

Politecnico di Milano
Facoltà di Ingegneria dell'Informazione



Corso di Laurea Magistrale in Ingegneria Informatica
Dipartimento di Elettronica, Informazione e
Bioingegneria

Avoiding CRUD operations lock-in in NoSQL
databases: extension of the CPIM library

Advisor: Elisabetta DI NITTO

Co-Advisor: Marco SCAVUZZO

Master thesis by:

Fabio ARCIDIACONO matr. 799001

Academic Year 2013-2014

dedica...

Ringraziamenti

Ringraziamenti vari, massimo una o due pagine.

Milano, 1 Aprile 2005

Fabio.

Estratto

abstract in italian

Abstract

abstract in english

Table of Contents

List of Figures	xv
List of Tables	1
1 Introduction	3
2 State of the art	5
2.1 Introduction	5
2.2 NoSQL databases	5
2.2.1 NoSQL characteristics	6
2.2.2 NoSQL classification	7
2.3 Approaches for a common language	9
2.3.1 SQLifying NoSQL	9
2.3.2 ORM approaches	10
2.4 The JPA interface	15
2.5 Cloud Platform Independent Model	17
2.6 Summary	17
3 Problem setting	19
3.1 Introduction	19
3.2 CPIM NoSQL service	19
3.3 Hegira integration	21
4 Kundera extension	23
4.1 Introduction	23
4.2 Overview of Kundera	23
4.2.1 Kundera's Client Extension Framework	25
4.2.2 Approaching the extension	25

TABLE OF CONTENTS

4.3	Developing client extensions	26
4.3.1	Google App Engine Datastore client	27
4.3.2	Azure Table client	35
4.4	Summary	40
5	CPIM extension	41
5.1	Introduction	41
5.2	CPIM architecture	41
5.2.1	NoSQL service	42
5.3	Kundera integration	43
5.3.1	Problems encountered	45
5.4	Hegira integration	46
5.4.1	Migration Manager	47
5.5	Intercept user operations	48
5.5.1	Intercepting CRUD operations	48
5.5.2	Intercepting queries	49
5.6	Data synchronization	51
5.6.1	Contacting the synchronization system	53
5.7	Build statements from user operations	56
5.7.1	Build statements from objects	58
5.7.2	Build statements from JPQL queries	59
5.7.3	Sending statements to Hegira	61
5.8	Interoperability of stored data	61
5.8.1	Kundera clients modification	63
5.9	Summary	64
6	Evaluation	65
6.1	Introduction	65
6.2	Test CRUD operations	65
6.2.1	Tests structure	66
6.3	Performance tests	67
6.3.1	Yahoo Cloud Serving Benchmark	68
6.3.2	YCSB adapters	68
6.3.3	YCSB tests results	68
6.3.4	Discussion	68

TABLE OF CONTENTS

6.4	Hegira generator	68
6.4.1	Exploited CPIM features	69
6.5	Summary	70
7	Conclusions and future Works	73
	Appendices	75
A	Configuring Kundera extensions	77
A.1	Introduction	77
A.2	Common configuration	77
A.3	GAE Datastore	78
A.4	Azure Table	80
B	Configuring CPIM migration	83
B.1	Introduction	83
B.2	<i>migration.xml</i>	83
B.2.1	Configure the ZooKeeper client	84
B.2.2	Configure a sequence number backup	85
B.3	Use CPIM without migration system	86
C	Run YCSB tests	87
C.1	Introduction	87
C.2	Preliminary operations	87
C.3	Run tests for low-level API version	88
C.3.1	Property files	88
C.4	Run tests for Kundera version	90
C.4.1	<i>persistence.xml</i> configuration	90
	Bibliography	91

List of Figures

2.1	Architecture of Spring Data [19]	12
2.2	SOS architecture [15]	15
4.1	Kundera architecture [5]	24
5.1	NoSQL service architecture	42
5.2	The modified NoSQL service architecture	44
5.3	High level schema of interaction	46
5.4	<code>MigrationManager</code> class diagram	47
5.5	<code>MigrationManager</code> states	47
5.6	Sequence numbers handling architecture	52
5.7	Contacting the synchronization system	54
5.8	Interaction flow chart	55
5.9	Statements structure	56
5.10	Statement builders	57
6.1	ER diagram of Hegira-generator model	69

List of Tables

4.1	Mapping of entity fields on Google Datastore	31
4.2	JPQL clauses support for the developed extension	33
4.3	Mapping of entity fields on Azure Tables	37
5.1	Column family and Key mapping among supported databases. .	62

Chapter 1

Introduction

Introduzione al lavoro. Inizia direttamente, senza nessuna sezione.

Argomenti trattati suddivisi sezione per sezione. . .

Original Contributions

This work include the following original contributions:

- two brand new Kundera clients, one for Google Datastore and one for Azure Tables;
- a completely rewritten CPIM library NoSQL service, capable of interacting with a migration system for data synchronization and migration;
- new database adapters for the YCSB benchmark.

Outline of the Thesis

This thesis is organized as follows:

- In Chapter 2 is described the evolution of NoSQL. As a first introduction is discussed why in this years this technology have emerged over SQL solutions and what are the main differences among those technology, the second part aims to underline the lack of a common language for NoSQLs in contrast to DBMS in which SQL exists.

Introduction

- In Chapter 3 we analyze the current available technologies for NoSQL databases and propose a work for extending the CPIM library to make its interaction with NoSQL world even easier and much more extensible. Furthermore we analyze the requirements of modern web application motivating the choice of integrating in the CPIM NoSQL service a mechanism of data migration.
- Chapter 4 is dedicated to the develop of the two Kundera client extension that have been developed in order to support Google Datastore and Azure Tables that will be then used in CPIM as adapters for the relative database.
- In Chapter 5 is presented the work made on CPIM. As a first step is described a modification in the CPIM NoSQL service aimed to integrate Kundera as unique persistence layer for NoSQL access using the standard JPA interface, the library was previously using several different JPA implementation one for each of the supported databases. Furthermore is discussed the extension of CPIM to include an interaction with the migration system *Hegira*.
- In Chapter 6 are described the various tests that have been performed on the developed Kundera extensions, to guarantee the correctness of the operation and to provide a measurement of performance. Moreover is presented a test application developed to be able to test the migration of the data generated through the CPIM library through the NoSQL service.
- In Chapter 7 draws the conclusions on the entire work and proposes some possible future works.

Chapter 2

State of the art

2.1 Introduction

In this chapter, NoSQL databases are firstly introduced and are described their main characteristics and a general classification. In section 2.3 are listed some of the solution that has been developed trying to define a common language (or interface) to interact with different NoSQL databases.

In section 2.4 is described the JPA interface and JPQL, the query language used for JPA queries. In section 2.5 the CPIM library is introduced as a tentative of defining a common interface to interacts with different vendors in a PaaS environment, which include accessing their NoSQL solution.

2.2 NoSQL databases

The relational model and SQL were invented at a time when data management targeted primarily administrative applications. However, the data management landscape has evolved, and today's landscape of data management applications is much more diverse than it was when the relational model and SQL were born. There are cases where RDBMSs performances are not adequate and the structure of the relational model, while being effective for many traditional applications, is considered to be too rigid or not useful in other cases. At the same time, the full power of relational databases, with complex transactions and complex queries, is not needed in some contexts. Also ACID consistency, the complete form of consistency guaranteed by RDBMSs, is not essential,

and can be sacrificed for the sake of efficiency. Many Internet application domains, for example the social networking domain, require both scalability and flexibility in structure, that can be satisfied with simple operations and weak forms of consistency.

With these motivations, a number of new systems, not following the RDBMS paradigm, have been developed. Their common features are scalability and support to simple operations only, with some flexibility in the structure of data. Most of them also relax consistency requirements. They are often indicated as NoSQL systems, which stands for *Not only SQL*, even if other thinks that it would be more appropriate to call them non-relational, because they can be accessed by APIs that offer much simpler operations than those that can be expressed in SQL.

Thus, while relational database systems were first proposed as a way to store and manage structured data, NoSQL databases have emerged as a way to store unstructured data and other complex objects such as documents, data streams, and graphs. With the rise of the real-time web, NoSQL databases were designed to deal with very large volumes of data.

2.2.1 NoSQL characteristics

While DBMS systems tends to *scale up* and thus adding resources to a single node (such as CPUs or memory) in the system to increase its computational capabilities, NoSQL systems, to afford the great amount of data they have to deal with, are designed to *scale out* and thus by adding more nodes in the system.

While *scaling up* is a good solution for certain type of application with well structured data, in today's technical landscape, especially in the web, is increasing the desire to *scale out*. This is due to the fact that this approach is much cheaper since singular nodes does not require high computational capabilities, and, especially, due to the ability to run fault tolerant.

In this scenario Eric Brewer's CAP theorem comes into play, it states that, in a distributed system, we can only have two out of three of the following guarantees:

- **Consistency**, a read is guaranteed to return the most recent write for a given client;
- **Availability**, a non-failing node will return a reasonable response within a reasonable amount of time (no error or timeout);
- **Partition Tolerance**, the system will continue to function when network partitions occur.

Given that networks aren't completely reliable, partitions must be tolerated. According to the CAP theorem, this means that essentially two are the remaining valid options: Consistency and Availability.

- **Consistency/Partition Tolerance**, wait for a response from the partitioned node which could result in a timeout error. This solution is adopted when business requirements dictate atomic reads and writes;
- **Availability/Partition Tolerance**, return the most recent version of the data in the system even if it could be stale. This solution is adopted when business requirements allow for some flexibility around when the data in the system synchronizes;

2.2.2 NoSQL classification

NoSQL databases born to handle various type of unstructured data. Each one of them tries to solve the problem with different approaches due to different requirements on the data but all of them share the general objective of offering simple operations in a scalable way, with possibly massive throughput. Beside the great diversity of the data, and thus of the solution that have been adopted, four main general category can be pointed out.

Key/Value stores

In Key/Value stores, data is stored within fields composed of a name and a value which are then grouped and assigned to a key. This way, given a key, is possible to retrieve the associated value which in turn is the data composed of the various fields. This kind of databases are very similar to data structures

State of the art

such as Maps or Hashtables. Examples of this kind of databases are Redis¹ and Voldemort².

Column-oriented databases

In Column-oriented databases, entity properties are stored inside Columns, data structures that can be generally grouped inside Column Families. Set of columns are then identified by a key.

Examples of this kind of databases are Cassandra³ and HBase⁴.

Document-oriented databases

Document-oriented databases are designed for storing, retrieving, and managing document-oriented information, also known as semi-structured data. These systems are designed around an abstract notion of a Document identified in the database via a unique key. Document database typically offer a query language that allows the user to retrieve documents based on their content because they extract and index all kinds of meta-data and usually also the entire content of the documents. Documents can be stored in many different ways such as JSON, BSON, YAML or XML.

An example of this kind of database is MongoDB⁵ and Couchbase⁶.

Graph databases

Graph databases are databases that use graph structures with nodes, edges, and properties to represent and store data. The node are the entity persisted into the database and edges can represent relationships among them. Nodes maintain the information about the entity they represent by storing them into properties.

An example of this kind of database is Neo4j⁷.

As we write there are more than 150 [3] different NoSQL databases and not all of them can be strictly categorized in one of the previous classification. Hybrid

¹<http://redis.io>

²<http://www.project-voldemort.com>

³<http://cassandra.apache.org>

⁴<http://hbase.apache.org>

⁵<http://www.mongodb.org>

⁶<http://www.couchbase.com>

⁷<http://neo4j.com>

solutions came to be more versatile and appetible to the industry. An example is OrientDB⁸ which is a hybrid solution which data model span across graph and document databases.

2.3 Approaches for a common language

The variety of NoSQL systems is huge and the lack of a a common standardized language for NoSQL databases is a great concern for companies interested in adopting any of these systems, applications and data are expensive to convert and competencies and expertise acquired on a specific system get wasted in case of migration. Also, most of the NoSQL interfaces support a lower level of interaction than SQL, which appear to be a step back with respect to DBMS.

2.3.1 SQLifying NoSQL

A first approach that is emerging is the *SQLfication* of NoSQL databases. NoSQL vendors, to overcome the problem of industry of wasting the expertise matured over SQL systems, started to create, around their NoSQL solutions, SQL-like wrappers, which typically offer different features from those of a query language for a traditional relational database, but maintains a grammar similar to that of SQL.

For example Google, for Datastore, provides GQL, a SQL-like language for retrieving entities or keys from Datastore. Other NoSQL database such as Cassandra (with CQL) or OrientDB provides natively such type of SQL-like language support.

There exists also some independent projects that aim to create such kind of SQL-like languages upon existing NoSQL databases.

Apache Phoenix

Apache Phoenix [10] aims to become the standard means of accessing HBase data through a well-defined, industry standard API. Is a relational database layer over HBase delivered as a client-embedded JDBC driver over HBase data. Apache Phoenix takes standard SQL queries, compiles them into a series of

⁸<http://www.orienttechnologies.com>

HBase scans, and orchestrates the running of those scans to produce regular JDBC result sets.

UnQL

Unstructured Data Query Language [6], or UnQL (pronounced Uncle), is a tentative to bring a familiar and standardized data definition and manipulation language to the NoSQL domain. The project was started in 2011 by the joint effort of Couchbase and SQLite.

After the project was started, and after some burst of activity, the project came to a hold. So it seems, that at least as a project UnQL has been a failure.

2.3.2 ORM approaches

Object Relational Mapping (ORM) solutions came into existence to solve OO-impedance mismatching problem. Each ORM solution had its own API and object query language (like HQL for Hibernate) which made it difficult for programmers to switch from one framework to another. As a result, efforts were made to make standards and specifications.

People depend upon their knowledge of SQL and JDBC to work on databases, switching to another database requires little or almost no effort, which otherwise is painful for NoSQL, the problem, in fact, is that people lack in-depth knowledge of NoSQL and even if they do, their knowledge is limited to a couple of them. .

The idea of the project with this approach, is to give to developers a way to interact with NoSQL which they are comfortable with , leaving the complexity of NoSQLs to the ORM.

Kundera

Kundera is an open source project started by **Impetus Inc.** an India based tech company active in Big Data and Cloud engineering. Kundera provides a JPA 2.1 compliant object-datastore mapping library for NoSQL datastores leveraging the existing NoSQL database libraries, and builds on top of them a wrapper compliant to the JPA specifications.

2.3 Approaches for a common language

The main advantage of the Kundera approach is that, using a well known and defined interface, developers do not need to learn a new framework, furthermore, the use of the JPA interface permits code re-usability since each annotated entity and each JPQL query will work independently by the underlying technology actually used.

Spring-data

Spring Data [9] is a high level **SpringSource** project whose purpose is to unify and ease the access to different kinds of persistence stores, both relational database systems and NoSQL data stores. Is an umbrella project which contains many sub-projects that are specific to a given database. The database currently supported are the following:

- JPA
- MongoDB
- Redis
- Neo4j
- JDBC
- CouchBase
- Elasticsearch
- Cassandra
- DynamoDB

JPA introduced a standard for object/relational mapping (i.e. mapping object graphs to relational database tables), with Spring Data, this support is extended to NoSQL datastores with object-like data structures. Each type of datastore comes with its own set of annotations to provide the needed meta information for the mapping. An example of such diversity in handling different datastore mapping is reported in the code 2.1.

```
1 // MongoDB mapping
2 @Document(collection="usr")
```

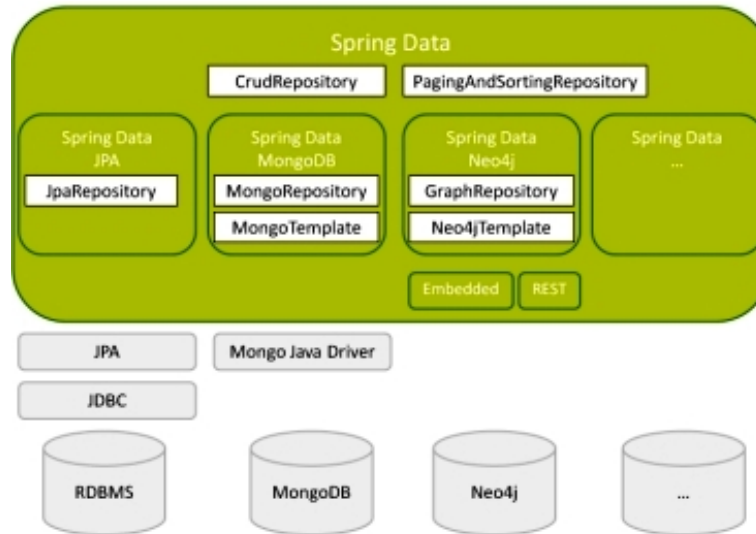


Figure 2.1: Architecture of Spring Data [19]

```
3 public class User {
4     @Id private String id;
5     @Field("fn") private String name;
6     private Date lastLogin;
7     ...
8 }
9
10 // Neo4j mapping
11 @NodeEntity
12 public class User {
13     @GraphId Long id;
14     private String name;
15     private Date lastLogin;
16     ...
17 }
```

Listing 2.1: Spring Data object mapping

When working with data, developers generally write some DAO (Data Access Object) classes that enclose the boiler plate code for CRUD and query operations. With JPA, CRUD operations are available through the `EntityManager` interface, queries instead needs various operations: creation, parameter set and execution. With Spring Data, DAO classes are completely handled by the framework, requiring the user only to provide an interface of the DAO that extends a specific Spring Data repository which will map the operation to the underlying database specific implementation. An example of this is reported in the code 2.2.

2.3 Approaches for a common language

```
1 public interface UserRepository extends MongoRepository<User, String> {  
2     List<User> findByName(String name);  
3     List<User> findByEmail(String email);  
4 }
```

Listing 2.2: Spring Data repositories

PlayORM

PlayORM [8] is an open-source library developed by **Buffalo Software** with the aim of speeding up developer productivity of developing a NoSQL scalable solution. Currently supports Cassandra, MongoDB and HBase.

PlayORM takes great inspiration from JPA interface but recognizes that JPA was designed for DBMS and thus they have re-defined the JPA interface for NoSQL purposes. The framework makes use of some JPA interfaces such as `EntityManager`, for CRUD operations, and the `Query` interface, for queries, but it re-define all the annotations. Furthermore it defines an extension of JPQL called S-JQL which stands for Scalable JQL that adds to JPQL the keyword `PARTITIONS` that allows the user to specify the specific data partition on which execute the query.

An example of entity defined with PlayORM is shown in the code snippet 2.3 and shows the similarities with the JPA approach.

```
1 @NoSqlEntity  
2 public class Employee {  
3     @NoSqlId  
4     private String id;  
5     private String lastName;  
6     @OneToOne  
7     private Phone phone;  
8     ...  
9 }
```

Listing 2.3: PlayORM object mapping

Apache Gora

The aim of Apache Gora [7] is to extend the concept of Object Relational Mapping tools (ORM) to introduce Object-to-Datastore Mapping where the underlying technological implementations rely mostly on non-relational data

modeling. In essence Gora provides storage abstraction for NoSQL technologies. Gora thus gives the user an easy-to-use in-memory data model and persistence for big data framework with data store specific mappings and built in Apache Hadoop support.

The objectives of Gora can be grouped as follows:

- **Data Persistence:** persisting objects to Column stores such as Apache HBase, Apache Cassandra, Hypertable; key-value stores such as Voldemort, Redis, etc; SQL databases, such as MySQL, HSQLDB, flat files in local file system of Hadoop HDFS;
- **Data Access:** an easy to use Java-friendly common API for accessing the data regardless of its location;
- **Analysis:** accessing the data and making analysis through adapters for Apache Pig, Apache Hive and Cascading;
- **MapReduce support:** out-of-the-box and extensive MapReduce (Apache Hadoop) support for data in the data store.

SOS Platform

The SOS (Save Our Systems) Platform [15] is a academic project developed by Università Roma Tre.

The platform achieve interoperability among NoSQL databases by defining a common interface through a meta-layer of abstraction used to maintains entities information. Database specific handlers, read the meta-layer and translate the meta-operations to database-specific operations that are finally performed over the database instance. The architecture is shown in figure 2.2.

The particularity of this approach is that meta-model has been defined spotting common concepts in the model of the supported database. The meta-layer thus span among different types of NoSQL databases, in fact, three database has been chosen by the authors: Hbase to represent Column-based databases, MongoDB to represent Document-oriented databases and Redis for Key/Value stores.

The resulting meta-layer, exploiting the models similarities, is actually very simple; it is composed by three main constructs: Struct, Set and Attribute.



Figure 2.2: SOS architecture [15]

Attributes contains simple values, such as Strings or Integers; Structs and Sets are instead complex elements whose values may contains both Attributes and Sets or Structs as well. Each database is represented as a Set of collections whose is a Set itself, containing an arbitrary number of objects. Each object is identified by a key that is unique in the collections it belongs to.

2.4 The JPA interface

The Java Persistence API [14] was first released as part of Enterprise JavaBeans 3.0 in 2006. As a more general-purpose object-relational mapping facility, it was quickly recognized as such, and was expanded at the request of the community to support use in Java SE environments as well as in the other Java EE container types.

The Java Persistence API provides an object/relational mapping facility to Java developers for managing relational data in Java applications. Java Persistence consists of three areas:

- the Java Persistence API;
- object/relational mapping meta-data;

- the query language.

Mapping meta-data are defined by the user as Java annotations upon the classes that he wants to be mapped to the underlying database. The user annotated classes represents entities; typically an entity represents a table in a relational database, and each entity instance corresponds to a row in that table. Entities are managed by the entity manager, the `EntityManager` API creates and removes persistent entity instances, finds entities by their primary key, and allows queries to be run on entities. The `EntityManager.createQuery` and `EntityManager.createNamedQuery` methods are used to query the database using Java Persistence query language queries.

The set of all entity classes managed by the `EntityManager` instance, is defined by a *persistence unit*. Persistence units are defined in the *persistence.xml* configuration file, each persistence unit is identified with a name that is unique to the persistence units scope.

JPA supports two methods for expressing queries to retrieve entities and other persistent data from the database: query languages and the criteria API. The primary query language is Java Persistence Query Language (JPQL), a database-independent query language that operates on the logical entity model as opposed to the physical data model. Queries may also be expressed in SQL to take advantage of the underlying database. The criteria API provides an alternative method for constructing queries based on Java objects instead of query strings.

JPQL have its roots in the Enterprise JavaBeans Query Language (EJB QL) that was first introduced in the EJB 2.0 specification to allow developers to write portable find and select methods for container-managed entity beans. It was based on a small subset of SQL and it introduced a way to navigate across entity relationships both to select data and to filter the results. As part of JPA was then introduced JPQL that significantly extends EJB QL, eliminating many of its weaknesses while preserving backward compatibility.

2.5 Cloud Platform Independent Model

Cloud Platform Independent Model [13] is a Java library build in order to make Java developers able to abstract their application logic from the specific Cloud Provider on which the application will actually be deployed.

The aim of CPIM is to overtake the vendor lock-in that affect the current PaaS industry. Each cloud provider define its own API for the services available in the PaaS environment and, even if services are the same among various providers, they expose different API; this locks an application to the PaaS environment it was developed for, and is a problem known as vendor lock-in. Since there is no a common interface for such services, if the need of change Cloud Provider arises, maybe due to an increased cost of maintenance, the costs of re-engineer the application for the new Cloud provider environment dissolves the benefit of a provider migration.

CPIM fills this gap providing a common interface that is mapped at run-time, through some XML configuration files, to the specific cloud provider service interface.

2.6 Summary

In this chapter has been introduced some of the main reasons that leads to the NoSQL database definition and why industry is so interested in those kind of technology. Has been presented the main projects that have born trying to define a standard NoSQL language or a standard way to communicate with different NoSQL databases, giving a quick overview of the choices made by each one. Finally has been presented an overview of the JPA interface and the CPIM library, a more general approach for a common language definition in PaaS environment.

Chapter 3

Problem setting

3.1 Introduction

In this chapter we analyze the motivations that led to this work, in particular we analyze the current problems in the NoSQL service implementation of CPIM and propose a solution to address them and at the same time extending the number of NoSQL database supported by the library. Furthermore we will analyze why we decided to include the possibility for the user of the CPIM library to be able to migrate and synchronize data with the *Hegira* migration and synchronization system.

3.2 CPIM NoSQL service

CPIM is using JPA interface to ease the communication to different NoSQL databases. There exists some limitation in this approach, a first limitation is that as the NoSQL service is implemented, is not possible to choose a different NoSQL service with respect to the chosen cloud provider. For example, if Google App Engine is the PaaS on which the application will be deployed, the only possible NoSQL solution available is Datastore, the NoSQL solution available in the App Engine environment. We would give to the user the ability to persist data in the database that best fits his requirements. For example if the user application will generate data that will be processed with Hadoop, the best solution is to store those data in an HBase instance since it integrates easily in Hadoop. Therefore we want to make the user able to persist different

Problem setting

entities in different datastore based on his needs and without the limitation of a specific NoSQL technology.

Another problem the current JPA implementation of the NoSQL service of CPIM is that is not perfectly transparent to the underlying database. The problem reside in the fact that for each of the currently supported database has been found, and integrated into CPIM, a specific implementation of the JPA interface. Even through JPA is a well defined standard, not every JPA provider follows strictly the specification and thus different provider can behave differently while persisting the same entities since they interpret differently the semantic of some JPA annotation.

An example of this problem is how Collection fields are currently handled in CPIM. In the Google JPA implementation for Datastore and in the JPA implementation for Amazon SimpleDB, Collection fields are handled correctly, with respect to the JPA specification, thought the `@ElementCollection` annotation, while, in the JPA implementation for Azure Tables, Collection fields needs to be annotated with the `@Embedded` annotation. This require a modification of the code and thus eliminates the effort of CPIM in achieving code portability among PaaS.

Beside the problems by which the current NoSQL implementation of CPIM suffer, we want to go further and extends the number of NoSQL databases that the CPIM can interacts with.

The proposed solution is to user Kundera as unique persistence layer for the NoSQL service. This integration will produce several benefits to the NoSQL service of CPIM resolving the previously stated problems:

- since Kundera will be the unique persistence provider for the library we will relay only on one implementation of the JPA interface overtaking the problems related to different interpretation of the JPA annotation and thus achieving complete portability of the code of the model since no modifications are required to work with different NoSQL database through Kundera;
- the integration of Kundera permits a redesign of the NoSQL service aimed to decouple the chosen PaaS provider and the NoSQL technology

giving to the user the ability to decide which technology is more suitable for his needs. Furthermore exploiting the polyglot-persistence provided by Kundera, the user will be able to persist entities within different NoSQL databases at the same time simply by define accordingly the persistence unit in the *persistence.xml* file;

- choosing Kundera as persistence layer we can actually take advantage of the already developed extension for many different NoSQL databases adding as a result the support of those database to CPIM;

There are other reasons why we choose to use Kundera as persistence provider for the NoSQL service of CPIM. The main reason is that Kundera, through the use of the JPA interface will permit to the user to handle the complexity of NoSQL databases with expertise he already uses for SQL systems. Furthermore Kundera is in the field from 2010 so have a big and active community, built in many years of activity, and has been used successfully in some production environment.

The only drawback is that Kundera does not support any of the NoSQL data-store currently supported by CPIM; here comes one more reason by which we choose Kundera. Kundera have as its primary goal to make the library as much extensible as possible to let developers build their own client around new NoSQL technology. The solution will thus be to develop the needed extensions for Kundera.

In this ambit the work roadmap is the following:

- refactor the NoSQL architecture of CPIM to integrate Kundera as the unique persistence provider;
- develop two brand new Kundera extensions, one for Google Datastore and one for Azure Tables.

3.3 Hegira integration

NoSQL technologies do not offer a common language for interaction as SQL is for DBMS, furthermore they offer a simpler interface with respect to DBMS.

Problem setting

This require user to interact with NoSQL databases at a lower level of interaction, moreover no effort is made by NoSQL database in hiding to the user the physical representation of the data, this move a good amount of developing effort toward the user. This approach, and the many different NoSQL solution available nowadays, causes a lock-in on the technology chosen since re-engineer an application is often an operation with huge costs for companies.

To mitigate this lock-in problem we want to extend CPIM to make it able to interact with *Hegira* a migration system able to perform interoperable data migration and synchronization across column-based NoSQL databases [11].

Hegira is already able to migrate data offline but in many cases this solution is not acceptable since this require to turn off the application for a period of time that depends on how many data needs to be migrated to the new database. Downtime cost and risk of data loss can be problematic so *Hegira* was extended to be able to perform a live-migration of the data by keeping them synchronized on the source and the destination database. This feature needs to be exploited at application level and thus we decide to embed it inside the CPIM NoSQL service in order to make it as transparent as possible to the user.

CPIM needs to be aware of the state of both the synchronization and migration systems and acts accordingly intercepting user operation and sending data manipulation queries (DMQ) to the migration system while keeping the data synchronized interacting with the synchronization system when required.

Chapter 4

Kundera extension

4.1 Introduction

This chapter briefly presents in section 4.2 Kundera modular architecture, the way in which Kundera is supposed to be extended, the problems occurred in the process and how the community helped in achieving the result.

In section 4.3 are discussed the detail of the two developed Kundera extension, in particular section 4.3.1 describe the extension for Google Datastore while section 4.3.2 the one for Azure Tables.

4.2 Overview of Kundera

Kundera [5] is an implementation of the JPA interface that currently supports various NoSQL datastore. It supports by itself cross-datastore persistence in the sense that its allows an application to store and fetch data from different datastores. Kundera provides all the code necessary to implement the JPA 2.1 standard interface, independently from the underlying NoSQL database which is being used.

Currently supported NoSQL databases are:

- Oracle NoSQL (versions 2.0.26 and 3.0.5)
- HBase (version 0.96)
- MongoDB (version 2.6.3)

Kundera extension

- Cassandra (versions 1.2.9 and 2.0.4)
- Redis (version 2.8.5)
- Neo4j (version 1.8.1)
- CouchDB (version 1.0.4)
- Elastic Search (version 1.4.2)

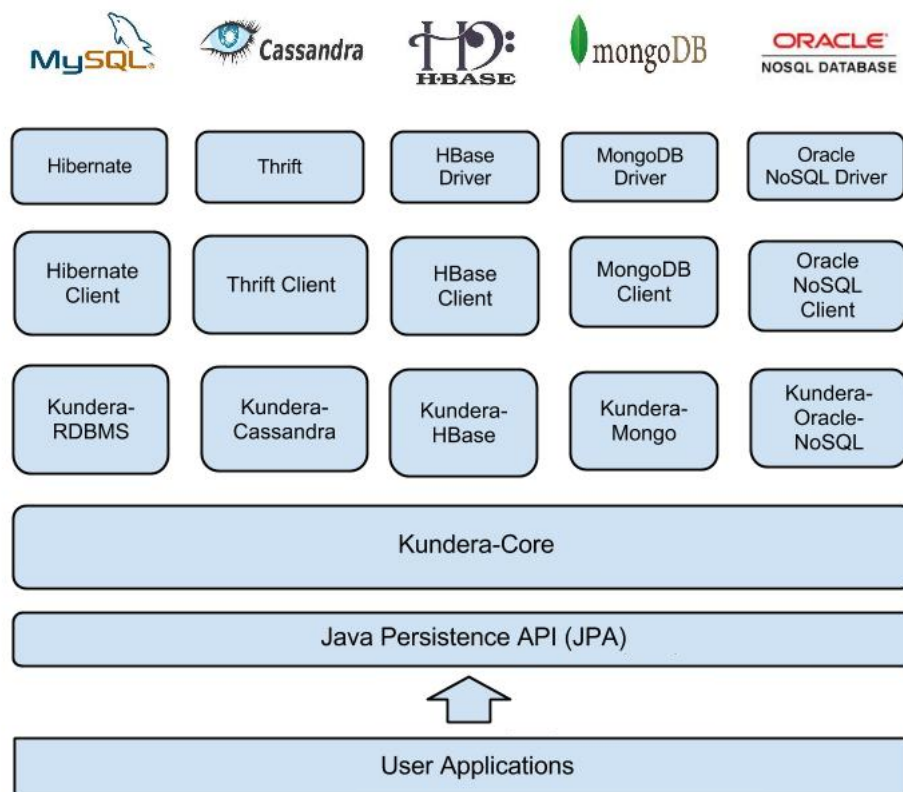


Figure 4.1: Kundera architecture [5]

The architecture of Kundera is shown in Figure 4.1. The figure highlights the fact that the user application interacts with Kundera simply by exploiting the standard JPA interface implemented in the Kundera-Core.

Kundera-Core, each time an operation need to be executed on the underlying database, delegates the operation to the appropriate `Client` (creating it through a `ClientFactory` if it does not exists yet). Clients are then responsible of actually executing the operation on the underlying database.

4.2.1 Kundera's Client Extension Framework

Kundera tries to offer a common way to interact with NoSQL databases through a well defined interface furthermore, since it is as an open source project, it makes other developers able to extend it, adding support for other databases. The *Client Extension Framework*, described in the Kundera documentation, provides a short description about how Kundera clients should work and gives a description of interfaces and classes that should be developed in order to make the client work properly.

Basically to build a new Kundera client, these are the blocks to be developed:

- the **Client**, which is the gateway to CRUD operations on database, except for JPQL queries and named queries;
- the **ClientFactory**, which is used by Kundera to instantiate the new Client;
- the **QueryImplementor**, which is used by Kundera to run JPA queries by invoking appropriate methods in Entity Readers;
- the **EntityReader**, which is used by Kundera to translate the queries into correct client method calls;
- optionally the **SchemaManager**, to support automatic schema generation.

4.2.2 Approaching the extension

While trying to extend Kundera we faced several problems that were not covered by the documentation, two were the main problem in understating what to do and how:

- when actually defined the classes and implemented the interfaces, it turns out that there are actually little differences both on interfaces and the required methods;
- the documentation lacks completely in describing what kind of information are carried by the argument of the methods that needs to be implemented.

After getting the updated information from the community it turns out that the `Entity Reader` was unnecessary and all the translation, from JPA queries to datastore specific queries, and their executions, should be done in the `QueryImplementor`. Unfortunately no help was given by the community about the issue on methods arguments. Hence the most valid solution to approach the development of the extension was in a test driven way trying so to reverse engineer those arguments.

4.3 Developing client extensions

The work carried out has also focused on the development of two Kundera extensions, the first one for Google Datastore and the second one for Azure Tables.

Kundera *Client Extension Framework* provides a generic interface which methods are supposed to carry out a lot amount of code. An example of this is the persist operation that is handled by the `onPersist` method. Besides actually perform the persist operation, it have to create an object that can be persisted in the specific database by reading all the entity meta-data given as arguments, looking for example to relational fields. The adopted solution is a template pattern in which each method maintains the main algorithm structure and delegates every operation to a specific hook method. An example of this approach for the Datastore case, is reported in pseudo code in the snippet 4.1.

```
1  @Override
2  protected void onPersist (...) {
3      Entity gaeEntity = DatastoreUtils.createEntity(entityMetadata, id);
4      handleAttributes(gaeEntity, entityAttributes);
5      handleRelations(gaeEntity, relationHolders);
6      handleDiscriminatorColumn(gaeEntity, entityMetadata);
7      performPersist(gaeEntity);
8  }
```

Listing 4.1: Template for the persist operation

For the Azure Tables extension, since it has been developed as the last one, the same structure has been kept and so it was only necessary to update the code of the hook methods.

The following sections presents these extensions separately, describing each one of the supported features.

4.3.1 Google App Engine Datastore client

Google App Engine Datastore [2] is the NoSQL solution build on top of Google BigTable a sparse, distributed, persistent multidimensional sorted map available in the App Engine platform [12].

JPA identifier

The most basic unit that can be stored in Google Datastore is an *Entity*, which is identified by a *Key* and it is composed of *Properties*. Keys contain various information about the entity itself:

- the entity *Kind*, which is used to group entities of the same type;
- an entity identifier, used to distinguish entities of the same type;
- an optional parent entity .

Inspired by the Google JPA implementation for Datastore [4] the idea was to use the Java class representing the datastore *Key* as identifier for the entity, but, unfortunately, this was not possible since Kundera support only a pre-defined defined set of Java data types.

Hence the adopted solution is to handle the key internally. Each time an operation on Datastore is required the key, relative to the entity, is built. The *Kind* is directly mapped to the table name and the Key identifier is the user defined id specified in the `@Id` annotation. The `@Id` annotation, in fact, is the annotation (available in the JPA specification) that is used to identify the class field that will be used as primary key in the resulting table on the underlying database.

IDs can be specified by the user or automatically generated, and they can be associated to three different data types

- `@Id` annotation on a `String` type field
- `@Id` annotation on a `Long` type field
- `@Id` annotation on a primitive `long` type field

Kundera extension

Since Kundera supports the JPA feature for auto-generated IDs by using the annotation `@GeneratedValue`, this possibility has been exploited also for the Datastore extension and so the user can annotate a `String` ID field so as that it will be auto-generated and its value will be a string representation of a random java `UUID`.

Auto-generated IDs are supported by Kundera only with `AUTO` or `TABLE` strategy, it was not possible to use the Datastore API to generate IDs since it is necessary to know the *Kind* of the entity to be persisted but neither the `AUTO` strategy nor the `TABLE` one provides this information at generation time.

Consistency

In Datastore entities are organized in *Entity Groups* based on their *Ancestor Path*. The Ancestor Path is a hierarchy of entities whose keys have relation among themselves.

Consistency is managed through entity groups and so by defining the ancestor paths. Entities within the same entity group are managed in a strongly consistent means. Entities which are not in an entity group are treated with eventual consistent policy.

Datastore allows to create ancestor paths by defining entities parental relationships between entities and is it a task left to the user. Datastore low-level API also leave this task to the user, for example in Objectify [17], a wrapper for these API, the developer makes use of a `@Parent` annotation to make the user able to specify the parent relationships and hence to be able to organize entities through the ancestor path.

Since JPA is a well defined standard, adding such kind of annotation will break the standard and the only alternative left is trying to automatically guess the ancestor path.

An approach to do so can be to look at JPA relationships since they are clearly a good place to found information for guessing if two entity kind can be hierarchically related, hence for each type of relation we may define some solutions that can be adopted:

- for **One to Many** and **One to One** relationships, since there is an owning side of the relationship, the owning entity can be used as parent for every related entity.

- **Many to One** relationships can be considered as **One to Many** relationships.
- as regards **Many to Many** relationships, a solution can be to persist the elements of the join table as child of the entity in the owning side of the relationship but the specular solution (persist elements as child of the entity on the non-owning side) can be adopted too. The only solution that is not acceptable in this case is to persist both the entities, the one on the owning side and the one on the non-owning side, as parent to an element of the join table. This is principally due to the fact that this will require, as pointed out later, the Key of the join table element to be able to retrieve the entities from Datastore.

Even though it could have been possible to infer such relationships we choose not to implement it inside the Kundera extension for two main reasons:

1. entities are not required to have a single relationship so, for example, if an entity contains two different relationships of type *One to One* there is no way to decide which one should be used, unless asking to the user;
2. entities with a parent require, beside their own Key, the parent Key (and thus its Kind and identifier) to be universally identified. For how Kundera is structured those information are not available and even if the parent entity Kind can be retrieved from Kundera meta-data (by searching in the relationships meta-data), its identifier is not available inside meta-data as thus, since the complete Ancestor Path cannot be built, the entity cannot be retrieved.

For those reasons it was not possible to automatically guess ancestor paths by means of JPA relationships or make the user able manage them directly through a specific annotation without causing errors. Each Kind is persisted as a root Kind hence each entity is stored as a separated entity group identified by its own Kind (the name of the JPA table associated to the entity).

JPA relationships

All the JPA supported relationships have been implemented in the client as it would have been done in a relational database. So for **One to One** and **One**

Kundera extension

to **Many** relationships, on the owning side of the relationship, a *reference* to the non-owning side entity is saved.

For **Many to One** relationships there would be two solutions:

- to persist a list of *references* to the related entities;
- not to persist anything within the entity and fill the relationship with a query.

The second solution has been adopted since it is more consistent with the other Kundera client implementations and with the classic implementations in relational databases.

As regards **Many to Many** relationships a join table is created based on user directives specified by means of the entity class annotations. The join table is filled each time a many to many related entity is persisted and a new *row* is created inside the join table with the *references* to the entities involved in the relationship.

The so far called *reference* for Datastore is exploited by persisting within the entity the Key (Kind and identifier) of the related entity.

Can be useful at this point to show how an entity, annotated with the JPA standard, is then mapped to a datastore entity. Let's take as example the case described in the code 4.2, the **Employee** class is annotated with many JPA annotations.

- the **@Entity** annotation specify to the JPA provider that this will be mapped to an entity in the underlying database and the **@Table** annotation specify the name that the table should have and the persistence unit to which the entity refer;
- the **id** field will handle the identifier for this entity as it is annotated with the **@Id** annotation and furthermore this id will be auto-generated due to the presence of the **@GeneratedValue** annotation;
- the **@Column** annotations specify to the JPA provider under which name the fields should be persisted on the underlying database.

4.3 Developing client extensions

The same is for the **Phone** entity which is related to **Employee** with a one to one relationships and thus a *reference* of the related phone entity will be persisted within the employee one.

The resulting entities on Datastore will be persisted as shown in table 4.1.

```
1  @Entity
2  @Table(name = "EMPLOYEE", schema = "keyspace@pu")
3  public class Employee {
4      @Id
5      @GeneratedValue(strategy = GenerationType.AUTO)
6      @Column(name = "EMPLOYEE_ID")
7      private String id;
8
9      @Column(name = "NAME")
10     private String name;
11
12     /* an employee have one and only one phone */
13     @OneToOne
14     @JoinColumn(name = "PHONE_ID")
15     private Phone phone;
16 }
17
18 @Entity
19 @Table(name = "Phone", schema = "keyspace@pu")
20 public class Phone {
21     @Id
22     @GeneratedValue(strategy = GenerationType.AUTO)
23     @Column(name = "PHONE_ID")
24     private String id;
25
26     @Column(name = "NUMBER")
27     private Long number;
28 }
```

Listing 4.2: Example entities

Key	ID/Name	NUMBER
PHONE:3cb26744	3cb26744	123456789

(a) PHONE

Key	ID/Name	NAME	PHONE_ID
EMPLOYEE:112b18e7	112b18e7	Fabio	PHONE:3cb26744

(b) EMPLOYEE

Table 4.1: Mapping of entity fields on Google Datastore

Queries

Kundera queries are to be expressed in JPQL; the standard JPA query language, which is a object oriented query language based on SQL [14]. Kundera supports all of the clauses of JPQL, but with some restrictions since clauses can be applied only on primary key attributes (the ones annotated with the `@Id` annotation) and column attributes (the ones annotated with the `@Column` annotation).

Once a JPQL query is parsed and validated by Kundera it is passed to the `Query Implementor` together with some meta-data extracted from it which then need to be read in order to build a database specific compatible query.

Google Datastore has on its own a very good support to queries so almost all the clauses are supported except for the *LIKE* one.

To be able to execute queries on properties, Datastore needs to construct secondary indexes for those properties. Those indexes consume the App Engine application quotas to be stored and maintained. The API provides the possibility to decide which property should be indexed, by calling a different method when adding the property to an entity; in fact, `setProperty(String name, Object value)` method is used to set a property which will be automatically indexed, where `setUnindexedProperty(String name, Object value)` can be used to create a non-indexed property.

Since a discriminator is needed to choose between the two methods, other wrappers around Google Datastore low-level API (such Objectify [17]) provide to the user an `@Index` annotation to be placed upon the field that needs to be indexed, but as previously explained, it is not convenient to add other annotation to the JPA standard since this will break interoperability. For those reasons, and in order to be able to actually execute queries, all properties are set as indexed. This choice make queries able to be executed upon every property of an entity but this, as stated before, requires App Engine to maintains secondary indexes, consuming application quota.

Table 4.2 shows a complete list of the Kundera supported JPQL clauses and their support for both the developed extensions.

JPA-QL Clause	Datastore support	Tables support
<i>Projections</i>	✓	✓
<i>SELECT</i>	✓	✓
<i>UPDATE</i>	✓	✓
<i>DELETE</i>	✓	✓
<i>ORDER BY</i>	✓	✗
<i>AND</i>	✓	✓
<i>OR</i>	✓	✓
<i>BETWEEN</i>	✓	✓
<i>LIKE</i>	✗	✗
<i>IN</i>	✓	✗
<i>=</i>	✓	✓
<i>></i>	✓	✓
<i><</i>	✓	✓
<i>>=</i>	✓	✓
<i><=</i>	✓	✓

Table 4.2: JPQL clauses support for the developed extension

Embeddable Classes

Embeddable classes are user defined persistable classes that function as value types. As with other non entity types, instances of an embeddable class can only be stored in the database as embedded objects, i.e. as part of a containing entity object. A class is declared embeddable by annotating it with the `@Embeddable` annotation and can then be used in an entity, as a value type, annotating the field as embedded with the `@Embedded` annotation.

Implementation of those kind of entities is straightforward for Datastore because the embeddable classes can be mapped to the natively supported `EmbeddedEntity`. The implementation makes use of such feature by translating the embeddable entity into a Datastore embeddable entity and then persisting it within the parent entity.

Collection fields

JPA standard supports collection or maps to be used as entities field by using the annotation `@ElementCollection`.

Java Collections are natively supported by Google Datastore but are supported only if composed of one of the supported Datastore data types which includes the main Java data types, such as `String` and `Long`, and Datastore specific ones, such as `Key`.

To be able to save whatever kind of collection (or map) independently of the data type that composes it, the collection (or map) itself is serialized into a `byte` array when persisted and de-serialized when read. To simplify the development, also Lists of primitive types, even if supported natively, are serialized.

Enum fields

Enum fields are supported by the JPA through the annotation `@Enumerated`, by simply persisting its string representation and, when the entity is read back, by instantiating the corresponding enum type.

Schema Manager

The schema manager, as required by Kundera, has to make use of four operations:

- *validate*, which validates the persisted schema based on the entity definition;
- *update*, which updates the persisted schema based on the entity definition;
- *create*, which creates the schema and, thus the tables, based on the entity definitions;
- *create_drop*, which drops (if it exists) the schema and then re-creates it by re-creating the tables based on the entity definitions.

The first two cases are quite useless for Google Datastore and in general for NoSQL databases, since there is typically no fixed schema for the entities.

Entities with same *Kind* can have different properties without restriction. Also the *create* case is meaningless for Datastore since when a new entity of an unknown *Kind* is persisted it is created without the need of explicitly defining it first as a new *Kind*.

The last case *create_drop* will just drop the current schema, deleting all the persisted kinds and so all the related entities, without re-creating the schema since it constructs by itself.

Datastore specific properties

Kundera offers the possibility to define some datastore specific properties in an external XML file that needs to follow a simple structure. This file is referenced inside the `persistence.xml` and it is optional.

This possibility is exploited by the Datastore extension and make the user able to configure the following properties:

- `datastore.policy.read`, to set the read policy;
- `datastore.deadline`, to define the RPCs calls deadline;
- `datastore.policy.transaction`, to specify if Datastore has to issue implicit transactions.

Those properties are read by the `Client Factory` and used to initialize the datastore connection with the required parameters.

A complete reference of Google Datastore extension configuration is available in the the appendix A.3.

4.3.2 Azure Table client

Azure Tables [1] is the NoSQL solution developed by Microsoft, it is a key-value storage and it is available inside Azure environment.

JPA identifier

In Azure Tables an entity to be persisted must either implement a special interface `TableServiceEntity` or be translated into a `DynamicEntity` which

Kundera extension

is basically a dynamic property container (i.e. it does not impose a fixed data scheme). An entity is then uniquely identified inside a table by a *partition-key* and a *row-key*. Partition keys are used to handle consistency, strong consistency is guaranteed for entities which are stored within the same table and having the same partition key, otherwise consistency will be eventual by default.

Since both partition-key and row-key support only the data type `String` and since the JPA annotation `@Id` can be declared only on one field per class, the partition-key and the row-key are concatenated in a single `String` field and handled internally by the extension through the class `AzureTableKey` (a custom class built *ad hoc* for Azure Tables, since there is no such a class that encapsulate both the partition-key and the row-key). This way the user has complete control over partition-key and row-key and thus on the consistency mechanism.

The user can handle those identifiers in three different ways:

1. manually define the row-key and the partition-key;
2. manually define only the row-key;
3. let the extension handle completely the identifier, annotating the ID field also with `@GeneratedValue(strategy = GenerationType.AUTO)` annotation.

In the first case, to help the user in define both the partition-key and the row-key independently by how are handled internally by the extension, a static method `AzureTableKey.asString(String partitionKey, String rowKey)` is provided; its usage is not required, but in case the ID is manually specified, it must follow the convention used internally by the extension which is `partitionKey_rowKey`.

To be able to specify only the row key, while keeping the partition key set to the default value (which can be modified in the datastore specific property file described later on), to have a more fluent API, an utility method is provided: `AzureTableKey.asString(String rowKey)`

The third and last method will generate a java random `UUID` for the row key and set the partition key to the default value.

JPA relationships

Also for Azure Tables extension, relationships are implemented similarly to relational systems as described previously for Google Datastore in section 4.3.1. In Azure Tables to universally identify an entity the partition-key, the row-key and the table name are required. Since the table name is always provided by Kundera (and is available in the entity meta-data), the only required information to identify an entity are the partition-key and the row-key. When two entities are related, the partition-key and the row-key of the related entity are persisted within the entity that owns the relationship.

Taking the same example described for Google Datastore in section 4.3.1 and reported in the code 4.2, the resulting mapping of the entities fields for Azure Tables is the one reported in table 4.3.

Partition Key	Row Key	NUMBER
DEFAULT	3cb26744	123456789

(a) PHONE

Partition Key	Row Key	NAME	PHONE ID
DEFAULT	112b18e7	Fabio	DEFAULT_3cb26744

(b) EMPLOYEE

Table 4.3: Mapping of entity fields on Azure Tables

Queries

Supporting queries for Azure Tables was straightforward, the procedure was the same described in 4.3.1 but due to the different operator supported by Tables, beside the *LIKE* clause, also the *IN* and the *ORDER BY* clauses are not supported.

Table 4.2 shows a complete list of the Kundera supported JPQL clauses and their support for both the developed extensions.

Embeddable Classes

Embeddable classes (described in 4.3.1) are not supported natively by Azure Tables hence the solution adopted is to serialize the field annotated with `@Embedded`, in order to be able to persist it to the storage like a `byte` array and de-serializing it when the entity is read back.

Collection fields

As described for Datastore in section 4.3.1, JPA supports collections, but these are not supported in Azure Tables, even if composed of supported data types. To support collections and maps, the simplest solution is to serialize the entire collection (or map) to a `byte` array when persisting the entity. When reading back from the database, the entity is de-serialized properly.

Enum fields

Enum fields are supported by the JPA through the annotation `@Enumerated`, by simply persisting its string representation and, when the entity is read back, by instantiating the corresponding enum type.

Schema Manager

The Schema manager (as described in section 4.3.1) has also been implemented for Azure Tables and, like Google Datastore, the first two cases are quite useless since there is no fixed data schema and entities, within the same Table, can have different properties without restrictions.

Azure Tables needs that the table in which entities are stored exists before trying to create entities inside of it so, the *create* case simply iterates over all table names and creates them in the database.

For the *create_drop* case, all tables should be dropped (and so all the contained entities) and re-created. The problem here is that tables deletion is performed asynchronously and so there exists an unpredictable amount of time in which the table cannot be re-created since it still exists, even if it is not listed anymore. To overcome this problem two solutions can be adopted:

- catch the `StorageException`, thrown when trying to create the table while it still exists, put the process to sleep for certain amount of time and then try again until it succeeds;
- Do not delete the table itself, but delete all its entities in bulk.

The first method is clearly dangerous since no deadline is given or even guaranteed for the table delete operation. The second solution is actually not so convenient because, even if deletion is performed as a batch operation, both the partition key and row key must be specified and thus one or more queries must be performed over the table to retrieve at least the partition-key and the row-key for each entity in the table; this will require an high number of API calls and thus an high cost of usage.

We have so decided that for the *create_drop* case a drop of all the Tables is performed and then these are re-created even if this can cause the previously mentioned conflict. This option is left as is for testing purposes since in the storage emulator the problem is not showing up because the Tables storage is emulated over a SQL server instance.

Datastore specific properties

As described for Datastore in section 4.3.1, Kundera provides datastore specific properties file that let the user set some specific configuration.

This possibility is supported also for Azure Tables with the following available properties:

- `table.emulator` and `table.emulator.proxy`, to make the user able to test against the local storage emulator on Windows;
- `table.protocol`, to make the user able to decide between *HTTP* or *HTTPS* for storage API RPCs;
- `table.partition.default`, to let the user specify the value for the default partition key.

For a complete reference to Azure Tables extension configuration see the appendix A.4.

4.4 Summary

In this chapter has been introduced in details how the Google Datastore and the Azure Tables Kundera extensions have been developed, the problems encountered during the development, how they have been addressed and the details of the implementation of the two extensions, including the currently supported features.

Chapter 5

CPIM extension

5.1 Introduction

In this chapter will be presented the work made for CPIM extension. In section 5.2 and 5.3 is described the previous state for the NoSQL service of CPIM and how it has been modified to integrate Kundera as unique persistence provider and what problem has been faced during the process.

From section 5.4 are described the various part developed for *Hegira* integration, what are the feature supported by this integration and which design choices has been put in place.

5.2 CPIM architecture

To be able to expose a common interface for the multiple services supported by the library, CPIM adopts heavily the factory and singleton patterns.

The main access point of the library is the **MF** (Manager Factory) a singleton object which is responsible of reading the configuration files and exposing a set of methods that will build instances for the service factories. The initialization is done through the first call to **MF.getFactory()** which read the configuration files and build an instance of the **CloudMetadata** class which will be referenced by all the other services and contains all the information stored in the configuration files.

The library is organized in several packages each of one is responsible of

a particular service. Each service exposes a factory class which is invoked through the MF factory, the service factory maintains a singleton instance of the provider-specific service implementation which is built at the first call based on the configuration available inside the singleton instance of **CloudMetadata**. The result of this process is that with the same method call, based on the configuration file, is instantiated one service implementation or another.

5.2.1 NoSQL service

The architecture of the NoSQL service before this work has been reported in figure 5.1.

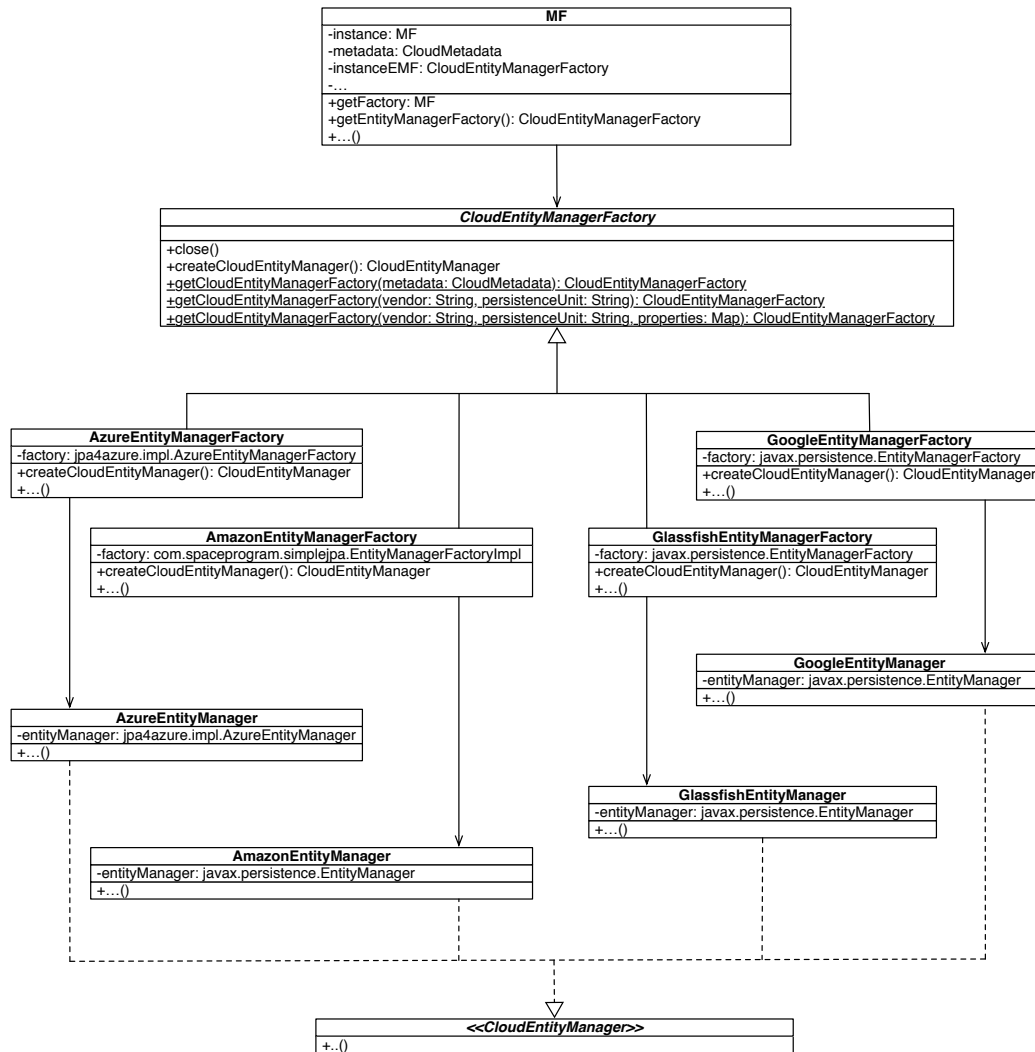


Figure 5.1: NoSQL service architecture

To use the service, the first step is instantiate a `CloudEntityManagerFactory` and, depending on the configuration file, this factory instantiate the vendor specific factory. For example in case that Google is the chosen vendor, the instantiated factory will be `GoogleEntityManagerFactory`. Each provider-specific `EntityManagerFactory` is responsible of instantiating an `EntityManager` which is the gateway to the underlying database. All the vendor-specific `EntityManager(s)` implement the common `CloudEntityManager` interface to achieve uniformity in methods and behavior. The various implementation of the `CloudEntityManager` delegates every method call to the vendor-specific persistence provider.

JPA is not a default language for NoSQL but, due to its wide usage among Java developers, several JPA implementation has been build for various NoSQL databases both developed by the vendor of the NoSQL storage or by the community. This means that to support the NoSQL service through the JPA interface, an implementation of the JPA interface must be found or developed *ad hoc*. For this reason there were three different persistence provider in CPIM, one for each cloud provider:

- for *Google Datastore* its used an official JPA implementation, available inside the SDK;
- for *Amazon SimpleDB* its used **SimpleJPA**, a third-party implementation of the JPA interface;
- for *Azure Tables* its used **jpa4azure**, a third-party implementation of the JPA interface.

There are couple of things to notice: Amazon SimpleDB has been deprecated in favor of DynamoDB and *jpa4azure* is not being maintained anymore, therefore CPIM needs to be updated in order to get rid of those outdated software.

5.3 Kundera integration

To solve these problems and reduce the number of software on which the CPIM rely on to provide the NoSQL service, the proposed solution to modify

the current CPIM architecture with a unique persistence provider that has been identified in Kundera.

The renewed architecture is resumed in figure 5.2 in which the benefit of having a single JPA provider are clearly visible, the architecture is slightly less articulated and no check on the selected underlying technology is needed since this is handled by Kundera while reading the *persistence.xml* file in which the user will define what datastore is interested in. Another benefit of this architecture is that the choice of the NoSQL technology is no more bound to the vendor specified in the CPIM configuration file, is in fact possible deploy the application in one of the supported PaaS provider and choose as NoSQL solution of another one which will be addressed remotely simply by configuring the *persistence.xml*. Moreover its possible exploiting the Kundera polyglot persistency, to persist part of the data in a database and another part in another one defining the persistence units accordingly.

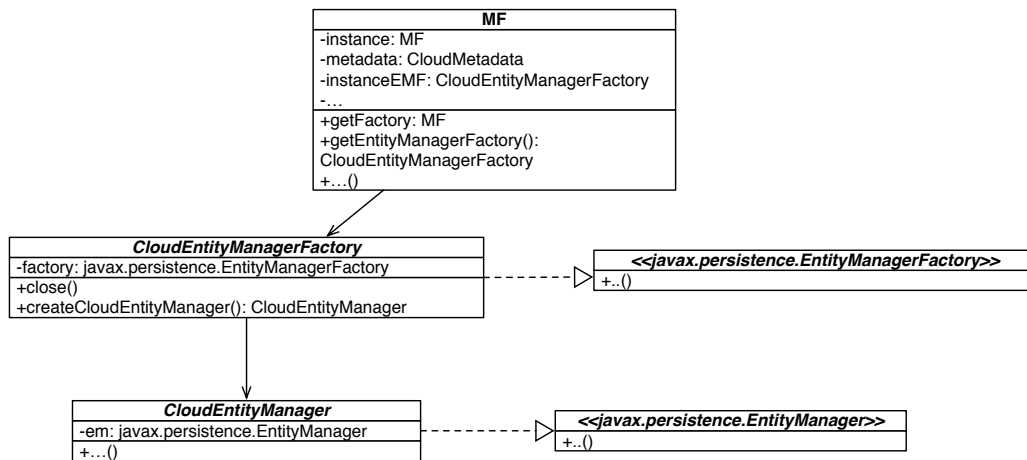


Figure 5.2: The modified NoSQL service architecture

The actual implementation is completely provider agnostic in the sense that actually Kundera is not required as dependency and in fact is not listed as a dependency for CPIM. At run-time, when a Kundera client will be listed in the dependency of the user application, as well as CPIM, the persistence provider dependency will be satisfied.

This provider agnostic implementation is due to the fact that the `CloudEntityManagerFactory` and the `CloudEntityManager` implements

respectively the JPA interfaces `EntityManagerFactory` and `EntityManager`. The actual call to the run-time provider is within the `CloudEntityManager` that on construction instantiate an instance of the provider `EntityManager` and uses that reference to delegate every method execution to it.

This can seems a over-designed architecture but it turns out to be extremely necessary in order to provides a transparent interaction with the migration system as it will explained later on in this chapter.

5.3.1 Problems encountered

Kundera provides an uniform access through the JPA interface independently from the provider, the desired database is defined in the *persistence.xml* through the Kundera client selection. For this reasons all the old libraries that provides a JPA implementation for a specific provider can be removed from the CPIM. This tentative of cleaning the dependency of CPIM caused two main problems:

1. *jpa4azure* turns out to be used also for Queue and Blob service of Windows Azure;
2. Kundera seems to have problem when multiple persistence provider are found in the classpath and has not be found a way to force the selection of Kundera as persistence provider (besides specifying it in the *persistence.xml* file).

To solve the first problem, the code of the extended version of *jpa4azure* has been inspected. The library previously was extended to support some missing functionalities of the JPA interface and contains two main packages:

- `jpa4azure`, which contains the code that implement the JPA interface;
- `com.windowsazure.samples`, which contains the code do ease the communication with the Azure services.

The `jpa4azure` package has been removed and the library rebuild since the other package is the one used in the Blob and Queue service. Its possible to completely remove `jpa4azure` but is necessary to rewrite also the CPIM Blob storage service for Azure using the API provided by the Azure SDK.

CPIM shows more errors of the code in the Queue service and after some investigations, turns out that when *jpa4azure* was extended the class `AzureQueueManagerFactory` and other were introduced. The problem was that `AzureQueueManagerFactory` use the JPA interface to communicate with the Queue service so removing the support to JPA interface we have lost the support to Azure Queue service. A solution to this would be rewrite the CPIM Queue services for Azure using the API provided by the Azure SDK.

5.4 Hegira integration

To support data synchronization and migration, the NoSQL service was further modified to integrate **Hegira** [16]. An high level schema of the interaction we want to achieve is reported in figure 5.3

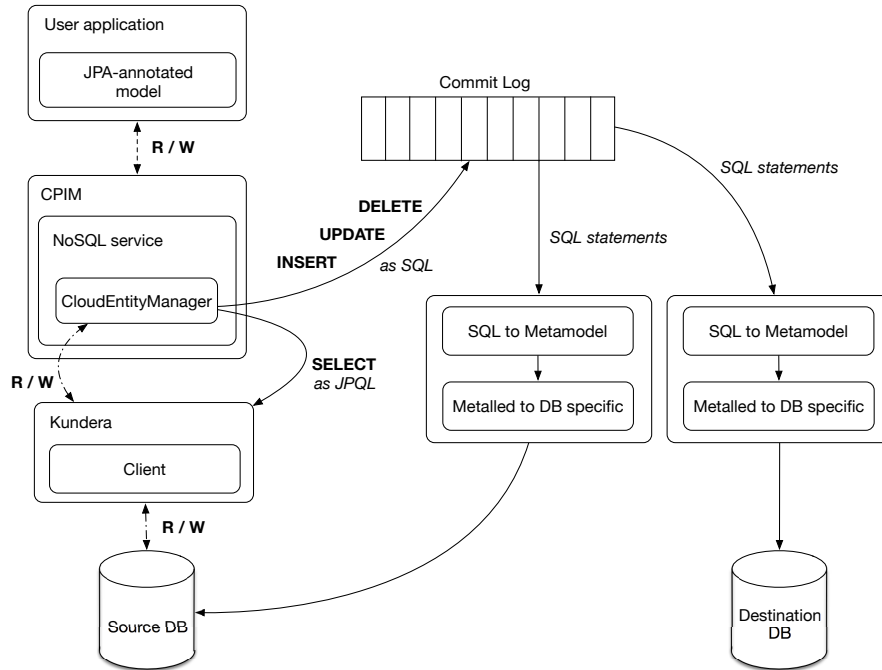


Figure 5.3: High level schema of interaction

In the above schema, *dashed* lines represents the normal flow of data from the user application to the local database, the filled ones represents the behavior in case a migration is in process.

CPIM library needs to connect to the migration system in order to understand when migration is in progress and in that case only bypass the interaction with Kundera by building a string representation of the user operation as a SQL statement, then this string is sent to the commit log of *Hegira* that then will pop the statements and translate then into a datastore-specific operation.

5.4.1 Migration Manager

Interaction with the migration system is handled primarily by the `MigrationManager` class which follows a state pattern represented in the class diagram 5.4.

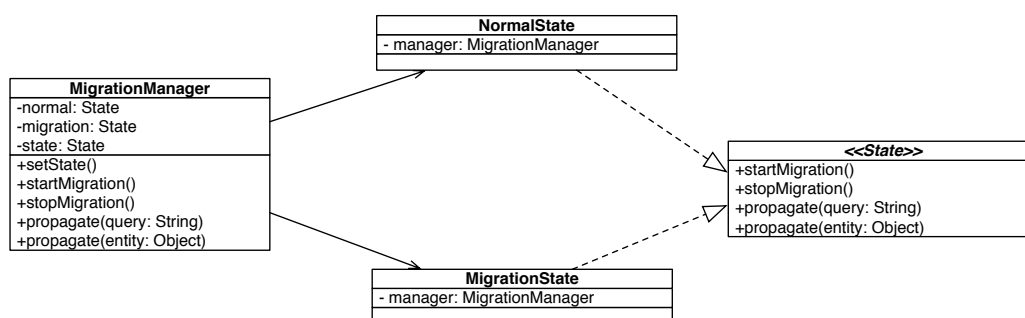


Figure 5.4: MigrationManager class diagram

The pattern permits to the `MigrationManager` to delegates the method execution to the current state, the state diagram is the one represented in figure 5.5 and is composed by two states `Migration` and `Normal` that encapsulate the required behavior.

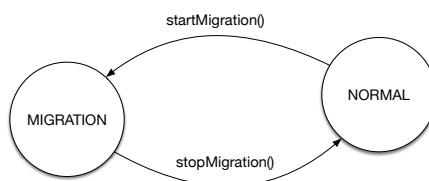


Figure 5.5: MigrationManager states

This part of the design was actually made before knowing how the interactions will exactly be since the component to interact with were not complete yet. Hence in order to have a well-defined place in which behavior has to be encaps-

sulated, the state pattern was the best solution even for future extensibility in case the interaction with the migration system will become more complex.

5.5 Intercept user operations

The first operation that needs to be analyzed is where is possible to intercept user operation is a way that is completely transparent to the user. The operation that we want to intercept are the insert, update and delete operation cause those are the operation that alter the structure of the data and thus are the one that needs to be processed by the migration system.

5.5.1 Intercepting CRUD operations

CRUD operation are handled by the `EntityManager`, three are the methods that needs to be intercepted:

- `EntityManager.persist(Object entity)` for insert operations;
- `EntityManager.merge(Object entity)` for update operations;
- `EntityManager.remove(Object entity)` for delete operations.

User does not invoke methods directly on the provider entity manager but interacts with the persistence provider through the `CloudEntityManager` class. Without the support for the migration system the `CloudEntityManager`, as stated previously, delegates every method call to the provider entity manager, to integrate migration and synchronization logic, the methods mentioned above should contain a little more amount of logic shown in the snippet of code 5.1 taking as example the update operation.

```
1 public <T> T merge(T entity) {
2     if (MigrationManager.isMigrating()) {
3         MigrationManager.propagate(entity, OperationType.UPDATE);
4         return entity;
5     } else {
6         return delegate.merge(entity);
7     }
8 }
```

Listing 5.1: Integrate migration logic

In case of migration the provider is bypassed and is visible a call to the `propagate` method, it accept two arguments: the entity to be converted to a statement and the operation that needs to be generated. The method is called on the `MigrationManager` which then delegates the execution to the current state, which should be the migration one. The `propagate` method of the migration state is responsible of building the requested statements using the statement builders and then sending the generated statements to the commit log of *Hegira*. Both action are described in detail in the following sections.

5.5.2 Intercepting queries

Looking at the JPQL specification [14] turns out that JPQL does not support *INSERT* statements and so the only way user have to persist entities is through `EntityManager.persist(Object entity)` that is one of the case described in the previous section, so only the remaining cases (*UPDATE* and *DELETE*) needs to be intercepted as query.

JPA interface provides several ways to build and execute queries, all available by calling the proper methods defined in the `EntityManager` interface:

- `createQuery`, which creates a `Query` instance from JPQL query string;
- `createQuery`, which creates a `Query` instance from an instance of `CriteriaQuery`;
- `createNamedQuery`, which creates a `Query` instance from a JPQL query identified by name and declared statically on classes;
- `createNativeQuery`, which creates a `Query` instance from a string representation of the underlying database specific SQL dialect.

Native queries are not supported by Kundera and thus from the migration system because there are not so many storage that provides a SQL-like language to specify queries; `createQuery` and `createNamedQuery` are supported, instead query creation through `CriteriaQuery` is currently not supported.

JPA does not provide, through the `Query` interface, a way to get the JPQL representation of the query. Queries are supposed to be written as method

argument when creating them through the `EntityManager` or called by name if they are defined as named queries upon some class. This was actually a problem since in order to be able to parse the query its JPQL representation is crucial.

The easiest solution was to implement the interfaces for `Query` and `TypedQuery` respectively with the classes `CloudQuery` and `TypedCloudQuery`.

The wrapping of the persistence provider queries is achieved in the entity manager and is performed in the query creation method in both the versions that return an instance of `Query` and `TypedQuery`. The actual JPA query generation is delegated to the persistence provider then, before returning to the user the result query is wrapped in a `CloudQuery` that contains both the generated query and its string representation.

For named queries things are little trickier since the user create instance of `Query` or `TypedQuery` just by giving the query name. As can be seen from the code snippet 5.2, named queries meta-data are maintained inside the `PersistenceMetadata` class. This class, besides maintaining information about named queries, maintains principally a mapping between table names and their class canonical name (full package plus the class name). The content of this class is built the first time is queried (since is a singleton instance) and does not read directly the configuration files but the `CloudMetadata` instance that has been modified to include all the required parameters that needs to be read from configuration files. Information of table to class mapping is required for statements building and for sequence number handling both described in the following sections.

```
1 public Query createNamedQuery(String name) {
2     String queryString = PersistenceMetadata.getNamedQuery(name);
3     Query queryInstance = delegate.createNamedQuery(name)
4     return new CloudQuery(queryString, queryInstance);
5 }
```

Listing 5.2: Wrap named queries

5.6 Data synchronization

In this section is faced the problem of synchronization that allows the migration to be performed live.

A special look needs to be reserved to the insert operation. When the user updates or delete an entity no matter if through the entity manager or through a query, he already knows the identifier of that entity since the insert operation have already persisted the entity into the underlying database and thus generated the identifier. Since we want to guarantee a synchronization with the migration system, user cannot define its own identifiers but them needs to be assigned from the migration system. The main caveats is that such assignment has to be made even if the migration is not running yet so the identifier assignment has to be made in two cases:

1. insert statements built from persist operation during a migration phase
2. *standard* insert operation through the entity manager during a normal state

The solution is actually quite simple since everything can be checked inside the `EntityManager.persist` method as described in the snippet of code 5.3.

```
1 public void persist(Object entity) {
2     if (MigrationManager.isMigrating()) {
3         MigrationManager.propagate(entity, OperationType.INSERT);
4     } else {
5         String tableName = ReflectionUtils.getJPATableName(entity);
6         int id = SeqNumberProvider.getNextSequenceNumber(tableName);
7         ReflectionUtils.setEntityId(entity, id);
8         delegate.persist(entity);
9     }
10 }
```

Listing 5.3: Persist operation

In the code snippet is visible a call to the `SeqNumberProvider` class which is the class responsible of actually interacts with the synchronization service of Hegira and handle the *sequence numbers* i.e. the entities identifiers defined by Hegira to achieve synchronization.

Handling the sequence numbers

The sequence numbers are handled by the class `SeqNumberProvider`, a singleton instance that provides a simple way to get the assigned sequence numbers per table. The class diagram of this component and of the component it interacts with is shown in figure 5.6



Figure 5.6: Sequence numbers handling architecture

The `SeqNumberProvider` keeps an instance of `SeqNumberDispenser` for each table that needs to be persisted and is responsible of:

1. provide a unique access point where requesting the next assigned sequence number for a table
2. initialize or restore the state of the dispenser for each of the persisted tables

The first is performed through the method `getNextSequenceNumber(String tableName)` that delegates the operation to the correct `SeqNumberDispenser` associated to the requested table. Since `SeqNumberDispenser` is an interface, the actual implementation is delegated to the `SeqNumberDispenserImpl` class, this mechanism has been used to be able to create more dispensers with different logic. The `SeqNumberDispenserImpl` class maintains internally the assigned range of identifiers provided by the synchronization system by specifying the first and the last element of the range. The class consumes one by one the identifiers in the range and when the range has been completed

requests the next range. This mechanism is internally handled, in fact the `SeqNumberProvider` is only required to call the `getNextSequenceNumber()` method on the dispenser.

In case the user wants to have control over the sequence number range for a particular table, it has been made configurable at run-time. At construction time each `SeqNumberDispenserImpl` class reads the default range from `CloudMetadata` but by calling the method `setOffset(String tableName, int offset)` on the `SeqNumberProvider`, will be changed the offset of the `SeqNumberDispenser` responsible of the given table.

The second functionality is achieved by requesting to the `SeqNumberDispenser(s)` their state representation (as a `byte` array) by calling the method `save()` on the dispensers and then saving it to a Blob storage or to file depending to the configuration specified inside *migration.xml*, described in appendix B. The restoring phase is performed just after construction, if a backup exists either on file or on the Blob storage, the method `restore(byte[] state)` is called on the dispensers giving them its state representation to restore. In this mechanism the `SeqNumberProvider` is completely agnostic to the actual state representation chosen by the `SeqNumberDispenser(s)`, this design choice has been made to make future extensibility more easy and less constrained. The list of all the tables to be persisted is retrieved from the `PersistenceMetadata` mentioned previously for named queries.

5.6.1 Contacting the synchronization system

The interaction with the synchronization system as now was only described as a method call. Those calls are made on an external library (`zkWrapper`) that connects to a zookeeper instance to communicate with the synchronization system and receive the assigned sequence numbers. Since the zookeeper library issues threads to handle communication, was not possible to use this library for Google App Engine since the App Engine run-time does not permit to spawn thread. Two are the feature that requires to communicate with the synchronization system and so use the `zkWrapper` library:

- the migration state listener that modify the `MigrationManager` state accordingly;

- the `SeqNumberDispenser(s)` that needs to retrieve the sequence number assigned to tables.

The solution adopted was to modify the `zkWrapper` library to include an HTTP version that handle the calls not by connecting directly to a zookeeper instance but contacting a remote server through some defined API that ultimately interacts with the migration system.

A simple structure has been built to make both the `MigrationManager` and the `SeqNumberDispenser(s)` transparent to the type of client that is used to retrieve information from the synchronization system. The architecture is shown in figure 5.7



Figure 5.7: Contacting the synchronization system

The `HegiraConnector` is the class responsible of deciding which kind of client needs to be instantiated reading the configuration parsed in `CloudMetadata`. The `HegiraConnector` keeps internally an instance of the chosen client and provides access to its method by delegation. The two available clients implements the interface `ZKAdapter`, built to uniform the methods of the two implementations.

Thread-based client If the user deploy the application on a thread-capable client and configure the *migration.xml* accordingly, an instance of `ZKThread` is built. This version of the client uses directly the implementation of the

5.6 Data synchronization

library `zkWrapper` since there should not be any problem in thread spawning. The `isSynchronizing()` method returns a value which is kept inside the `ZKThread` instance and is queried by the `MigrationManager`. Both the state of the `MigrationManager` and the value inside `ZKThread` are modified by the `SynchronizationListener` which is asynchronously notified by the `zkWrapper` library when the migration state change.

HTTP-based client In case that threads are not supported by the cloud provider the client version that is instantiated (by looking at the configuration) is `ZKHttp` which uses the API-caller added to the `zkWrapper` library. Since no listener can be register and asynchronously notified of a change in the migration state and is not possible to somehow cache the state or make assumption on it, each call of the `MigrationManager` to the method `isSynchronizing()` will perform an API call to the remote server and will return the state of the synchronization just queried.

Before focusing on the statements building, it may be useful to visualize the interaction so far presented in the high-level flow chart presented in figure 5.8.

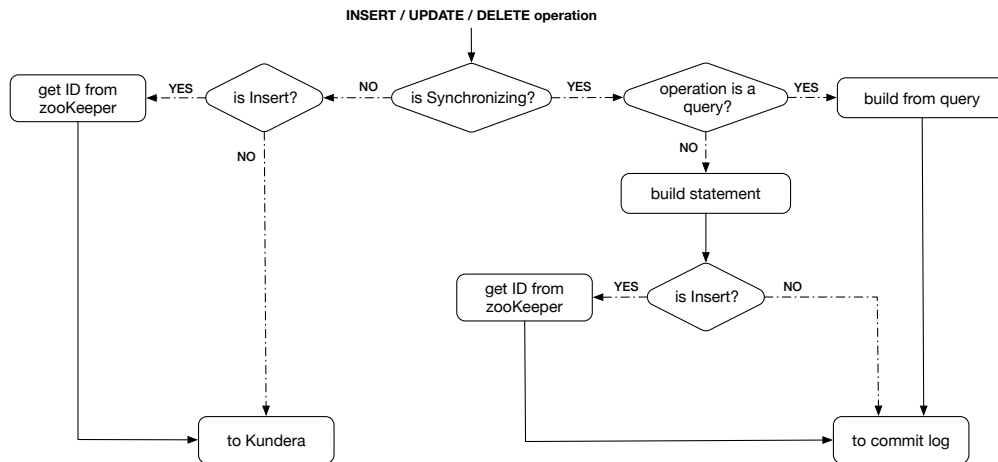


Figure 5.8: Interaction flow chart

5.7 Build statements from user operations

In the previous section we have focused on the sequence number retrieval, in this section we will focus on the generation of the statements to be sent to *Hegira*.

To be able to create SQL-like statements from queries and operation upon entity objects, the first step has been to introduce the *statement* concept in the library. This has been done through the abstract class **Statements** that encapsulate the structure needed for maintaining the necessary data for the statements and is then extended by the three classes **InsertStatement**, **UpdateStatement** and **DeleteStatement** that basically implements the `toString()` method to actually build the specific statement. The class diagram of this statements structure is shown in figure 5.9



Figure 5.9: Statements structure

The **Statement** class maintains three main fields:

- **table**, that contains the table which the statements refer to;
- **fields**, a list of element of class **Filter** that contains the elements presents in the *SET* clause in case of *UPDATE* statements or the inserted values in case of *INSERT* statements;
- **conditions**, a linked list of **Filter** elements and **CompareOperator** elements, to represents the *WHERE* clause.

5.7 Build statements from user operations

Since not all those elements are needed in all the statements type, specific statements implementations overrides the method that **Statements** provide for handling those fields to deny their usage. For example since the *INSERT* statements does not permit a *WHERE* clause, trying to add a condition on that kind of statements will result in an **UnsupportedOperationException**. Another case is the *DELETE* statements that requires only the *WHERE* clause so the exception is thrown trying to add to it a *field*.

Defined the statements structure is then necessary to provide a way to build the correct instance of statement starting by the query or by the operation on an object. To do this in an agile way a builder class has been implemented.

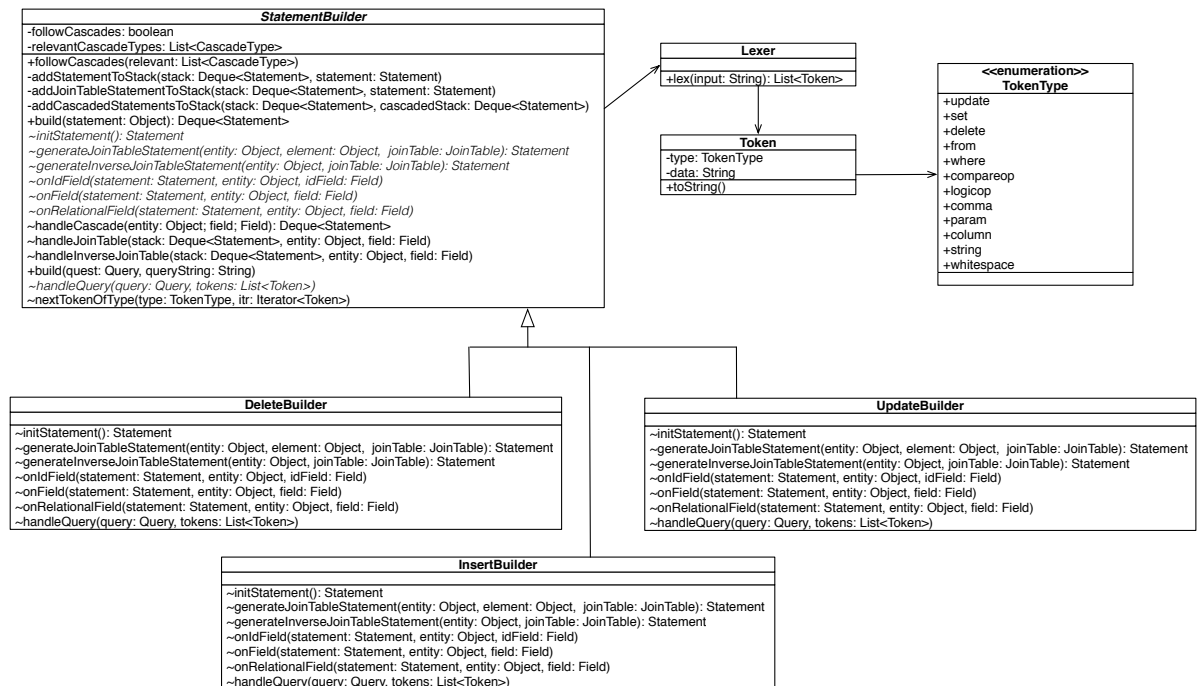


Figure 5.10: Statement builders

The class diagram of the builders, shown in figure 5.10, shows that the same pattern used for statements has been adopted.

The main abstract class **StatementBuilder** provides the facilities to build a generic statements both from object and from a query string. Since many operations are the same for all the three types of statements to be built, the **StatementBuilder** class provides an implementation of those common behaviors, and define some *abstract* methods that are statement-specific and han-

dled in different ways in the three statement builder classes: `InsertBuilder`, `UpdateBuilder` and `DeleteBuilder`. This degree of abstraction has been possible due to the abstract definition of the `Statement` class, this allow to the `StatementBuilder` to acts independently from the specific statement type and then delegate to the specific builder in the cases in which such abstraction is not sufficient anymore.

5.7.1 Build statements from objects

The main problem in generating statements form objects were the cascade type. From the JPA specification [14], the user, on relational fields, can define which type of cascade type he wants to be applied upon operations on the entity. The cascade type can be specified through the annotation `@CascadeType`, four are the relevant values:

- `PERSIST`, when the entity is persisted, every related entity is persisted too, without the need of any explicit persist for that entity;
- `MERGE`, when the entity is updated, every related entity is updated too, without the need of any explicit merge for that entity;
- `REMOVE`, when the entity is deleted, every related entity is deleted too, without the need of any explicit delete for that entity
- `ALL`, which enclose all the previous types.

The problem in supporting such operations is that statements generated by cascade must keep a logical order, for example if an entity *A* is inserted and is related to another new entity *B*, the entity *B* must be inserted after the insert of the first entity. Even if it's possible to guarantee this ordering, the main problem is that the migration system cannot guarantee operation orderings since such operations should be executed within a transaction.

Even if the migration system does not support transactions yet, has been decided to implement also the case of following the cascade types in case the migration system will be able to guarantee operation ordering in future versions. This behavior has been made configurable, the default value can be changed through the relative voice in the `migration.xml` (see the appendix B

5.7 Build statements from user operations

for further details) but also at run-time by calling the appropriate methods on the class `BuildersConfiguration`. The statements builders, when created, asks to that class in order to decide if the build process should or not consider the cascade types and if its the case they set the `relevantCascadeTypes` accordingly. The relevant cascade types has been defined as follow:

1. `ALL` and `PERSIST`, for *INSERT* statements
2. `ALL` and `MERGE`, for *UPDATE* statements
3. `ALL` and `REMOVE`, for *DELETE* statements

To define the statements ordering has been taken the ordering that should be respected as if the statements are for a SQL database. In this situation *join table statements* must be taken with particular care since inserts in the join table must be happen **after** the insert of the entity itself and deletes in the join table must be happen **before** the delete of the entity itself.

The builder abstract class `StatementBuilder` provides a single entry point for statements building which is the method `build(Object entity)`. This method is designed following a template pattern, the designed general algorithm (reported in algorithm 1) perform all the operations needed to build the statement and calls several methods defined as abstract, which are implemented in the specific builders since they require specific logic, and several hook methods that can be overridden by the specific builders to change the algorithm behavior.

Cascade generation is handled through the method `handleCascade(Object entity, Field field)` where `field` is the field of the entity that represents the related entity. The `handleCascade` method checks whenever a statements needs to be generated based on `relevantCascadeTypes` and then recursively calls `build(Object entity)` passing as `entity` the related object.

5.7.2 Build statements from JPQL queries

Cascade modification for *UPDATE* and *DELETE* statements should raise if the statement, beside modifying the entity directly stated in the query, modify another related entity. Fortunately this is not a possible case for JPQL, for the

Algorithm 1 Template algorithm for statements building

```

1: function BUILD(object)
2:   stack  $\leftarrow$  empty queue
3:   cascadedStack  $\leftarrow$  empty queue
4:   statement  $\leftarrow$  INITSTATEMENT
5:   SETTABLENAME(statement, object)
6:   for all field  $\leftarrow$  GETFIELDS(statement) do
7:     if ISRELATIONAL(field) & OWNRELATION(field) then
8:       if handle_cascades then
9:         cascadedStack  $\leftarrow$  HANDLECASCADE(object, field)
10:      end if
11:      if ISMANYTOMANY(field) then
12:        HANDLEJOINTABLE(stack, entity, field)
13:      else
14:        ONRELATIONALFIELD(statement, entity, field)
15:      end if
16:    else
17:      if ISMANYTOMANY(field) then
18:        HANDLEINVERSEJOINTABLE(stack, entity, field)
19:      end if
20:    end if
21:    if ISID(field) then
22:      ONIDFIELD(statement, entity, field)
23:    else
24:      ONFIELD(statement, entity, field)
25:    end if
26:  end for
27:  ADDSTATEMENTTOSTACK(stack, statement)
28:  if ISID(field) then
29:    ADDCASCADEDSTATEMENTSTOSTACK(stack, cascadedStack)
30:  end if
31: end function

```

object case this is possible since objects keeps reference to the related entity and if that has been modified, a cascade operation should be performed.

The main problem for JPQL queries is parsing. Since JPQL is a object query language it make use of an object identifier on which use the dot notation to specify the object properties, furthermore JPQL allows the user to define parameter placeholders (the ones starting with ":",") that are filled later through the method `setParameter(String name, Object value)` of the `Query` class. The translation that should be performed is shown in the following snippet:

```

# JPQL query string
UPDATE Test t SET t.name = :name WHERE t.salary >= :salary

# SQL version

```

5.8 Interoperability of stored data

```
UPDATE Test SET name = 'Fabio' WHERE salary >= '42'
```

Listing 5.4: JPQL to SQL translation

The parameter mapping can be done easily since `CloudQuery` and `TypedCloudQuery` by implementing the required JPA interfaces can intercept the `setParameter` method and so maintain the name-value mapping.

To solve the parsing problem, the Kundera code was inspected to understand how JPQL queries are parsed but turns out they used a custom quite-complex parser especially for validation purposes. Even looking online no specific JPQL parser has been found so, since we are not interested in validating queries or build complex logic on them, a simple and less time consuming solution was to write a lexer that through regular expressions tokenize the JPQL string. Even the building of statements from queries follows a template pattern, the `StatementBuilder` class provides the template method `build(Query query, String queryString)` that tokenize the query using the lexer and then call the abstract method `handleQuery(query, tokens)` that is implemented in `DeleteBuilder` and in `UpdateBuilder` which are responsible of iterate over the tokens to build the correct `Statement` instance. The `build(Query query, String queryString)` calls other various hook methods that can be overridden by the specific builders to change the algorithm behavior.

5.7.3 Sending statements to Hegira

Both the method `propagate(Query query)` and `propagate(Object entity, OperationType operation)` fill a statement stack which contains the generated statements in the execution order.

The statement stack is iterated and each time a statement is removed from the head of the stack (LIFO order). Each one of the extracted statement is then sent to Hegira.

5.8 Interoperability of stored data

The Kundera client developed and described in chapter 4 was developed to be as much as consistent to the other client developed for Kundera to be more

likely accepted by the community and so are not completely interoperable. In an optic of data migration what we want to achieve is that data stored within a database and migrated to another one are still readable to the application without changes besides the new database configuration.

The problem for Kundera clients are the relationships. Each database have its own ways to define identifier for the persisted entities, for Google Datastore there's the **Key** with *Kind* and an *identifier*, for Azure there are the *partition-key* and the *row-key*. Concepts are different but actually quite similar since both databases are key-value columnar databases. A solution to the problem would have been to modify the migration system in order to make it aware of the problem and let it translate the relational columns in the format of the target database, in this way the relational columns should have been identified in some way to let the system recognize them by adding a pre-defined prefix or a suffix to those columns. Since this solution require a good amount of changes in the migration system, other solution have been explored.

Back to the concept of identifier, generally, in columnar databases, columns are grouped in a *column family* and set of columns are identified by a *key*, actually the *key* can span among different *column families* but that's not the case either in Datastore or Azure Table. The pair $\langle \text{column family}, \text{key} \rangle$ is sufficient to identify an entity (composed by one or more columns), so is needed a mapping between database-specific terminology to the more general one, this mapping is shown in table 5.1.

General concept	Datastore	Azure Table
Column Family	Kind	partition-key
Key	key-identifier	row-key

Table 5.1: Column family and Key mapping among supported databases.

At this point is needed a common way of persisting relationships as column family and key in a way that is interoperable among both the client extension. The proposed solution is to persist `columnFamilyKey`. This solution has to

be preferred w.r.t the one that require modification of the migration system since the interoperability is achieved transparently to it.

5.8.1 Kundera clients modification

Since lot of work has already been done on the Kundera clients, the modification to them has been made on a separate branch of the projects named *migration*.

Google Datastore The Datastore extension has been modified to persist relationships as `kind_key-identifier` instead of the `Key` instance. Join tables require particular care, Kundera is not providing the class of the entities involved in the join table but just the column names and the identifier (the one with the `@Id` annotation). Queries are possible even if the *Kind* is unknown since Kundera provides the entity class with the entity identifier as arguments to find operation. To be more consistent and apply the newly defined identifier pattern (`kind_key-identifier`) even for join tables, a map is maintained in the client and built inspecting Kundera meta-data to keep track of which entity classes are involved in which many to many relationship.

Azure Table The Azure Table extension has been modified too to reflect the newly defined standard for relationships. In Azure Table relationships were already being saved as `partition-key_row-key` due to the lack of a class similar to `Key` for Datastore that encapsulate them. The actual problem here is that user can manually handle the partition-key but is not a possibility that can be guaranteed since if an entity is persisted with a partition-key, it will be read by the Datastore extension as of that *Kind*. Since the *Kind* in Datastore extension is the entity table name, has been decided to lock the Azure Table partition-key to the table name so user cannot decide its own since this will break the interoperability of data.

The same discussion for the join tables made previously for Datastore applies as is also for the Azure Table extension.

5.9 Summary

In this chapter has been rapidly described the CPIM structure and the architecture of the NoSQL service before this work. Then has been described how was possible to integrate Kundera as unique persistence provider in the NoSQL service and the problem encountered in the process.

From section 5.4 has been described the general interaction we wanted to build to make CPIM and Hegira communicate and was then introduced and described the architecture and the design choices operated in order to develop such interaction.

Chapter 6

Evaluation

6.1 Introduction

In this chapter, in section 6.2 will be discussed the tests used to develop the two Kundera extensions. In section 6.3 will be described the YCSB framework that we have used to test the performance of the developed extensions with respect to the low level API. Finally in section 6.4 we present the application developed to test the data synchronization capabilities of CPIM while persisting data through the Datastore Kundera extension.

6.2 Test CRUD operations

The Kundera extensions development, due to the lack of information both in the documentation and from the community, has been approached in a test driven way. The first step was then writing the required JUnit tests for the features we have planned to support.

We primarily want to achieve code portability of model classes, this should be exploited by the usage of the JPA interface but, as stated in chapter 3, there were problems in the old NoSQL service implementation relatively to this point. Secondary we want to be sure that while entities are persisted in the underlying NoSQL database, they can be restored without any loss of information and thus the mapping between entities and the NoSQL database data model behave correctly in both verses. Hence test the extensions can-

Evaluation

not be done directly by testing single methods behavior inside the extensions code, this will for sure test the correctness of the operations but, since Kundera clients are not obliged to follow a rigid structure for their code in the implementation of the required interfaces, tests written for a client are not guaranteed to run correctly for another one.

The approach we adopted was to define a single test suite, that will test each one of the feature we planned to support, by interacting directly with Kundera through the JPA interface. This make us able to use the same tests independently of the specific extension and thus testing the correctness of CRUD operations through the JPA interface and the portability of the code by means of tests portability.

Those tests have been primarily used to test the extensions during the development phase but they have also been executed on the remote databases instances by connecting to them through the network from the development machine. This test has been made to guarantee the correct functioning of the two extensions on real databases instance since tests runned locally are executed against emulators of real storages.

6.2.1 Tests structure

Tests are composed by the entities, annotated with the JPA annotations, and a test class for each feature. There are 20 defined entities that includes:

- simple entities related with the JPA relationships annotations, used to test relationships among entities;
- embeddable entities and specific entities that uses those embeddable entities as data types, both types used to test the embedded feature;
- entities with enum fields, used to test the enum fields support;
- entities declared with different data types for the primary key identifier, used to test ids auto-generation and user-defined ids validation.

The test classes developed for testing the correctness of relationships are:

- `MTMTest`, to test the *Many to Many* relationship type;
- `MTOTest`, to test the *Many to One* relationship type;

- `OTMTest`, to test the *One to Many* relationship type;
- `OTOTest`, to test the *One to One* relationship type;

All of those test classes implements two different methods: `testCRUD()`, that test the relationship by interacting with the method of the `EntityManager` interface, and `testQuery()`, that test the relationships by reading, updating and deleting entities through JPQL queries.

The remaining tests classes are:

- `ElementCollectionTest`, that tests the JPA feature for persisting list of entities within another one;
- `EmbeddedTest`, that tests the JPA feature of persisting user-defined data-types as field of entities;
- `EnumeratedTest`, that tests the JPA feature of persisting enum fields;
- `QueryTest`, that tests the execution of various *SELECT* queries and the support for the various JPQL clauses in queries.

6.3 Performance tests

We wanted to test the overhead of the developed Kundera extensions with respect to direct use of low-level API. To test those kind of performance in terms of throughput and latency of the read and write operations, we have used Yahoo Cloud Serving Benchmark [18]. We choose this approach since it was already used by Kundera developers to estimate the overhead that Kundera adds to the low-level API versions of its clients. Hence by using the same method we are able to compare our results to the ones of Kundera.

6.3.1 Yahoo Cloud Serving Benchmark

6.3.2 YCSB adapters

6.3.3 YCSB tests results

6.3.4 Discussion

6.4 Hegira generator

To be able to test the interaction between the CPIM library and the synchronization system and to provide an example of usage of the extended CPIM library, we have developed *Hegira generator*.

The application provides two behaviors through command line interface, a **clean** command to clean-up the remote Datastore instance by deleting all the entities of all Kinds, and a **generate** command that take as argument the number of entities to be generated per table and generates them.

Data generation is done upon a pre-defined entity model inside the application and described by the ER diagram of figure 6.1. Build an entity generator agnostic to the entities model was not our goal and it would have required a way to automatically build the dependency graph of the entities since entities related to other ones should have a reference to the entity they depends on. Hence the application is aware of the entities dependencies and generates them accordingly.

To be able to generate random entities, two methods are used:

- **persist(Class master)** that generates and persist entities without dependencies (such as **Employee** in the application model);
- **persist(Class master, Class slave, DependencyType type)** that generates and persist the entities of the *master* class, then uses randomly extracted entities among those just generated to fill the dependencies for the entities of the *slave* class. The **DependencyType** would be **SINGLE**, if the *slave* class needs just one element to fill the dependency (which is the case of *One to One* and *Many to One* relationships), or **COLLECTION**,

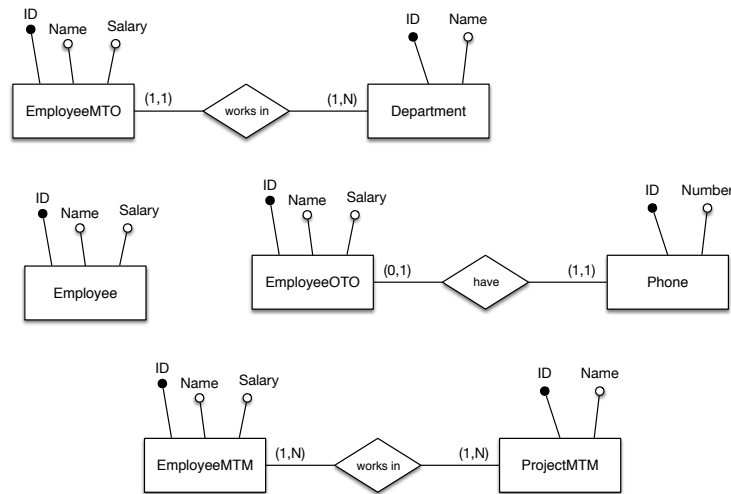


Figure 6.1: ER diagram of Hegira-generator model

if the *slave* class needs more than one element to fill the dependency (which is the case for *Many to Many* relationships).

The actual entity generation is delegated to the entity itself through reflection since each entity of the model implements the `Randomizable` interface. An example of entity generation through this interface is shown in the snippet 6.1.

```

1  @Entity
2  public class EmployeeOTO implements Randomizable<EmployeeOTO, Phone> {
3      ...
4      @Override
5      public EmployeeOTO randomize(Phone dependency) {
6          setName(RandomUtils.randomString());
7          setSalary(RandomUtils.randomLong());
8          setPhone(dependency);
9          return this;
10     }
11 }
  
```

Listing 6.1: Entities generation

6.4.1 Exploited CPIM features

To perform the persist operation of the generated entities is used the `EntityManager` interface on which is called the `persist` method, this is completely JPA compliant and the user is not aware of what is done under the

Evaluation

hood since communication with the synchronization system is handled automatically. An example is provided in the code 6.2.

```
1 CloudEntityManager em = MF.getFactory().getEntityManager();
2 Department dep = new Department("Computer_Science")
3 em.persist(dep)
```

Listing 6.2: Persisting entities in CPIM

The `persist` operation through `CloudEntityManager` contacts the synchronization system to get the assigned sequence numbers for the specific tables and assign the first of them to the entity before delegating to Kundera the `persist` operation.

The application make use of the possibility of modifying at run-time the size of sequence numbers range that is requested to the synchronization system. Hence before the `persist` operation, the size of the sequence number range is set to the double of the number of entities to be generated. This is done through a call to `SeqNumberProvider.getInstance().setOffset(tableName, offset)`, if the resulting range size is grater than the maximum size that can be requested, is limited to that value.

the last feature that is exploited by the application is the sequence number backup to file. The backup is configured in the `migration.xml` file as described in the appendix B. This permit to the application, when is restarted, to restore the sequence numbers without the need of contacting the synchronization system.

Furthermore, to avoid execution of `persist` operations on a table which entities generation was completed in a previous execution, a file with the list of the table completely generated is kept in the same folder specified for the sequence numbers backup files.

6.5 Summary

In this chapter we have presented the test of correctness and performance made for the two developed Kundera extension showing the minimal performance loss that Kundera add to the low-level API. Finally we have presented *Hegira*-

6.5 Summary

generator, the application developed to test the mechanisms developed inside CPIM to interacts with the synchronization system.

Chapter 7

Conclusions and future Works

Conclusioni del lavoro e sviluppi futuri. Massimo una o due pagine.

Appendices

Appendix A

Configuring Kundera extensions

A.1 Introduction

In this appendix are described in detail the configurations available for the two developed Kundera extensions. Are described the required properties that needs to be configured in the *persistence.xml* file and the available properties that can be defined in the external datastore specific properties file.

A.2 Common configuration

The main configuration is performed in the *persistence.xml* file and it follows the JPA standard. The template of the file is as follow:

```
1 <?xml version="1.0" encoding="UTF-8" standalone="no"?>
2 <persistence ... >
3     <persistence-unit name="...">
4         <provider>com.impetus.kundera.KunderaPersistence</provider>
5         <class> ... </class>
6         <exclude-unlisted-classes>true</exclude-unlisted-classes>
7         <properties>
8             <!-- kundera properties -->
9         </properties>
10    </persistence-unit>
11 </persistence>
```

Listing A.1: persistence.xml template

A name for the persistence unit is mandatory as it will be referenced inside the classes of the model as shown in the snippet A.2 in which has been declared as schema the `kundera.keyspace` property to the persistence unit name. The full

Configuring Kundera extensions

name of the classes that needs to be handled through this persistence unit must be specified in the `<class>` tag. Each extension needs different configuration that needs to be specified inside the `<properties>` tag.

```
1 @Table(schema = "gae-test@pu")
2 public class Employee {
3
4     @Id
5     @Column(name = "EMPLOYEEID")
6     private String id;
7
8     @Column(name = "NAME")
9     private String name;
10
11    @Column(name = "SALARY")
12    private Long salary;
13 }
```

Listing A.2: Declaring the schema

A.3 GAE Datastore

Two configuration are possible:

1. use the datastore instance within the app engine application;
2. use a remote datastore instance through remote API.

The properties to be specified inside the `<properties>` tag for the first case are:

- `kundera.client.lookup.class` (*required*), must be set to `it.polimi.kundera.client.datastore.DatastoreClientFactory`;
- `kundera.ddl.auto.prepare` (*optional*), possible values are:
 - `create`, which creates the schema (if not already exists);
 - `create-drop`, which drop the schema (if exists) and creates it;
- `kundera.client.property` (*optional*), the name of the xml file containing the datastore specific properties.

In addition to the previous properties and in case of remote API, those properties are also necessary:

- `kundera.nodes` (*required*), url of the app engine application on which the datastore is located;
- `kundera.port` (*optional*) default is **443**, port used to connect to datastore;
- `kundera.username` (*required*), username of an admin on the remote server;
- `kundera.password` (*required*), password of an admin on the remote server.

To test against local app engine run-time emulator the configuration is as follow:

```
1 <property name="kundera.nodes" value="localhost"/>
2 <property name="kundera.port" value="8888"/>
3 <property name="kundera.username" value="username"/>
4 <property name="kundera.password" value="" />
```

Listing A.3: GAE Datastore emulator configuration

in this case the value for `kundera.password` does not matter.

Datastore specific properties file

A file with client specific properties can be created and placed inside the classpath, its name must be specified in the `persistence.xml` file through the property `<property name="kundera.client.property" value="filename.xml"/>`. The template of the file is the following:

```
1 <?xml version="1.0" encoding="UTF-8"?>
2 <clientProperties>
3   <datastores>
4     <dataStore>
5       <name>datastore</name>
6       <connection>
7         <properties>
8           <property name="..." value="..."></property>
9         </properties>
10      </connection>
```

Configuring Kundera extensions

```
11     </dataStore>
12   </datastores>
13 </clientProperties>
```

Listing A.4: GAE Datastore - datastore specific configuration

The available properties are:

- `datastore.policy.read` (*optional*) [`eventual|strong`] default is **strong**. Set the read policy;
- `datastore.deadline` (*optional*). RPCs deadline in seconds;
- `datastore.policy.transaction` (*optional*) [`auto|none`] default is **none**. Define if use implicit transaction.

A.4 Azure Table

The properties to be specified inside the `<properties>` tag are:

- `kundera.username` (*required*), the storage account name available from azure portal;
- `kundera.password` (*required*), the storage account key available from azure portal;
- `kundera.client.lookup.class` (*required*), must be set to `it.polimi.kundera.client.azuretable.AzureTableClientFactory`;
- `kundera.ddl.auto.prepare` (*optional*), possible values are:
 - `create`, which creates the schema (if not already exists);
 - `create-drop`, which drop the schema (if exists) and creates it.
- `kundera.client.property` (*optional*), the name of the xml file containing the datastore specific properties.

Datastore specific properties file

A file with client specific properties can be created and placed inside the class-path, its name must be specified in the `persistence.xml` file. The template of the file is the following:

```
1 <?xml version="1.0" encoding="UTF-8"?>
2 <clientProperties>
3   <datastores>
4     <dataStore>
5       <name>azure-table</name>
6       <connection>
7         <properties>
8           <property name="..." value="..."></property>
9         </properties>
10      </connection>
11    </dataStore>
12  </datastores>
13 </clientProperties>
```

Listing A.5: Azure Tables - datastore specific configuration

The available properties are:

- `table.emulator` (*optional*) [true|false] default is **false**. If present (and set to true) storage emulator is used. When using development server `kundera.username` and `kundera.password` in *persistence.xml* are ignored;
- `table.emulator.proxy` (*optional*) default is **localhost**. If storage emulator is used set the value for the emulator proxy;
- `table.protocol` (*optional*) [http|https] default is **https**. Define the protocol to be used within requests;
- `table.partition.default` (*optional*) default is **DEFAULT**. The value for the default partition key, used when no one is specified by the user.

Appendix B

Configuring CPIM migration

B.1 Introduction

In this appendix is presented the new configuration file added to CPIM to support the various configurations available for the interaction with the migration system.

B.2 *migration.xml*

The template of the *migration.xml* file is the following:

```
1 <?xml version="1.0" encoding="UTF-8" standalone="no"?>
2 <migration>
3     <zooKeeper>
4         <type>...</type>
5         <connection>...</connection>
6         <range>...</range>
7     </zooKeeper>
8     <backup>
9         <execute>...</execute>
10        <type>...</type>
11        <directory>...</directory>
12        <prefix>...</prefix>
13    </backup>
14    <followCascades>...</followCascades>
15 </migration>
```

Listing B.1: migration.xml template

Three are the main section that can be configured:

Configuring CPIM migration

1. ZooKeeper client;
2. sequence number backup;
3. follow cascades while build statements.

The first two options are the most complex and are described in the following sections, the third option can assume be *true* or *false* but is *optional* since is set to **false** by default. In case the value is set to *true*, the statement builders when builds the statements from objects will read the values specified for the `@CascadeType` annotation and, if necessary, builds the cascade statements and sends them to *Hegira* in the correct execution order as described in 5.7.

B.2.1 Configure the ZooKeeper client

For ZooKeeper client, must be chosen the *thread* or the *http* version as described in 5.6.

Thread version An example configuration would be the following one:

```
1 <zooKeeper>
2   <type>thread</type>
3   <connection>localhost:2181</connection>
4   <range>50</range>
5 </zooKeeper>
```

Listing B.2: ZooKeeper - thread type configuration

The `<connection>` tag is **required** and should contains an address in the form `host:port` which should be the host address and the port on which the ZooKeeper service is running.

The `<range>` is *optional* since the default is **10** and is the default dimension of the range that `SeqNumberDispenser(s)` use to ask sequence numbers to the synchronization system.

HTTP version An example configuration would be the following one:

```
1 <zooKeeper>
2   <type>http</type>
3   <connection>http://server.com/hegira-api/zkService</connection>
4   <range>50</range>
5 </zooKeeper>
```

Listing B.3: ZooKeeper - http type configuration

In this case the `<connection>` tag should contains the API base path of the server in which the service is running.

For the `<range>` tag the same consideration made for the thread case applies.

B.2.2 Configure a sequence number backup

A sequence number backup can be configured either on a blob storage (when running on PaaS) or to file (when running on IaaS).

The `<execute>` tag define if backup should or should not be performed, the possible values are *yes* or *no*. This tag is *optional* since its default is **yes**. In case backups must be turned off, the configuration should be the following:

```
1 <backup>
2   <execute>no</execute>
3 </backup>
```

Listing B.4: Turning off sequence numbers backup

For the other configuration options, two cases must be distinguished:

Backup to Blob An example configuration would be the following one:

```
1 <backup>
2   <type>blob</type>
3   <prefix>SeqNumber.</prefix>
4 </backup>
```

Listing B.5: Backup to blob

The text in the `<prefix>` tag will be prefixed to each blob created to avoid file name conflicts. This prefix is *optional* field as default is set to **SeqNumber..**

Backup to file An example configuration would be the following one:

```
1 <backup>
2   <type>file</type>
3   <directory>/backups</directory>
```

Configuring CPIM migration

```
4     <prefix>SeqNumber.</prefix>  
5 </backup>
```

Listing B.6: Backup to file

The `<directory>` tag is **mandatory** and must contain the path to the directory in which the backup files should be stored.

For the `<prefix>` tag the same considerations made for backup to blob applies.

B.3 Use CPIM without migration system

The *migration.xml* file is not necessary if the user would not use the migration system. If the file is not present inside the **META-INF** folder, the NoSQL service will interact only with the underlying persistence provider without instantiating any of the classes required for the interaction with the migration system. This is possible due to the lazy initialization of those components that are initialized only the first time are actually used since are built with a singleton pattern.

Appendix C

Run YCSB tests

C.1 Introduction

In this appendix is described the required procedure to build the benchmark project that contains the YCSB adapters, then are shown the required commands to be executed in order to execute the two phases of an YCSB benchmark and the available values to be configured for each of the supported adapters.

C.2 Preliminary operations

In order to build the benchmark project, (available at <https://github.com/Arci/kundera-benchmark>) some libraries need to be downloaded since are not available in any maven repository:

- Azure Table extension
<https://github.com/Arci/kundera-azure-table>
- GAE Datastore extension
<https://github.com/Arci/kundera-gae-datastore>

The Azure Table extension tests to run requires a reachable storage emulator on Windows so if this is not possible, skip tests by running `mvn clean install -DskipTests`.

Tests for the Datastore extension can be executed without any configuration as they are executed through Google in-memory Datastore stub.

Run YCSB tests

Also YCSB is not available in any maven repository, it must be downloaded (<https://github.com/brianfrankcooper/YCSB>) and installed locally, always through `mvn install`.

When all the required dependency for `kundera-benchmark` are resolved, is possible to install it with `mvn clean install` and then lunch the command `mvn dependency:copy-dependencies`, this will create a directory called `dependency` in the `target` directory containing all the jars of the dependencies. The `dependency` folder will be used for defining the classpath later on.

C.3 Run tests for low-level API version

The two phases of the YCSB benchmark can be executed through the command:

```
java -cp KUNDERA-BENCHMARK-JAR-LOCATION:PATH-TO-DEPENDENCY-FOLDER/*
com.yahoo.ycsb.Client -t -db DATABASE-ADAPTER-CLASS-TO-USE
-P PATH-TO-WORKLOAD -P PATH-TO-PROPERTY-FILE
-s -threads THREAD-TO-USE -PHASE > OUTPUT-FILE
```

Listing C.1: Run low-level API benchmarks

where PHASE should be `load` for **load** phase or `t` for **transaction** phase.

Available adapter classes are:

- `it.polimi.ycsb.database.AzureTableClient` for Azure Table;
- `it.polimi.ycsb.database.DatastoreClient` for GAE Datastore;
- `it.polimi.ycsb.database.KunderaHBaseClient` for Hbase.

C.3.1 Property files

As can be seen from the command, a property file must be specified. Properties files must provide information to locate the database to test when running the benchmarks on the low-level API versions.

Google Datastore The available properties are:

- `url` (*required*);
- `port` (*optional*), default is 443;
- `username` (*required*), the username of an admin on the remote application;
- `password` (*required*), can be omitted if tests are against localhost.

Azure Table The available properties are:

- `emulator` (*optional*) [true—false];
- `account.name` (*required*) if not using emulator, available from azure portal;
- `account.key` (*required*) if not using emulator, available from azure portal;
- `protocol` (*optional*) [http—https], default is https.

If `emulator` is set to *true* the remaining properties are ignored.

Hbase The properties must be configured inside the adapter class because, to be more accurate w.r.t. the Kundera client, connection cannot be done in the `init()` method.

The properties can be set modifying the following constants:

- `node`, the master node location;
- `port`, the master node port;
- `zookeeper.node`, the node location for `hbase.zookeeper.quorum`;
- `zookeeper.port`, the node port for `hbase.zookeeper.property.clientPort`.

Since property file is not needed for Hbase, it does not need to be specified while running the benchmarks.

C.4 Run tests for Kundera version

Two phases of the YCSB benchmark can be executed through the command:

```
java -cp KUNDERA-BENCHMARK-JAR-LOCATION:PATH-TO-DEPENDENCY-FOLDER/*
com.yahoo.ycsb.Client -t -db DATABASE-ADAPTER-CLASS-TO-USE
-P PATH-TO-WORKLOAD -s -threads THREAD-TO-USE -PHASE > OUTPUT_FILE
```

Listing C.2: Run Kundera clients benchmarks

where PHASE should be `load` for **load** phase or `t` for **transaction** phase.

Available adapter classes are:

- `it.polimi.ycsb.database.KunderaAzureTableClient` for `kundera-azure-table` extension;
- `it.polimi.ycsb.database.KunderaDatastoreClient` for `kundera-gae-datastore` extension;
- `it.polimi.ycsb.database.KunderaHBaseClient` for `kundera-hbase` extension.

C.4.1 *persistence.xml* configuration

In the *persistence.xml* file each persistence unit must be configured to locate the database to test.

The possible configurations are described in the appendix A.

Hbase configuration make use also of a datastore specific property file `hbase-properties.xml` in which can be configured the value for `hbase.zookeeper.quorum` and `hbase.zookeeper.property.clientPort`.

Bibliography

- [1] Azure table storage. <http://azure.microsoft.com/en-us/documentation/articles/storage-java-how-to-use-table-storage>. [Online].
- [2] Google app engine datastore. <https://cloud.google.com/datastore/docs/concepts/overview>. [Online].
- [3] nosql-database.org. <http://nosql-database.org/>. [Online, Accessed 14 March 2015].
- [4] Using jpa with app engine. <https://cloud.google.com/appengine/docs/java/datastore/jpa/overview>. [Online].
- [5] Kundera. <https://github.com/impetus-opensource/Kundera>, 2010. [Online].
- [6] Unql. <http://unql.sqlite.org/>, 2011. [Online].
- [7] Apache gora. <http://gora.apache.org/index.html>, 2012. [Online].
- [8] Playorm. <http://buffalosw.com/products/playorm>, 2012. [Online].
- [9] Spring data. <http://projects.spring.io/spring-data/>, 2013. [Online].
- [10] Apache phoenix. <http://phoenix.apache.org/index.html>, 2014. [Online].
- [11] Elisabetta Di Nitto, Marco Scavuzzo, Michele Ciavotta, Fabio Arcidiacono. Modacloudml package on data partition and replication. Technical report, Politecnico di Milano, September 2014.

BIBLIOGRAPHY

- [12] Fay Chang, Jeffrey Dean, Sanjay Ghemawat, Wilson C. Hsieh, Deborah A. Wallach, Mike Burrows, Tushar Chandra, Andrew Fikes, Robert E. Gruber. Bigtable: A distributed storage system for structured data. Technical report, Google, 2006.
- [13] Filippo Giove, Davide Longoni. Un approccio per lo sviluppo di applicazioni portabili per sistemi di cloud computing. Master's thesis, Politecnico di Milano, 2012.
- [14] Keith Mike, Schincariol Merrick. *Pro JPA 2*. Apress, Berkely, CA, USA, 2nd edition, 2013.
- [15] Paolo Atzeni, Francesca Bugiotti, Luca Rossi. Uniform access to non-relational database systems: the sos platform. Technical report, Università Roma Tre, 2012.
- [16] Marco Scavuzzo. Interoperable data migration between nosql columnar databases. Master's thesis, Politecnico di Milano, 2013.
- [17] Jeff Schnitzer. Objectify. <https://code.google.com/p/objectify-appengine/wiki/IntroductionToObjectify>. [Online].
- [18] Brian F. Cooper, Adam Silberstein, Erwin Tam, Raghu Ramakrishnan, Russell Sears. Benchmarking cloud serving systems with ycsb. Technical report, Yahoo! Research, 2010.
- [19] Tobias Trelle. Spring data one api to rule them all? <http://www.infoq.com/articles/spring-data-intro>, August 2012. [Online, Accessed 14 March 2015].