

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

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

<sup>1</sup> Université Jean Moulin Lyon 3, Centre de Recherche Magellan, IAE, France  
`daniel.carvalho@univ-lyon3.fr`

<sup>2</sup> Instituto Federal do Rio Grande do Norte - IFRN, Natal, Brazil  
`placido.neto@ifrn.edu.br`

<sup>3</sup> Université Jean Moulin Lyon 3, LIRIS, Centre de Recherche Magellan, IAE, France  
`chirine.ghedira-guegan@univ-lyon3.fr`

<sup>4</sup> LIRIS, INSA-Lyon, France  
`nadia.bennani@insa-lyon.fr`

<sup>5</sup> 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. 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 enhancing quality on data integration in a cloud context. This paper presents a data integration approach which takes into account user's integration requirements while producing and delivering her results. The service selection and service composition are guided by the service level agreement - SLA exported by different services (from one or more clouds). In addition, our matching algorithm (called *Rhone*) that addresses query rewriting for data integration is presented 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 imposed by the cloud architecture. The quality conditions and penalties in case of its violation 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 she can access, the conditions in which they can be accessed (duplication, geographical location) and their associated cost. Thus, for a given requirement, a user could decide which cloud services (from one or several cloud providers) to use for retrieving, processing and integrating data according to the type of contracts she can establish 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 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 possibility of having an unlimited access to cloud resources, the user is limited to the resources and the budget agreed by her cloud subscription. The aim of this paper is tackle these problems and design a data integration solution guided by SLAs in a multi-cloud context. In addition, we present our service-based query rewriting algorithm guided by user preferences and SLAs as proof of concept.

This paper is organized as follows. Section 2 discusses related works. Section 3 introduces our data integration approach considering a running scenario and the data integration challenges. Section 4 describes the *Rhone* algorithm and its formalization. Experiments and results are described in the section 5. Finally, section 6 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]. Existing works addressing this issue can be grouped according to two different lines of research: (i) data integration and services [6, 9, 14, 15]; and (ii) service level agreements (SLA) and data integration [3, 12].

[6] proposes a query rewriting method for achieving RDF data integration. The objective of the approach is: (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. [9] introduces a system (called SODIM) which combine data integration, service-oriented architecture and distributed processing. 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. [15] focuses on data privacy in order to integrate data. Based on users' integration requirements, the repository supports the retrieval

and integration of data across different services. [14] 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.

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. [12] proposes a data integration model guided by SLAs in a grid environment. Their work uses SLAs to define database resources. Then, resources can be evaluated (in terms of processing cost, amount of data and price of using the grid) and selected to the integration. A matching algorithm is proposed to produce query plans. The most appropriated solutions based on the QoS are selected as final results. Apart from our previous work [3], to the best of our knowledge, there is no evidence of researches on SLA applied to data integration in a (multi-)cloud context.

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 [10, 11, 8, 13]. 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] proposes a query rewriting approach which processes queries on data provider services. [4] introduces a service composition framework to answer preference queries. Two algorithms inspired on [2] are presented to rank the best rewritings based on previously computed scores. [1] extends [7] and presents 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. In general, these approaches share the same performance problem as the traditional database algorithms. Furthermore, they do not take into consideration user's integration requirements what can lead to produce rewritings that are not satisfactory to the user in terms of quality requirements and cost.

### 3 SLA guided data integration

Let us assume the following medical scenario in which users are able to retrieve and integrate data concerning (i) *patients that were infected by a disease*; (ii) *regions most affected by a disease in specific region*; (iii) *patients' personal information*; and (iv) *patients' DNA information*.

The figure 1 illustrates our vision of data integration. Data is delivered as *data services* deployed in a multi-cloud context. Each *data service* and cloud export their SLA specifying the level of services, the available services and their cost, and the access conditions the user can expect. Therefore, given a user query, her integration quality requirements and her cloud subscription, it is rewritten in terms of cloud services (*data services* and *data processing services*) composition that fulfill the integration requirements and deliver the expected results to the user.

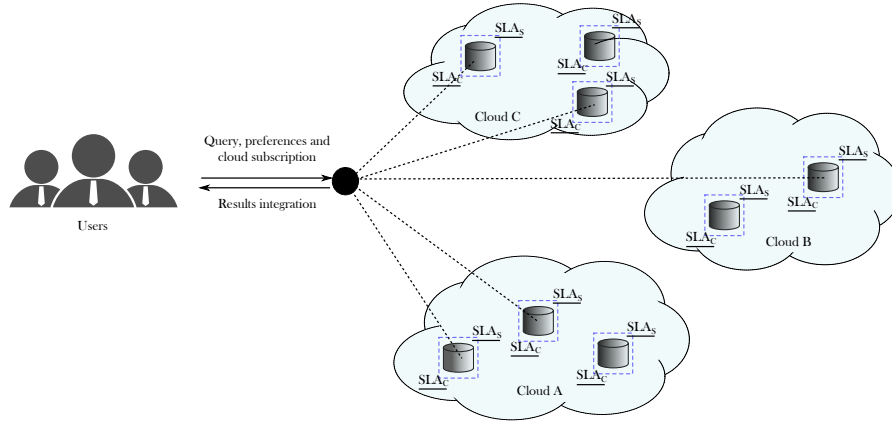


Fig. 1: Data integration scenario

Taking into consideration the medical scenario, Doctor *Marcel*'s research is interested in the type of people suffering of *flu* in the Europe. He has at his disposal a set of cloud services delivered by different clouds. To reach his needs, he wants to query the personal information 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\$. This new context brings challenges to data integration, such as:

- **Performance.** In the multi-cloud, the amount of available services is high. Consequently, the time necessary to service compositions (given the high number of services) to the user query is also high.
- **Economic model.** Even with the possibility of having an unlimited access to resources, the user is limited to the resources she has contracted and to the budget she is ready to pay for. Thus, it is necessary to produce the rewritings considering the user integration requirements.
- **Quality.** Part of the rewritings produced to the user query does not satisfy her quality requirements concerning privacy, data provenance, cost, among others. Producing these rewritings implies increasing time processing and cost.

- **Matching problem.** While producing the rewritings, it is necessary to match the user requirements with the different SLAs exported by the cloud providers and cloud services. In the multi-cloud, cloud providers and cloud services export SLAs with different semantics and structure that makes the matching SLA and user requirement challenging. In addition, it also deals with incompatibilities of SLAs.
- **Reuse.** Rewriting and executing the user query is computationally costly in terms of processing time and economic cost. Thus, it is necessary to propose a manner of reusing previous integration in order to save time and money, but also meeting the user expectations.

Thus, motivated by these challenges, a SLA guided data integration approach can be divided in four steps. Given a user query, a set of user preferences associated to it, cloud providers and cloud services:

**SLA derivation.** This step creates an *integrated SLA* that includes a set of measures corresponding to the user preferences. The *integrated SLA* guides the query evaluation, and the way results are computed and delivered.

**Filtering data services.** The *integrated SLA* is used (i) to filter previous SLA derived for a similar request in order to reuse previous results; or (ii) to filter possible data services that can be used for answering the query.

**Query rewriting.** Given a set of data services that can potentially provide data for integrating the query result, a set of service compositions is generated according to the *integrated SLA* and the agreed SLA of each data service.

**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 *integrated SLA* (that expresses user requirements). Here, the clouds resources needed to execute the composition and how to use them is decided taking in consideration the economic cost determined by the data to be transferred, the number of external calls to services, data storage and delivery cost.

Although *the SLA derivation* is the big challenge while dealing with SLAs and particularly for adding quality dimensions to data integration, the focus in this paper is our query rewriting algorithm which deals with user preferences and SLAs exported by different cloud providers and data services. Here, we are assuming that there is a mechanism responsible to extract the services' quality aspects from SLA, and to provide this information as input to the algorithm. The figure 2 illustrates the structure of SLA and its measures that are considered in the approach we will detail in the next section.

## 4 Rhone service-based query rewriting algorithm

This section describes our quality-based query rewriting algorithm guided by user preferences and services' quality aspects extracted from service level agreements (SLA) called *Rhone*. The *Rhone* assumes a previous step in our data integration approach in which the services' definition and their associated quality measures are extracted from their respective SLAs.

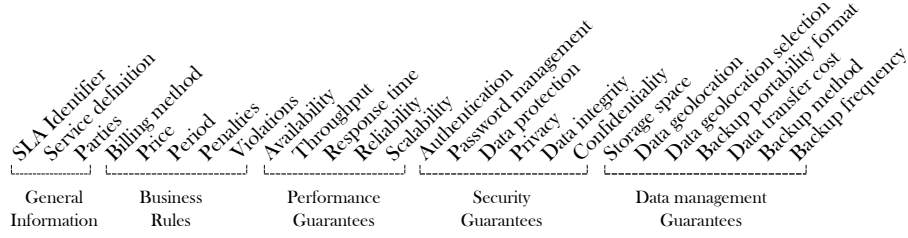


Fig. 2: Cloud SLA

#### 4.1 Preliminaries

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

**Definition 1 (*Abstract service*).** A *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  $A(\bar{I}; \bar{O})$  where:

- $A$  is a name which identifies the *abstract service*.
- $\bar{I}$  and  $\bar{O}$  are a set of comma-separated input and output parameters, respectively.

The table 1 exemplifies *abstract services* concerning our medical scenario described in the section 3.

<b>Abstract service name</b>	<b>Description</b>
$A1(x; y)$	Given a disease name $x$ , $A1$ returns a list of infected patients' id $y$ .
$A2(w; z)$	Given a patient id $w$ , $A2$ returns her DNA information $z$ .
$A3(w; a)$	Given a patient id $w$ , $A3$ returns her personal information $a$ .
$A4(x; r)$	Given a disease name $x$ , $A4$ returns the most affected region $r$ .

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 measures* extracted from its SLA according to the grammar:

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

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  $\bar{I}$  and output  $\bar{O}$  variables, respectively. Variables in the *head* are identified by  $\bar{I}_h$  and  $\bar{O}_h$ , and called *head* variables. They appear in the *head* and in the *body* definition. Variables appearing only in the *body* are identified by  $\bar{I}_l$  and  $\bar{O}_l$ , and are called *local* variables.

*Concrete services* are defined in terms of *abstract services*  $(A_1, A_2, \dots, A_n)$ , and they include a set of service's quality aspects (quality measures)  $(M_1, M_2, \dots, M_g)$ . These measures are extracted from the respective SLA exported by the service.  $M_i$  is in the form  $x \otimes c$ , where  $x$  is a special class of identifiers associated to the services;  $c$  is a constant; and  $\otimes \in \{\geq, \leq, =, \neq, <, >\}$ . For example, consider the following *concrete service*  $S1$  which retrieves infected patients given a disease:

$$S1(d; p) := A1(d; p)[availability > 99\%, price\ per\ call = 0.1\$]$$

$S1$  is written using the *abstract service*  $A1$  defined before.  $d$  and  $p$  are *head* variables. *Availability* and *pricepercall* are quality measures extracted from  $S1$  SLA.

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

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

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  $(C_1, C_2, \dots, C_m)$ . These constraints are used while querying the databases. The user *integration preferences* over the services or over service compositions are specified in  $P_1, P_2, \dots, P_k$ .  $C_i$  and  $P_j$  are in the form  $x \otimes c$ , where  $x$  is a identifier;  $c$  is a constant; and  $\otimes \in \{\geq, \leq, =, \neq, <, >\}$ .

User preferences can be of two types, single and composed. Single preferences are associated directly to each service involved in the composition. Composed preferences are linked to the entire composition. They are defined in terms of single preferences. 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 the medical scenario (section 3) 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, *Marcel* should compose the *abstract services*  $A1$ ,  $A2$  and  $A3$  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 (Figure ??, left-side) 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 user *integration preferences availability* higher than 98 percent, *price per call* less than 2 cents, and *total cost* less than 2 dollars.

## 4.2 Overview on the algorithm

The main function of the *Rhone* is described in the algorithm 1. The input data for this function is a query, which includes a set of user preferences, 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.

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### Algorithm 1 - RHONE

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**Input:** A query  $Q$ , a set of user preferences, and a set of concrete services  $\mathcal{S}$ .

**Output:** A set of rewritings  $R$  that matches with the query and fulfill the user preferences.

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1: function rhone( $Q, \mathcal{S}$ )
2:  $\mathcal{L}_S \leftarrow \text{SelectCandidateServices}(Q, \mathcal{S})$ 
3:  $\mathcal{L}_{CSD} \leftarrow \text{CreateCSDs}(Q, \mathcal{L}_S)$ 
4:  $I \leftarrow \text{CombineCSDs}(\mathcal{L}_{CSD})$ 
5:  $R \leftarrow \text{ProduceRewritings}(Q, I)$ 
6: return  $R$ 
7: end function

```

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In the first step, the algorithm looks for concrete services that can be matched with the query (line 2), resulting in a set of candidate concrete services. For this set of services, the Rhone tries to create *concrete services description* (CSD) for each service (line 3). A CSD is a structure that maps a concrete service to the query, or part of it. The result of this step is a list of CSDs. Given all produced CSDs (line 4), they are combined among each other to generate lists of CSD combinations, in each element represents a possible rewriting. Finally, given the list of combinations, the *Rhone* identifies the ones matching with the query and fulfilling the user preferences (line 5). In the next sections, each phase of the algorithm is described in detail.

## 4.3 Selecting services

One contribution of our approach concerns the services selection process. Services are selected based on the user preferences and on the services' quality aspects collected from service level agreements. While selecting services, the algorithm deals with three matching problems: *measures* matching, *abstract service* matching and *concrete service* matching.

**Definition 3 (Measures matching).** Given a *user preference*  $P_i$  and a service's quality measure  $Q_j$ , a matching between them can be made if: (*i*) the identifier



$c_i$  in  $P_i$  has the same name of  $c_j$  in  $Q_j$ ; and (ii) the evaluation of  $Q_j$ , denoted  $eval(Q_j)$ , must satisfy the evaluation of  $P_i$  ( $eval(P_i)$ ). In other words,  $eval(Q_j) \subset eval(P_i)$ .

**Definition 4 (Abstract service matching).** Given two abstract services  $A_i$  and  $A_j$ , a match between *abstract services* occurs when an *abstract service*  $A_i$  can be matched to  $A_j$ , denoted  $A_i \equiv A_j$ , according to the following conditions: (i)  $A_i$  and  $A_j$  must have the same abstract function name; (ii) the number of input variables of  $A_i$ , denoted  $vars_{input}(A_i)$ , is equal or higher than the number of input variables of  $A_j$  ( $vars_{input}(A_j)$ ); and (iii) the number of output variables of  $A_i$ , denoted  $vars_{output}(A_i)$ , is equal or higher than the number of output variables of  $A_j$  ( $vars_{output}(A_j)$ ).

**Definition 5 (Concrete service matching).** A *concrete service*  $S$  can be matched with the *query*  $Q$  according to the following conditions: (i)  $\forall A_i \text{ s. t. } \{ A_i \in S \}, \exists A_j \text{ s. t. } \{ A_j \in Q \}$ , where  $A_i \equiv A_j$ . For all *abstract services*  $A_i$  in  $S$ , there is one *abstract service*  $A_j$  in  $Q$  that satisfies the *abstract service* matching problem (Definition 4); and (ii) for all *single preferences*  $P_i$  in  $Q$ , there is one *service quality measure*  $Q_i$  in  $S$  that satisfies the *measures* matching problem (Definition 3).

The process of selecting candidate concrete services is described in the algorithm 2. Given the query and a set of concrete services, the algorithm looks for concrete services that can be used in the rewriting process. While iterating all concrete services in the list  $\mathcal{S}$  (line 3), firstly, each service is checked to analyze if all its quality measures satisfies the user preferences in  $Q$  (line 4). If it satisfies, each abstract service in  $S_i$  is checked to confirm if it matches or not with the query (lines 6-11). Once the service satisfies all the matching problems, a set of candidate concrete services is produced (line 12-13). The result is a list of *candidate concrete services*  $\mathcal{L}_S$  which probably can be used in the rewriting process (line 17).

Let us consider the *query* and *concrete services* in our medical scenario (see figure 3). The *Rhone* iterates in the *concrete service* list looking for services satisfying the matching problems. Taking into account the *query* and *concrete services* specified in the *Examples 1*, the *concrete services*  $S2$  and  $S3$ ,  $S4$  and  $S5$  are selected as candidate concrete service once they satisfy all matching problems. However,  $S1$ ,  $S6$  and  $S7$  are not select once their measures violate the user *integration preference* ‘price per call’. In addition,  $S7$  is not also selected because it contains a *abstract service* that does not contribute to answer the *query*.

#### 4.4 Candidate service description

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.

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**Algorithm 2** - Select candidate services
 

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**Input:** A query  $Q$  and a set of concrete services  $\mathcal{S}$ .

**Output:** A set of candidate concrete services  $\mathcal{L}_S$  that can be used in the rewriting process and fulfill the user preferences.

```

1: function SelectCandidateServices( $Q, \mathcal{S}$ )
2:    $\mathcal{L}_S \leftarrow \emptyset$ 
3:   for all  $S_i$  in  $\mathcal{S}$  do
4:     if SatisfyQualityMeasures( $Q, S_i$ ) then
5:        $b \leftarrow \text{true}$ 
6:       for all  $A_j$  in  $S_i$  do
7:         if  $Q.\text{notContains}(A_i)$  then
8:            $b \leftarrow \text{false}$ 
9:           break
10:        end if
11:      end for
12:      if  $b = \text{true}$  then
13:         $\mathcal{L}_S \leftarrow \mathcal{L}_S \cup \{S_i\}$ 
14:      end if
15:    end if
16:  end for
17:  return  $\mathcal{L}_S$ 
18: end function
  
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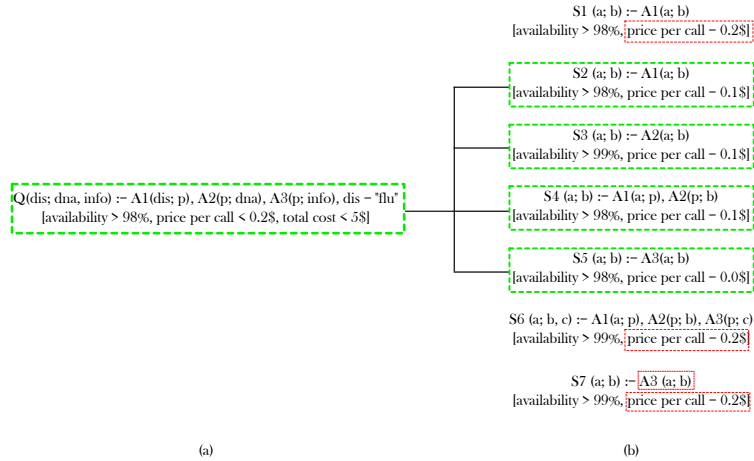


Fig. 3: Service selection.

**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  $S$ .  $\varphi$  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 *quality measures* 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 this an output local variable is used as input in another abstract service.

The algorithm 3 describes the creation of CSDs. Given the query  $Q$  and a list of candidate concrete services  $\mathcal{L}_S$ , a list of CSDs  $\mathcal{L}_{CSD}$  is produced. The algorithm iterates on each service in  $\mathcal{L}_S$  (line 3), verifying if the mappings rules are being satisfied (line 4). For the ones which satisfies the mapping rules, a fresh copy of the abstract services in the concrete service is done in  $G$  (lines 7-9) and a copy of the service quality measures in done in  $P$  (lines 10-12). Then, a CSD is created (line 13), and added to the final list of CSDs  $\mathcal{L}_{CSD}$  (line 14). The result of this phase is a list of CSDs that can be used to build rewriting of the query (line 17).

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**Algorithm 3** - Create candidate service descriptions (CSDs)

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**Input:** A query  $Q$  and a set of candidate concrete services  $\mathcal{L}_S$ .

**Output:** A set of candidate service descriptions (CSDs)  $\mathcal{L}_{CSD}$  that contains mappings from candidate concrete service to the query.

```

1: function CreateCSDs( $Q, \mathcal{L}_S$ )
2:    $\mathcal{L}_{CSD} \leftarrow \emptyset$ 
3:   for all  $S_i$  in  $\mathcal{L}_S$  do
4:     if There are mappings  $h$  and  $\varphi$  from  $S_i$  to  $Q$  then
5:        $G \leftarrow \emptyset$ 
6:        $P \leftarrow \emptyset$ 
7:       for all  $A_j$  in  $S_i$  do
8:          $G \leftarrow G \cup \{A_j\}$ 
9:       end for
10:      for all  $M_k$  in  $S_i$  do
11:         $P \leftarrow P \cup \{M_k\}$ 
12:      end for
13:       $CSD := \langle S_i, h, \varphi, G, P \rangle$ 
14:       $\mathcal{L}_{CSD} \leftarrow \mathcal{L}_{CSD} \cup \{CSD\}$ 
15:    end if
16:  end for
17:  return  $\mathcal{L}_{CSD}$ 
18: end function

```

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*Example 1.* Given the candidate concrete services selected in the *Example 3*. The algorithm builds CSDs to concrete services satisfying the mapping rules. *S1*, *S3* and *S4* satisfy all mapping rules. Consequently, CSDs for them are created. For instance,  $CSD_1$  is produced to *S1* as follows:  $\langle S1, h = \{d \rightarrow d, p \rightarrow p\}, \varphi = \{d \rightarrow dis, p \rightarrow p\}, G = \{GetPatients\}, P = \{availability > 99\%, price\ per\ call = 0.1\$ \}\rangle$ . However, a CSD for *S5* 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, *S5* must cover all abstract services in the query depending on this variable, but the abstract service *GetInfo* is not covered.

#### 4.5 Combining and producing rewritings

Given the list of CSDs  $\mathcal{L}_{CSD}$  produced, the *Rhone* produces all possible combinations of its elements. Building combinations *I* (Algorithm 1, line 4) 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.

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##### Algorithm 4 - Producing rewritings

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**Input:** A query  $Q$  and a list of lists of CSDs  $I$ .

**Output:** A set of rewritings  $R$  that matches with the query and fulfill the user preferences.

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1: function ProduceRewritings( $Q, I$ )
2:  $R \leftarrow \emptyset$ 
3:  $\mathcal{T}_{init} \llbracket Agg(Q) \rrbracket$ 
4:  $p \leftarrow I.next()$ 
5: while  $p \neq \emptyset$  and  $\mathcal{T}_{cond} \llbracket Agg(Q) \rrbracket$  do
6:   if  $isRewriting(Q, p)$  then
7:      $R \leftarrow R \cup Rewriting(p)$ 
8:      $\mathcal{T}_{inc} \llbracket Agg(Q) \rrbracket$ 
9:   end if
10:   $p \leftarrow I.next()$ 
11: end while
12: return  $R$ 
13: end function

```

---

The last step identifies rewritings matching with the query and fulfilling the user preferences (Algorithm 4). The set of rewritings  $R$  is initialized empty (line 2). Another contribution in our algorithm concerns the aggregation functions  $\mathcal{T}_{init} \llbracket Agg(Q) \rrbracket$ ,  $\mathcal{T}_{cond} \llbracket Agg(Q) \rrbracket$  and  $\mathcal{T}_{inc} \llbracket Agg(Q) \rrbracket$ . They are responsible to initialize (line 3), check conditions (line 5) and increment (line 8) composed preferences defined by the user. This means for each element in the CSD list  $p$  the value of a composed measure is computed and incremented. Rewritings are produced while the user preferences are respected.

The *Rhone* algorithm verifies if a given CSD list  $p$  is a rewriting of the original query (line 6). The algorithm 5 describes this process in detail. Given the CSD list  $p$  (line 2), the function return *true* if it is a rewriting of the query.  $p$  is a rewriting if it satisfies two conditions: (i) the number of abstract services resulting from the union of all CSDs in  $p$  must be equals to the number of abstract services in the query; and (ii) the intersection of all abstract services in each CSD on  $p$  must be empty. It means that is forbidden to have abstract services replicated among the set  $p$ .

---

**Algorithm 5** - Validating a combination of CSDs

---

**Input:** A query  $Q$  and a set of candidate services descriptions  $p$ .

**Output:** A boolean value. *True*, if the set  $p$  is a rewriting of the query. *False*, otherwise.

```

1: function isRewriting( $Q, p$ )
2: let  $p = \{CSD_1, CSD_2, \dots, CSD_k\}$ 
3: if (a) The number of elements in the union  $CSD_1.G_1 \cup CSD_2.G_2, \dots, \cup CSD_k.G_k$ 
    is equal to the number of abstract services in  $Q$ 
    (b) The intersection  $CSD_1.G_1 \cap CSD_2.G_2, \dots, \cap CSD_k.G_k$  is empty then
4:   return true
5: end if
6: return false
7: end function

```

---

*Example 2.* Let us consider the CSDs  $CSD_1$ ,  $CSD_3$  and  $CSD_5$  produced in the *Example 4* refers to the concrete services  $S1$ ,  $S3$  and  $S4$ , respectively. The *Rhone* produces combinations as follows:

$$\begin{aligned}
p_1 &= \{CSD_1\} \\
p_2 &= \{CSD_1, CSD_3\} \\
p_3 &= \{CSD_1, CSD_3, CSD_4\}
\end{aligned}$$

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.

## 5 Evaluation

This section describes the experiments performed as proof of concept to the algorithm. The Rhone prototype is implemented in Java. 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.

Currently, our approach runs in a controlled environment. Different experiments were produced to analyze the algorithm’s behavior. We will present two experiments: *experiment 1* and *experiment 2*. The service registry used has 100 concrete services. In each experiment, there are a set of tests in which the number of concrete services varies from 5 until to reach 100.

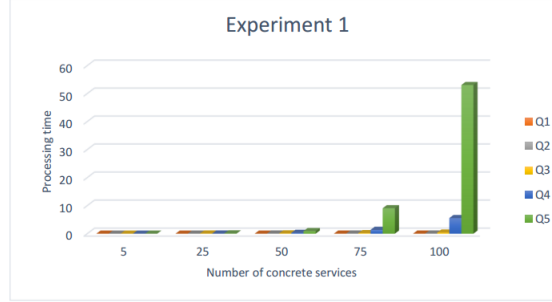


Fig. 4: Query rewriting evaluation.

In the *experiment 1* (figure 4), there are five different queries that differ on the quantity of abstract services (increasing from 2 to 6). Analyzing the first experiment, it is easily to identify that the algorithm shares the same problem as existing query rewriting approaches using views: increasing the processing time when the size of the query and the number of concrete services increase.

The *experiment 2* (figure 5) presents the results while testing the algorithm in the presence of user preferences and services’ quality aspects extracted from SLAs. The difference between *Test 1* and *Test 2* concerns the way services are selected and the query is rewritten. Once *Test 1* do not consider quality measures as any other existing query rewriting approach, *Test 2* uses the user preferences statements and services’ quality aspects to guide the service selection and query rewriting. Both include queries with six abstract services and quality requirements concerning availability, response time, price per call and integration cost (total cost). The figure 5 shows our results.

The results while considering user preferences and SLAs are promisingly. The *Rhone* increases performance reducing rewriting number (around 50 percent) which allows to go straightforward to the rewriting solutions that are satisfactory avoiding any further backtrack and thus reducing successful integration time. Moreover, once the services selection and service composition (rewritings) process are fully guided by the user requirements and SLA, the algorithm avoid producing and executing composition that are not interest for the user. In this sense, the reduces the integration economic cost while delivering the expected results.

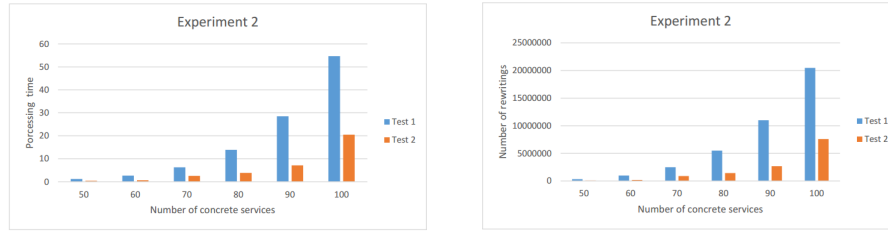


Fig. 5: Results concerning processing time (left-side) and rewritings number (right-side).

## 6 Final Remarks and Future Works

This work proposes a query rewriting algorithm for data integration quality named *Rhone*. Given a query, user preferences and a list of concrete services as input, the algorithm derives rewritings in terms of concrete services that matches with the query and fulfill the user preferences. The formalization and experiments are presented. The results 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 improvements in the implementation and setting up a multi-cloud simulation in in order to evaluate the performance of the *Rhone* in such context.

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