««< HEAD ======= »»»> 08f0ce832ab84bc50439b222b926422501ceb8db

««< HEAD ======= »»»> 08f0ce832ab84bc50439b222b926422501ceb8db

UNIVERSITY OF LYON

DOCTORAL SCHOOL OF COMPUTER SCIENCE AND MATHEMATICS

Thesis Advancement Report

Trusted SLA Guided Data Integration on Multi-Cloud Environments

PhD Student:	Daniel Aguiar da Silva CARVALHO	-	Centre de Recherche Magellan Jean Moulin Lyon3 University
Advisors:	Prof. Chirine GHEDIRA-GUEGAN	-	LIRIS, Magellan Research Center Jean Moulin Lyon3 University
	Prof. Genoveva VARGAS-SOLAR	-	CNRS-LIG, Grenoble
	Prof. Nadia BENNANI	-	LIRIS, INSA-Lyon

March 2017

Contents

Chapter 1

Identification

Contents

1.1 PhD student identification

Name:	Daniel Aguiar da Silva Carvalho
Date of birth:	16/09/1988
Nationality:	Brazilian
Professional mail:	daniel.carvalho@univ-lyon3.fr
Personal mail:	danielboni@gmail.com

1.2 Laboratory and Supervision

Current I am working in the *Magellan Research Center* (Lyon3) and attached to the *InfoMaths* doctoral school (Lyon1).

The thesis project is being developed under the supervision of Prof. Chirine GHEDIRA-GUEGAN, Prof. Genoveva VARGAS-SOLAR and Prof. Nadia BENNANI.

1.3 Subject and Funding

The thesis is entitled «*Trusted SLA-Guided Data Integration on Multi-Cloud Environments*». It is funded by the project ARC 6 2014.

Chapter 2

Professional and Scientific Aspects

Contents

2.1 Courses

The list of courses followed during the project are presented below:

- *Français pour non francophones niveau 1 beginner (2014-2015).* Code E. Transversal.
- *Français pour non francophones niveau 1 beginner/débutant, élémentaire (2015-2016).* Code E. Transversal.
- *Français pour non francophones niveau 2 intermédiaire (2015-2016).* Code E. Transversal.
- *Writing a scientific paper step by step (2015-2016).* Code E. Transversal.
- *E1a Français langue étrangére-niveaux débutant à élémentaire - French as a Foreign language-beginner to elementary levels (2016-2017).* Code E. Transversal.

2.2 Scientific production

Daniel Carvalho, Nadia Bennani, Genoveva Vargas-Solar, Chirine Ghedira, Placido Souza Neto. **Can Data Integration Quality be Enhanced on Multi-cloud using SLA?**. DEXA 2015, Sep 2015, Valencia, Spain. Lecture Notes in Computer Science 9262, Springer 2015.

D. A. S. Carvalho, P. A. Souza Neto, G. Vargas-Solar, N. Bennani, C. Ghedira, **Rhone: a quality-based query rewriting algorithm for data integration**, Short paper, 20th East-European Conference on Advances in Databases and Information Systems, ADBIS 2016.

2.3 Research activities

Paper proposal presentation. **Trusted SLA-Guided Data Integration on Multi-cloud Environments**. Seminar presented to the Information System group from the Magellan's Research Center. In March 5th 2015.

Participating on to the **1st French Brazilian School on Smart cities and Big Data** at the University of Grenoble Alpes (http://fr-br-school.imag.fr). April 2015.

Poster presentation. **SLA-Guided Data Integration on Multi-cloud Environments**. Poster presented in the « Journée Scientifique de l'Arc 6 » held in 20th November 2015 at Grenoble, France.

PhD proposal and query rewriting algorithm presentation. **Trusted SLA-Guided Data Integration on Multi-cloud Environments**. Seminar presented to the Service-Oriented Computing team meeting from LIRIS, Lyon 1. In 3rd December 2015.

Query rewriting algorithm and ongoing works presentation. **A Service-based Query Rewriting Algorithm**. to the Information System group from the Magellan's Research Center. In 4th February 2016.

Paper presentation. **Rhone: a quality-based query rewriting algorithm for data integration** at the 20th East-European Conference on Advances in Databases and Information Systems, ADBIS 2016.
Seminar concerning the paper accepted to the ADBIS 2016. **Rhone: a quality-based query rewriting algorithm for data integration**. Presented to the Information System group from the Magellan's Research Center. In September 22th 2016.

Poster presentation. **SLA-Guided Data Integration on Multi-cloud Environments**. Poster presented in the « Journée Scientifique de l'Arc 6 » held in 24th November 2016 at Lyon, France.

Chapter 3

Thesis Advancement

Contents

3.1 Context and motivation

The emergence of multi-cloud environments opens new challenges to data processing. Current data integration implies consuming data by matching and composing different data services, and integrating the results while respecting data consumers quality requirements. These requirements are exposed in service level agreement (SLA) contracts established between data consumers and cloud providers. The SLA defines what a data consumer can expect as system behavior, but also the properties of the data such as its provenance, veracity, freshness, whether the consumer accepts to pay for data, and how much is he/she ready to pay for the resources necessary for integrating his/her expected result.

Several researches have introduced algorithms for data integration in service-oriented architectures. They have designed methods for matching, selecting and composing services according to some data requirements and constraints. These works share a performance problem while combining and producing compositions. To tackle it, authors have proposed heuristics for computing and identifying the best services and compositions based on quality aspects. However, current works focus on performance capabilities of services neglecting data properties and the new constraints imposed by the multi-cloud context.

In this sense, the objective of this work is to address data integration in a multi-cloud context. The originality of our approach consists in guiding the entire data integration solution taking into consideration (i) data consumer requirement statements with respect to performance capabilities of data services (for instance, availability and response time) and to data collection properties (provenance, freshness, veracity, data type, among others); (ii) infrastructure properties (reliability, computing, storage and memory capacity, and cost) imposed by the multi-cloud context; and (iii) SLA contracts exported by different data services and cloud providers.

3.2 Problem statement

The multi-cloud architecture brings new challenges to data integration and data processing applications. Instead of taking into consideration the user query and his/her requirements with respect to services' performance capabilities (such as percentage of availability and response time) in isolation, the integration process must consider in addition the new constraints imposed by context:

– User requirements concerns not only data services' performance capabilities but also quality requirements of the data which is provided (such as freshness, cost, provenance, data type, veracity among others).

– Data provision is constrained to the available computing resources agreed between data services and cloud providers on service level agreement (SLA) contracts.

– The data integration process requires a high level of computing resources. The huge amount of data and data services on multi-cloud settings increases even more the complexity of the solutions.

In this sense, current data integration solutions introduces a multi-dimensional matching problem that should take into account:

– Expressing data consumer requirements with respect to performance capabilities of data services and to the quality of the expected data.

– Matching and selecting data services according to the data consumer expectations (concerning performance and data quality requirements) with respect to data services quality measures defined in SLA contracts.

– Matching and selecting data services which have available resources according to different SLAs that they have agreed with different cloud providers.

– Delivering results with respect to the data consumer requirements and expectations depending on the context which he/she consumes the data.

Thus, the intention of this thesis project is to address data integration on multi-cloud environments. The aim is propose a data integration approach adapted to the multi-cloud context in which data is delivered according to data consumers expectations by profiting from previous integration results instead of launching the expensive data integration process from the first step.

3.3 State of the Art

The state of the art comprehend four topics, which are discussed in the following sections: (i) data integration and data quality in the database domain; (ii) data integration approaches in the cloud and in service-oriented contexts; (iii) query rewriting approaches; and (iv) service level agreements for cloud computing.

3.3.1 Data integration and data quality in the database domain

The data integration problem intends to offer to data consumers an integrated view of data build by combining and merging several databases *known-in-advance*. This problem has been widely examined in the database theory. [Lenzerini 2002] discussed theoretical aspects in data integration including modeling applications, query evaluation, dealing with inconsistencies and reasoning queries. The core of data integration is the rewriting process. Many authors have reported algorithms for this purpose. For instance, [Levy 1996] proposed the *bucket algorithm*, which generates combinations of the different *buckets* (views mapped to a given subgoal), and checks whether each one is a rewriting of the query. [Duschka 1997] introduced the *inverse-rules algorithm*, which produces a set of *inverse rules* from local views to the global view. Then, a rewriting is obtained by unfolding the query in terms of the *inverse rules*. [Pottinger 2001] presented the *MiniCon algorithm* funded in ideas of [Duschka 1997]. Although *MiniCon* has shown a more efficient implementation, these kind of algorithm share the same performance problem while combining views to produce a rewriting. Several query rewriting approaches were reviewed in [Halevy 2001].

Data quality issues in data integration have been explored in many researches. [Gertz 1998] designed a framework for modeling quality aspects (such as timeliness, accuracy and completeness) in databases integration. The framework stores quality aspects as meta-data in the integration level, and based on this information delivers a high-quality data from local databases. [Scannapieco 2004] presented a data quality broker that allows to submit queries with associated quality requirements over a global schema and to provide results according to them. [Batista 2007] proposed a quality criteria (such as reputation, availability, response time, completeness, among others) analysis of data integration elements (sources, schemas and data) to improve quality on query execution. [Abdel-Moneim 2015] proposed a method to improve quality in data integration solutions by adding and storing a set of data quality measures in data sources. Then, given a user query and quality preferences, the most relevant sources are selected to answer the query. [Monem 2016] introduced a framework (called DIRA), which produces the *top-k* query answers using an algorithm that selects data sources based on quality aspects stored as meta-data in a data source such as accuracy, validity, completeness, among others. Others data integration issues and quality aspects in data integration systems are tackled in [Batini 2006, Angeles 2009, Boufares 2012].

3.3.2 Data integration in the cloud and in service-oriented domains

The data integration has also been addressed in cloud and service-oriented contexts. For instance, [Yau 2008] introduced a repository in which based on user integration requirements, the repository retrieves and integrates the data collected from different services focusing on data privacy issues. [Tian 2010] proposed an inter-cloud data integration system which considers privacy requirements and the cost for protecting and processing data. According to the user privacy requirements, the system decides where is the best location to execute the query while meeting privacy and cost constraints: direct on service providers or on its own cloud repository. [Benslimane 2013] designed a composition-based approach for data integration taking into consideration the privacy of the data manipulated by web services and compositions. [Yau 2008, Tian 2010, Benslimane 2013] considered privacy and cost while integrating data, but other quality aspects associated to data itself (such as veracity, type, freshness, among others) and to the infrastructure are still missing.

Some authors have addressed data integration in service-oriented contexts taking into consideration the requirement of computing resources for integrating data across several data service. For instance, [Correndo 2010] presented a method for data integration using SPARQL on Linked Data. The objective is to solve the entity co-reference problem and to exploit ontology alignments interested in data manipulation. [Thor 2011] introduced an mashup-based integration system called *CloudFuice*. It provides a language for specifying dataflows for performing parallel data integration tasks. [Alsubaiee 2012] introduced a system which allows to store, consume, integrate and analyze social and wed data in a scalable manner. [Mubeen 2012] proposed a new architecture for web-scale data integration in which the data extracted from services are stored in a single cloud data store. [ElSheikh 2013] designed the *SODIM* which combines data integration, service oriented architecture and distributed processing applying MapReduce techniques. The system works on a pool of collaborative services and it can process a large number of databases represented as web services. [Hong 2014] introduced a cloud data service system to integrate data from distributed data services considering three level of data security focusing on data privacy. In general, [Correndo 2010, Thor 2011, Alsubaiee 2012, Mubeen 2012, ElSheikh 2013, Hong 2014] exploited parallel settings for implementation costly data integration processes.

3.3.3 Query rewriting approaches

In traditional databases theory, query rewriting activities are essential to data integration solutions. On cloud and service-oriented context query rewriting issues are commonly referred as a service matching and composition problem in which given a query, the objective is to match and compose services that can contribute to produce a result. [Barhamgi 2010] proposed a query rewriting approach which processes queries on data provider services. The query and data services are modeled as RDF views. Then, a rewriting answer is a service composition in which the set of data service graphs fully satisfy the query graph. Inspired by [Barhamgi 2010], [Benouaret 2011] introduced a service composition framework to answer preference queries which ranks the compositions based on previously computed scores. [Costa 2013] presented a refinement approach of web service compositions in which given an abstract query specification, a set of concrete service compositions are produced. [Ba 2014] extended [Costa 2013] introducing the notion of user preferences and scores used to rank services and compositions while rewriting the query specification. As in the database domain, the algorithms discussed above deal with performance issues while rewriting depending on complexity of the query and on the number of available services. Although [Benouaret 2011, Ba 2014] have considered preferences and scores to produce rewritings, the multi-cloud context introduces new requirements and constraints to the integration process. Currently, the approaches are not sufficient to cover the new challenges. Thus, they should be revisited and adapted in order to make the integration efficient in this environment.

3.3.4 Service level agreements for cloud computing

Service level agreements (SLA) state what a *consumer* can expect from a system or system behavior. Several researchers have reported studies on SLAs in different domains [Alhamad 2011]. On cloud computing, contributions associated to SLAs manly comprehend: *(i)* management, negotiation and matching of SLAs; *(ii)* security issues; and *(iii)* resource allocation.

For instance, [Redl 2012] introduced a method for matching of SLA elements exported by different cloud providers. [Mavrogeorgi 2013] presented a SLA management framework responsible to negotiate and enforce customized SLAs enriched with the information of the cloud federation and renegotiation rules. [Son 2014] introduced SLA negotiation strategies for a multi-cloud broker and discussed design issues. [Falasi 2016] designed an SLA negotiation model to based on the game-theory to allow cloud services to specify, negotiate and establish SLAs.

Other proposals intends to assure security aspects in the cloud by defining and including security requirements on contracts. For instance, [Rak 2013] introduced an approach to specify, assess and integrate security requirements to cloud services. [Rojas 2016] proposed a framework for management of SLA security requirements and enforcing them during the entire SLA lifecycle. [Casola 2016] specified a catalogue of security services that can be monitored and negotiated through SLAs.

Finally, several works address SLA monitoring to detect and avoid violations. For example, [Brandic 2010] designed a model to identify and propagate SLA violation to the cloud providers. [Leitner 2010] introduced a event-based system to predict SLA violations and take necessary measures before they have impacted the provider SLA. [Emeakaroha 2012] proposed a system to monitor SLA in order to detect violation and provide tools for resource allocation and scheduling. [Hussain 2015] described a profile-based SLA prediction model, which predicts the necessary resources based on user reputation history.

To the best of our knowledge, related work on SLA models does not seem to address data integration in multi-cloud architectures. Probably, because the contributions are mainly interested in specifying and monitoring performance aspects (for example, response time, memory, availability, among others) in the SLA rather than quality issues regarding the data properties (such as data type, veracity, freshness, provenance and others). Thus, we strongly believe that SLAs can be used to explicitly introduce the notion of quality in the current data integration solutions. In this sense, the use of SLAs to guide the entire data integration in a multi-cloud context seems original and promising for providing new perspectives to the data integration problem.

3.4 Synthesis of the work

In order to address our research problem (see section 3.2), we have proposed data integration approach in which given a query and a set of user requirements associated to it, the query execution process is divided in three phases. The figure 3.1 illustrates our approach.

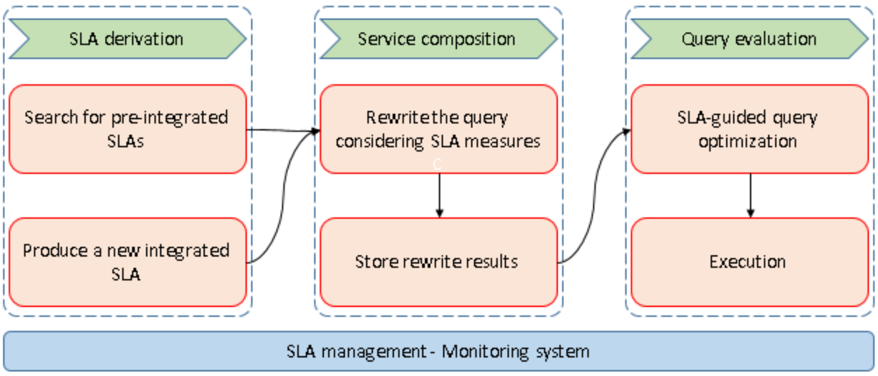


Figure 3.1: SLA-guided data integration approach

The first phase is the SLA derivation in which a SLA for the user request is created. It consists in looking for a (stored, integrated) SLA derived for a similar request in our history. If a similar SLA is found, the request is forwarded to the query evaluation phase. Otherwise, a new SLA to the integration (called integrated SLA) is produced. In the second phase, service composition, the query is rewritten in terms of different *data services* considering the user requirements (according to service properties and data properties) and the SLAs of each service involved in the composition. The rewriting result is stored in the history for further uses. Finally, in the query evaluation phase, the query is optimized in terms of user preferences and SLAs concerning the consumed resources and the economic cost of the query. Once optimized, the query processed in the execution engine. In addition, we are assuming a SLA management module and monitoring system responsible to verify if the SLA contracts are being respected.

Following the contributions of this work are presented. Note that this work was built based on a set of papers collected by applying the systematic mapping methodology. This exercise allowed us to identify new trends and open issues concerning data integration and SLA. As result, we have published a paper on DEXA 2015 (See appendix A).

Service-based query rewriting algorithm: Based on the related work, we have developed and formalized the *Rhone* service-based query rewriting algorithm guided by service level agreements (SLA). The *Rhone* assumes that there are a set of quality measures associated to services which we suppose they are previously extract from their SLA. These measures will guide the service selection and the entire rewriting process. Our work address this issue and proposes the algorithm with two original aspects: (i) the user can express her quality preferences and associated them to his query; and (ii) service's quality aspects defined in SLAs guide the service selection and the whole rewriting process taking into consideration that services and rewritings should meet the user requirements, and the different cases of incompatibilities of SLAs, uncompleted SLA and the integration SLA. Given a set of abstract services, a set of concrete services and a user query (both defined in terms of abstract services), and a set of user quality preferences, the *Rhone* derives a set of service compositions that answer the query and that fulfill the quality preferences regarding the context of data service deployment. The algorithm consists in four steps: (i) *Selecting concrete services*. Similar to [Levy 1996, Pottinger 2001] our algorithm selects services based on the abstract services that exists in the query, but it includes two differences: first, a concrete service cannot be select if it contains an abstract service that is not present in the query; and second, the service' quality aspects (extracted from its SLA) must be in accordance with the user quality preferences; (ii) *creating mappings from concrete services to the query (called concrete service description (CSD))* inspired in [Pottinger 2001] including also the information concerning the services' SLA; (iii) *combining CSDs*; and (iv) *producing rewritings* until fulfilling the user requirements according to the services' SLA. Each phase of the algorithm and each concept (query, concrete services, mapping rules, for instance) were formally specified and described. As result to this work, we have published a paper on ADBIS 2016 (See appendix B).

Algorithm implementation and evaluation, and the cloud infrastructure: In order to evaluate our approach and the *Rhone* algorithm, we began configuring a multi-cloud environment. We have searched for open source solutions instead of privates once they are (i) quite expensive; and (ii) do not allow to extend and access directly the different level of SLAs. The OpenStack was selected as our technology. We have installed and configured the different modules necessaries to the OpenStack. However, we have some issues: (i) the configuration and deployment of cloud infrastructure require important technical skills while configuring the network resources; (ii) it requires a powerful machine. Due to these reasons we have configured a simulation of cloud run our experiments.

Rhone was implemented using Java according to its formal definition. The algorithm was tested in a cloud simulation containing 100 services in its service registry. We have tested different types of query varying on size and on number of user preferences. Although our algorithm shares the same time performance problem as the previous approaches while combining compositions, the experiments have shown that the *Rhone* can enhance the quality and reduce the cost in data integration by considering the user preferences and service's quality aspects extracted from service level agreements. The results can be found in appendix B.

Data integration meta-model and SLA schemas: In order to better describe the our context to illustrate the approach, we have designed a meta-model for data integration. Current SLA schemas are focused on service properties aspects such as availability and response time. Thus, to better fit on the data integration requirements, we have proposed *cloud SLA* that is an agreement between a *data service* and a *cloud provider*, and a *service SLA* which is a new kind of agreement defined by *data services* exposing the properties of the data they provide. As result of this work, we had a paper accept in the ICSOC PhD Symposium 2016 (See appendix C).

A method for service and composition selection: Current data integration implies dealing with a huge number of *data services*. Consequently, query rewriting activities become more expensive in terms of computing resources and generation time. In this scenario, it is mandatory to develop a method to identify the best services to produce the best compositions that can achieve the user satisfaction. Thus, we have proposed an heuristic to rank *data services* and *compositions* based on SLA measures concerning service properties (percentage of availability, response time, throughput and others) and data properties (data type, freshness, veracity, provenance and others).

Definition and formalization of a taxonomy of queries: We have defined and formalized a set of possible relations between queries which differ in terms of *abstract services*, service properties and data properties.

A method for reusing queries: It is well-known that query rewriting is expensive. Thus, based on the proposed query taxonomy, we have designed and formalized a reusability approach which allows to reuse *data services* and *compositions* from previous integration in order to profit from them.

Query history data model and implementation: The reusability approach is based on a history of previous integrated queries. While defining the query taxonomy and reusability issues, we have identified the key information that should be part of the history allowing a satisfactory reusability process. A query history data model, which includes queries, abstract services, data services and compositions, was designed using the collected information. Further, the *Rhone* algorithm was adapted to be in accordance with the model.

Ongoing work: algorithms and experimentation. The reusability process required the specification of three algorithms to implement reusability functions.

These algorithms are being introduced in *Rhone*. Currently, we are in process of building the proof of concept to the approach: the query history was implemented in a relational database and we are running new experiments in order to compare them to the previous results. This work will result in a paper to the 36th International Conference on Conceptual Modeling (ER 2017) – to be submitted in 17th April 2017.

Appendix A

Can Data Integration Quality be Enhanced on Multi-cloud using SLA?

Can Data Integration Quality be Enhanced on Multi-cloud using SLA?

Daniel A. S. Carvalho[1], Plácido A. Souza Neto[3], Genoveva Vargas-Solar[4], Nadia Bennani[2], Chirine Ghedira[1]

[1] Université Jean Moulin, Lyon 3 MAGELLAN, IAE – France
daniel.carvalho@univ-lyon3.fr, chirine.ghedira-guegan@univ-lyon3.fr
[2] CNRS INSA-Lyon, LIRIS, UMR5205 – France
nadia.bennani@insa-lyon.fr
[3] Instituto Federal do Rio Grande do Norte, Natal – Brazil
placido.neto@ifrn.edu.br
[4] CNRS, LIG-LAFMIA, Saint Martin d'Hères – France
genoveva.vargas@imag.fr

Abstract. This paper identifies trends and open issues regarding the use of SLA in data integration solutions on multi-cloud environments. Therefore it presents results of a Systematic Mapping [8] that analyzes the way SLA, data integration and multi-cloud environments are correlated in existing works. The main result is a classification scheme consisting of facets and dimensions namely (i) data integration environment (cloud; data warehouse; federated database; multi-cloud); (ii) data integration description (knowledge; metadata; schema); and (iii) data quality (confidentiality; privacy; security; SLA; data protection; data provenance). The proposed classification scheme is used to organize a collection of representative papers and discuss the numerical analysis about research trends in the domain.

Keywords: Systematic Mapping, Service Level Agreement, Data Integration, Multi-cloud Environment.

1 Introduction

The emergence of new architectures like the cloud opens new opportunities for data integration. The possibility of having unlimited access to cloud resources and the "pay as U go" model make it possible to change the hypothesis for processing big data collections. Instead of designing processes and algorithms taking into consideration limitations on resources availability, the cloud sets the focus on the economic cost implied when using resources and producing results.

Integrating and processing heterogeneous huge data collections (i.e., Big Data) calls for efficient methods for correlating, associating, and filtering them according to their "structural" characteristics (due to data variety) and their quality (veracity), e.g., trust, freshness, provenance, partial or total consistency.

Existing data integration techniques must be revisited considering weakly curated and modeled data sets provided by different services under different quality conditions. Data integration can be done according to (i) quality of service (QoS) requirements expressed by their consumers and (ii) Service Level Agreements (SLA) exported by the cloud providers that host huge data collections and deliver resources for executing the associated management processes. Yet, it is not an easy task to completely enforce SLAs particularly because consumers use several cloud providers to store, integrate and process the data they require under the specific conditions they expect. For example, a major concern when integrating data from different sources (services) is privacy that can be associated to the conditions in which integrated data collections are built and shared [11]. Naturally, a collaboration between cloud providers becomes necessary [4] but this should be done in a user-friendly way, with some degree of transparency.

In this context, the main contribution of our work is a classification scheme of existing works fully or partially addressing the problem of integrating data in multi-cloud environments taking into consideration an extended form of SLA. The classification scheme results from applying the methodology defined in [8] called *systematic mapping*. It consists of dimensions clustered into facets in which publications (i.e., papers) are aggregated according to frequencies (i.e., number of published papers). According to the methodology, the study consists in five interdependent steps including (i) the definition of a research scope by defining research questions; (ii) retrieving candidate papers by querying different scientific databases (e.g. IEEE, Citeseer, DBLP); (iii) selecting relevant papers that can be used for answering the research questions by defining inclusion and exclusion criteria; (iv) defining a classification scheme by analyzing the abstracts of the selected papers to identify the terms to be used as dimensions for classifying the papers; (v) producing a systematic mapping by sorting papers according to the classification scheme.

The remainder of this paper is organized as follows. Section 2 describes our study of data integration perspectives and the evolution of the research works that address some aspects of the problem. Section 3 gives a quantitative analysis of our study and identifies open issues in the field. Section 6 concludes the paper and discusses future work with reference to the stated problem.

2 Data integration challenges: classification scheme

The aim of our bibliographic study using the systematic mapping methodology [8] is to (i) categorize and quantify the key contributions and the evolution of the research done on *SLA-guided data integration in a multi-cloud environment* and (ii) discover open issues and limitations of existing works. Our study is guided by three research questions:

RQ1: *Which are the SLA measures that have been mostly applied in the cloud?* This question identifies the type of properties used for characterizing and evaluating the services provided by different clouds.

RQ2: *How have published papers on data integration evolved towards cloud topics?* This question is devoted to identify the way data integration problems addressed in the literature started to include issues introduced by the cloud.

RQ3: *In which way and in which context has data integration been linked to Quality of Service (QoS) measures in the literature?* The objective of this question is to understand which QoS measures have been used for evaluating data integration and to determine the conditions in which specific measures are particularly used.

2.1 Searching and screening papers

According to our research questions and our expertise in data integration we chose a set of keywords to define a complex query to be used for retrieving papers from four target publication databases: IEEE [5], ACM [6], Science Direct [7] and CiteSeerX [8]. We used the following conjunctive and disjunctive general query which was completed with associated terms from a thesaurus and rewritten according to the expression rules of advanced queries in each database:

("Service level agreement" AND ("Data integration" OR "Database integration") AND ("Cloud" OR "Multi-cloud "))

We retrieved a total of 1832 publications. As a result of the filtering process proposed by the systematic mapping methodology [8] we excluded 1718 publications. The number of papers included for building the final collection were 114 publications [9].

2.2 Defining classification facets

We analyzed the titles and abstracts of the papers derived in the previous phase using information retrieval techniques to identify frequent terms. We used these terms for proposing a classification scheme consisting of three facets that group dimensions. The following lines define the facets and dimensions of the classification scheme we propose.

Data Integration Environment: This facet groups the dimensions that characterize the architectures used for delivering data integration services (*data warehouse* and *federated database*) and architectures used for deploying these services (*cloud* and *multi-cloud*).

Data Integration Description: This facet groups the dimensions describing the approaches used for describing the databases content in order to integrate them. Data integration can be done by using *meta-data, schema*, and *knowledge.*

[5] http://ieeexplore.ieee.org/
[6] http://dl.acm.org/
[7] http://www.sciencedirect.com/
[8] http://citeseerx.ist.psu.edu/
[9] List of references available in: https://github.com/danielboni/DEXA-2015-Can-Data-Integration-Quality-be-Enhanced-on-Multi-cloud-using-SLA.git

Data Quality: This facet groups the dimensions representing data quality measures. Measures can be related directly to data for instance *confidentiality, privacy, security, protection and provenance* and to the conditions in which data is integrated and delivered (i.e., dimension *SLA*).

The original vision of our classification scheme is that of adding the notion of *quality* to data integration represented by the facets *data quality* and *SLA*. With these facets our classification scheme shows the aspects that must be considered when addressing data integration in the cloud taking into account (i) the quality of data, (ii) the systems that integrate data and (iii) the quality warranties that a data consumer can expect expressed in SLAs.

3 Quantitative Analysis

This section discusses the quantitative analysis presented in bubble charts that combine different facets. In order to observe the evolution of the publication trends we defined a time screen between the years 1998 and 2014 (see Figure 1). SLA has emerged when Cloud issues started to be addressed around 2009. The number of publications has increased as cloud infrastructures have become more popular and accessible. It seems that data integration is an open issue when it is combined with SLA and cloud trends. Less recent papers seem to be devoted to the way data is described under schemata or knowledge representation strategies. This could be due to the fact that these strategies are consolidated today and to the emergence of NoSQL approaches with their schema-less philosophy [9].

We combined facets for answering the research questions proposed for guiding our study. The following lines discuss the answers.

RQ1: Which are the SLA measures that have been mostly applied in the cloud?

The facets SLA expression, data integration description and contribution give elements for determining which SLA measures have been applied to the cloud (Figure 2). The resulting bubble chart shows that most contributions propose SLA models and that *privacy* and *security* (11 papers - 9.65%) are the most popular measures considered by SLA models for the cloud. These measures concern the network, information, data protection and confidentiality in the cloud. Most contributions propose SLA models (53 papers - 46.49%) but some languages (8 papers - 7.02%) have also emerged. *Data provenance* is also a measure that emerges but only in papers dealing with multi-cloud environments. Data integration is merely addressed by using schemata (12 papers - 10.53%) and meta-data (4 papers - 3.51%) particularly through models (34 papers - 29.82%) and tools (25 papers - 21.93%). Still, some works propose surveys (8 papers - 7.02%).

RQ2: How have published papers on data integration evolved towards cloud topics?

Combining the facets data integration environment, contribution and research it is possible to observe the evolution of publications on data integration towards the cloud (Figure 3). *Data warehouse* environments are the most

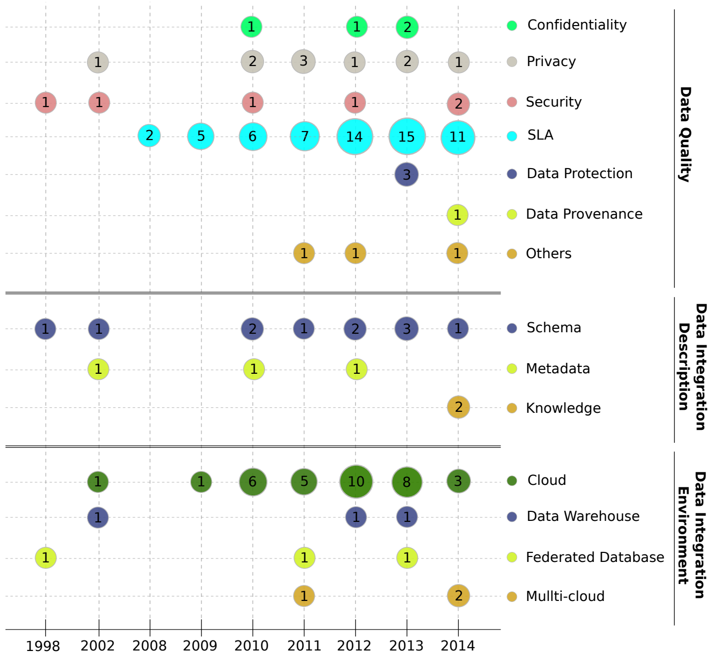


Fig. 1: Publications Per Year

common architecture. This can be explained by the increase of scientific and industrial applications needing to build integrated data sets for performing analysis and decision making tasks. The proposals are delivered as *models* (14 papers - 12.27%) and *tools* (18 papers - 15.78%) used for facilitating data integration, mostly done in the *cloud*. The most popular deployment environment of recent papers is the *cloud*. Given the importance and crucial need of data integration most papers present concrete solutions as algorithms, methods and systems (31 papers - 27.19%).

RQ3: In which way and in which context has data integration been linked to QoS measures in the literature?

We answered RQ3 by combining the facet *data quality* with the facets *data integration environment* and *data integration description* (Figure 4). Data integration and QoS measures are associated within environments like cloud (9.68%) and multi-cloud (4.39%).

According to our quantitative analysis we observe that QoS has started to be considered for integrating data. The cloud is becoming a popular environment to perform data integration in which security issues are most frequently addressed. We identify a promising research area concerning the need of studying SLA which is currently addressed for the cloud as a whole [7] but that needs to be specialized for data integration aspects. Therefore, it is important to iden-

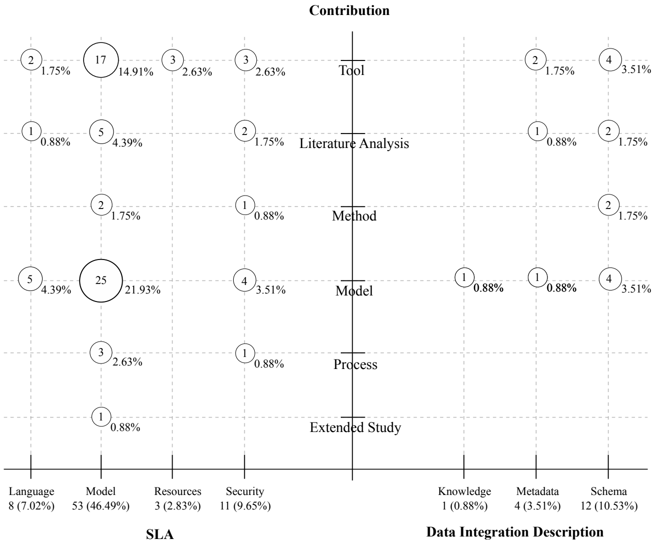


Fig. 2: Facets Contribution, SLA and Data Integration Description

tify the measures that characterize the quality of data and the quality measures associated to different phases of data integration. These phases include selecting data services, retrieving data, integrating and correlating them and building a query result that can be eventually stored and that must be delivered. The data integration phases are implemented by greedy algorithms and generate intermediate data that can be stored for further use. Therefore they consume storage, computing, processing and communication resources that have an associated economic cost. These resources must ensure some QoS guarantees to data consumers. This problem seems to be open in the domain, and we believe that it must be part of a new vision of data integration. We believe that it is possible to add and enhance the quality of data integration by including SLAs.

4 Enhancing Data Integration on Multi-Cloud environments with SLA

In order to illustrate our vision, let us consider an example from the domain of energy management. We assume we are interested in queries like: *Give a list of energy providers that can provision 1000 KW-h, in the next 10 seconds, that are close to my city, with a cost of 0,50 Euro/KW-h and that are labeled as green?* We consider a simplified SLA cloud contract inspired in the cheapest contract provided by Azure: *cost of \$0,05 cents per call, 8 GB of I/O volume/month, free data transfer cost within the same region, 1 GB of storage.* Suppose that the user is ready to pay a maximum of *\$5 as total query cost*; she requests

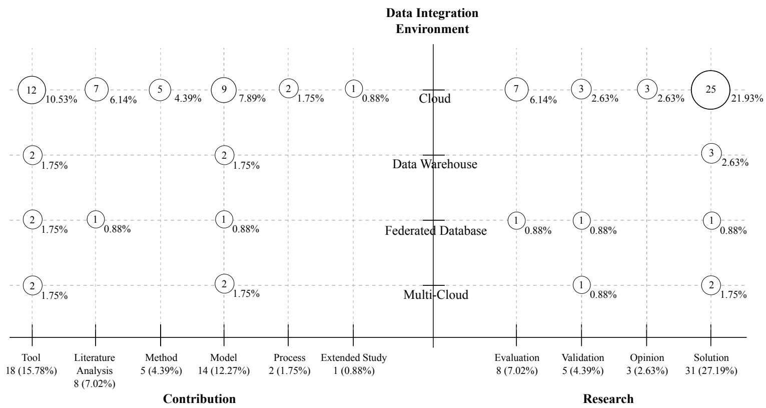


Fig. 3: Facets Data Integration Environment, Contribution and Research

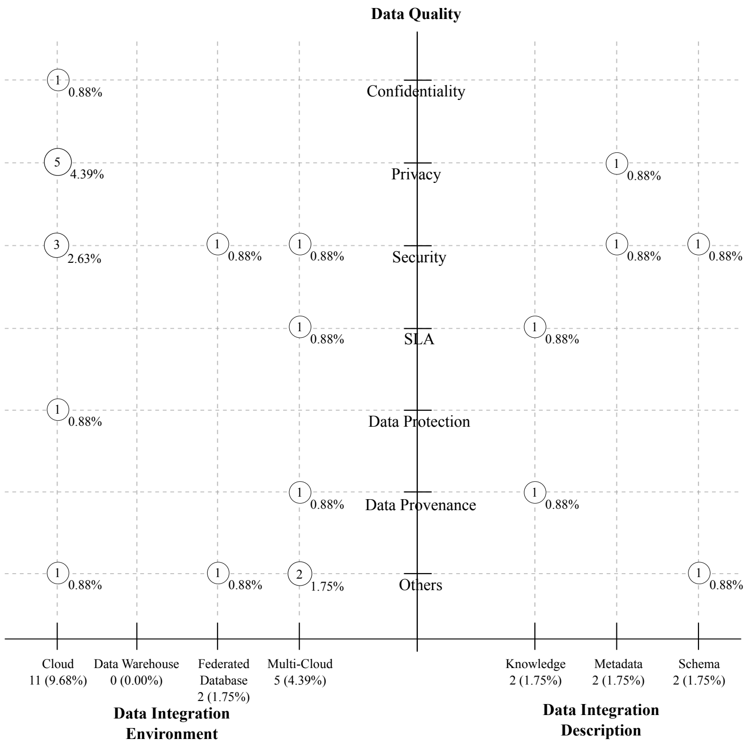


Fig. 4: Facets Data Quality, Data Integration Environment and Data Integration Description

that only *green* energy providers should be listed (provenance), with at least *85%* of precision of provided data, even if they are not fresh; she requires an availability rate of at least 90% and a response time of *0,01 s*. The question is how can the user efficiently obtain results for her queries such that they meet her QoS requirements, they respect her subscribed contracts with the involved cloud provider(s) and such that they do not neglect services contracts?

According to our classification scheme that resulted from our systematic mapping, we propose a new vision of data integration. This vision includes the description of the context in which data integration is done in modern environments. It also identifies the phases of the data integration process with their associated problems and challenges when they must include SLAs and QoS preferences expressed by data consumers.

4.1 Data integration context

We assume that data integration is done on a (multi)-cloud service oriented environment shown in Figure 5. We consider that data integration is done under new conditions with respect to the type of data sources, the environment where it is performed and the preferences of data consumers and the SLA.

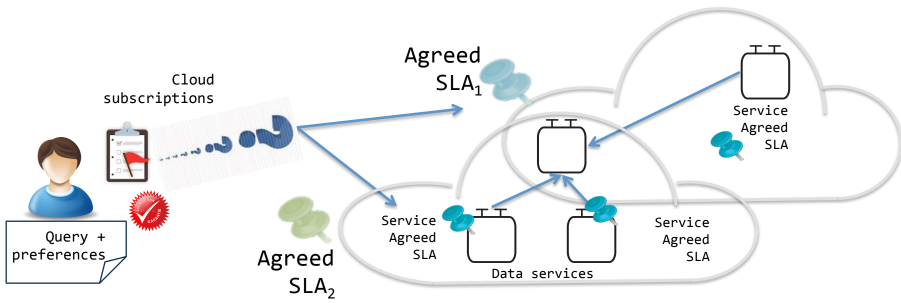


Fig. 5: New data integration context

There are data providers that are services possibly deployed in clouds and available through their API or in a REST architecture. We assume that each service exports an agreed SLA that specifies the economic cost per call, the maximum number of calls that can be done per day, the availability of the service, the average response time when a method is called, the reliability, the privacy of the produced data (whether they can be stored or not), the precision of their responses, freshness and provenance of the produced data.

Cloud providers define also their SLA contracts expressing subscription contracts that specify, the cost per request (cost/request), the volume of data that can be exchanged per month (I/0 volume/month), the cost of transferring data or applications within the same data centre or between data centres (datatransfer-Cost/region), and storage space (storageSpace). For example some cloud providers enable the customer to choose the zone to install PaaS services and deploy applications (e.g. zone 1 is Europe). If the customer wishes to deploy services in zone 1 but store data in zone 2 the transfer cost will change.

Some of these measures (cost/call, maxCall/day) are static and explicitly specified by the service provider. In contrast, the other measures should be computed by monitoring the conversations between the service and the applications that contact it.

In our vision a query expressed in an SQL-like language is associated to a set of QoS preferences expressing the requirements of the user. For example, the economic cost she is ready to pay for executing the query, the provenance of the data, the reputation of data services and the expected time response. The answer of such a query is the result of integrating data from different services according to a series of phases described in the following section.

4.2 SLA guided data integration

Given a query, its associated QoS preferences, cloud providers and services that can potentially be data providers (see Figure 5), SLA guided data integration can consist in four steps.

Generating a derived SLA The key and original aspect of our proposed data integration and provision process is to define a vertical mapping of user QoS preferences and agreed SLAs. This leads to a *derived SLA* that guides the evaluation of a query.

A query has associated preferences expressed as macroscopic constraints (i.e. user preferences statement): execution time, pay / no pay, data reliability, provenance, freshness, privacy, partial/full results, delivery mode. These constraints are coupled with the profile of the user which is in general stated in her cloud subscription (amount of assigned storage space, number of requests, I/O transferred Mega bytes, etc.).

Given agreed SLA's and a user preferences statement the challenge is to compute a *derived SLA* that maps SLA measures and preferences attributes. The derived SLA is defined as a set of measures that correspond to the user preferences computed as a function of different static, computed and hybrid measures. The *derived SLA* will guide the way the query will be evaluated, and the way results will be computed and delivered. Therefore, we propose to classify SLA measures to represent the relationship between fine grained measures used by agreed SLAs and coarse grained measures used in user preferences statements. It is also necessary to specify how to compute coarse grained measures with fine grained ones. For example, data precision will be computed as a function of availability, freshness and provenance exported by data services.

Filtering data services The derived SLA is used for filtering possible data services that can be used for answering the query. This is done using a set of matching algorithms based on graph structures and RDF specifications. This step may lead either to the rejection of integration in case of total incompatibility, or to a negotiation between SLA which will lead to the proposal for a negotiated SLA integration and thus the need for an adaptive setting.

Query rewriting Given a set of data services that can potentially provide data for integrating the query result, we compute possible data service compositions that give partial or exhaustive results according to the derived SLA and the agreed SLA of each data service. The objective is to generate a number k of service compositions, combining as much as possible the services available such that the constraints of the derived SLA are verified.

Integrating a query result The service compositions are executed in one or several clouds where the user has a subscription. The execution cost of service compositions must fulfill the derived SLA (that expresses user requirements). In this phase we generate an execution plan considering the derived SLA and the subscription of the user to one or several clouds. We consider for example the economic cost determined by the data to be transferred, the number of external calls to services, data storage and results delivery costs and we decide how to use clouds resources for executing the composition. A first approach for performing this phase has been addressed in [5].

The first phase is an open issue for dealing with SLAs and particularly for adding quality dimensions to data integration. The problem is complex because SLA describe different elements participating in the data integration process: data services, cloud services at the different levels of the architecture (i.e., IaaS, PaaS, SaaS), data consumers subscriptions to cloud providers. The SLAs contain measures related to the way services are provided but also related to the data they provide. All these aspects must be considered for matching resources (i.e., services) with data consumers preferences. As shown in the following section and in our study SLA models and languages have been proposed. In contrast efficient preferences and SLAs matching algorithms need to be proposed to compute derived SLAs. Concerning the other data integration phases, they have been partially addressed by existing works, where some quality dimensions are considered (e.g., data privacy). In our vision there are open issues to be addressed in order to have solutions that consider SLA in order to enhance data integration in multi-cloud environments.

5 Related Works

Existing works addressing data integration can be grouped according to two different lines of research that correspond to the facets of the classification scheme that we propose: *(i)* data integration and services; and *(ii)* service level agreements and data integration.

5.1 Data integration and services

As shown in our classification scheme data integration description is a major topic. Existing works address knowledge oriented approaches for addressing the problem. For example, [2] proposes a query rewriting method for achieving RDF data integration using SPARQL. The principle of the approach is to rewrite the RDF graph pattern of the query using data manipulation functions in order to: (i) solve the entity co-reference problem which can lead to ineffective data integration; and (ii) exploit ontology alignments with a particular interest in data manipulation. [3] introduces the Service Oriented Data Integration based on MapReduce System (SODIM) which combines data integration, service oriented architecture and distributed processing. SODIM works on a pool of collaborative services and can process a large number of databases represented as web services. The novelty of these approaches is that they perform data integration in service oriented contexts, particularly considering data services. They also take into consideration the requirement of computing resources for integrating data. Thus, they exploit parallel settings for implementation costly data integration processes.

A major concern when integrating data from different sources (services) is privacy that can be associated to the conditions in which integrated data collections are built and shared. [11] focusses on data privacy based on a privacy preserving repository in order to integrate data. Based on users' integration requirements, the repository supports the retrieval and integration of data across different services. [10] proposes an inter-cloud data integration system that considers a trade-off between users' privacy requirements and the cost for protecting and processing data. According to the users' privacy requirements, the query plan in the cloud repository creates the users' query. This query is subdivided into sub-queries that can be executed in service providers or on a cloud repository. Each option has its own privacy and processing costs. Thus the query plan executor decides the best location to execute the sub-query to meet privacy and cost constraints. As said before, the most popular "quality" property addressed in clouds when dealing with data is privacy. The majority of works addressing data integration in the cloud tackle security issues. We believe that other SLA measures need to be integrated in the data integration solutions if we want to provide solutions that cope to the characteristics of the cloud and the expectations of data consumers.

5.2 Service level agreement and data integration

Service level agreement (SLA) contracts have been widely adopted in the context of Cloud computing. Research contributions mainly concern (i) SLA negotiation phase (step in which the contracts are established between customers and providers) and (ii) monitoring and allocation of cloud resources to detect and avoid SLA violations.

[6] proposes a data integration model guided by SLAs in a Grid environment. Their architecture is subdivided into four parts: (i) a *SLA-based Resource Description Model* that describes the database resources; (ii) a *SLA-based Query Model* that normalizes the different queries based on the SLA information; (iii) an *SLA-based Matching Algorithm* selects the databases and finally (iv) a *SLA-based Evaluation Model* to obtain the final query solution. Considering our previous

work [1], to the best of our knowledge, we have not identified more proposals concerning the use of SLAs combined with a data integration approach in a multi-cloud context.

6 Conclusion and final remarks

This paper introduces the challenge of integrating data from distributed data services deployed on different cloud providers guided by service level agreements (SLA) and user preferences statements. The data integration problem is stated as a continuos data provision problem that has associated SLAs and that uses techniques for ensuring different qualities of delivered data (fresh, precise, partial). The problem statement was derived from a classification scheme that resulted from a study of existing publications identified by applying the systematic mapping method. Our contribution is the definition of a classification scheme that shows the aspects that characterize a modern vision of data integration done in multi-cloud environments and that can be enhanced by including SLAs in its process.

Current big data settings impose to consider SLA and different data delivery models. We believe that given the volume and the complexity of query evaluation that includes steps that imply greedy computations. It is important to combine and revisit well-known solutions adapted to these contexts. We are currently developing the strategies and algorithms of our vision applied to energy consumption applications and also to elections and political campaign data integration in order to guide decision making on campaign strategies.

References

1. N. Bennani, C. Ghedira-Guegan, M.A. Musicante, and G. Vargas-Solar. Sla-guided data integration on cloud environments. In *2014 IEEE 7th International Conference on Cloud Computing (CLOUD)*, pages 934–935, June 2014.
2. Gianluca Correndo, Manuel Salvadores, Ian Millard, Hugh Glaser, and Nigel Shadbolt. SPARQL query rewriting for implementing data integration over linked data. In *Proceedings of the 1st International Workshop on Data Semantics - DataSem '10*, page 1, New York, New York, USA, March 2010. ACM Press.
3. Ghada ElSheikh, Mustafa Y. ElNainay, Saleh ElShehaby, and Mohamed S. Abougabal. SODIM: Service Oriented Data Integration based on MapReduce. *Alexandria Engineering Journal*, 52(3):313–318, September 2013.
4. Mohamad Hamze, Nader Mbarek, and Olivier Togni. Self-establishing a Service Level Agreement within autonomic cloud networking environment. In *2014 IEEE Network Operations and Management Symposium (NOMS)*, pages 1–4. IEEE, May 2014.
5. Carlos-Manuel Lopez-Enriquez, Victor Cuevas-Vicenttin, Genoveva Vargas-Solar, Christine Collet, and Jose-Luis Zechinelli-Martini. A planning-based service composition approach for data-centric workflows. In *First International Workshop on Knowledge Aware Service Oriented Applications, KASA 2014, Paris, France, November 3, 2014. Proceedings*, 2014.

6. Tiezheng Nie, Guangqi Wang, Derong Shen, Meifang Li, and Ge Yu. Sla-based data integration on database grids. In *Computer Software and Applications Conference, 2007. COMPSAC 2007. 31st Annual International*, volume 2, pages 613–618, July 2007.
7. Carlos Pedrinaci, Jorge Cardoso, and Torsten Leidig. Linked USDL: A vocabulary for web-scale service trading. In *The Semantic Web: Trends and Challenges - 11th International Conference, ESWC 2014, Anissaras, Crete, Greece, May 25-29, 2014. Proceedings*, pages 68–82, 2014.
8. Kai Petersen, Robert Feldt, Shahid Mujtaba, and Michael Mattsson. Systematic mapping studies in software engineering. In *Proceedings of the 12th International Conference on Evaluation and Assessment in Software Engineering*, EASE'08, pages 68–77, Swinton, UK, UK, 2008. British Computer Society.
9. Pramod J Sadalage and Martin Fowler. *NoSQL distilled: a brief guide to the emerging world of polyglot persistence*. Pearson Education, 2012.
10. Yuan Tian, Biao Song, Jimupimg Park, and Eui nam Huh. Inter-cloud data integration system considering privacy and cost. In Jeng-Shyang Pan, Shyi-Ming Chen, and Ngoc Thanh Nguyen, editors, *ICCCI (1)*, volume 6421 of *Lecture Notes in Computer Science*, pages 195–204. Springer, 2010.
11. Stephen S. Yau and Yin Yin. A privacy preserving repository for data integration across data sharing services. *IEEE T. Services Computing*, 1(3):130–140, 2008.

Appendix B

Rhone: a quality-based query rewriting algorithm for data integration

Rhone: a quality-based query rewriting algorithm for data integration.

Daniel A. S. Carvalho[1], Plácido A. Souza Neto[2], Chirine Ghedira-Guegan[3], Nadia Bennani[4], and Genoveva Vargas-Solar[5]

[1] Université Jean Moulin Lyon 3, Centre de Recherche Magellan, IAE, France
`daniel.carvalho@univ-lyon3.fr`
[2] Instituto Federal do Rio Grande do Norte - IFRN, Natal, Brazil
`placido.neto@ifrn.edu.br`
[3] Université de Lyon, CNRS, IAE - Université Lyon 3, LIRIS, UMR5205, France
`chirine.ghedira-guegan@univ-lyon3.fr`
[4] LIRIS, INSA-Lyon, France
`nadia.bennani@insa-lyon.fr`
[5] CNRS-LIG, Grenoble, France
`genoveva.vargas@imag .fr`

Abstract. Nowadays, data provision is mostly done by data services. Data integration can be seen as composition of data services and data processing services that can deal with to integrate data collections. With the advent of cloud, producing service compositions is computationally costly. Furthermore, executing them can require a considerable amount of memory, storage and computing resources that can be provided by clouds. Our research focuses on how to enhance the results on the increase of cost on data integration in the new context of cloud. To do so, we present in this paper our original data integration approach which takes into account user's integration requirements while producing and delivering the results. The service selection and service composition are guided by the service level agreement - SLA exported by different services (from one or more clouds) and used by our matching algorithm (called *Rhone*) that addresses the query rewriting for data integration presented here as proof of concept.

Keywords: Data integration. Query rewriting. Query rewriting algorithm. Cloud computing. SLA.

1 Introduction

Current data integration implies consuming data from different data services and integrating the results according to different quality requirements related to data cost, provenance, privacy, reliability, availability, among others. Data services and data processing services can take advantage from the on-demand and *pay-as-you-go* model offered by the cloud architecture. The quality conditions and penalties under which these services are delivered can be defined in contracts using Service Level Agreements (SLA).

Cloud services (data services, data processing services, for instance) and the cloud provider export their SLA specifying the level of services the user can expect from them. A user willing to integrate data establishes a contract with the cloud provider guided by an economic model that defines the services he/she can access, the conditions in which they can be accessed (duplication, geographical location) and their associated cost. Thus, for a given requirement, cloud services (from one or several cloud providers) are chosen to retrieve, process and integrate data according to the type of contracts he/she established with them.

In this context, data integration deals with a matching problem of the user's integration preferences which includes quality constraints and data requirements, and his/her specific cloud subscription with the SLA's provided by cloud services. Matching SLAs can imply dealing with heterogeneous SLA specifications and SLA-preferences incompatibilities. Moreover, even with the possibility of having an unlimited access to cloud resources, the user is limited to the resources and to the budget agreed by his/her cloud subscription. Inspired by these problems and Carrying on the ideas presented in a previous work [3], the aim of this paper is to introduce our service-based query rewriting algorithm guided by user preferences and SLAs which enhances the quality on the results integration in a multi-cloud context.

This paper is organized as follows. Section 2 discusses related works. Section 3 describes the *Rhone* algorithm and its formalization. Experiments and results are described in the section 4. Finally, section 5 concludes the paper and discusses future works.

2 Related works

In recent years, the cloud have been the most popular deployment environment for data integration [5]. Researches have proposed their works addressing this issue [6, 8]. Moreover, once query rewriting is strictly related to data integration, rewriting algorithms have been presented [1, 2, 4].

In [6], the authors introduced a system (called SODIM) which combines data integration, service-oriented architecture and distributed processing. The novelty of their approach is that they perform data integration in service oriented contexts, particularly considering data services. A major concern when integrating data from different sources (services) is privacy that can be associated to the conditions in which integrated data collections are built and shared. [8] proposed an inter-cloud data integration system that considers a trade-off between users' privacy requirements and the cost for protecting and processing data. According to the users' privacy requirements, the query plan in the cloud repository creates the users' query. Thus, the query plan executor decides the best location to execute the sub-query to meet privacy and cost constraints. This work is mostly interested in privacy and performance issues forgetting other users' integration requirements.

The main aspect in a data integration solution is the query rewriting. In the database domain, the query rewriting problem using views have been widely discussed [7]. Similarly, data integration can be seen in the service-oriented domain as a service composition problem in which given a query the objective is to lookup and compose data services that can contribute to produce a result. Generally, data integration solutions on the service-oriented domain deal with query rewriting problems. [2] proposed a query rewriting approach which processes queries on data provider services. [4] introduced a service composition framework to answer preference queries. Two algorithms are presented to rank the best rewritings based on previously computed scores. [1] presented an refinement algorithm based on *MiniCon* that produces and order rewritings according to user preferences and scores used to rank services that should be previously define by the user. Furthermore, they do not take into consideration user's integration requirements which can lead to produce rewritings that are not satisfactory in terms of quality requirements and constraints imposed by the user and the cloud environment. We assume that these requirements and constraints be expressed on SLAs. In the next section, we introduce our query rewriting algorithm that deals with SLAs while selecting, filtering and producing results.

3 Rhone service-based query rewriting algorithm

This section describes our quality-based query rewriting algorithm called *Rhone*. It is guided by user requirements and constraints, and services' quality features extracted after structuring service level agreements (SLA). Our algorithm has two original aspects: *first*, the user can express his/her quality requirements and constraints, and associate them to his/her queries; and, *second*, service's quality features defined on Service Level Agreements (SLA) guide service selection and the whole rewriting process.

3.1 Preliminaries

The idea behind our algorithm consists in deriving a set of service compositions that fulfill the users' integration requirements and constraints concerning the context of data service deployment given a set of *abstract services*, a set of *concrete services*, a user' *query* defined hereafter and a set of user' *integration requirements and constraints.*

Definition 1 (*Abstract service*). An *abstract service* describes the small piece of function that can be performed by a cloud service. For instance, retrieve patients, DNA information and personal information. The *abstract service* is defined as A ($\overline{I}$; $\overline{O}$) where: A is a name which identifies the *abstract service*; and $\overline{I}$ and $\overline{O}$ are a set of comma-separated input and output parameters, respectively. The table 1 exemplifies *abstract services* in a medical scenario. The decorations ? and ! differentiate input and output parameters, respectively.

***Abstract service* name**	**Description**
$A1$ ($d\_name?$; $p\_id!$)	Given a disease name d_name, $A1$ returns a list of infected patients' id p_id.
$A2$ ($p\_id?$; $p\_dna!$)	Given a patient id p_id, $A2$ returns her DNA information p_dna.
$A3$ ($p\_id?$; $p\_info!$)	Given a patient id p_id, $A3$ returns her personal information p_info.
$A4$ ($d\_name?$; $regions!$)	Given a disease name d_name, $A4$ returns the most affected region $regions$.

Table 1: List of *abstract services*.

Definition 2 (*Concrete service*). A *concrete service* is defined as a set of *abstract services*, and by its *quality features* extracted from its SLA according to the following grammar:

$$S(\overline{I}_h;\overline{O}_h) := A_1(\overline{I}_{1l};\overline{O}_{1l}), A_2(\overline{I}_{2l};\overline{O}_{2l}), .., A_f(\overline{I}_{fl};\overline{O}_{fl})[M_1, M_2, .., M_g]$$

The left-hand of the definition is called the *head*; and the right-hand is the *body*. A *concrete service* S includes a set of input $\overline{I}$ and output $\overline{O}$ variables, respectively. Variables in the *head* are identified by $\overline{I}_h$ and $\overline{O}_h$, and called *head* variables. They appear in the *head* and in the *body* definition. Variables appearing only in the *body* are identified by $\overline{I}_l$ and $\overline{O}_l$, and are called *local* variables. *Head* variables can be accessed and shared among different services. On the other hand, *local* variables can be used only by the service which define them.

Concrete services are defined in terms of *abstract services* $(A_1, A_2, .., A_n)$, and they include a set of service's quality features $(M_1, M_2, .., M_g)$ that are extracted from the SLA exported by the service S. M_i is in the form $x \otimes c$, where x is a special class of identifiers associated to the services; c is a constant; and $\otimes \in \{\geq, \leq, =, \neq, <, >\}$.

Let us consider the following *concrete services* specified using the *abstract services* previously presented to be used as examples to the algorithm:

```
S1(a?;b!) := A1(a?;b!) [availability > 98%, price per call = 0.2$]
S2(a?;b!) := A1(a?;b!) [availability > 98%, price per call = 0.1$]
S3(a?;b!) := A2(a?;b!) [availability > 99%, price per call = 0.1$]
S4(a?;b!) := A1(a?;p!), A2(p?; b!)
                       [availability > 98%, price per call = 0.1$]
S5(a?;b!) := A3(a?;b!) [availability > 98%, price per call = 0.0$]
S6(a?;b!,c!) := A1(a?;p!), A2(p?;b!), A3(p?;c!)
                       [availability > 99%, price per call = 0.2$]
S7(a?;b!) := A4(a?;b!) [availability > 99%, price per call = 0.2$]
```

For instance, $S1$ is written using the *abstract service* $A1$. a and b are *head* variables. *Availability* and *price per call* are identifiers associated to $S1$'s quality features with an associated constant value extracted from $S1$'s SLA.

Definition 3 (*User query*). A user *query* Q is defined as a set of *abstract services*, a set of *constraints*, and a set of *user integration requirements* in accordance with the following grammar:

$$Q(\overline{I}_h;\overline{O}_h) := A_1(\overline{I}_{1l};\overline{O}_{1l}), A_2(\overline{I}_{2l};\overline{O}_{2l}), .., A_n(\overline{I}_{nl};\overline{O}_{nl}), C_1, C_2, .., C_m[P_1, P_2, .., P_k]$$

The *query* definition is similar to a *concrete service* concerning the variables and *abstract services*. In addition, queries have constraints over the input or output variables $(C_1, C_2, .., C_m)$. Constraints are used while querying the databases ($i.e$ in the "*where*" clause). The user *integration requirements* over the services or over service compositions are specified in $P_1, P_2, .., P_k$. C_i and P_j are in the form $x \otimes c$, where x is an identifier; c is a constant; and $\otimes \in \{\geq, \leq, =, \neq, <, >\}$.

User requirements can be of two types, single and composed. Single are associated directly to each service involved in the composition. Composed are linked to the entire composition. They are defined in terms of single requirements. For instance, the total response time is a composed preference obtained by adding the response time of each service involved in the composition.

Let us suppose a query specification based on a medical scenario in which doctor *Marcel* wants to query the personal and DNA information from patients that were infected by *flu*, using services with availability higher than 98%, price per call less than 0.2$ and integration total cost less than 5$. To achieve his needs, the *abstract services* $A1$, $A2$ and $A3$ should be composed as follows.

```
Q(dis?;dna!,info!) := A1(dis?;p!), A2(p?;dna!), A3(p?;info!), d = "flu",
             [availability > 98%, price per call < 0.2$, total cost < 5$]
```

The *Marcel's query* plan begins by retrieving infected patients ($A1$). This operation returns patients' ids p. The *abstract services* $A2$ and $A3$ use patient ids to return their DNA and personal information (dna and $info$). The *query* contains a constraint *dis* (disease name) equal to flu, and three identifiers define the user' *integration preferences* with their associated constant value.

The input data for the *Rhone* is a query and a set of concrete services. The result is a set of rewriting of the query in terms of concrete services, fulfilling the user preferences. The main function of the algorithm is divided in four steps: selecting candidate concrete services, creating candidate service descriptions and combining and producing rewritings. In the next sections, each step of the algorithm will be described.

3.2 Selecting candidate concrete services

While selecting services, the algorithm deals with three matching problems: (i) *quality features* matching, each *feature* in a query should be found in a concrete service. Moreover, the evaluation of a *feature* in a concrete service must satisfy the evaluation of a *feature* in the query; (ii) *abstract service* matching, abstract services can be matched if they have the same abstract function name and if the number and type of variable are equivalent; and (iii) *concrete service* matching, all abstract services in the concrete service must exist in the query, and all of them should satisfy the *feature* and *abstract service matching* problems. Compared to [1], our algorithm includes the *features* matching and extends the *concrete service* matching by not accepting *concrete services* that covers useless *abstract services* to the query rewriting.

3.3 Candidate service description creation

After producing the set of candidate concrete services, the next step creates candidate service descriptions (CSDs). A CSD maps abstract services and variables of a concrete service into abstract services and variables of the query.

Definition 6 (candidate service description). A CSD is represented by an n-tuple:

$$\langle S, h, \varphi, G, P \rangle$$

where S is a *concrete service*. h are mappings between variables in the *head* of S to variables in the *body* of S. φ are mapping between variables in the *concrete service* to variables in the *query*. G is a set of *abstract services* covered by S. P is a set of *quality features* associated to the service S.

A CSD is created according to 4 rules: (i) for all head variables in a concrete service, the mapping h from the head to the body definition must exist; (ii) Head variables in concrete services can be mapped to head or local variables in the query; (iii) Local variables in concrete services can be mapped to head variables in the query; and (iv) Local variables in concrete services can be mapped to local variables in the query if and only if the concrete service covers all abstract services in the query that depend on this variable. The relation "depends" means that an output local variable is used as input in another abstract service.

Given the query Q and a list of candidate concrete services $\mathcal{L}_{\mathcal{S}}$, a list of CSDs $\mathcal{L}_{\mathcal{CSD}}$ is produced. A CSD is created only for candidate concrete services in which the mappings rules are being satisfied.

Given the candidate concrete services `S2`, `S3`, `S4` and `S5` selected in the previous step. The algorithm builds CSDs to `S2`, `S3` and `S5` once they satisfy all the mapping rules as follows. For instance, CSD_2 is produced to `S2` as follows: $\langle S2,\ h = \{a \rightarrow a,\ b \rightarrow b\},\ \varphi = \{a \rightarrow dis,\ b \rightarrow p\},\ G = \{A1\},\ P = \{availability > 98\%,\ price\ per\ call = 0.1\$\}\rangle$. However, a CSD for `S4` is not build because it violates the rule for local variables. It contains a local variable (p) mapped to a local variable in the query. Consequently, `S4` must cover all abstract services in the query depending on this variable, but the abstract service $A3$ is not covered.

3.4 Combining and producing rewritings step

Given the list of CSDs $\mathcal{L}_{\mathcal{CSD}}$ produced, the *Rhone* produces all possible combinations of its elements. Building combinations deals with a NP hard complexity problem. The effort to process combinations increases while the number of CSDs and abstract services in the query increases.

The last step identifies rewritings matching with the query and fulfilling the user preferences. The *Rhone* algorithm verifies if a given CSD list p is a rewriting of the original query. The function return *true* if (i) the number of abstract services resulting from the union of all CSDs in p is equal to the number of abstract services in the query; and (ii) the intersection of all abstract services in each CSD on p is empty. It means that is forbidden to have abstract services replicated among the set p.

Let us consider CSD_2, CSD_3 and CSD_5 are CSDs that refer to the concrete services `S2`, `S3` and `S5`, respectively. The *Rhone* produces combinations taking into account the part of the query covered by the service as follows:

$p_1 = \{CSD_2\}$
$p_2 = \{CSD_2, CSD_3\}$
$p_3 = \{CSD_2, CSD_3, CSD_5\}$

Given the combinations, the *Rhone* checks if each one of them is a valid rewriting of the original query.

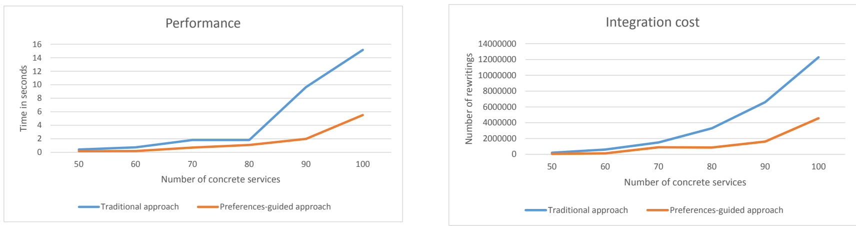
– p_1 and p_2 are not valid rewritings; their number of abstract services do not match with the number of abstract services in the query.
– p_3 is a valid rewriting; the number of abstract services matches and there is no repeated abstract service.

4 Evaluation

Different experiments were produced to analyze the algorithm's behavior. The *Rhone* [6], so far, was evaluated in a local controlled environment simulating a mono-cloud including a service registry of 100 concrete services. Some experiments were produced to analyze the its behavior concerning performance, and quality and cost of the integration. The experiments include two different approaches: (i) the *traditional approach* in which user preferences and SLAs are not considered; and (ii) the *preference-guided approach* (P-GA) which considers the users' integration requirements and SLAs. Figures 1a and 1b summarize our first results.

The results P-GA are promisingly. Our approach increases performance reducing rewriting number which allows to go straightforward to the rewriting solutions that are satisfactory avoiding any further backtrack and thus reducing successful integration time (Figure 1a). Moreover, using the P-GA to meet the user preferences, the quality of the rewritings produced has been enhanced and the integration economic cost has considerable reduced while delivering the expected results (Figure 1b).

[6] The *Rhone* algorithm is implemented in Java and it includes 15 java classes in which 14 of them model the basic concepts (*query*, *abstract services*, *concrete services*, etc), and 1 responsible to implement the core of the algorithm.



(a) Performance evaluation.

(b) Integration cost.

Fig. 1: *Rhone* execution evaluation.

5 Final Remarks and Future Works

Rhone still need to be tested in a large scale case and in a context of parallel multi-tenant to test efficacy. However, the results can show that the *Rhone* reduces the rewriting number and processing time while considering user preferences and services' quality aspects extracted from SLAs to guide the service selection and rewriting. We are currently performing a multi-cloud simulation in order to evaluate the performance of the *Rhone* in such context.

References

1. Ba, C., Costa, U., H. Ferrari, M., Ferre, R., A. Musicante, M., Peralta, V., Robert, S.: Preference-driven refinement of service compositions. In: Int. Conf. on Cloud Computing and Services Science. Proceedings of CLOSER 2014 (2014)
2. Barhamgi, M., Benslimane, D., Medjahed, B.: A query rewriting approach for web service composition. Services Computing, IEEE Transactions on Services Computing (2010)
3. Bennani, N., Ghedira-Guegan, C., Musicante, M., Vargas-Solar, G.: Sla-guided data integration on cloud environments. In: 2014 IEEE 7th International Conference on Cloud Computing (CLOUD). pp. 934–935 (June 2014)
4. Benouaret, K., Benslimane, D., Hadjali, A., Barhamgi, M.: FuDoCS: A Web Service Composition System Based on Fuzzy Dominance for Preference Query Answering (2011), 37th International Conference on Very Large Data Bases (VLDB 2011)
5. Carvalho, D.A.S., Souza Neto, P.A., Vargas-Solar, G., Bennani, N., Ghedira, C.: Can Data Integration Quality Be Enhanced on Multi-cloud Using SLA?, pp. 145–152. Springer International Publishing (2015)
6. ElSheikh, G., ElNainay, M.Y., ElShehaby, S., Abougabal, M.S.: SODIM: Service Oriented Data Integration based on MapReduce. Alexandria Engineering Journal (2013)
7. Halevy, A.Y.: Answering queries using views: A survey. The VLDB Journal 10(4), 270–294 (Dec 2001)
8. Tian, Y., Song, B., Park, J., nam Huh, E.: Inter-cloud data integration system considering privacy and cost. In: ICCCI. Lecture Notes in Computer Science, vol. 6421, pp. 195–204. Springer (2010)

Appendix C

Towards a Quality Guided Data Integration on Multi-Cloud Settings

Towards Quality Guided Data Integration on Multi-Cloud Settings

Daniel A. S. Carvalho
(Supervised by Chirine Ghedira-Guegan, Genoveva Vargas-Solar and Nadia Bennani, with inputs from Plácido A. Souza Neto)

Université Jean Moulin Lyon 3, Centre de Recherche Magellan, IAE, France
daniel.carvalho@univ-lyon3.fr

Abstract. This PhD project addresses data integration considering data quality (freshness, provenance, cost, availability) properties in a multi-cloud context. In fact, in a multi-cloud context, data is made available through a huge offer of services deployed on different clouds with heterogeneous quality of service features. By users who thank to their contracts with the clouds expressed by traditional SLA according to their rights. Consequently, data integration in this context needs to take into account these new constraints. The aim of our work is to revisit previously proposed data integration solutions in order to adapt them to the multi-cloud context. Our solution consists in defining over the clouds a layer that provides a reasoning on the best services combination that meets services and user constraints and willings, the best way to deploy the integration process. This layer should let further data integration easier thank to the definition of a new kind of SLA called *Integration SLA*. This paper gives a model-oriented vision of our proposal.

Keywords: Data integration. Query rewriting algorithm. Cloud computing. SLA.

1 Introduction

Our work addresses data integration considering data quality properties (freshness, provenance, cost, availability) and service level agreements (SLA). Existing approaches - guided by heterogeneous data structures and formats, semantics and integrity constraints - have already tackled quality issues. Furthermore, this work explicitly considers infrastructure properties (reliability, computing, storage and memory capacity, and cost) imposed by the multi-cloud context and data providers quality to guide the integration process. In this new context, existing solutions are not sufficient as they need an infrastructure over the clouds that (i) allow services to express quality aspects; (ii) integration solutions to take into account the huge service offer and the multi-cloud paradigm constraints/advantages; and (ii) an intelligent entity to decide which services to select, where and in which conditions further integration demands could be treated using the past integration experience. The objective is to customize data providers (services) look up and the data integration considering different data consumers requirements and expectations depending on the context in which they consume data (e.g., mobile devices with few physical capacities, critical decision making). Our work relies on two assumptions: (1) the data integration process is totally or partially externalized on different clouds that provide necessary resources under different conditions (SLA); (2) data can be retrieved from several data providers (i.e., services) with different quality properties.

Let us suppose that during Brazilian Olympic games in 2016, Lucas wants to know two days in advance the weather forecast near his location to make decisions about the events he wants to attend. According to the weather, OGApp is an application that proposes possible matches in different stadiums with available seats (sunny seats or not, in the middle or in the sides, and on the side of a specific team). Lucas has several preferences regarding privacy (i.e. he wants his personal data to be anonymous), time, schedule, budget, cost (e.g., using free data services or not). Several data provision and computing services can be composed by OGApp to integrate data that can help Lucas to make his decision. Furthermore, since Lucas often looks for data in his mobile devices he is subscribed to several clouds to externalize "costly" processes (e.g., storage of retrieved data, correlation and aggregation of data coming from different providers, data transmission on 3G). OGApp will rely on the clouds to perform the integration process for Lucas respecting his preferences and the conditions of his subscriptions in the clouds. Suppose now that later Geraldine asks for the same result as Lucas but her constraint is to obtain the results with a minimum cost. Using Lucas' previous integration plan, the OGApp could be able to answer partially her query. Consequently, the same integration plan could be replayed. Thus, the data integration process becomes a combinatorial problem where a query result is a data collection integrated by composing different data providers and data processing (cloud) services that fulfill quality constraints and SLAs specified by a data consumer. Given a user query, the integration process deals with different matching problems: (i) matching the *query* and *data provider services* - the data provider services should be able to produce a (complete or partial) result for the query; (ii) matching the *user preferences* and the *quality guarantees* provided by the data provider (iii) matching the *user preferences* and *user's type of subscriptions* - the user may have several subscriptions with different clouds that should influence the way to choose the services according to the cloud resources offered thank to user subscription; and (iv) the *data provider services* and *their type of subscriptions* - the data provider services also have subscription with the clouds, and this imposes to adapt the way the service is delivered according to the resources to which it has access.

We assume the quality conditions that the user can expect from a service are defined in service level agreements (SLA). In our context, we need to identify which SLAs measures apply to the data integration process and how they should be taken into consideration for providing a final result that fulfills data consumers requirements.

This PhD project proposes an approach for data integration guided by quality and SLAs partially or totally performed over a multi-cloud settings. The originality of our approach consists in guiding and personalizing the entire data integration process - while selecting, filtering and composing cloud services, and delivering the results - taking into account (a) user preferences statements; (b) SLAs exported by different cloud providers; and (c) QoS measures associated to data collections (for instance, trust, privacy, economic cost).

The reminder of this paper is organized as follows. Section 2 discusses the related works. Section 3 gives an overview of our SLA-based data integration approach. Section 4 describes the research plan, and Section 5 concludes the paper.

2 Related works

Related works rely on four topics: (i) data integration and data quality in the database domain; (ii) data integration approaches in the cloud and in service-oriented contexts; (iii) query rewriting approaches; and (iv) service level agreements for cloud computing.

Data integration has been widely discussed in the database domain. [10] discussed theoretical aspects in data integration including modeling applications, query evaluation, dealing with inconsistencies and reasoning queries. Moreover, [9] reviewed several query rewriting approaches. [3] surveyed data quality aspects in data integration systems. [11] presented a data quality broker that allows to submit queries with associated quality requirements over a global schema and to provide results according to them.

[6, 8] performed data integration in service-oriented contexts, particularly considering data services. However, they consider computing resources consumption versus performance for guiding the data integration process. [12] proposed an inter-cloud data integration system considering privacy requirements and the cost for protecting and processing data. [11–13] tackled quality aspects of the integration, but do not consider crucial aspects such as data consumers and data providers requirements and constraints, the associated infrastructures and the data quality itself.

As traditional databases theory, data integration on cloud and service-oriented context deals with query rewriting issues. Existing works like [1, 2, 4, 7] have refered it as a service composition problem. Given a query, the objective is to lookup and compose data services that can contribute to produce a result. In general, these works must address performance issues, because they use algorithms that can become expensive according to the complexity of the query and on the number of available services. Although [1, 4] have considered preferences and scores to produce rewritings, the multi-cloud context introduces new requirements and constraints to the integration process. Currently, the approaches are not sufficient to cover the new challenges. Thus, they should be revisited and adapted in order to make the integration efficient in this new environment.

Research contributions related to SLA in cloud computing concern (i) SLA management; (ii) inclusion of security requirements on SLAs; (iii) SLA negotiation; (iv) SLA matching; and (v) monitoring and allocation of cloud resources to detect and avoid SLA violations. We strongly believe that SLAs can be used to explicitely introduce the notion of quality in the current data integration solutions. In this sense, the use of SLAs to guide the entire data integration in a multi-cloud context seems original and promising for providing new perspectives to the data integration problem.

3 An SLA-based Data Integration Approach: a model oriented vision

To explain our solution, in this section we present a metamodel that depicts implied entities and their relationship. Then a meta-process will introduce the functionalities of the proposed solution.

According to our metamodel (Figure 1), the *Multi-Cloud* is viewed as a set of *Cloud Infrastructures*. *Data producers* and *Data consumers* subscribe to *Cloud infrastructures*. Their subscription credentials are illustrated thanks to a *SLA* (*Consumer SLA* or *Producer SLA*) defining what the *Cloud infrastructure* offers to them through their subscription. *Data* are provided and consumed by *Data Producers* and *Data Consumers*, respectively. The *integration SLA* is a new type of SLA we introduce to reflect a multi-cloud contract between the user and the implied services according to the constraints imposed by the environment.

The data integration meta-process (see Figure 2) implies the entities presented in the metamodel. It consists of three macro-steps. *First*, *query management* activities to process the user query and preferences; *second*, *SLA management* activities to enforce the SLA associated to the involved services, search and reuse previous *integration SLAs*, and create a new one for the current request; *third*, *query rewriting* activities [5] to search and filter *data producers*, to generate and execute the integration plan, and to compute results.

The activities defined in our meta-process bring the following challenges to our research:

1. SLA design. The issue is what are the important information that should be inserted in the integration SLA to facilitate further integration? How these information should be collected and stored during the integration to help next integrations.
2. Integration reuse. How to exploit cleverly the past integration processes?
3. Rewriting process. How to optimize it to make the execution time viable? Retrieving, integrating and delivering are tasks that requires a large amount of resources and processing time. Thus, it is necessary to study a efficient manner to make efficient the overall execution.

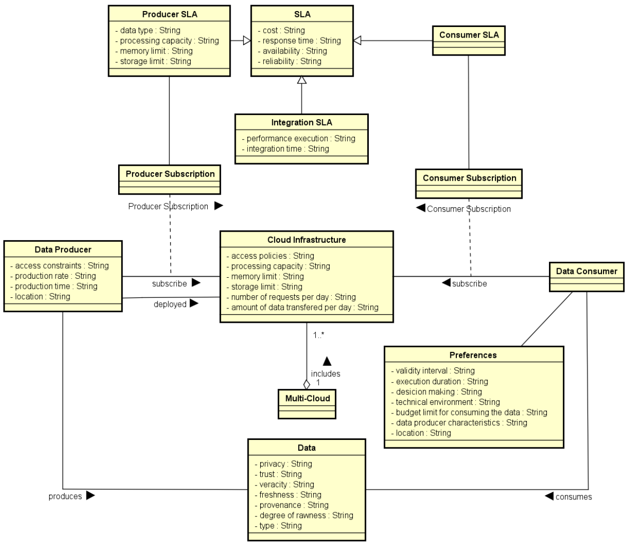


Fig. 1: Data integration metamodel

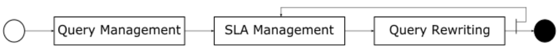


Fig. 2: Data integration meta-process

4 Research plan

We started proposing a query rewriting algorithm called *Rhone*. It serves as proof of concept for the feasibility of our data integration process guided by cloud constraints and user preferences [5]. The first results are promising: *Rhone* reduces the rewriting number and processing time while considering user preferences and services' quality aspects extracted from SLAs to guide the service selection and rewriting. Furthermore, the integration quality is enhanced, and the integration total cost is reduced. For the time being, quality enhancement is assessed through benchmarks and use cases deployed on an experimental multi-cloud environment.

We are currently working on an SLA model for the integration process to express the constraints and the quality feature of a previous data integration. Other important research aspects are how to make efficient the rewriting process by reducing the composition search space.

5 Conclusions

This paper introduced a new data integration solution, adapted to the multi-cloud context. The solution is described thank to a metamodel describing the implied entities and a meta-process presenting the activities and the corresponding challenges.

References

1. Ba, C., Costa, U., H. Ferrari, M., Ferre, R., A. Musicante, M., Peralta, V., Robert, S.: Preference-driven refinement of service compositions. In: Int. Conf. on Cloud Computing and Services Science. Proceedings of CLOSER 2014 (2014)
2. Barhamgi, M., Benslimane, D., Medjahed, B.: A query rewriting approach for web service composition. Services Computing, IEEE Transactions on Services Computing (2010)
3. Batini, C., Scannapieco, M.: Data Quality Issues in Data Integration Systems, pp. 133–160. Springer Berlin Heidelberg (2006)
4. Benouaret, K., Benslimane, D., Hadjali, A., Barhamgi, M.: FuDoCS: A Web Service Composition System Based on Fuzzy Dominance for Preference Query Answering (2011), 37th International Conference on Very Large Data Bases (VLDB 2011)
5. Carvalho, D.A.S., Souza Neto, P.A., Vargas-Solar, G., Bennani, N., Ghedira, C.: New Trends in Databases and Information Systems, chap. Rhone: A Quality-Based Query Rewriting Algorithm for Data Integration. Springer International Publishing Switzerland (2016)
6. Correndo, G., Salvadores, M., Millard, I., Glaser, H., Shadbolt, N.: SPARQL query rewriting for implementing data integration over linked data. In: Proceedings of the 1st International Workshop on Data Semantics - DataSem '10. ACM Press, New York, New York, USA (2010)
7. Costa, U., Ferrari, M., Musicante, M., Robert, S.: Automatic refinement of service compositions. In: Web Engineering, Lecture Notes in Computer Science, vol. 7977. Springer Berlin Heidelberg (2013)
8. ElSheikh, G., ElNainay, M.Y., ElShehaby, S., Abougabal, M.S.: SODIM: Service Oriented Data Integration based on MapReduce. Alexandria Engineering Journal (2013)
9. Halevy, A.Y.: Answering queries using views: A survey. The VLDB Journal 10(4), 270–294 (Dec 2001)
10. Lenzerini, M.: Data integration: A theoretical perspective. In: Proceedings of the Twenty-first ACM SIGMOD-SIGACT-SIGART Symposium on Principles of Database Systems. pp. 233–246. PODS '02, ACM, New York, NY, USA (2002)
11. Scannapieco, M., Virgillito, A., Marchetti, C., Mecella, M., Baldoni, R.: The daquincis architecture: A platform for exchanging and improving data quality in cooperative information systems. Inf. Syst. 29(7), 551–582 (2004)
12. Tian, Y., Song, B., Park, J., nam Huh, E.: Inter-cloud data integration system considering privacy and cost. In: ICCCI. Lecture Notes in Computer Science, vol. 6421, pp. 195–204. Springer (2010)
13. Yau, S.S., Yin, Y.: A privacy preserving repository for data integration across data sharing services. IEEE T. Services Computing 1 (2008)

«««< HEAD ======= »»»> 08f0ce832ab84bc50439b222b926422501ceb8db

Bibliography

[Abdel-Moneim 2015] Mohamed Samir Abdel-Moneim, Ali Hamed El-Bastawissy and Mohamed Hamed Kholief. *Quality Driven Approach for Data Integration Systems*. In The 7th International Conference on Information Technology, pages 409–420, 2015. (Cited on page 7.)

[Alhamad 2011] Mohammed Alhamad, Tharam S. Dillon and Elizabeth Chang. *A Survey on SLA and Performance Measurement in Cloud Computing*. In OTM Conferences (2), volume 7045 of *Lecture Notes in Computer Science*, pages 469–477. Springer, 2011. (Cited on pages 9 and 7.)

[Alsubaiee 2012] Sattam Alsubaiee, Alexander Behm, Raman Grover, Rares Vernica, Vinayak Borkar, Michael J. Carey and Chen Li. *ASTERIX: Scalable Warehouse-style Web Data Integration*. In Proceedings of the Ninth International Workshop on Information Integration on the Web, IIWeb '12, pages 2:1–2:4, New York, NY, USA, 2012. ACM. (Cited on page 8.)

[Angeles 2009] Maria del Pilar Angeles and Francisco GarcÃa-Ugalde. *A Data Quality Practical Approach*. International Journal on Advances in Software, vol. Vol.2, no. No.2 & 3, 2009. (Cited on page 7.)

[Ba 2014] Cheikh Ba, Umberto Costa, Mirian H. Ferrari, Rémy Ferre, Martin A. Musicante, Veronika Peralta and Sophie Robert. *Preference-Driven Refinement of Service Compositions*. In Int. Conf. on Cloud Computing and Services Science, 2014, Proceedings of CLOSER 2014, 2014. (Cited on pages 9 and 7.)

[Barhamgi 2010] M. Barhamgi, D. Benslimane and B. Medjahed. *A Query Rewriting Approach for Web Service Composition*. Services Computing, IEEE Transactions on, vol. 3, no. 3, pages 206–222, July 2010. (Cited on pages 8, 9 and 7.)

[Batini 2006] Carlo Batini and Monica Scannapieco. Data quality issues in data integration systems, pages 133–160. Springer Berlin Heidelberg, 2006. (Cited on page 7.)

[Batista 2007] Maria da Conceição Moraes Batista and Ana Carolina Salgado. *Information Quality Measurement in Data Integration Schemas*. In Venkatesh Ganti and Felix Naumann, editors, Proceedings of the Fifth International Workshop on Quality in Databases, QDB 2007, at the VLDB 2007 conference, Vienna, Austria, September 23, 2007, pages 61–72, 2007. (Cited on page 7.)

[Benouaret 2011] Karim Benouaret, Djamal Benslimane, Allel Hadjali and Mahmoud Barhamgi. *FuDoCS: A Web Service Composition System Based on Fuzzy Dominance for Preference Query Answering*, September 2011. VLDB - 37th International Conference on Very Large Data Bases - Demo Paper. (Cited on pages 9 and 7.)

[Benslimane 2013] Djamal Benslimane, Mahmoud Barhamgi, Frédéric Cuppens, Franck MORVAN, Bruno Defude and Ebrahim Nageba. *PAIRSE: A Privacy-Preserving Service-Oriented Data Integration System.* SIGMOD record, vol. vol. 42, no. n° 3, pages pp. 42–47, September 2013. (Cited on page 8.)

[Boufares 2012] F. Boufares and A. Ben Salem. *Heterogeneous data-integration and data quality: Overview of conflicts.* In 2012 6th International Conference on Sciences of Electronics, Technologies of Information and Telecommunications (SETIT), pages 867–874, March 2012. (Cited on page 7.)

[Brandic 2010] I. Brandic, V. C. Emeakaroha, M. Maurer, S. Dustdar, S. Acs, A. Kertesz and G. Kecskemeti. *LAYSI: A Layered Approach for SLA-Violation Propagation in Self-Manageable Cloud Infrastructures.* In 2010 IEEE 34th Annual Computer Software and Applications Conference Workshops, pages 365–370, July 2010. (Cited on page 9.)

[Casola 2016] V. Casola, A. d. Benedictis, M. Erascu, M. Rak and U. Villano. *A Security SLA-driven Methodology to Set-Up Security Capabilities on Top of Cloud Services.* In 2016 10th International Conference on Complex, Intelligent, and Software Intensive Systems (CISIS), pages 549–554, July 2016. (Cited on page 9.)

[Correndo 2010] Gianluca Correndo, Manuel Salvadores, Ian Millard, Hugh Glaser and Nigel Shadbolt. *SPARQL query rewriting for implementing data integration over linked data.* In Proceedings of the 1st International Workshop on Data Semantics - DataSem '10, New York, New York, USA, 2010. ACM Press. (Cited on pages 8 and 7.)

[Costa 2013] UmbertoS. Costa, MirianHalfeld Ferrari, MartinA. Musicante and Sophie Robert. *Automatic Refinement of Service Compositions.* In Florian Daniel, Peter Dolog and Qing Li, editors, Web Engineering, volume 7977 of *Lecture Notes in Computer Science*, pages 400–407. Springer Berlin Heidelberg, 2013. (Cited on pages 9 and 7.)

[Duschka 1997] Oliver M. Duschka and Michael R. Genesereth. *Answering Recursive Queries Using Views.* In Proceedings of the Sixteenth ACM SIGACT-SIGMOD-SIGART Symposium on Principles of Database Systems, PODS '97, pages 109–116, New York, NY, USA, 1997. ACM. (Cited on page 7.)

[ElSheikh 2013] Ghada ElSheikh, Mustafa Y. ElNainay, Saleh ElShehaby and Mohamed S. Abougabal. *SODIM: Service Oriented Data Integration based on MapReduce.* Alexandria Engineering Journal, 2013. (Cited on pages 8 and 7.)

[Emeakaroha 2012] V. C. Emeakaroha, T. C. Ferreto, M. A. S. Netto, I. Brandic and C. A. F. De Rose. *CASViD: Application Level Monitoring for SLA Violation Detection in Clouds*. In 2012 IEEE 36th Annual Computer Software and Applications Conference, pages 499–508, July 2012. (Cited on page 9.)

[Falasi 2016] A. A. Falasi and M. A. Serhani. *SLA Specification and Negotiation Model for a Network of Federated Clouds: CloudLend*. In 2016 Intl IEEE Conferences on Ubiquitous Intelligence Computing, Advanced and Trusted Computing, Scalable Computing and Communications, Cloud and Big Data Computing, Internet of People, and Smart World Congress (UIC/ATC/ScalCom/CBDCom/IoP/SmartWorld), pages 772–779, July 2016. (Cited on pages 9 and 7.)

[Gertz 1998] M. Gertz and I. Schmitt. *Data Integration Techniques based on Data Quality Aspects*. 3rd National Workshop on Federal Databases, 1998. (Cited on page 7.)

[Halevy 2001] Alon Y. Halevy. *Answering Queries Using Views: A Survey*. The VLDB Journal, vol. 10, no. 4, pages 270–294, December 2001. (Cited on page 7.)

[Hong 2014] X. Hong and C. Rong. *Multiple Data Integration Service*. In 2014 28th International Conference on Advanced Information Networking and Applications Workshops, pages 860–865, May 2014. (Cited on page 8.)

[Hussain 2015] W. Hussain, F. K. Hussain, O. Hussain and E. Chang. *Profile-Based Viable Service Level Agreement (SLA) Violation Prediction Model in the Cloud*. In 2015 10th International Conference on P2P, Parallel, Grid, Cloud and Internet Computing (3PGCIC), pages 268–272, Nov 2015. (Cited on page 9.)

[Leitner 2010] P. Leitner, A. Michlmayr, F. Rosenberg and S. Dustdar. *Monitoring, Prediction and Prevention of SLA Violations in Composite Services*. In Web Services (ICWS), 2010 IEEE International Conference on, pages 369–376, July 2010. (Cited on pages 9 and 7.)

[Lenzerini 2002] Maurizio Lenzerini. *Data Integration: A Theoretical Perspective*. In Proceedings of the Twenty-first ACM SIGMOD-SIGACT-SIGART Symposium on Principles of Database Systems, PODS ’02, pages 233–246, New York, NY, USA, 2002. ACM. (Cited on page 7.)

[Levy 1996] Alon Y. Levy, Anand Rajaraman and Joann J. Ordille. *Querying Heterogeneous Information Sources Using Source Descriptions*. In Proceedings of the 22th International Conference on Very Large Data Bases, VLDB ’96, pages 251–262, San Francisco, CA, USA, 1996. Morgan Kaufmann Publishers Inc. (Cited on pages 7, 11 and 10.)

[Mavrogeorgi 2013] N. Mavrogeorgi, V. Alexandrou, S. Gogouvitis, A. Voulodimos, D. Kiriazis, T. Varvarigou and E. K. Kolodner. *Customized SLAs in Cloud Environments*. In P2P, Parallel, Grid, Cloud and Internet Computing (3PGCIC), 2013 Eighth International Conference on, pages 262–269, Oct 2013. (Cited on pages 9 and 7.)

[Monem 2016] Reham I. Abdel Monem, Ali H. El-Bastawissy and Mohamed M. Elwakil. *DIRA : A Framework of Data Integration Using Data Quality*. International Journal of Data Mining & Knowledge Management Process (IJDKP) Vol.6, No.2, March 2016, vol. Vol.6, no. No.2, 2016. (Cited on page 7.)

[Mubeen 2012] Asfia Mubeen, Mohd Murtuza Ahmed Khan and Sana Mubeen Zubedi. *Web Service Integration Using Cloud Data Store*. International Journal of Computer Science and Network (IJCSN), vol. Vol.1, no. Isuue 6, 2012. (Cited on page 8.)

[Pottinger 2001] Rachel Pottinger and Alon Halevy. *MiniCon: A Scalable Algorithm for Answering Queries Using Views*. The VLDB Journal, vol. 10, no. 2-3, pages 182–198, September 2001. (Cited on pages 7, 11 and 10.)

[Rak 2013] M. Rak, N. Suri, J. Luna, D. Petcu, V. Casola and U. Villano. *Security as a Service Using an SLA-Based Approach via SPECS*. In Cloud Computing Technology and Science (CloudCom), 2013 IEEE 5th International Conference on, volume 2, pages 1–6, 2013. (Cited on pages 9 and 7.)

[Redl 2012] C. Redl, I. Breskovic, I. Brandic and S. Dustdar. *Automatic SLA Matching and Provider Selection in Grid and Cloud Computing Markets*. In 2012 ACM/IEEE 13th International Conference on Grid Computing, pages 85–94, Sept 2012. (Cited on pages 9 and 7.)

[Rojas 2016] M. A. T. Rojas, N. M. Gonzalez, F. V. Sbampato, F. F. Redigolo, T. Carvalho, K. W. Ullah, M. Naslund and A. S. Ahmed. *A framework to orchestrate security SLA lifecycle in cloud computing*. In 2016 11th Iberian Conference on Information Systems and Technologies (CISTI), pages 1–7, June 2016. (Cited on page 9.)

[Scannapieco 2004] Monica Scannapieco, Antonino Virgillito, Carlo Marchetti, Massimo Mecella and Roberto Baldoni. *The DaQuinCIS Architecture: A Platform for Exchanging and Improving Data Quality in Cooperative Information Systems*. Inf. Syst., vol. 29, no. 7, pages 551–582, 2004. (Cited on page 7.)

[Son 2014] S. Son, D. J. Kang and J. M. Kim. *Design considerations to realize automated SLA negotiations in a multi-Cloud brokerage system*. In 10th IEEE International Conference on Collaborative Computing: Networking, Applications and Worksharing, pages 466–468, Oct 2014. (Cited on pages 9 and 7.)

[Thor 2011] Andreas Thor and Erhard Rahm. *CloudFuice: A Flexible Cloud-based Data Integration System.* In Proceedings of the 11th International Conference on Web Engineering, ICWE'11, pages 304–318, Berlin, Heidelberg, 2011. Springer-Verlag. (Cited on page 8.)

[Tian 2010] Yuan Tian, Biao Song, Jimupimg Park and Eui nam Huh. *Inter-cloud Data Integration System Considering Privacy and Cost.* In ICCCI, volume 6421 of *Lecture Notes in Computer Science*, pages 195–204. Springer, 2010. (Cited on pages 8 and 7.)

[Yau 2008] Stephen S. Yau and Yin Yin. *A Privacy Preserving Repository for Data Integration across Data Sharing Services.* IEEE T. Services Computing, vol. 1, no. 3, pages 130–140, 2008. (Cited on pages 8 and 7.)