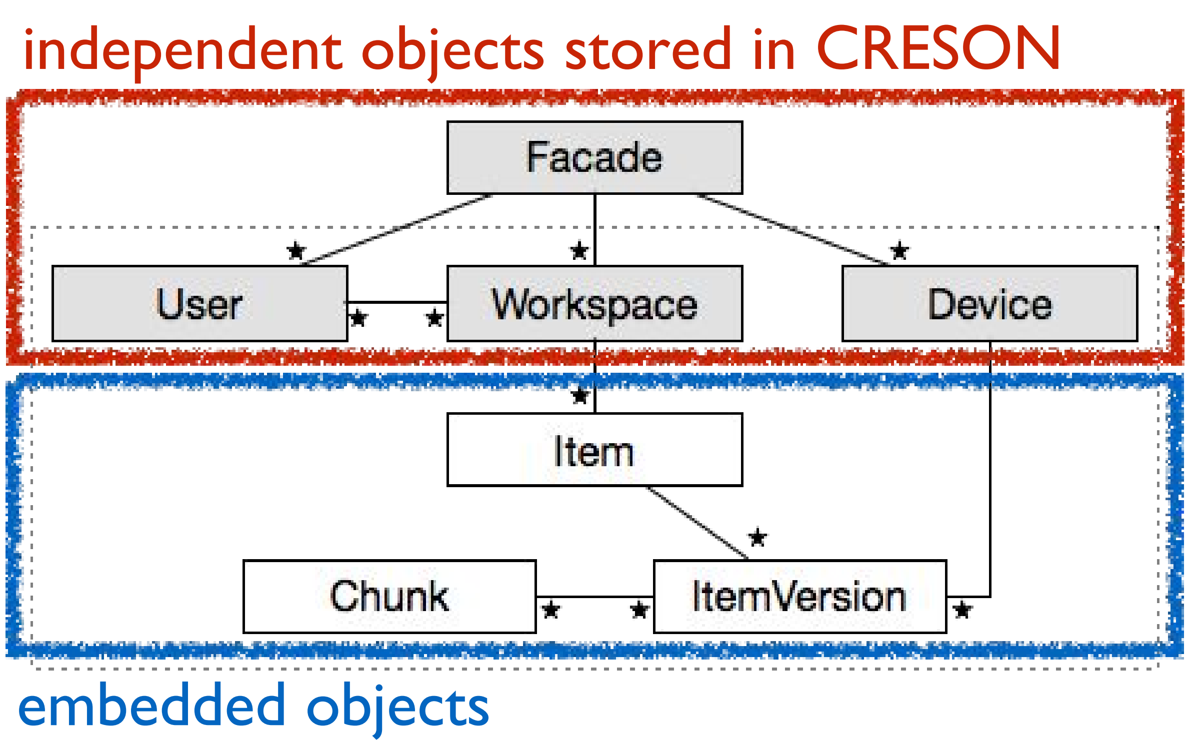
Metadata Management with CRESON

- Logic for metadata management re-implemented in plain Java, as methods in StackSync's classes
- Which objects to store in CRESON ?
  - Embedding `Item`, etc. to `Workspace`
- Portage was less than a week of effort
  - Code is simpler and more coherent than with SQL



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CRESON interface

- Integration in Java (using AspectJ)
  - using JPA
- `@Entity(key = "id")` annotation
  - Object o of this class stored in CRESON under key `(classname+":"+o.id)`
  - Store static field in CRESON under key `(classname+":"+id)`
    - Only applies to static fields!
- No further action required from developer
- Shared maps (e.g. deviceIndex) are transparently stored as collections in LKVS

```
@Entity(key = "id")
public class Workspace {

  public UUID id;
  private Item root;
  private List<User> users;

  /* ... */

  public boolean isAllowed(User user) {
    return users.contains(user.getId());
  }
}
```

```
@Entity(key = "id")
public class Facade {

  @Entity(key = "deviceIndex")
  public static Map<UUID,Device> devices;

  @Entity(key = "workspaceIndex")
  public static Map<UUID,Workspace> workspaces;

  @Entity(key = "userIndex")
  public static Map<UUID,User> users;

  public UUID id;

  /* ... */

  public boolean add(Device device) {
    return deviceMap.putIfAbsent(
             device.getId(),device) == null;
  }
}
```


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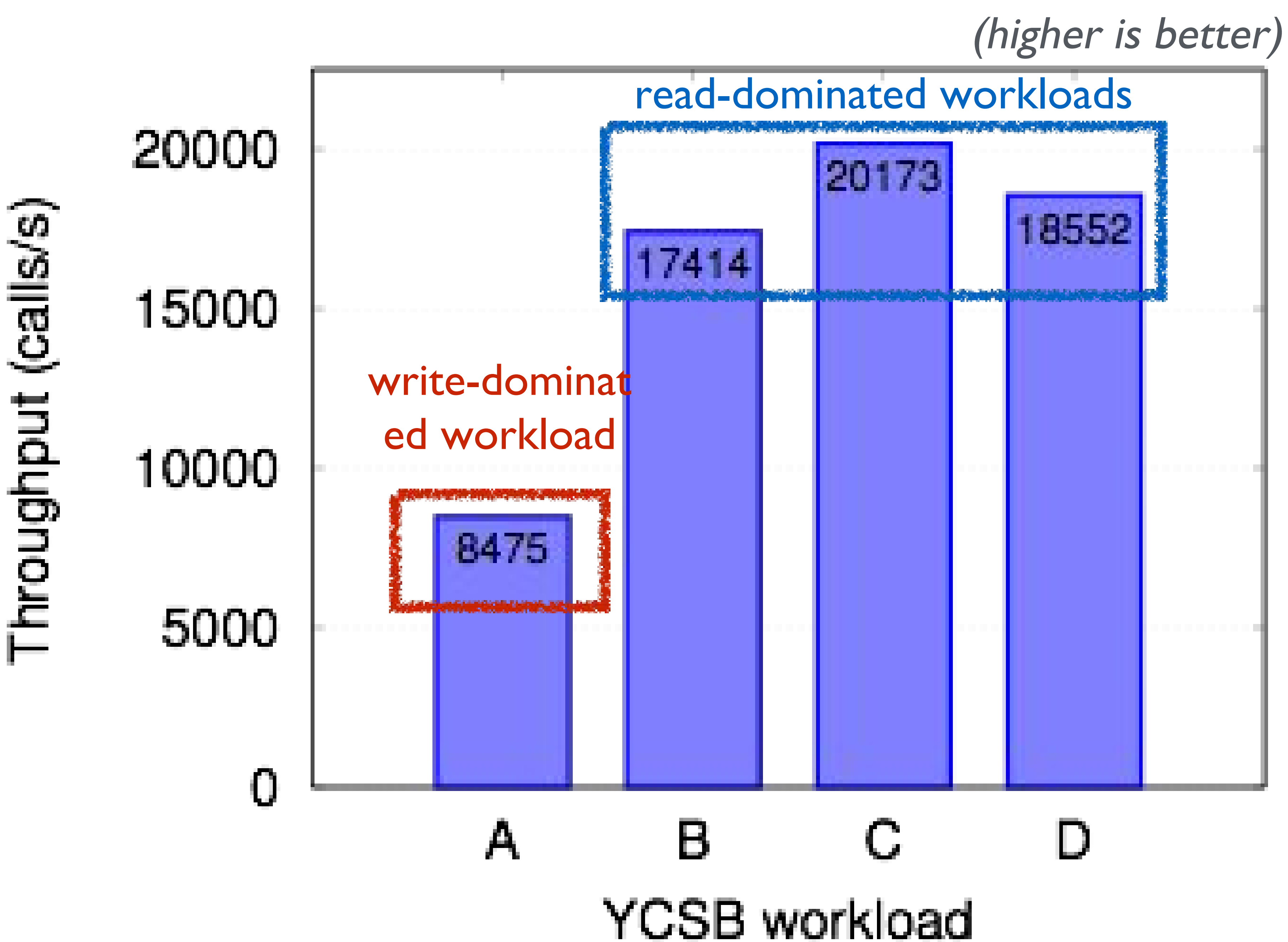
CRESON implementation

- LKVS support added to Infinispan
  - Industrial-grade NoSQL in-memory DB
  - Basis for Red Hat JBoss Data Grid product
  - CRESON integration (staging) as core ISPN feature
- Implementation in Java
  - LKVS = 13,500 SLOC ; CRESON = 4,000 SLOC
- Optimizations (not covered)
  - Listener mutualization
  - Chaining calls idempotency
  - Client-side caching

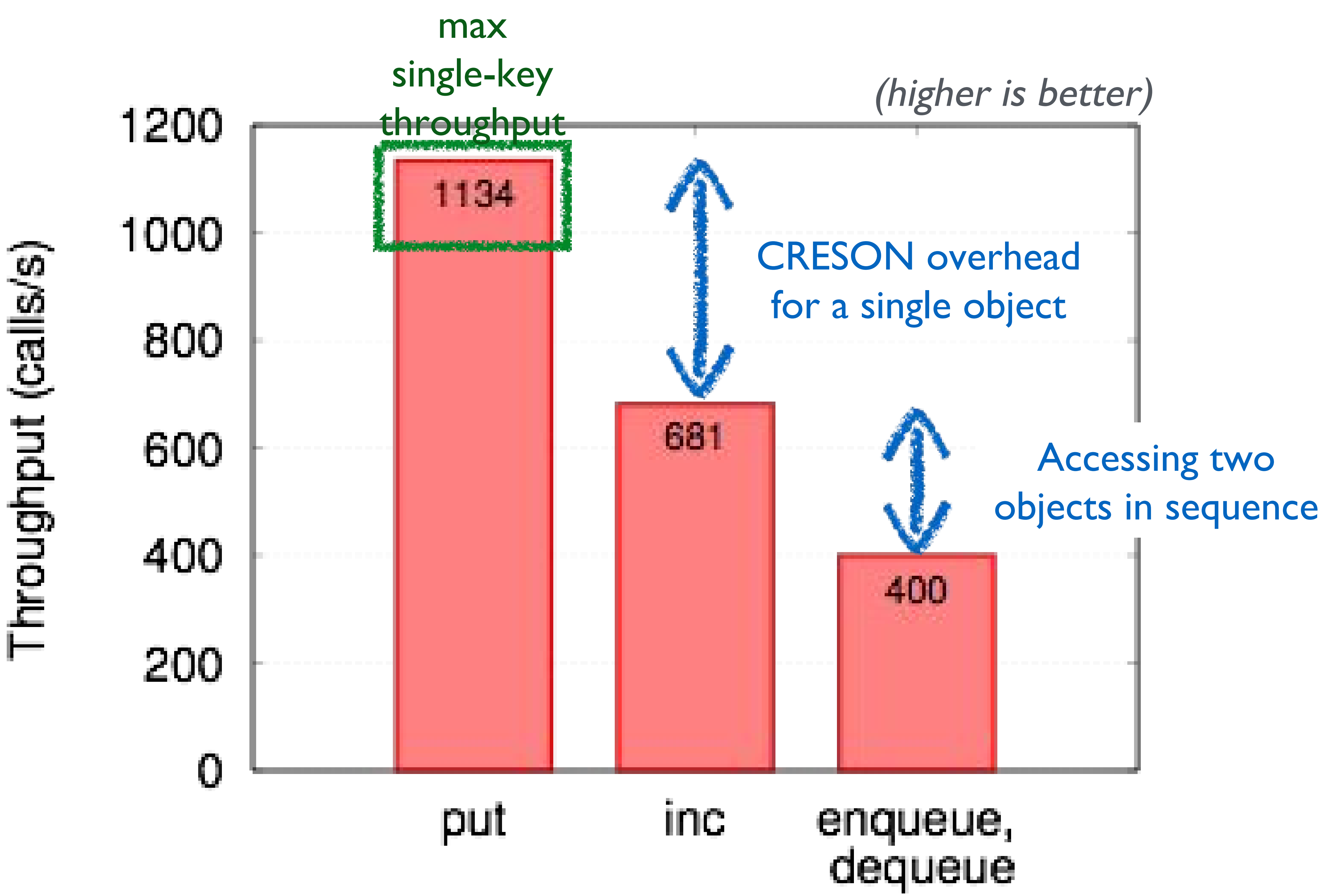
Evaluation

- Cluster of 8-core/8GB Xeon 2.5 GHz, switched 1 Gbps network
- 2 to 6 Infinispan servers (default = 3)
  - Each server maintain a cache of 10^5 recently-used values (serialized objects after their closing)
  - Passivated to disk in the background
  - Replication factor is 2 by default

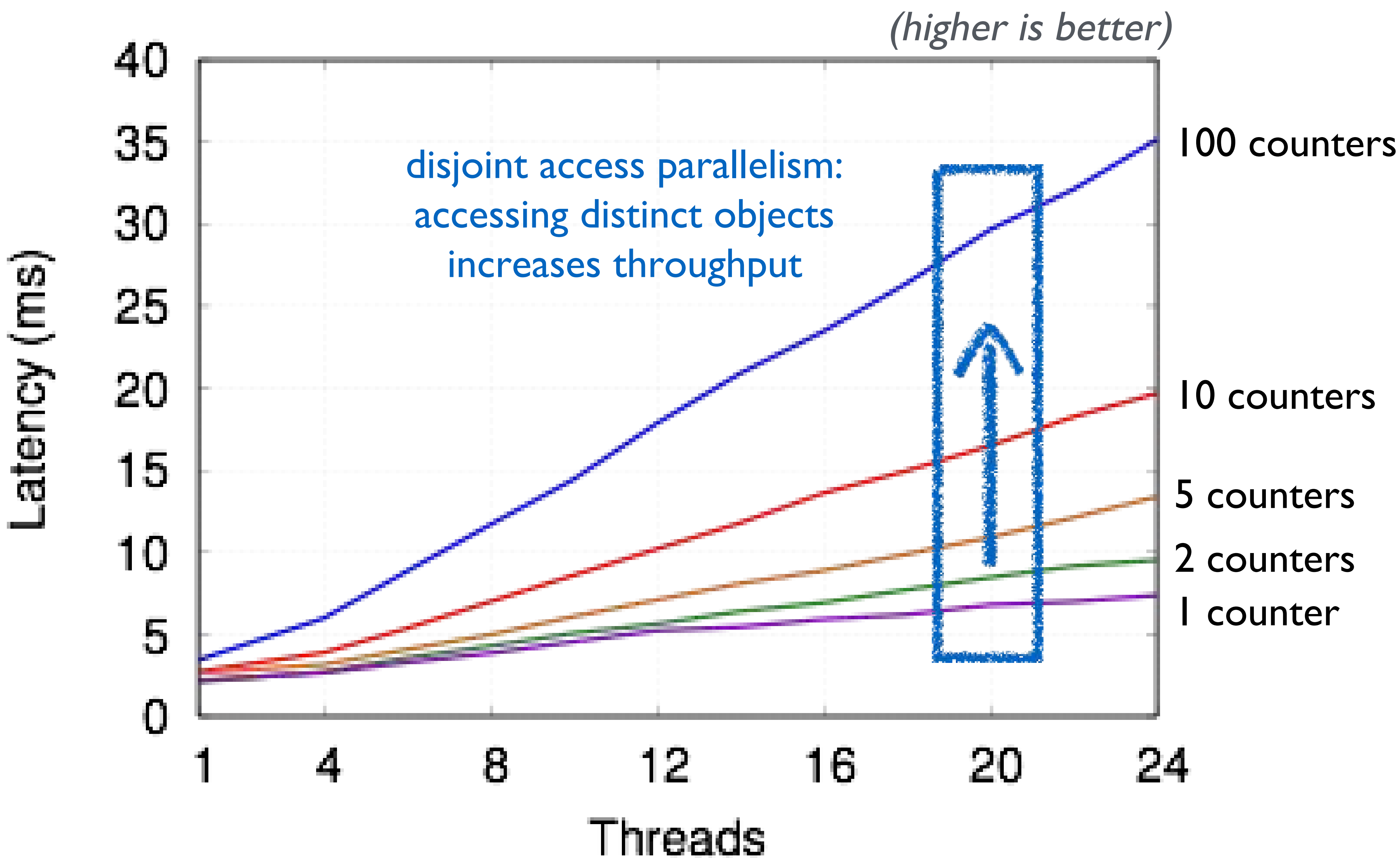
Base Infinispan performance



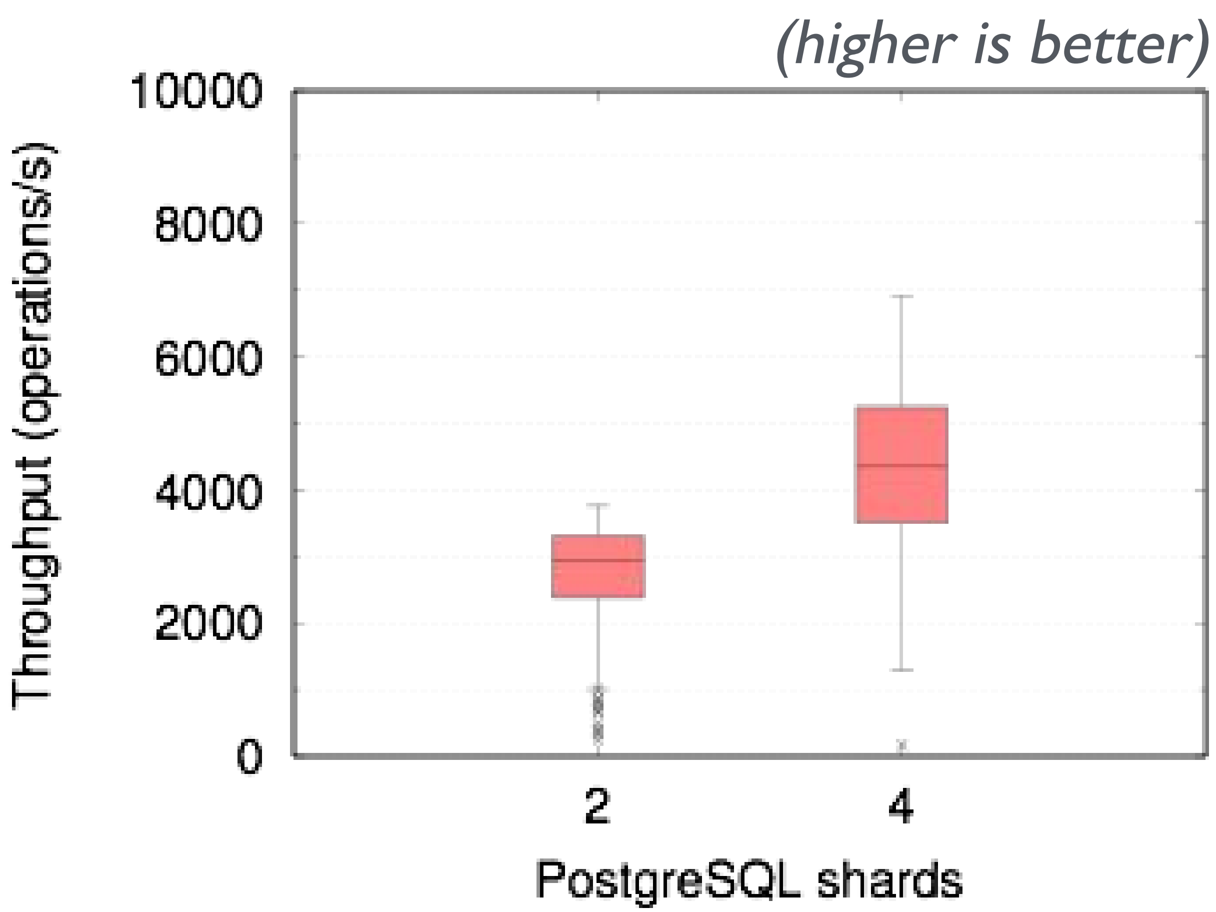
Single-object performance



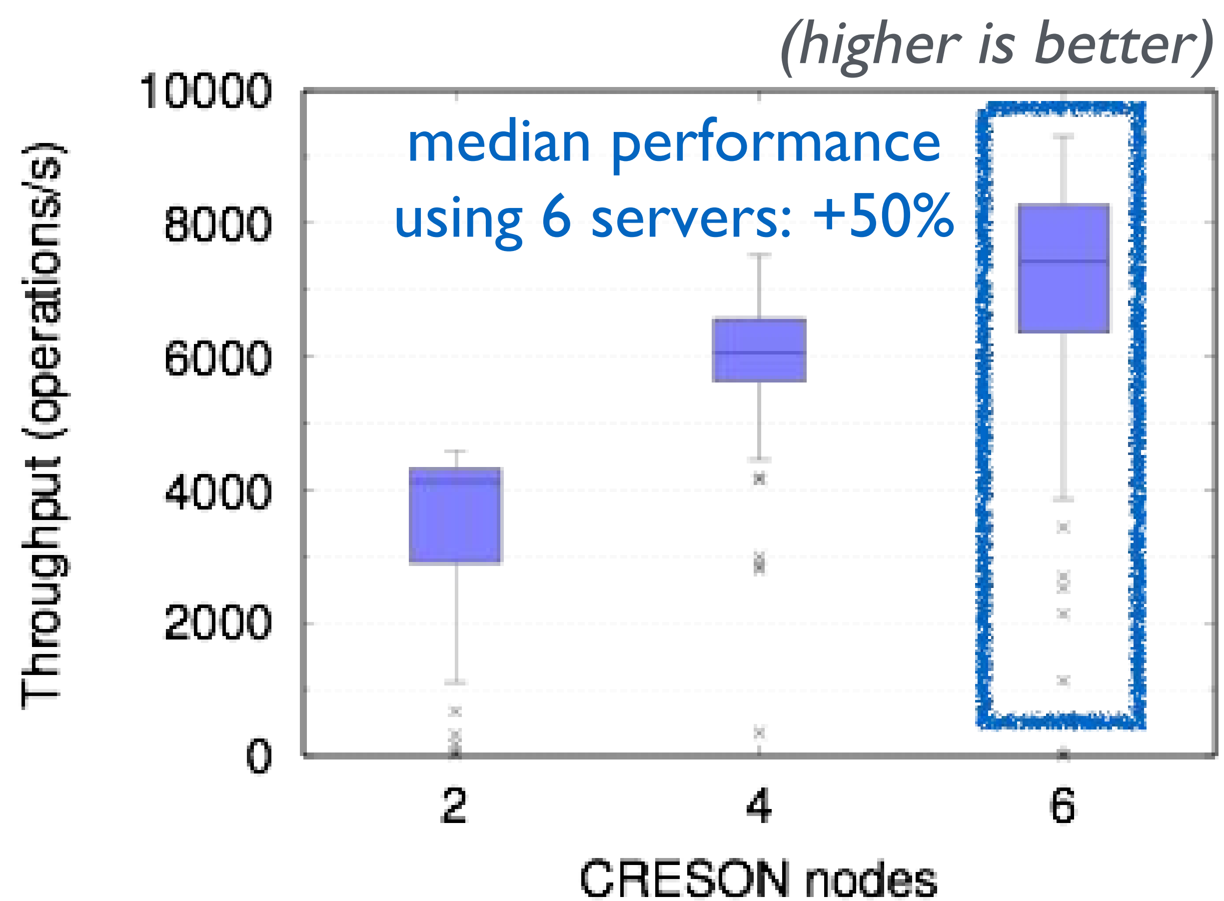
Performance with multiple objects



StackSync performance: throughput

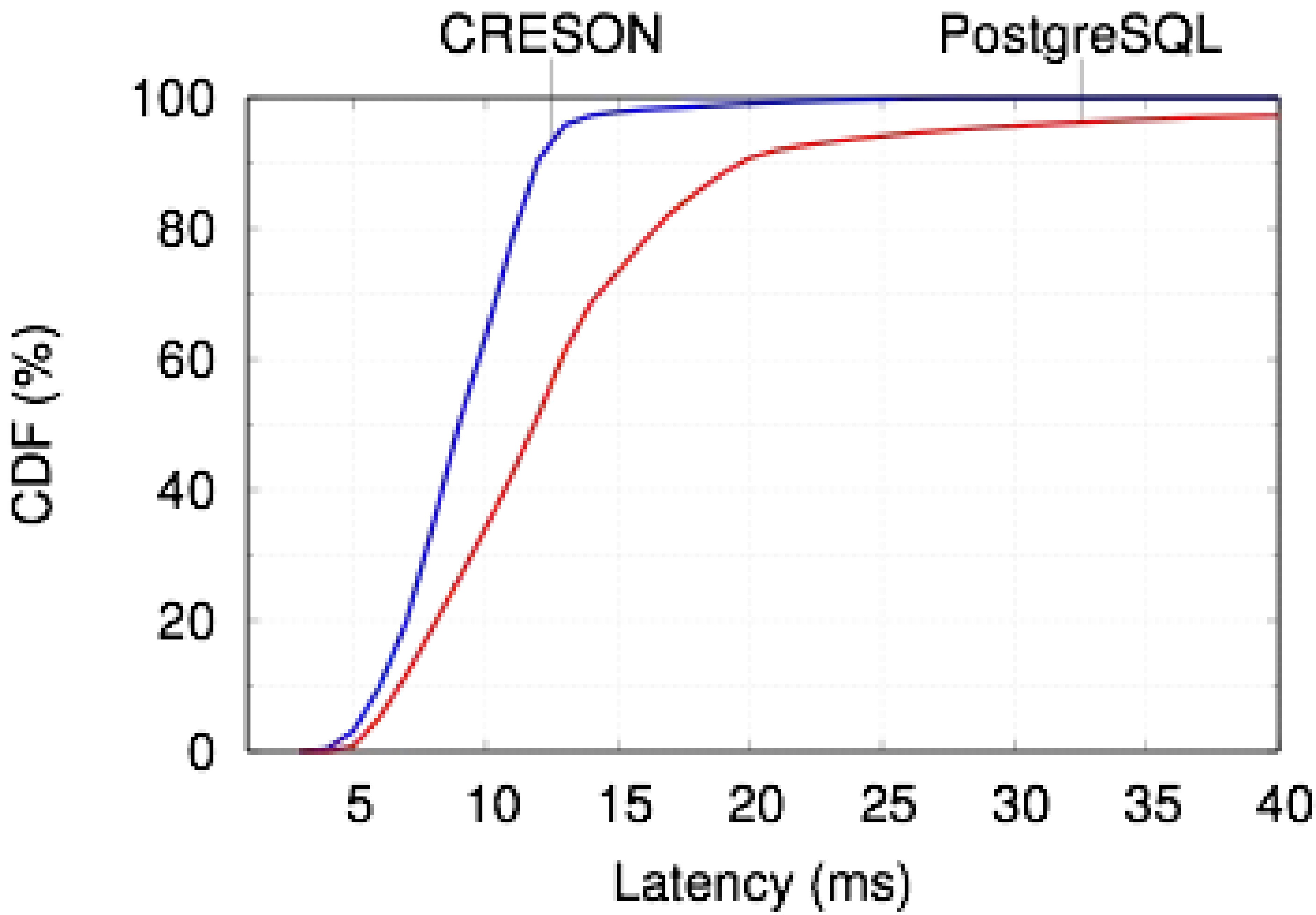


+ 2 additional PL/Proxy nodes



StackSync performance: latency

(leftmost is better)



Conclusion

- NoSQL databases: scalability, elasticity and performance
  but object-SQL mapping is costly

- CRESON = callable shared objects NoSQL
  - Novel LKVS abstraction
  - Simple programming model

- Better performance and elasticity than PostgreSQL

- Future work: support for queries over objects