Cardinality heterogeneities in Web service composition: Issues and solutions

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Abstract. Data exchanges between Web services engaged in a composition raise several heterogeneities. In this paper, we address the problem of data cardinality heterogeneity in a composition. Firstly, we build a theoretical framework to describe different aspects of Web services that relate to data cardinality, and secondly, we solve this problem by developing a solution for cardinality mediation based on constraint logic programming.
Keywords. Web services, Composition, Mediation, Cardinality.

1 Introduction

Web services are independent software components that users or other peers can invoke in order to utilize their functionalities, like `WeatherForecast` and `RoomBooking`. Web services combine the benefits of service-oriented computing paradigm and platform-independent protocols (HTTP [6]) to enable and sustain business-to-business collaborations. To make these collaborations happen and last for long periods of time, Web services rely on a set of XML-based protocols and languages that support their discovery (UDDI [10]), description (WSDL [3]) and invocation (SOAP [2]).

Composition orchestrates the functionalities of several Web services into the same loosely-coupled business processes to answer complex users' needs. Different languages exist to specify composition scenarios in terms of Web services to include, interactions to allow, exceptions to handle, just to cite a few. `WS-BPEL` is nowadays the *defacto* composition standard [4]. However despite this "battery" of protocols and languages, composition remains a tedious task. Web services continue to be designed in isolation from each other, which increases the levels of heterogeneities between them. In today's economy, it is unlikely that suppliers will develop the same types of Web services and comply with the same design options.

In this paper, we look into these heterogeneities from a data-cardinality perspective. Cardinality typically refers to the number of elements in a set or group,

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and is considered as a property of that grouping (Wordnet [1]). In the context of Web services composition, we refer to cardinality as the number of data instances contained in the messages that Web services engaged in composition exchange. Web services have different *limitations* in terms of minimum and maximum data cardinalities, and this for several reasons such as technical limitations, search for interoperability with specific partners, quality of service depending on the number of results provided, etc. We refer to these limitations as *cardinality constraints*. Mismatching cardinality constraints will for sure hamper the smooth progress of a composition by making Web services, for example, indefinitely wait for the right number of elements or return invalid responses because of the lack of appropriate elements. Additional illustrative examples are provided throughout this paper.

While cardinality heterogeneities have been tackled in the field of schema matching [7], and despite the large amount of work on Web services mediation, the resolution of cardinality heterogeneities between Web services remains somehow marginalized. In [8], Nagarajan et al. present a classification of Web services heterogeneities. In spite of an exhaustive classification, the authors do not explicitly mention cardinality heterogeneities. Instead, they mention an "entity level" category of data incompatibilities, to which cardinality heterogeneities belong. In the following, we specifically focus on cardinality heterogeneities, and assume that semantic and structural data heterogeneities are already fixed.

The rest of this paper is structured as follows. Section 2 presents the vocabulary and theoretical background that was developed to tackle the cardinality concern. Section 3 lists the different cases of cardinality heterogeneities that arise between Web services. Section 4 describes the proposed solution along with its theoretical and implementation framework, prior to concluding in Section 5.

2 Theoretical framework

Our work starts by defining various concepts such as data flow, Web service, and composition. The purpose of these definitions is to formalize the cardinality issue, and provide a solid background for the proposed solution.

2.1 Data flow representation

A composition orchestrates several Web services into a business process. In this process, Web services typically manage data and exchange them with peers in compliance with some predefined flows.

Characteristics of data flow: Fig. 1 illustrates a simple data flow between two Web services: data are passed on from a source Web service WS_1 (*sender*) to a target Web service WS_2 (*receiver*). These data are organized in terms of input and output messages that are structured using several parts. Each message part has a *type* described with an XML Schema [11]. This *type* may contain additional elements integrated into a complex structure. Cardinality constraints

on data are expressed at the type level using $minOccurs$ and $maxOccurs$ XML Schema attributes. Examples of such constraints in Fig. 1 are $[min_{A1}, max_{A1}]$, $[min_{AP}, max_{AP}]$, $[min_{A1'}, max_{A1'}]$, and $[min_{AP'}, max_{AP'}]$.
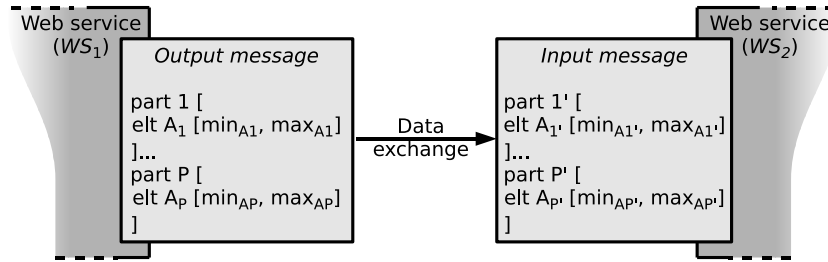

Fig. 1. Simple data flow in a composition

For simplification purposes, this paper deals with messages that contain one part with a data type that contains one couple of $minOccurs$ and $maxOccurs$ cardinality constraints. However, this does not limit the applicability of our solution to complex data structures and multi-part messages.

Constraints on data flows: In a composition, different constraints that relate to the cardinality concern apply to data flows. We illustrate these constraints with the following examples:

- **Example 1:** Editor WS_1 sends data to printing WS_2.
- **Example 2:** Google-like WS_1 sends data to mashup WS_2.
- **Example 3:** Shopping WS_1 sends data for payment to banking WS_2.

Data selection constraint. Denotes the possibility of selecting some elements out of the data flow. In Example 1, data selection is not authorized, i.e., all data from WS_1 must be printed. Similarly, all shopping items must be processed by the banking Web service in Example 3. Data flows in both examples are not data-selection tolerant. In Example 2, WS_2 only selects the first elements in the list, because search results are classified according to their relevance, and as a consequence the first results are the most relevant. If the mashup WS_2 offers three entries for the search answers, only the first three results are selected. In this example, the data flow is data-selection tolerant.

Duplicate constraint. Denotes whether receiver Web services tolerate incoming data with duplicate elements. In Examples 1 and 3, data flows are duplicate tolerant. Indeed, a same document can be printed several times, and a shopping item bought several times needs to be paid several times. In Example 2, duplicates are not tolerated and should be merged into a unique element, as users are not interested in duplicate search results, so the data flow is not duplicate tolerant.

Ordering constraint. Relates to how much changes in the order of elements in the data flow are accepted. Both Data flows of examples 1 and 2 are not order-change tolerant, i.e., the order of transmitted elements needs to be maintained. Indeed, the order of search results is important to the user, and the order of printed documents in also relevant to the printing Web service. In Example 3, data flow is order-change tolerant, all the bought items have the same priority and the payment order does not affect the banking Web service.

The aforementioned three types of constraints permit describing data flows along the following aspects: (i) *data selection* attribute (boolean) denotes whether specific parts of data can be selected, (ii) *duplicate* attribute (boolean) denotes whether duplicate elements are tolerated in the data flow, and (iii) *ordering* attribute (boolean) denotes whether the order of the elements must be conserved. This classification of constraints is particularly relevant during the cardinality-mediation exercise (Section 4). Each attribute impacts the number and organization of elements that Web services exchange and the mediation to adopt per type of constraint.

2.2 Data schema and constraint representation

To highlight the cardinality issue in the definition of data schema, we follow the definition of a *schema graph* given in [9]. A schema graph is a labeled directed graph with property sets. In this graph, nodes represent element types, edges represent relationships, and property sets on nodes or edges describe specific XML features. In this paper, we define a *constrained schema* as a schema graph with its cardinality constraints described via property sets, but we remind that property sets also describe other XML features in the original work [9].

Definition 1 (Constrained Schema). *A constrained schema is a tuple* $CS = \langle ET, R, s, t, PS \rangle$ *where:*

- *ET is a nonempty finite set of element types;*
- *$R \subseteq (ET \times ET)$ is a finite set of relationships;*
- *$s : R \to ET$ is a function that indicates the source of a relationship;*
- *$t : R \to ET$ is a function that indicates the target of a relationship;*
- *$PS : \{ET \cup R\} \times P \to V$ is a function that represents property sets, where P is a set of properties and V is a set of values including the null value.*

In the context of XML Schema, $V = \mathbb{R} \cup \mathbb{S} \cup \mathbb{U} \cup \{\varnothing\}$ where $\mathbb{R}$, $\mathbb{S}$, $\mathbb{U}$ are sets of real numbers, strings, and user-defined labels, respectively.

Definition 2 (Cardinality Constraint). *A cardinality constraint k is a property of a constrained schema $CS = \langle ET, R, s, t, PS \rangle$, as aforementioned. This property is associated with a relationship r of CS and is defined as follows:*

- **minCard:** *$minCard(r) = i$ where $i \in \aleph^+$;*
- **maxCard:** *$maxCard(r) = j$ where $j \in \aleph^+$ and $i \leq j$.*

In the rest of this paper, a cardinality constraint on a relation $r \in R$ is denoted as $k_r = [i, j]$.

2.3 Web service representation

We simply represent Web services as black boxes accepting inputs and returning outputs. Additionally, we consider the possibility for a Web service to be invoked several times and to return additional results. Such invocation possibility can be exploited for the purpose of cardinality mediation.

Maximum number of invocations. Invoking a same Web service several times may help gather additional data for the purpose of cardinality mediation. However, some Web services cannot be indefinitely invoked when participating in a composition, for several reasons such as cost of the invocation, real world modifications, change of the Web service state, etc. For example, "add-to-cart" or "pay" operations of a shopping Web service must be invoked exactly once, as their executions make changes in the real world like updating a customer's banking account. On the contrary, some Web services can be indefinitely invoked without any changes in the environment, such as random number generator Web services.

According to the characteristics detailed above, we provide a definition of Web services that includes all the relevant aspects to cardinality mediation:

Definition 3 (Web service). *A Web service WS along with respective cardinality constraints is defined as a tuple $\langle ws, CS_{In}, CS_{Out}, Inv_{max} \rangle$ where,*

- ws is the Web service's identifier.
- CS_{In} and CS_{Out} are the constrained schemas that define the schema and cardinality constraints on data input and data output of ws.
- Inv_{max} is the maximum number of allowed invocations in the composition.

For the purpose of cardinality mediation, we noticed a specific category of Web services that are indefinitely invocable and provide new data on each invocation. These Web services present interesting characteristics for cardinality mediation as they allow gathering new data on each invocation and thus they can to a certain extent fulfill the cardinality constraints of other Web services in case of lack of data. We qualify these Web services as *data providers*. Data provider Web services include: (i) biological Web service that sends pieces of DNA information, (ii) mathematical Web services that generate random numbers, (iii) Web services that give up-to-date information on a patient (heartbeat, blood pressure, etc.), (iv) geographical localization Web services, (v) weather Web services, etc.

2.4 Constrained composition representation

A constrained composition is represented as a combination of Web services and data flows with shared constraints. Indeed, two data flows connecting to the same Web service share the constraint on its maximum number of invocations.

Definition 4 (Constrained Web services composition). *A constrained Web services composition C is defined as a set of Web services WS and data flows df where a data flow is defined as a tuple $\langle WS_s, WS_r, dup, sel, ord \rangle$, WS_s is the sender Web service, WS_r is the receiver Web service, dup expresses the tolerance to duplicates, sel expresses the possibility to select data in the data flow, and ord denotes whether the order of data elements must be conserved.*

To graphically model a constrained Web services composition and facilitate cardinality mediation, a labeled directed graph representation with property sets is adopted (Fig. 2). In this graph, Web services and data flows correspond to nodes and edges, respectively. A Web service is represented by its constrained input and output schemas and a property that describes the maximum number of times it can be invoked in the composition. An edge has three constraints respectively related to data selection, duplicates and ordering. In Fig. 2 a simple data flow between WS_1 and WS_2 is represented. The properties in this data flow are: data selection is not allowed, data ordering must be conserved, and data duplicates are tolerated. Properties associated with Web services are as follows: Editor WS_1 can be invoked at most once, and printing WS_2 can be invoked as many times as required.
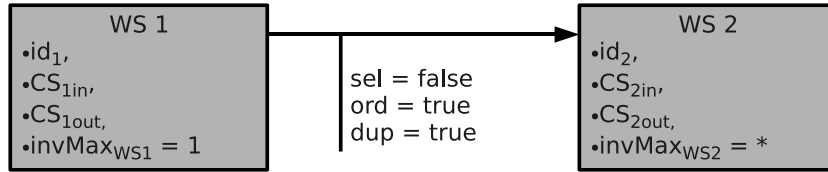

Fig. 2. Editor WS_1 sending out documents to printing WS_2

3 Classification of cardinality heterogeneities

Let us consider the composition of Fig. 2. WS_1 generates a list of elements that comply with a constrained schema $CS_{1out} = (ET, R, s, t, PS_{1out})$ and WS_2 requires the reception of elements that comply with a constrained schema $CS_{2in} = (ET, R, s, t, PS_{2in})$. In such a composition, cardinality constraints compatibility consists in checking out if the constraints PS_{1out} and PS_{2in} are compatible[1].

Given two cardinality constraints $k_{r1} = [i, j] \in PS_{1out}$ and $k_{r2} = [m, n] \in PS_{2in}$, respectively associated with CS_{1out} and CS_{2in}, different correspondence cases can be identified as shown below:

Case a. $j < m$: Guaranteed lack of elements. To be executed, WS_2 needs at least m elements from WS_1. However, WS_1 can return at most j elements,

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[1] We remind the reader our work is limited to one couple of constraints per schema for simplicity purpose.
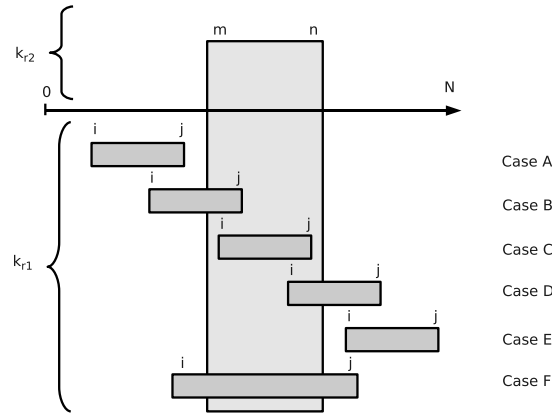
Fig. 3. Cardinality constraints compatibility cases

which is less than needed. As a result, there is a lack of required elements to make a WS_2 invocation possible.

Case b. $i < m \wedge m \leq j \leq n$: Potential lack of elements. A lack of elements will only occur if, at runtime, the number of data instances in the WS_1 result is smaller than the minimum number of elements expected by WS_2 as an input. Otherwise, cardinality constraints PS_{1out} and PS_{2in} are compatible.

Case c. $i \geq m \wedge j \leq n$: No cardinality constraints compatibility.

Case d. $m \leq i \leq n \wedge j > n$: Potential overabundance. When invoked, the Web service WS_2 might receive more elements than needed. There is therefore a potential overabundance of elements when WS_2 is invoked.

Case e. $i > n$: Guaranteed overabundance. When invoked, the Web service WS_2 will receive more elements than needed. There is therefore a guaranteed overabundance of elements when WS_2 is invoked.

Case f. $i < m \wedge j > n$: Potential lack and overabundance. Depending on the real number of elements of the WS_1 result, a lack or overabundance of elements might occur as explained previously.

Total satisfaction of constrained schema compatibility only happens in case c. However, in the other cases, it is still possible to reconcile cardinality constraints of Web services by applying appropriate mediation strategies. We remind that cardinality mediation occurs at the instance level. Then, we can group different schema-level heterogeneities into common mediation cases.

- Lack of elements: cases a and b, possibly case f.
- Overabundance of elements: cases d and e, possibly case f.

We note that case f, depending on the actual number of instances sent, may belong to the "lack of elements" situation, to the "overabundance of elements" situation.

4 Cardinality mediation for Web services

In this section, we rely on the theoretical framework developed previously and propose a solution based on constraint logic to handle data cardinality in Web services composition. First, we describe the requirements of cardinality mediation for a data flow, and show how these requirements apply by extension to a composition ; second, we quickly introduce constraint logic and show its relevance for the purpose of describing the requirements of cardinality mediation ; and third we present the sets of constraints we developed and show their applicability with a graphical data flow simulation implementation.

4.1 Requirements of cardinality mediation

Cardinality mediation requires complex computations in order to adapt data flows between Web services. In the following, we formally describe the requirements for obtaining successful cardinality mediation in a data flow. We identify different situations depending on the *duplicate tolerant* and *data selection tolerant* constraints on the data flow, and explain how the ordering constraint is dealt with.

In order to demonstrate the requirements of cardinality mediation, we consider a data flow between two Web services WS_1 and WS_2, with structurally matching constrained schemas CS_{1out} and CS_{2in}. CS_{1out} holds a constraint $k_{r1} = [a, b]$ and CS_{2in} holds a constraint $k_{r2} = [x, y]$. We also define the number of invocations m and n of WS_1 and WS_2 respectively. $[a, b]$ and $[x, y]$ are intervals that represent the possible number of instances that can be obtained on one invocation of WS_1 and WS_2 respectively, and the operator $*$ applies to these intervals as follows: $m * [a, b]$ is equivalent to $[m * a, m * b]$ to represent the number of instances that can be obtained after m invocations of a Web service.

Duplicate tolerant/data selection untolerant data flows. Let us consider that the aforementioned data flow is duplicate tolerant and data selection untolerant, with $k_{r1} = [9, 11]$ and $k_{r2} = [6, 8]^2$. At first sight, k_{r1} cannot meet the cardinality constraints of k_{r2}. Indeed, a first call to WS_1 binds k_{r1} to $[9, 11]$ and a second call to WS_1 binds k_{r1} to $[18, 22]$, and both do not match k_{r2}.

However, we notice that three invocations to WS_2 bind k_{r2} to $[18, 24]$. Then, a reconciliation between WS_1 and WS_2 is possible if WS_1 is invoked twice and WS_2 is invoked three times, as in this case $k_{r1} \subset k_{r2}$. Hence, the number of elements required by WS_2 is provided by WS_1. By extrapolation, we devise when a cardinality mediation for this type of data flow is probably successful when:

$$\exists m, n \in (\mathbb{N}^+)^2 \text{ such that } (m * [a, b]) \cap (n * [x, y]) \neq \emptyset.$$

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[2] Such cardinality constraints are improbable but they illustrate the complexity of cardinality mediation and show that our solution is applicable to any couples of constraints.

This situation becomes more and more unlikely to happen as n grows and as $(m*[a,b]) \cap n*[x,y]$ becomes small. Accordingly, cardinality mediation for this type of data flow is certain to be successful when:

$$\exists m, n \in (\mathbb{N}^+)^2 \text{ such that } (m*[a,b]) \subseteq (n*[x,y]),$$

which means that m and n verify the following condition: $\dfrac{x}{a} \leqslant \dfrac{m}{n} \leqslant \dfrac{y}{b}$. We remind that such condition applies to duplicate tolerant and data selection untolerant data flows only.

Duplicate tolerant/data selection tolerant data flows. Duplicate and data selection tolerant data flows need calling WS_1 as many times as required to exceeding the minimal cardinality required by WS_2, and then select elements depending on the users' selection policy (the *"select"* operation is detailed below). The formal representation is trivial and is:

$$\exists m \in \mathbb{N}^+ \text{ such that } (m*a) \geqslant x,$$

Duplicate untolerant/data selection untolerant data flows. In duplicate untolerant data flows the number of duplicates in a message part is undetermined. Hence, the number of unique elements contained in a message part may vary between 0 and the maximum number of elements. On a single run of WS_1, the number of unique elements contained in CS_{1out} is bound between 0 and $n*b$. As duplicate detection and removal applies to the instance level, it is not possible to determine a priori whether or not cardinality mediation will be successful. However, it is possible to describe it at runtime.

Being given i the number of data instances returned by WS_1 and a function f that remove duplicates, cardinality mediation for a data selection untolerant, duplicate untolerant data flow successful when:

$$\exists n \in \mathbb{N}^+ \text{ such that } f(i) \in (n*[x,y]).$$

Duplicate untolerant/data selection tolerant data flows. Accordingly, if data selection is allowed, then cardinality mediation is successful when:

$$\exists n \in \mathbb{N}^+ \text{ such that } f(i) \geqslant (n*x).$$

Ordering on data flows. It is not possible to determine order-change tolerance without the intervention of the composition designer. Then, the data ordering is left to the user via an user interface that interacts with the user if necessary. If the data flow supports unordered lists, the cardinality mediator simply concatenates data elements. If ordering is important, alternative strategies are proposed to the user (concatenation of results, mixing of results depending on an algorithm, or manual ordering).

Application to a composition. In this section, we presented the requirements of a composition for one data flow. Indeed, these requirements can be scaled up to a composition. In such case, numbers of invocations m, n, cardinality constraints $[a, b]$, $[x, y]$ are shared between several data flows. Such situations reduces the number of possibilities of the composition to succeed, however it simplifies the resolution of cardinality requirements as it provides a unified view of the whole business process with all the cardinality constraints.

4.2 Constraint logic for cardinality mediation

It turns out that constraint logic programming is well-suited for modelling cardinality mediation. More precisely, constraint logic programming over finite domain variables allows to specify constraints over these variables and to use these constraints in an a priori way to reduce the search space. The resulting framework is quite elegant since, on the one hand, it conserves the declarative expression of logic programming, including the multi-directionalities of its queries, and, on the other hand, it integrates an efficient way of solving constraints.

This is very appealing in our cardinality mediation context. For instance, the following predicate $basic\_mediation(A, B, X, Y, M, N, D, S)$ aims at determining whether there are M, N such that M * [A,B] is a subset of N * [N,M] for a duplicate tolerant and data selection untolerant data flow. Such predicate describes the constraints we devised:

```
basic_mediation(A,B,X,Y,M,N,Mmax,Nmax,D,S) :-

    fd_domain([M],1,Mmax),
    fd_domain([N],1,Nmax),
    N * X #=<# M * A,
    M * B #=<# N * Y,
    fd_labeling([M,N]).
```

The couples A, B and X, Y represent the cardinality constraints of respectively WS_1 and WS_2, M, N are the number of invocations of WS_1 and WS_2 to be found, $Mmax$ and $Nmax$ their maximum number of possible invocations, D and S are booleans that describe duplicate tolerance and data selection respectively.

The code first defines the intervals [1..Mmax] and [1..Nmax] as finite domains for the variables M and N and then specifies the constraints as given before, with the symbols `#=<#` indicating the less than equal relation. Finally, the $fd\_labeling$ predicate is used to start an exhaustive search but by first fixing a value for M, then by propagating this value in the constraints to reduce the domain of N and finally by searching in the reduced domain N for a value.

An example is worth to capture what this means. Let us consider two Web services that hold [9, 11] and [6, 8] as cardinality constraints. The corresponding query is $basic\_mediation(9, 11, 6, 8, M, N, 10, 10, true, false)$. Thus the domains of M and N are both limited to [1..10]. Then M is fixed to 1 and the constraints

become $N * 6 \leqslant 9$ and $11 \geqslant N * 8$. All the possible values of N are then searched but there is no integer value of N that is comprised between $11/8$ and $9/6$. Then M is fixed to 2 and the constraints become $N * 6 \leqslant 18$ and $22 \geqslant N * 8$. In such case, $N = 3$ is comprised between $22/8$ and $18/6$. Hence, the first solution returned by the Prolog engine is the couple of values $(M = 2, N = 3)$. Other solutions are possible but they require additional invocations of WS_1 or WS_2, thus the first solution is the most interesting one.

4.3 Implementation

We developed a proof-of-concept prototype tool that simulates a data flow between Web services and shows the possibilities offered by our cardinality mediation approach (Figure 4). This prototype tool relies on Java platform, and connects to a Prolog reasoner that contains cardinality mediation functions encoded as shown in the above. Our Java program is a client application and the Prolog engine is currently deployed in a Web server as a CGI program that relies on GNU Prolog [5]. The Java program is actually a CGI client and user frontend, its performs the CGI calls and interacts with the end-user. The mediation process is performed by the Prolog engine, it depends on the constraints on Web services and data flow entered via the interface.

Our solution operates as follows: for each data flow, the end-user feeds a Prolog engine with the different constraints on Web services and data flow via our graphical interface. Then, the Prolog engine calculates the possibilities to obtain a successful result and selects the best result if found.

The constraints are *a priori* required and the user needs to provide them before runtime. These are the constraints on the maximum number of executions for WS_1 and WS_2, together with the constraints on data flow (Data selection, duplicates and ordering), which are described neither in typical (WS-BPEL) business processes nor in typical Web service descriptions (WSDL). We are currently working on a Web service composition platform that connects to our cardinality mediation simulator and feeds it with the composition parameters, in order to apply our constraint-based reasoning to the whole composition.

Cardinality mediation involves different operations on data flows. We defined the following operations:

- $select(O, strategy)$ selects particular elements of the result set O depending on a user selection strategy (first elements, each two elements, last elements, manual selection...)
- $merge(O_1, O_2, strategy)$ merges lists of results O_1 and O_2 depending on a user merging strategy (concatenate elements of the second call to the first, mix each two elements, concatenate elements of the first call to the second, manual merging...)
- $rm\_dup(O, strategy)$ removes all the duplicates in O according to a user selection strategy (remove first duplicate first, remove last duplicate first).

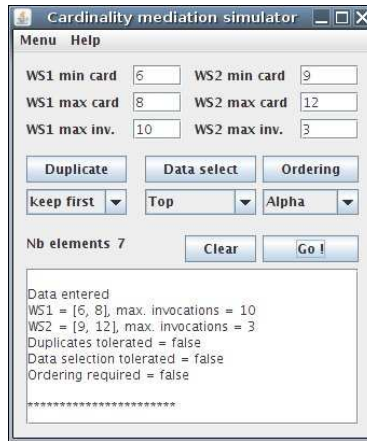These operations are performed with the help of the user via the graphical interface.

Fig. 4. Screenshot of the data cardinality mediation simulator

5   Conclusion

In this paper, we shed the light on an important issue that could refrain the smooth progress of service composition scenarios if not addressed properly. This issue, which we referred to as cardinality heterogeneity, stresses out the importance of quantifying the data that Web services engaged in these scenarios exchange. Little research work has been done to address this issue. In this paper, we proposed a classification of cardinality heterogeneities and highlighted for example how a Web service could be overloaded with data that it might not need, and how lack of expected data could degrade the Web service compostition. A constraint logic-based cardinality mediation approach is proposed. It aims to adapt data flows between Web services by considering the requirements of both data flows in terms of tolerance to duplicate, selection and ordering, and Web services in terms of number of allowed invocations and constrained schemas.

As a future work, we intend to study how different heterogeneous web services providing a same functionality could be combined to cover the cardinality constraint of a service. A Web services community-based approach could be adopted. We are also interested in handling data cardinality of web services in the context of data privacy where some data might be hidden or shown depending on the existing privacy policies.

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