

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

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**Abstract.** Data integration arises in the cloud computing as a service composition problem. Producing service compositions is computationally costly; and executing them require a considerable amount of memory, storage and computing resources. Our research focus on how enhancing the quality on data integration in a cloud context. This paper presents a rewriting algorithm named *Rhone* that addresses query for data integration. The originality of *Rhone* is the rewriting process guided by quality measures associated to data providers (services) and user preferences. The paper uses a running scenario to describe the *Rhone*'s formalization and its implementation. We also present an experimental evaluation. It shows that quality can be improved on data integration solutions. In addition, perspectives concerning our data integration approach and algorithm are presented.

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

## 1 Introduction

Data integration problem has been studied by many researchers in the database domain. It consists in merging data which is distributed across different data sources, and providing a unified view of it to the user. Current data integration implies consuming data from different data services and integrating the results while meeting users' quality requirements. Such requirements include the data that is retrieved and integrated, but also the properties of the data, its producers and the conditions in which such data is produced and processed. For example, whether the user accepts to pay for data, its provenance, veracity and freshness

and how much is the user ready to pay for the resources necessary for integrating her expected result.

Data services provide data according to specific APIs that specify method headers with input parameters describing the data to be retrieved and the type of results they can produce. Moreover data provision can be done by services according to different data quality measures. Such measures describe the conditions in which a service can provide or process data. These measures can be expressed in a service level agreement (SLA). An SLA states, what the user can expect from a service or system behavior. For example, whether it implements an authentication process, if it respects data consumer's privacy and the quality of the data the service can deliver, like freshness, veracity, reputation and other non-functional conditions like the business model that controls data delivery.

Data provision and data processing services may need a considerable amount of storage, memory and computing capacity that can be provided by cloud architectures. Furthermore, users could need to integrate the data provisioned by services in a homogeneous and general result. The integration process can also require important computing resources that can be obtained from the cloud too. Data provision and processing services can be deployed in the cloud. Their SLA includes the measures about the cloud services that they require to execute their requests. The cloud, itself exports a general SLA that specifies the conditions in which users can access the services (infrastructure, platform and software) deployed in it. A user willing to use the cloud services 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. Different cloud providers have different possible contracts to establish with users (i.e., platinum, silver, gold, ivory users). 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.

Thus, the *first challenge* is to compute what we call an integrated SLA that matches the user's integration preferences (including quality constraints and data requirements) with the SLA's provided by cloud services, given a specific user cloud subscription. Computing an integrated SLA can imply dealing with heterogeneous SLA specifications and SLA-preferences incompatibilities. The *second challenge* is to guide data integration taking into consideration the integrated SLA. Here, the data integration process includes (i) looking up services that can be used as data providers, and for services required to process retrieved data and build an integrated result; (ii) performing data retrieval, processing and integration and (iii) deliver results to the user considering her preferences (quality requirements, context and resources consumption). The integrated SLA can guide services filtering in the look up phase; it can help to control the amounts of data to retrieve and process according to consumption rights depending on the user subscription to the participating cloud providers and how to deliver data considering the user's context.

Based on the open challenges, the long-term objective of this research is design a data integration solution guided by SLAs in a multi-cloud context. In this paper, we focus on presenting our service-based query rewriting algorithm guided by user preferences and services' quality aspects extracted from SLAs. Our work addresses these issues and proposes the algorithm (we called *Rhone*) with two original aspects: (i) the user can express her quality preferences and associate them to her queries; and (ii) service's quality aspects defined on SLAs guide service selection and the whole rewriting process. Yet, to the best of our knowledge, we have not identified any other work that combines SLA and data integration solution in the (multi-)cloud context.

This paper is organized as follows. Section 2 discusses about data integration and service level agreements (SLA). Section 3 contains the running scenario and challenges. Section 4 presents some related works. Section 5 describes the *Rhone* algorithm and its formalization. Experiments and results are described in the section 6. Finally, section 7 concludes the paper and discusses future works.

## 2 Data integration and Service level agreements

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] proposed a query rewriting method for achieving RDF data integration. The objective of the approach is 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. [9] introduced a system (called SODIM) which combines 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] focused 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. [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] proposed 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 describes the database resources; (ii) a SLA-based query model normalizes the different queries based on the SLA; (iii) a SLA-based matching algorithm selects the databases; and finally (iv) a SLA-based evaluation model obtains the final query solution. 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.

## 2.1 SLA guided data integration

Given a user query, a set of user preferences associated to it, cloud providers and services, our SLA guided data integration process can be divided in four steps.

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 1 illustrates the structure of SLA and its measures that are used inside our approach.

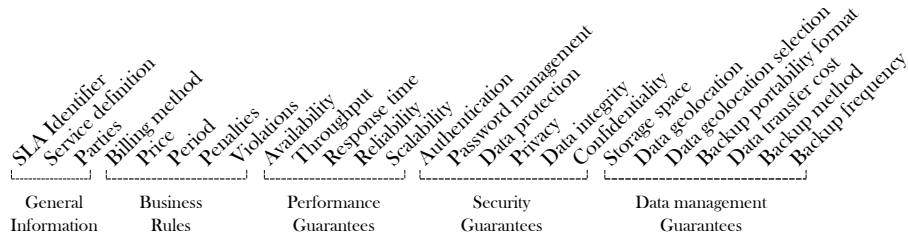


Fig. 1: Cloud SLA

### 3 Scenario

This section is devoted to describe the motivation scenario concerning our data integration approach.

Let us assume the following scenario in the medical domain. Users are able to retrieve information about (i) patients that were infected by a disease; (ii) regions most affected by a disease in Europe; (iii) patients' personal information; and (iv) patients' dna information. To perform these actions, four family of services are necessary: family **A** has services which given a disease name, it retrieves the list of infected patients; family **B** has services which given a disease name, it retrieves the list of cities most affected by that disease; family **C** has services which given a patient id, it retrieves patients' personal information; and family **D** has services which given a patient id, it retrieves patients' dna information.

Doctor Marcel would like to study the type of people suffering of a particular disease. For instance, he needs to query the patients' personal information and patients' dna information from the set of patients that were infected by flu. Presuming that Marcel has at his disposal a cloud including a set of services from the families **A**, **B**, **C** and **D**. To achieve his needs, Marcel can use the data services as follows: (i) he invokes service **S1** (family **A**) with the disease information then he gets the set of people infected by flu; (ii) then he invokes service **S2** (family **C**) with the obtained patients in order to retrieve their personal information; just after (iii) Doctor Marcel invokes service **S3** (family **D**) with the obtained patients to retrieve their dna information. Finally, the query results is integrated and returned.

Depending on the amount of services in each family type, a lot of other service compositions could be done to answer Marcel's query. A large quantity of algorithms for this purpose have been developed, and all of them share the same problems: (1) producing rewritings when a big amount of services are available is extremely expensive; and (2) not always the quality of the rewriting (composition) produced is enough for meeting your needs. Motivated by these problems, our approach proposes a new vision of data integration as follows.

Assuming the same medical scenario and the same families of data services. Let us suppose Marcel would like to study the type of people suffering of a particular disease as before. However, in this new scenario, he is also capable to express his preferences while integrating services. For instance, he needs to query

the patients' personal information and patients' dna information from patients that were infected by flu, using services with availability higher than 98%, price per call less than 0.2\$ and total cost less than 2\$. Marcel has at his disposal a set of services from the families **A**, **B**, **C** and **D** geographically disposed on different cloud providers (configuring a multi-cloud environment). To achieve his needs, Marcel can use the data services as before invoking one service from the families **A**, **C** and **D** in sequence. However, in this new configuration all the services involved must satisfy the user preferences expressed in the query. The selection and rewriting process is guided by the service level agreements (SLA) exported from different services. The user preferences are matched with the service quality aspects that are defined on its SLAs.

This vision of data integration brings some reflections and questions considering the challenges presented previously, such as: (i) The amount of services involved in a multi-cloud context is bigger than in a single cloud. Consequently, the number of services that can be used in the rewriting process and the number of rewriting produced is higher. Such environment calls for a better services selection process, *i.e.*, guided by the SLAs and user preferences; (ii) How can the different SLAs associated to services and cloud provider can be integrated with the user preferences? There are different levels of SLAs: the one agreed between services and cloud providers; and the ones agreed between services and users. These SLAs should be integrated; and (iii) How can a previous processed query be reused for a next query?

In the next section we are going to discuss the related works concerning data integration and service level agreements, in order to identify the gap between the presented challenges and how the works address these problems.

## 4 Related works

The main aspect in a data integration solution is the query rewriting process executed by a mediator in accordance with the different databases. In this way, algorithms for rewriting queries have been proposed in two domains: (i) on the database domain; and (ii) on the service-oriented domain.

On the database domain, query rewriting approaches using views have been widely discussed [10]. For instance, the *bucket algorithm* [11], *inverse-rules algorithm* [8] and *MiniCon algorithm* [13] have tackled the rewriting problem on the database domain. In addition, [13] has inspired rewriting methods in service-oriented domain [7, 1].

Data integration solutions on the service-oriented domain deal with query rewriting problems. [5] identifies trends and open issues regarding the use of SLA in data integration solutions on multi-cloud environments. [2] proposes a query rewriting approach which processes queries on data provider services. The query and data services are modeled as RDF views. A rewriting answer is a service composition in which the set of data service graphs fully satisfy the query graph. [4] introduces a service composition framework to answer preference queries. In that approach, two algorithms based on [2] are presented to rank the best

rewritings based on previously computed scores. [1] presents an algorithm based on *MiniCon* that produces and order rewritings according to user preferences. The user preferences on this approach are scores used to rank services that should be previously define by the user. Considering the scenario presented in the previous section and the related works discussed in this one, we identify a gap between the application of quality measures in the context of data integration domain. Thus, the main and original proposal of our work is to use SLA to guide the entire data integration process.

Our approach differs from these works in three aspects: (i) the user can express quality measures and associate them to his queries, such as: *I want to use services with response time less than 2 seconds, price per request less than 1 dollar and location close to my city*; (ii) the user preferences guides the service selection. These preferences are matched with the services' quality aspects that are extracted from service level agreement contracts. Here, it is important to highlight that there is a previous phase in which the services' quality aspects are processed and extracted from SLAs. In our proposal we are assuming that these information are accessible and well-formatted to the algorithm; and (iii) the user preferences are also used to guide the rewriting process. The rewriting answers (services compositions) produced must be in accordance with the user preferences.

Here, it is important to highlight that this paper focus on the description and evaluation of the algorithm that rewrites queries in terms of services composition taking into account user preferences and service quality aspects expressed in SLA contracts. We are assuming that the extraction of quality aspects from SLAs is performed in a previous phase of our global data integration solution. In the next section, the Rhone service-based algorithm is described and formalized.

## 5 Rhone service-based query rewriting algorithm

This section describes the service-based query rewriting algorithm, called *Rhone*.

Given a set of *abstract services*, a set of *concrete services*, a *user query* and a set of *user quality preferences*, the *Rhone* derives a set of service compositions. These service compositions answer the query and that fulfill the quality preferences regarding the context of data service deployment.

The algorithm consists in four macro-steps: (i) select services; (ii) create variable mappings from services to the query; and (iii) combine the services and (iv) produce rewriting that matches with the query.

The input for the *Rhone* algorithm is: (1) a query, and (2) a list of concrete services.

**Definition 1 (query).** A query  $Q$  is defined as a set of abstract services, a set of constraints, and a set of user 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 left-hand of the definition is called the head of the query; and the right-hand is called the body.  $\bar{I}$  and  $\bar{O}$  are a set of comma-separated input and output parameters, respectively. Parameters can be of two types: head variables and local variables. Head variables are parameters appearing in the head of the query. They also appear in the body of the query. Local variables are parameters appearing only in the body of the query. The sets of input and output parameters tagged with a subscript  $h$  or  $l$  refer to head or local parameters, respectively. Two rules are applied to those parameters: the union and the intersection. For instance, the union of head and local input variables builds  $\bar{I}$  such as  $\bar{I} = \bar{I}_h \cup \{\bar{I}_{1l}, \dots, \bar{I}_{nl}\}$ ; the intersection of head and local input variables is never empty such as  $\{\bar{I}_h \cap \bar{I}_{1l} \cap \bar{I}_{2l}, \dots, \cap \bar{I}_{nl}\} \neq \emptyset$ . The same example can be used to output variables.

Abstract services  $(A_1, A_2, \dots, A_n)$  describe a set of basic service operations.  $C_1, C_2, \dots, C_m$  are constraints over the input and/or output parameters. These constraints are used while querying the databases. The user preferences (over the services) 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.

*Example 1.* Let us suppose a query specification based on the scenario (section 3). The decorations ? and ! differentiate input and output parameters, respectively.

$$Q(dis?; dna!, info!) := GetPatients(dis?; p!), GetDNA(p?; dna!), GetInfo(p?; info!) \\ d = "flu"[availability > 98\%, price\ per\ call < 0.2\$, total\ cost < 2\$]$$

The user provides a disease name and expects to retrieve the DNA and personal information of patients infected by the given disease. The query execution plan begins by retrieving infected patients (*GetPatients*). This operation returns patients' ids  $p$ . The abstract services *GetDNA* and *GetInfo* use patient ids to return their DNA and personal information (*dna* and *info*). The query contains a constraint  $d$  (disease name) equal to *flu*, and three user preferences *availability* higher than 98 percent, *price per call* less than 2 cents, and *total cost* less than 2 dollars.

**Definition 2 (concrete services).** A concrete service ( $S$ ) is defined as a set of abstract services, and by its quality measures according to the grammar:

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

A concrete service definition is similar to the query definition, excepting it does not have constraints. Parameters type and rules are applied in the same way. Concrete services are also defined in terms of abstract services  $(A_1, A_2, \dots, A_n)$ . They contain a set of service's quality aspects (quality measures)  $M_1, M_2, \dots, M_g$ . These measures are associated to the concrete service itself and reflect the quality



aspects guaranteed by the service. These aspects and penalties for its violation are agreed between the service and the provider in the service level agreement (SLA).  $M_i$  is in the form  $x \otimes c$ , where  $x$  is a special class of identifiers associated to the services;  $c$  is a constant; and  $\otimes \in \{\geq, \leq, =, \neq, <, >\}$ .

In this algorithm, we are assuming this inputs come from a previous phase in our approach. This phase allows (i) to extract the service's quality measures from SLAs; and (ii) to generate the expected input data according to the grammar.

*Example 2.* Assuming the query  $Q$  specified in the *Example 1*, five concrete services (that could be composed to answer it) are exemplified below.

$S1(d?; p!) := GetPatients(d?; p!)[availability > 99\%, price\ per\ call = 0.1\$]$   
 $S2(d?; p!) := GetPatients(d?; p!)[availability > 97\%, price\ per\ call = 0.2\$]$   
 $S3(p?; dna!) := GetDNA(d?; dna!)[availability > 98\%, price\ per\ call = 0.1\$]$   
 $S4(p?; info!) := GetInfo(d?; dna!)[availability > 98\%, price\ per\ call = 0.1\$]$   
 $S5(d?; dna!) := GetPatients(d?; p!), GetDNA(p?; dna!)[availability > 98\%, price\ per\ call = 0.1\$]$

$S1$ ,  $S2$ ,  $S3$ ,  $S4$  and  $S5$  are different concrete services defined in terms of abstract services or composition of abstract services (*i.e.*  $S5$ ). Each concrete service is tagged with its own quality measures.  $S1$  and  $S2$  retrieve infected patients, but they differ on the quality measures.  $S3$  returns DNA information from a given patient.  $S4$  retrieves personal information from patients. Finally,  $S5$  covers two abstract services. It returns infected patients and their DNA information.

## 5.1 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.

```

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

## 5.2 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).

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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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*Example 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* and *2*:  $S_1, S_3, S_4$  and  $S_5$  are selected as candidate concrete service once they satisfy all matching problems. However,  $S_2$  is not select once it measures violate the user preference *availability* which is higher than 97% and the user expects higher than 98%.

### 5.3 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.

**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 os 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).

---

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

---

**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

```

---

*Example 4.* 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.

#### 5.4 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.

---

##### Algorithm 4 - Producing rewritings

---

**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.

```

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 5.* 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.

## 6 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 analyse 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.

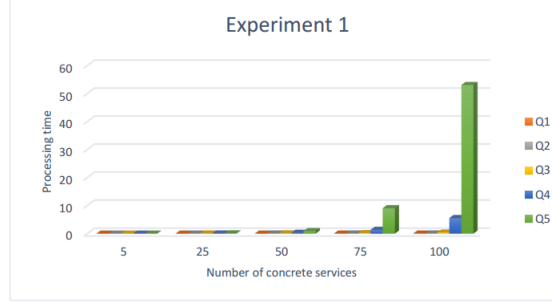


Fig. 2: Query rewriting evaluation.

In the *experiment 1* (figure 2), 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 3) 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 3 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.

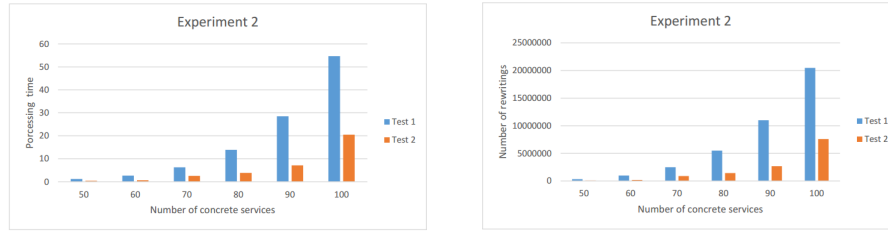


Fig. 3: Results concerning processing time (left-side) and rewritings number (right-side).

## 7 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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