CRESON: Callable and Replicated Shared Objects over NoSQL*

to appear in ICDCS 2017, Atlanta, GA, USA

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*slides by E. Rivière
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
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

Values are replicated for persistency

Client application instances
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
State-of-the-art: Object-DB mappers

- **Object-Relational Mapper**
  - Store application objects in relational database
  - Hibernate
  - Integration with OO language (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
CRESON: server-side mapping

Traditional Object-NoSQL mapping

in-memory object → serialized object → state-based replication

CRESON: callable and replicated shared objects

proxy → operation → operation-based replication

in-memory object → serialized object
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 (I)

- **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 UI 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
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

independent objects stored in CRESON

embedded objects
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

```java
@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());
    }
}
```

```java
@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;
    }
}
```
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

(higher is better)

Throughput (calls/s)

YCSB workload

write-dominated workload

read-dominated workloads

A  B  C  D

8475  17414  20173  18552

CRESON / RainbowFS kick-off / Pierre Sutra
Single-object performance

Throughput (calls/s)

- **max single-key throughput**
- **CRESON overhead for a single object**
- **Accessing two objects in sequence**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Throughput (calls/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>put</td>
<td>1134</td>
</tr>
<tr>
<td>inc</td>
<td>681</td>
</tr>
<tr>
<td>enqueue, dequeue</td>
<td>400</td>
</tr>
</tbody>
</table>
Performance with multiple objects

disjoint access parallelism: accessing distinct objects increases throughput
StackSync performance: throughput

+ 2 additional PL/Proxy nodes

median performance using 6 servers: +50%
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