R^{2}BA
Rationalizing R2RML Mapping by Assertion

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Abstract: The W3C RDB2RDF working group proposed R2RML as a standard mapping language that defines how to publish data stored in relational databases as RDF triples. However, R2RML mappings are sometimes difficult to understand, which may affect the users' understanding of the transformations the original data suffer until published as RDF triples. To address this problem, this paper extends a semi-automatic method to define R2RML mappings to include design rational, thereby helping publishers to document the design process and final users to consume the published data. The paper also proposes to use the design rationale captured to enrich the representation of the original data in RDF, which ontology matching algorithms may use to find potential links to other existing vocabularies, thereby promoting interoperability.

1 INTRODUCTION

Two main approaches are widely used for mapping relational databases into RDF: the *direct mapping* approach, where the database schema is directly mapped to ontology elements (Sequeda et. al., 2011), and the *customized mapping* approach, where the schema of the RDF may differ significantly from the original database schema. As an alternative to proprietary mapping languages, the W3C RDB2RDF Working group proposed R2RML as a standard mapping language (Das, et. al., 2012).

R2RML mappings allow the designer to express customized transformations over the original data, which may affect how the published data is consumed. Hence, it would help the user understanding such transformations if a transparency layer were added to the publishing process. Adding transparency would also help the data publisher to trace all the RDB-to-RDF process for maintenance purpose.

This paper therefore proposes a strategy, called R^{2}BA, to achieve transparency. R^{2}BA couples design rationale with a semi-automatic method to define R2RML mappings, called RBA (R2RML by assertion) (Vidal et. al., 2014). RBA adopts correspondence assertions as a convenient way to manually specify R2RML mappings and incorporates an automatic procedure to generate SQL Views and R2RML mappings from the correspondence assertions. Intuitively, R^{2}BA rationalizes the R2RML mappings, in the sense that it makes explicit all the RBA process.

This paper has two major contributions. First, it extends the RBA method to include design rational, creating what we called the R^{2}BA method. By capturing the design rationale, R^{2}BA helps publishers to document the design process and final users to consume the published data by giving them evidences to answer the following questions: (1) Did the original relational data suffer changes, when published as RDF triples, that could impact its quality?; (2) Is the translation from the original relational data to RDF triples correct?; (3) Is the chosen ontology the most appropriate to represent the original relational database?; (4) Did the original relational data lose some relevant information when published as RDF triples?

Second, the paper proposes to use the design rationale captured to enrich the vocabulary that will represent the original data as RDF. This enrichment can be used by ontology matching algorithms to find potential links to other existing vocabularies, thereby promoting interoperability.

This paper is organized as follows. Section 2 briefly outlines the semi-automatic method to define the previous R2RML mappings method and the new one proposed in thi spaper and the design rationale model; it also introduces a motivating example. Sections 3 to 5 detail the R^{2}BA approach. Section 6 contains the conclusion and suggestions for future.

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2 OVERVIEW OF THE METHODS

This section provides a brief overview of the semi-automatic method to define R2RML mappings and its extension to capture the design rationale. Sections 3 to 5 cover the details and give examples.

2.1 A Running Example

To illustrate the method, we will use the following example. Figure 1 depicts the relational schema *ISWC_REL*. Each table has a primary key, whose name ends with '*ID*'. *Persons* and *Papers* represent the main concepts. *Rel_Person_Paper* represents a N:M relationship between *Persons* and *Papers*. The labels of the arcs, such as *FK_Publications*, are the names of the foreign keys. Figure 2 depicts the ontology *CONF_OWL*, which reuses terms from *FOAF* (Friend of a Friend), *SKOS* (Knowledge Organization System), *VCARD* and *DC* (Dublin Core). The prefix *'conf'* is used for the new terms defined in the *CONF_OWL* ontology.

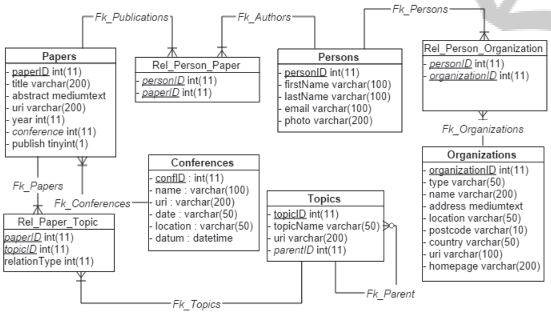


Figure 1: The ISWC_REL database schema.

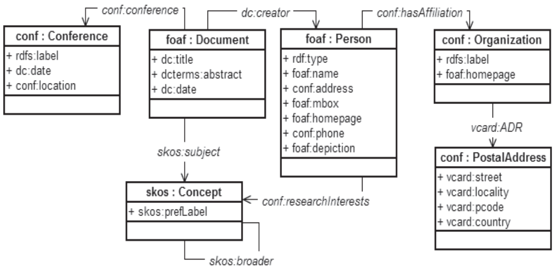


Figure 2: The CONF_OWL ontology.

2.2 The R2RML Mapping by Assertion Method (RBA)

The RBA method proposes to generate customized R2RML mappings based on correspondence assertions (Vidal et. al., 2014; Neto et. al., 2013). The inputs of the method are a relational database schema that will be published as RDF and a set of domain ontologies. The output is an *exported ontology*, which represents part of the relational data in RDF, the R2RML mappings and a set of SQL view definitions.

The first step of RBA is manual and relies on the user to define mappings between the relational database and the domain ontologies using correspondence assertions, which are much simpler to understand than R2RML and yet suffice to capture most of the subtleties of mapping relational schemas into RDF schema (Vidal et. al., 2014). A tool has also been developed to the designer in this step (Vidal et. al., 2014; Vidal et al., 2005)

Table 1 shows the abstract syntax and examples of the three types of correspondence assertions.

Class correspondence assertions (CCAs) (as in line 1 of Table 1) map tables into classes. Their abstract syntax is

$$\Psi\colon C \equiv R[A_1,\ldots,A_n]\,\sigma$$

where Ψ is the name of the CCA, C is a class of a domain ontology, $R[A_1,\ldots,A_n]$ is a relation schema with the attributes $A_1,\ldots,A_n$ (attributes of the primary key of R) and σ is an optional selection over R.

Object property correspondence assertions (OCAs) (as in line 2 of Table 1) map tables into object properties. Their abstract syntax is

$$\Psi\colon P \equiv R \,/\, \varphi$$

where Ψ is the name of the OCA, P is an object property of a domain ontology, R is a relation name of the relational database schema and φ is an optional path from R. A *path* is a set of foreign keys that connect relations in relational databases.

Datatype correspondence assertions (DCAs) (as in line 3 of Table 1) map tables into datatype properties. Their abstract syntax is

$$\Psi\colon P \equiv R \,/\, \varphi \,/\, \{A_1,\ldots,A_m\}$$

where Ψ is the name of the DCA, P is a datatype property of a domain ontology, R is a relation name of the relational database schema, φ is an optional path from R and $A_1,\ldots,A_n$ are attributes of R.

The vocabulary of the *exported ontology* is simply the set of classes and properties of the domain ontologies used in the correspondence assertions. Figure 3 shows the ISWC_RDF exported ontology generated from the correspondence assertions that map the ISWC_REL database schema of Figure 1 to the CONF_OWL ontology of Figure 2.

The second step is automatic and compiles the correspondence assertions into R2RML mappings and SQL view definitions, as depicted in Figure 4.

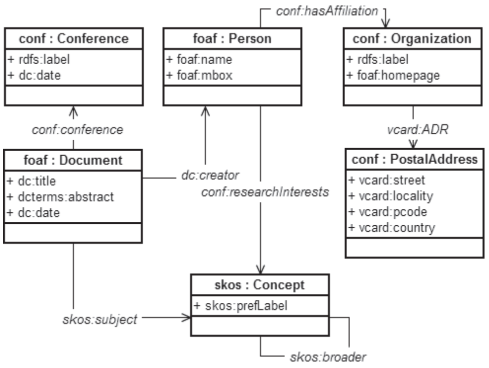


Figure 3: ISWC_RDF exported ontology schema.

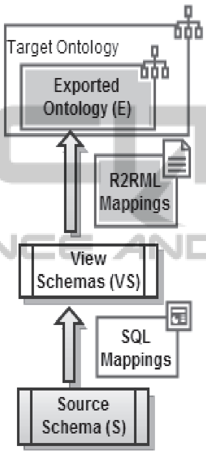


Figure 4: Output of the design process.

2.3 The Design Rationale Model

R^{2}BA uses the design rationale model detailed in (Berardi et al., 2013). The basic concept of the model, the *DR graph*, is composed of nodes that represent *reasoning elements*, that is, elements that have been traced, such as tables, classes, attributes. In each node, the design rationale is represented using a *question* whose answer is an *idea*. The questions record the process that the reasoning element suffers and the ideas represent what happened during this process. For each kind of question, there is a controlled vocabulary to express the ideas that answers it. The mechanism to automatically answer the questions will be explained in Sections 3 to 5.

The design rationale is incrementally recorded at each step of R^{2}BA by adding new reasoning elements and by capturing the new questions and ideas of the specific step. We will refer to each design rationale generated by the number of the corresponding step (Step1 generates DR1, etc.).

In terms of graphical representation, depending on the step, nodes are represented as rectangles or circles to facilitate understanding the graph. For instance, in steps DR1 and DR5, nodes are indicated as rectangles since they represent tables and attributes of the relational database; in the other steps, nodes are represented as circles and are related to ontology elements.

2.4 The Rationalizing R2RML Mapping by Assertion Method (R^{2}BA)

R^{2}BA is an extension of the RBA method to include design rationale. It uses the correspondence assertions to trace and record how the classes and properties are created in RDF. R^{2}BA extends RBA to capture the design rationale, which is then used to enrich the exported ontology and to establish a link between similar classes and properties.

R^{2}BA consists of 6 steps, divided into 3 groups according to their goals. Each one of these groups is discussed in detail in Sections 3 to 5.

The first group comprehends two steps: “Step 1: Creation of the correspondence assertions” and “Step 2: Creation of an exported ontology to represent relational data in RDF”. This group receives as input a relational schema, the data source schema, and several target ontologies of the user’s choice, where each ontology is composed by a vocabulary and set of constraints. As output, it produces an exported ontology

Table 1: DR interpretation for Class, Object Property and Data type property Correspondence Assertions.

Type	Definition	DR interpretation	Examples of Correspondences Assertions
CCA	*Ψ: C ≡ R[A_1,...,A_n] σ* *(σ is optional)*	*Class type Table[URI] FILTER* *(FILTER is omitted if so is σ)*	*$\Psi_{1:}$foaf:Person ≡ Persons[personID]* *$\Psi_{2:}$ skos:Concept ≡ Topics[topicID]* *$\Psi_{3:}$foaf : Document ≡ papers [PaperID], FILTER [papers.Year > 2002]*
OCA	*Ψ: P ≡ R / φ* *(φ is optional)*	*ObjP mapped Table_Domain / Ref_Att_URI_Range* *(Ref_Att_URI_Range is optional)*	*Ψ_4: conf:researchInterests ≡ Persons / [Fk_Authors, Fk_Publications, Fk_Papers, Fk_Topics]*
DCA	*Ψ: P ≡ R / φ / {A_1,...,A_m}* *(φ is optional)*	*DataP mapped Table_Domain / Ref_Att_Range / {Att_Lit_Range$_n$}* *(Ref_Att_Range is optional)*	*$\Psi_{5:}$foaf:name ≡ Persons / {firstName, lastName}*

and the design rationale DR1 of Step 1 and DR2 of Step 2.

The second group enriches the exported ontology to facilitate interoperability. It also comprehends two steps: "Step 3: Generating annotations" and "Step 4: Generating linking recommendations". This group receives as input the exported ontology and DR2. As output, it produces an enriched exported ontology and the corresponding design rationale (DR3 for Step 3 and DR4 for Step 4).

The last group generates SQL views according to the enriched exported ontology and the R2RML mappings. It comprehends two steps: "Step 5: *Generating SQL views*" and "Step 6: *Generating R2RML mappings*". This group receives as input the enriched exported ontology and DR4. As output, it produces: a set of relational views schemas; a set of R2RML mappings; and the final DR (DR5 for Step 5 and DR6 for Step 6.

3 GROUP 1 - CREATING THE MAPPINGS AND THE EXPORTED ONTOLOGY

3.1 Overview

The first group of steps of R^{2}BA creates the correspondence assertions and an exported ontology to represent relational data in RDF.

Step 1 – *Generating Correspondence Assertions.*
This step consists in a manual specification of a set of correspondence assertions between elements of the database relational schema and terms from vocabularies of user's choice. The design rationale captured in this step, referred to as DR1, records the original format of the data source schema elements and tracks which elements are not mapped.

To visualize the DR1 captured in this step, consider the *ISWC_REL* schema depicted in Figure 1. Observe the table *Persons* and its attributes *firstName*, *lastName*, *email* and *photo*. Their original formats are represented at DR1 in Figure 5 through the rectangular nodes with the same names.

The questions associated with DR1 are *Element* and *Map*. The *Element* question seeks to explicit the original format of the element, so it may be answered with relational database elements, such as *Table*, *Att*, *KeyAtt* or *FKAtt* for table, attribute, primary key attribute and foreign key attribute, respectively. For example the rectangular node *Persons* has the answer *Table* and the rectangular nodes *firstName* and *lastName* have *Att*. To represent a relationship between two tables, DR1 answers the question *Element* with *FKAtt* and creates a question *Ref* to be answered with the names of the table and attribute that is the reference of the *FKAtt*.

To record elements that are not mapped, R^{2}BA has a mechanism to compare the elements present in the correspondence assertions and the elements present in the original database schema. For example, attribute *photo* of table *Persons* has the question *Map* answered with *NOT*. At DR1, this is the only case where the question *Map* is asked.

Step 2 – *Generating the Exported Ontology*.
This step consists in using the set of correspondence assertions to automatically generate the exported ontology. According to the RBA method, the list of correspondence assertions is consumed to generate the exported ontology, in the following order: all Class Correspondence Asserions are first mapped to the exported ontology; then all Object Correspondence Assertions; and finally all Data type Correspondence Assertions. The design rationale captured in this step, referred to as DR2, records information parallel to each mapping created.

Together, DR1 and DR2 allow answering the following questions: (i) What is the original form of the data in the data source schema?; (ii) Are all elements in the data source schema mapped? If not, which were and which were not mapped?; (iii) For those elements that were mapped, how they were mapped as ontology elements?

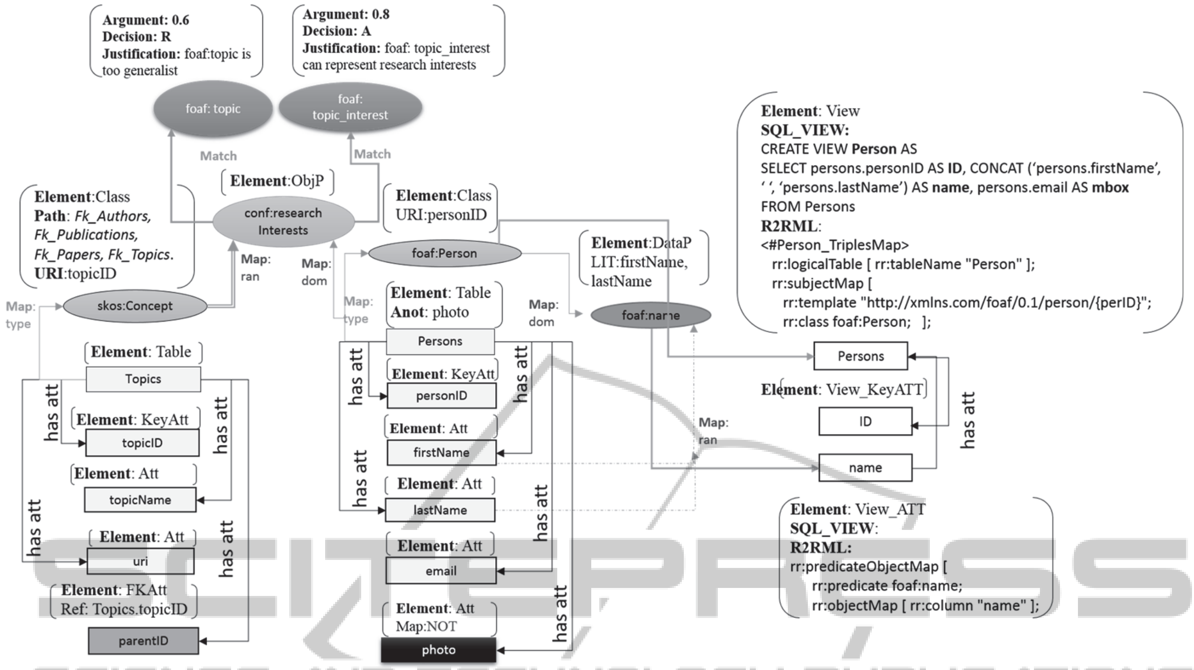
In order to trace how the elements were mapped and record this information at DR2, we developed a DR interpretation for each kind of CA, as shown in Table 1. Each interpretation expression is used to answer the questions asked during this step.

The next sections detail and exemplify how to generate the DR2 for Class Correspondence Assertion, Object Correspondence Assertion and Data type Correspondence Assertion.

3.2 Design Rationale for Class Correspondence Assertion

Consider a class correspondence assertion (CCA) of the form Ψ: C ≡ $R[A_1,...,A_n]$, that is, which does not use a filter (the first two examples in line 1 of Table 1). The DR interpretation for such CCAs is formalized as the expression *"Class type Table[URI]"*, read as *"a class that is mapped as type (rdf:type) from a table represented by R using attributes $A_1,...,A_n$ to build the URIs"*. For example, the assertion in the first line of Table 1

Ψ_1: *foaf:Person ≡ Persons[personID]*



```
Element: View
SQL_VIEW:
CREATE VIEW Person AS
SELECT persons.personID AS ID, CONCAT (‘persons.firstName’,
‘ ‘, ‘persons.lastName’) AS name, persons.email AS mbox
FROM Persons
R2RML:
<#Person_TriplesMap>
  rr:logicalTable [ rr:tableName "Person" ];
  rr:subjectMap [
    rr:template "http://xmlns.com/foaf/0.1/person/{perID}";
    rr:class foaf:Person;   ];
```

```
Element: View_ATT
SQL_VIEW:
R2RML:
rr:predicateObjectMap [
     rr:predicate foaf:name;
     rr:objectMap [ rr:column "name" ];
```

Figure 5: DR graph for the motivating example.

maps table *Persons* (see Figure 1) to class *foaf:Person* (see Figure 2) using attribute *personID* to build the URI of the class. The DR for this assertion therefore has *Class* as *foaf:Person, Table* as *Person*s and *URI* as the attribute *personID*. Figure 5 shows the representation of this example.

DR2 increments DR1 by adding a new circle node for *Class*, called *foaf:Person*, and connecting it to the corresponding node of *Table*, that is, the table

Persons. The questions for the new node *Class* are *Element*, *URI* and *Map*. To answer the question *Element*, the *Class* component of the DR interpretation expression is used. To answer the *URI* question, the instantiation of the component *URI* of the DR interpretation expression is used (*personID* in the example). Finally, the question *Map* is related to the connection arrow between the correspondent nodes *Class* and *Table*. To answer it, the component *type* of the DR interpretation expression is used.

Consider now a class correspondence assertion of the form *Ψ:* C ≡ $R[A_1,...,A_n]\sigma$, that is, which uses a filter σ (the third example in line 1 of Table 1). Such assertions are represented in DR2 with the help of the question *FILTER*, answered by recording the filter used in the correspondence assertion (not shown in Figure 5 due to space limitation).

3.3 Design Rationale for Object Correspondence Assertion

After recording the design rationale model for the class correspondence assertions, DR2 represents the design rationale for object property correspondence assertions (OCAs).

Consider an OCA of the form *Ψ: P ≡ R / φ* (as in line 2 of Table 1). The DR interpretation of an OCA is formalized as the expression *"ObjP mapped Table_Domain / Ref_Att_URI_Range",* read as "an object property *P* is mapped using a *Table R* as its *domain* and its *range* is represented by an URI composed by a key attribute of a table, that is found by following the path *φ* in *Ref_Att_URI_Range*".

For example, the OCA in line 2 of Table 1

OCA: conf:researchInterests ≡ Persons / [Fk_Authors, Fk_Publications, Fk_Papers, Fk_Topics]

maps the object property *conf:researchInterests* (in Figure 2) using the table *Persons* (in Figure 1) to represent the domain and the concept *skos:Concept* is found by following the path *[Fk_Authors, Fk_Publications, Fk_Papers, Fk_Topics]* (Figure 1 and Figure 2). The DR for this assertion therefore has *ObjP* as *conf:researchInterests*, *Table_Domain* as *Persons* and *Ref_Att_URI_Range* as *Fk_Authors, Fk_Publications, Fk_Papers, Fk_Topics*. Figure 5 shows the representation of this example. DR2 increments DR1 by adding a new circle node for *ObjP* called *conf:researchInterests*. The questions for the new node *ObjP* are *Element* and *Map*. To answer the question *Element*, the *ObjP* component of the DR interpretation expression is used. As *ObjP* is an object property, the domain and range are URIs. When the range is an URI composed by following a path in the correspondence assertion, DR2 records a question *Path* and answers it with the path φ provided by the correspondence assertions. Figure 5 shows this example for the range of the object property conf:researchInterest. The question *URI* is answered by the ID attribute used to compose the URI, which may be found by following a path in the correspondence assertion. To identify the arrows that are related to domain and range mappings, the DR model uses the question *Map* and the answers *dom* and *ran* for domain and range, respectively. Thus, the connection between the domain and range should be directed from the ontology element corresponding to the URIs. It is important to highlight that the OCA uses a table to represent the domain of the *ObjP*, but the true domain is the ontology element corresponding to this table (and likewise for the range representation).

For example, in the OCA of Table 1, the *ObjP* node is connected to the node labeled *foaf:Person*, which is the ontology element mapped from the table *Person*. The same happens with the connection between the *ObjP* node and its range. In the DR2 graph, a double arrow indicates a range defined by a path, while a single arrow indicates a range defined by a single attribute.

3.4 DR for Data Type Correspondence Assertion (DCA)

After having recorded the DR2 for CCAs and OCAs, finally the DR for DCAs is recorded.

Consider first a DCA of the form Ψ: $P \equiv R$ / $\{A_1,...,A_m\}$ (as in line 3 of Table 1), that is, which does not use a path. The DR interpretation of this correspondence assertion is formalized as the expression *"DataP mapped Table_Domain/ {Att_Lit_Range$_n$}"*, read as *"a datatype property P is mapped using table R as its domain and its range is a set of values generated using attributes {$A_1,...,A_m$}"*. Using this interpretation for the example in Table 1

DCA:foaf:name ≡ Persons / {firstName, lastName},

DataP is *foaf:name*, *Table_Domain* is *Persons* and *{Att_Lit_Range$_n$}* is *firstName,lastName*. This DCA maps the datatype property *foaf:name* (Figure 2) using the table *Persons* (Figure 1) as domain and the values of the attributes *firstName* and *lastName* (Figure 1) as range.

The representation of this example is shown in Figure 5 and is similar to the DR of an object property. The most important difference is that, in datatype properties, the range is not a class, but a XML data type defining a set of literals. So, the literals are generated from attribute values, as indicated in the DCA. Thus, the connection in the DR graph is directed from the attributes. As this example uses a composition of two attributes, both are connected to the node represented by dashed lines. When the DCA specifies only one attribute, a single line is used.

For a DCA of the form Ψ: $P \equiv R$ / φ / $\{A_1,...,A_m\}$, which uses a path, the DR follows likewise. Similarly to OCAs that uses a path to find ranges, a question *Path_ran* is created in the node associated with the data type property and answered with the path in the correspondence assertion. In this case, a double arrow in the DR graph indicates a range found by following a path in the correspondence assertion.

Table 2: Step 5 and 6 for classes.

Operation 1: For each class C in V_E where $K_1,...,K_n$ are the datatype properties of the key of C do
1.1 Create a relational view also named C;
Create a new node that is an Element:View in DR4
Connect the Element View to the node correspondent to the class C
1.2 Create K_1, … , K_n , the attributes of the primary key of view C;
Create a new node that is an Element:View_ Key_Att in DR 4
Connect the new Key_Att Element to the View Element correspondent and label it with "has_att"
1.3 Create the subject map referring to view C using template T1.
In the Element View node, create a question "R2RML" and answer it with the triple map created in substep 1.3.

4 GROUP 2 – ENRICHING THE EXPORTED ONTOLOGY

This group of steps enriches the exported ontology to facilitate interoperability.

Step 3 – *Generating annotations.* This step consists in generating annotations for those cases where the relational database is composed of a private parte (that is not published as RDF) and a public part (that is published). This is a new step in the RBA approach and aims at adding information about the private relational schema in the exported ontology.

DR3 increments the nodes in DR2 with annotations, according to a *neighboring mapping*, defined as: for each mapped element, look for a neighbor in the DR graph that has the question *Map* answered with *NOT*, which means it was not mapped to the exported ontology. If one such node exists, a new question is created *Anot* at the node that found an element that was not mapped. The question *Anot* is answered with the name of the unmapped node. This information is added to the exported ontology as a datatype property *rdfs:comment* whose value is a literal composed of the names of the unmapped nodes.

The search for unmapped neighbors follows an annotation strategy up to a certain depth in the DR graph. As an initial strategy and based on empirical observations, we considered a maximum of two levels. More specifically, we noticed that, for automatic annotations, including more than two levels becomes superfluous, as the additional levels are more likely to be out of context (Berardi et al., 2014). For instance, observe in Figure 5 that the attribute *photo* is marked with the question *Map:NOT* and is therefore annotated with the mapped node *Persons*.

The benefits of using the DR graph to generate annotations, instead of directly using the relational database, are: (i) Since the DR graph is created for provenance purposes, it can be accessed without having to create a new graph based on the relational schema to know what has to be annotated; (ii) Since the DR graph is created in all steps of R^{2}BA, it can be consumed whenever it is needed, without having to rerun the steps from the very beginning.

Step 4 – *Generating linking recommendations.*
This step consists in executing ontology matching algorithms using as input the annotated exported ontology . The annotation helps ontology matching techniques to keep the context of the elements in the exported ontology. When only part of the schema is published, this part can lose information that can be useful for Ontology Matching algorithms.

In order to promote interoperability, we seek to establish a link between similar classes or properties using *rdfs:equivalentClass* or *rdfs: equivalentProperty* properties. In this step the user interaction plays an essential role because the OM process gives a list of recommendations for the terms of the exported ontology. Ideally, the user should know the database domain so that he or she can accept or reject the recommendations. These links of the annotated exported ontology are part of the enriched exported ontology.

DR4 increments DR3 with two new nodes for the two largest recommendation similarity values. Then, the questions involved at this step are: *Argument*, answered with the similarity value output by the OM algorithms; *Decision*, with *A* or *R*, which represents the domain expert decision for accepting or rejecting the recommendation, respectively; and *Justification*, with the justification provided by the domain expert about her or his decision.

Table 3: Step 5 and 6 for object properties.

```
Operation 3: For each object property $P$ in $V_E$ do
Let $D$ and $R$ be the views that match to the domain and range of $P$, respectively, let $K_{D1},...,K_{Dn}$ be the attributes of the primary key of $D$ and let $K_{R1},...,K_{Rn}$ be the attributes of the primary key of $R$; // views D and R were created in Step 1
Case 3.2: $P$ has cardinality greater than 1.
3.2.1. Create relational view D_P;
Create a new node Element View
Connect the new node Element View to the Element ObjP node correspondent
3.2.2. Create attributes $K_{D1},...,K_{Dn}$ in D_P whose types are defined as in D;
Create a new node Element View_FK_PK
Connect the new node Element View_FK_PK to the Element View correspondent and label the connection with "has_att"
3.2.3. Create foreign key FK_D_P_D(D_P:{$K_{D1},...,K_{Dn}$}, D:{$K_{D1},...,K_{Dn}$});
Create the question "Ref" in the node Element View_FK_PK and answer it with D:{$K_{D1},...,K_{Dn}$ }
3.2.4. Create attributes $K_{R1}, ..., K_{Rn}$ in D_P whose types are defined as in R;
Create a new node Element  View_FK_PK
Connect the new node Element View_FK_PK to the Element View node correspondent
3.2.5. Create foreign key FK_D_P_R(D_P:{$K_{R1}, ..., K_{Rn}$}, R:{$K_{R1}, ..., K_{Rn}$});
Create the question Ref and answer it with D:{KD1,...,KDn })
3.2.6. Create the subject map referring to view D_P and predicate object map for P using template T5.
        Create the question "R2RML" in the Element View node and answer it with the result of the step 3..2.6
```

For instance, in Figure 5, the object property *conf:researchInterests* receives two recommendations for terms that seem to be equivalent to *foaf:topic* and *foaf:topic_interest*. The corresponding nodes of the recommendations are connected to the node of the term *conf:researchInterests*. This connection is labeled with *Match* to explicit that they are recommendations from the Ontology Matching techniques.
Together, DR3 and DR4 allow answering the following questions: (i) Which elements received annotations and what are the annotations?"; (ii) Which recommendations each term received from the OM techniques? (iii) Which recommendations were accepted and why? (iv) Which recommendations were rejected and why?

5 GROUP 3 – GENERATING SQL VIEWS AND R2RML MAPPINGS

The last group of steps generates SQL views according to the enriched exported ontology and the R2RML mappings.

Step 5 – *Generating SQL views.*

This step consists in automatically generating a set of relational view schemas that is a direct transformation of the enriched exported ontology. In (Neto et. al., 2013) an algorithm is presented to automatically generate the view schemas based on the exported ontology and the correspondence assertions.

Step 6 – *Generating R2RML mappings.*
This step consists in automatically generating R2RML mappings from the views to the enriched exported ontology, which is one-to-one. The DR5 and the final DR6 are captured in parallel and they allow to answer the following questions: (i) “Which SQL view is associated with each element of the enriched exported ontology?”; (ii) “Which R2RML mapping refers to each element of the enriched exported ontology?”. The final DR6 makes it possible to trace all the transformations that each element in the original relational schema suffered during the mapping process.

The algorithm that automatically generates the view schemas and the R2RML mappings has 3 main steps. Each one of these steps implements the SQL view and the R2RML mappings generation, respecting this order: classes first, then datatype properties and, finally, object properties. Tables 2 and 3 show the steps for classes and object properties mappings and DR composition respectively. Due to space limitations, we do not explore the operations for datatype properties.

The algorithm receives as input the enriched exported ontology and a set of templates for creating SQL views and R2RML mappings. The complete list of these templates can be found in (Vidal et. al., 2014).

Let V_{eEO} be the vocabulary of the enriched exported ontology and $K_1,…,K_n$ be the attributes of a view *C*. Table 2 shows the first part of the algorithm related to the class mapping. As an example of Step 1, consider the class *foaf:Person* of the exported ontology in Figure 3. Step 1 creates a view for this class called *Persons*, then DR5 generates a new rectangular node, also called *Person*, as shown in Figure 5.

At DR5, the questions involved are *Element* and *SQL_VIEW*. As DR5 is coupled with the view creation step, the algorithm is able to answer the question *Element* with *View*.

After having created the view, the algorithm also creates the ID attribute; DR4 then generates a new rectangular node. In this case, the question *Element* is answered with *View_KeyATT*. The question *SQL_VIEW* is answered as the view is in fact created. The new node *Persons* in DR5 represents the view *Persons*, which corresponds to the class *foaf:Person* in DR2, that consequently represents the Table *Persons* in DR1.

Following Step 1 of the algorithm, the last sub step is to generate the R2RML mapping. For that, the algorithm uses a list of templates according to each step. Space limitations do not permit to explore each template used, so we cover only one as an example.

For the class R2RML mapping, template T1 is used:

```
T1: <#C_TriplesMap>
        rr:logicalTable [rr:tableName “C”];
        rr:subjectMap [
        rr:template “namespaceOfC/{K1}/{K2}/…/{Kn}/…/”;
        rr:class C; ];
```

DR5 is incremented with the template information recording, so that DR6 is built. The last sub step of Operation 1 is to finish DR6 with the question *R2RML* in the *Element:View* node and answering it with the instantiation of the template T1 used.

```
<#Person_TriplesMap>
      rr:logicalTable [rr:tableName “Person”];
      rr:subjectMap [
      rr:template “http://xmlns.com/foaf/0.1/person/{personID}”;
        rr:class foaf:Person; ];
```

Finally, Table 3 shows the part of the algorithm related to the object property mappings. Similarly to the datatype property mappings, this part of the algorithm implements different strategies for object properties with cardinality equal to 1 (Case 3.1) or greater than 1 (Case 3.2). In our example, we explore Case 3.2 using as example the object property *conf:researchInterests* of the exported ontology in Figure 3.

In Step 3, a new view is created, called *Person_ResearchInterests*, with two ID attributes *ID_Person* and *ID_Concept*. Both are also foreign keys to construct the domain and range of the object property. The DR 5 related with this step is the creation of a new node, called *Person_ResearchInterest*, that is a view element, with two new nodes, *ID_Person* and *ID_Concept*, which are primary keys and foreign keys, represented as *View_FK_PK*, to answer the question *Element*.

Following Step 3 (Case 3.2), the next sub step is to generate the R2RML mapping. In this case, the triple map for object property mapping is created using template T5:

```
T5: <#D_P_TriplesMap>
  rr:logicalTable [ rr:tableName "D_P " ];
  rr:subjectMap [
    rr:template "namespaceOfD/{KD1}/{K D2}/... /{KDn}/";
    rr:class D;   ];
  rr:predicateObjectMap [
     rr:predicate P;
     rr:objectMap [
       rr:parentTriplesMap <R_TriplesMap>;
       rr:joinCondition [
         rr:child “KR1”;
         rr:parent “KR1”;   ];
       …
       rr:joinCondition [
      rr:child “KRn”;
           rr:parent “KRn”;  ];  ];  ];
```

The composition of DR6 is created by answering the question *R2RML* at the rectangular node *Person_ResearchInterests* with the help of template T5:

```
T5: <#Person_ResearchInterests_TriplesMap>
  rr:logicalTable [rr:tableName “Person_ResearchInterests”];
  rr:subjectMap [
    rr:template  "http://xmlns.com/foaf/0.1/person/{personID}";
    rr:class foaf:Person;   ];
  rr:predicateObjectMap [
    rr:predicate conf:researchInterests;
    rr:objectMap [
      rr:parentTriplesMap <Concept_TriplesMap>;
      rr:joinCondition [
        rr:child “topicID”;
            rr:parent “topicID”;  ];  ];  ] .
```

6 RELATED WORK

Typically, tools developed to support the customized mapping approach, such as Triplify (Auer et. al., 2009), D2R Server (Bizer and Cyganiak, 2006) and OpenLink Virtuoso (2006), do not address design rationale issues.

The notion of correspondence assertions was introduced in (Vidal et. al., 2005) to define mappings between instances of source schema to instances of XML view schema. The RBA tool was developed to simplify the generation of R2RML mapping and to help the publication of relational database by using correspondence assertions (Neto et. al., 2013). The RBA tool and, in fact, none of previous work on correspondence assertions (Vidal et al., 2014; Pequeno et al., 2014) considered design rationale questions.

In previous work (Berardi et al., 2013) we developed a method to capture design rationale for direct mapping processes.

R^2BA, introduced in this paper, extends the RBA tool to collect design rationale and to use it to find links to similar terms in known domain ontologies. It is the first method to capture design rationale for a customized mapping process as far as we know.

7 CONCLUSIONS

To improve the transparency of customized mappings using R2RML, we proposed to couple design rationale with correspondence assertions. With the help of a motivating example, we discussed how to represent this design rationale and how it can help answer questions regarding the awareness of the possible transformations that the published data suffered. By consuming the final design rationale captured, it is possible to observe the transformation of the data from their original format in the database, until their final format as an exported ontology, SQL views and R2RML mappings.

We discussed how to use design rationale for transparency and maintenance purposes. We also argued that design rationale may help address interoperability issues by creating an enriched exported ontology. The design rationale captured may help new users use R2RML mappings by observing how the mapping process of the original data was implemented. He or she can learn different situations where R2RML is used in a convenient way.

As for future work, we plan to extend the method proposed in this paper to capture the design rationale of complex correspondence assertions (Pequeno et. al., 2014). We also plan to simplify the design rationale model, in this specific case, by making it closer to the syntax of the complex correspondence assertions.

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