A Semi-Automatic Approach for Generating Customized R2RML Mappings

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**Abstract.** The Linked Data initiative brought new opportunities for building the next generation of Web applications. However, the full potential of linked data depends on how easy it is to transform data stored in conventional, relational databases into RDF triples. Recently, the W3C RDB2RDF Working Group proposed a standard mapping language, called R2RML, to specify customized mappings between relational schemas and target RDF vocabularies. However, the generation of customized R2RML mappings is not an easy task, which calls for the development of methods to support the definition and deployment of such mappings. This paper therefore proposes a strategy to simplify the specification of R2RML mappings. It first introduces correspondence assertions to manually model, in a convenient way, the relationship between a relational database schema and an RDF vocabulary. Then, the paper describes a method to automatically generate R2RML mappings from the correspondence assertions.

**Keywords:** Correspondence Assertions, Linked Data, RDB-to-RDF, R2RML.

1. Introduction

The Linked Data initiative [2] promotes the publication of previously isolated databases as interlinked RDF triple sets, thereby creating a global scale dataspace, known as the Web of Data. The success of the linked data initiative is partly due to the adoption of Web standards, such as URIs and HTTP, as well as Semantic Web standards, such as RDF and vocabularies. However, the full potential of linked data depends on how easy it is to transform data stored in conventional, relational databases (RDBs) into RDF triples. This process is often called RDB-to-RDF [12].

There are two main approaches for mapping relational databases into RDF: direct mapping and customized mapping. As the name implies, the direct mapping approach relies on automatic methods to derive ontologies that directly reflect relational schemas and to transform the relational data into RDF triples. A survey of systems based on the direct mapping approach is presented in [14].

The customized mapping approach relies on the designer to specify a mapping between the relational schema and a target ontology. The mapping is then used to transform the relational data into RDF triples. This approach divides the RDB-to-RDF process into two steps: mapping generation and mapping implementation. The mapping generation step results in a specification of how to represent relational schema concepts in terms of RDF classes and properties. It provides the ability to view existing relational data as RDF triples in a structure and in a target vocabulary of the designer’s choice. The mapping is conceptual and enables different implementation styles. For example, it can be used to materialize the RDF triples or to offer virtual access through an interface that queries the underlying database.

In fact, quite a few tools that support the customized mapping approach have been developed, such as Triplify [1], D2R Server [3, 4], and OpenLink Virtuoso [9, 10]. Early surveys of RDB-to-RDF tools [12, 14] pointed out that the tools typically adopt proprietary mapping languages for the mapping process and do not provide a way to easily generate customized mappings between a relational schema and a given domain ontology. Recently, the W3C RDB2RDF Working Group proposed a standard mapping language, called R2RML [8], to express RDB-to-RDF mappings. However, R2RML is somewhat difficult to use, which calls for the development of methods and tools to support the definition and deployment of mappings using R2RML.

This paper has two contributions. First, we propose correspondence assertions [15] as a convenient way to specify mappings between target RDF vocabularies and base relational schemas. Then, we introduce a method, backed up by a tool, to automatically generate R2RML mappings based on a set of correspondence assertions.

The remainder of this paper is organized as follows. Section 2 introduces the correspondence assertions. Section 3 presents the example used throughout the paper. Section 4 describes our approach for the automatic generation of R2RML mappings, based on the correspondence assertions. Section 6 contains the conclusions.

1. Correspondence Assertions
   1. Basic Concepts and Notation

In this section, we recall a minimum set of familiar concepts from the relational model and from ontologies and introduce some basic notation.

As usual, we denote a *relation scheme* as *R[A1,....,An]*, and adopt *mandatory* (or *not null*) *attributes*, *keys*, *primary keys* and *foreign keys* as relational constraints. In particular, we use *F(R:L,S:K)* to denote a foreign key, named *F*, from *R* to *S*, where *L* and *K* are lists of attributes from *R* and *S*, respectively, with the same length.

A *relational schema* is a pair ***S****=(****R****,****Ω****)*, where ***R*** is a set of relation schemes and ***Ω*** is a set of relational constraints such that: (i) ***Ω*** has a unique primary key for each relation scheme in ***R***; (ii) ***Ω*** has a mandatory attribute statement for each attribute which is part of a key or primary key; (iii) if ***Ω*** has a foreign key of the form *F(R:L,S:K)*, then ***Ω*** also has a constraint indicating that *K* is the primary key of *S*. The *vocabulary* of ***S***is the set of relation names, attribute names, key names, primary key names and foreign key names used in ***S***.

Let ***S****=(****R****,****Ω****)* be a relational schema. A *path* of ***S*** is a list *ϕ* = *[F1,... ,Fn-1]* of foreign key names of ***S*** such that *Fi* and *Fi+1* have a relation name in common; if *F1* is from *R1* to *R2* and *Fn-1* is from *Rn-1* to *Rn*, then we say that *ϕ* is *from* *R1 to Rn* and that tuples of *R1* *reference tuples of Rn**through φ*. We also say that *ϕ* is an *association path* iff *φ=[F1,F2]*, where the foreign keys are of the form *F1(R1:L1,R2:K2)* and *F2(R1:M1,R3:K3)*. For example, consider the relational schema *ISWC\_REL* in Figure 1. The list of foreign keys *[Fk\_Publications,Fk\_Authors]* is an association path of *ISWC\_REL* from *Papers* to *Persons*, but *[Fk\_Publications,Fk\_Persons]* is not a path.

Finally, given a relation scheme *R[A1,....,An]* and a *tuple variable t* ranging over *R*, we use *t.Ak* to denote the *projection* of *t* over an attribute *Ak* of *R*. We use *selections* over relation schemes, defined as usual.

We also recall a minimum set of concepts related to ontologies. A *vocabulary* ***V*** is a set of *classes*, *object* *properties* and *datatype properties.* An *ontology* is a pair ***O****=(****V****,Σ)* such that ***V*** is a vocabulary and *Σ* is a finite set of formulae in ***V***, the *constraints* of ***O***. Among the constraints, we consider those that define the *domain* and *range* of a property, as well as *cardinality constraints*, defined in the usual way.

* 1. Definition of the Correspondence Assertions

This section introduces the notion of correspondence assertion, leaving examples to Section 3. Let ***O****=(****V****,Σ)* be an ontology and ***S****=(****R****,****Ω****)* be a relational schema and assume that *Σ* has constraints defining the domain and range of each property.

**Definition 2.1:** A *class correspondence assertion (CCA)* is an expression of one of following forms:

*Ψ: C* ≡ *R[A1,...,An]*

*Ψ: C* ≡ *R[A1,...,An]σ*

where *Ψ* is the *name* of the CCA, *C* is a class of ***V***, *R* is a relation name of ***S***, *A1,...,An* are the attributes of the primary key of *R*, and *σ* is a selection over *R*. We also say that *Ψ* *matches* *C* with *R*.

**Definition 2.2:** An *object property correspondence assertion (OCA)* is an expression of one of following forms:

*Ψ: O* ≡ *R*

*Ψ: O* ≡ *R / ϕ*

where *Ψ* is the *name* of the OCA, *O* is an object property of ***V*** and *ϕ* is a path from *R*. We also say that *Ψ* *matches* *O* with *R*.

**Definition 2.3:** A *datatype property correspondence assertion (DCA)* is an expression of one of following forms:

*Ψ: P ≡ R / A*

*Ψ: P ≡ R / {A1,...,An}*

*Ψ: P ≡ R / ϕ / B*

*Ψ: P* ≡ *R / ϕ / {B1,...,Bn}*

where *Ψ* is the name ofthe DCA, *P* is a datatype property of ***V***, *R* is a relation name of ***S***, *A* is an attribute of *R*, *A1,...,An* are attributes of *R*, *ϕ* is a path from *R* to *T*, *B* is an attribute of *T*, and *B1,...,Bn* are attributes of *T*. We also say that *Ψ* *matches* *P* with *R*.

**Definition 2.4:** A correspondence assertion is *simple* iff it is of one of the forms:

*A CCA* of the form *Ψ: C* ≡ *R[A1,...,An].*

*A DCA* of the form *Ψ: P ≡ R / A.*

*A DCA* of the form *Ψ: P ≡ R / ϕ / B*, *where ϕ has only one foreign key.*

*An OCA* of the form *Ψ: O ≡ R / ϕ*, *where ϕ has only one foreign key* or *ϕ* is an association path.

**Definition 2.5:** A *mapping* between ***V*** and ***S*** is a set ***M*** of correspondence assertions such that:

1. For each class *C* in ***V***, ***M*** has at most one CCA that matches *C* with some relation scheme in ***S***.
2. For each datatype property *P* in ***V***, ***M*** has at most one DCA that matches *P* with some relation scheme *R* in ***S***. Furthermore, ***M*** must have a CCA that matches the domain of*P* with *R*.
3. For each object property *O* in ***V***, ***M*** has at most one OCA *Ψ* that matches *O* with some relation scheme *R* in ***S***. Furthermore, if *Ψ* is of the form *O ≡ R/ϕ,* where *ϕ* is a path from *R* to *T*, then ***M*** must have a CCA that matches the domain of*O* with *R*, and a CCA that matches the range of *O* with *T*; if *Ψ* is of the form *O ≡ R,* then ***M*** must have a CCA that matches the domain of*O* with *R*, and a CCA that matches the range of *O* also with *R*.
   1. Transformation Rules generated by Correspondence Assertions

In this section, we first introduce the notion of transformation rule and then show how to interpret correspondence assertions as transformation rules.

Let ***O****=(****V****,Σ)* be an ontology and ***S****=(****R****,****Ω****)* be a relational schema, with vocabulary ***U***. Let ***X*** be a set of *scalar variables* and ***T*** be a set of tuple variable, disjoint from each-other and from ***V*** and ***U***.

A *literal* is a *range expression* of the form *R(t)*, where *R* is a relation name in ***U*** and *t* is a tuple variable in ***T***, or a *built-in predicate* of one of the forms shown in Table 1. A *rule body* *B* is a list of literals. When necessary, we use *“B[x1,…,xk]”* to indicate that the tuple or scalar variables *x1,…,xk* occur in *B*. We also use   
*“R(t), B[t,x1,…,xk]”* to indicate that the rule body has a literal of the form *R(t).*

A *transformation rule*, or simply a *rule*, is an expression of one of the forms:

* *C(x) ← B[x]*, where *C* is a class in ***V*** and *B[x]* is a rule body
* *P(x,y)← B[x,y]*, where *P* is a property and *B[x,y]* is a rule body

Let ***M*** be a set of correspondence assertionsthat defines a mapping between ***V*** and ***S*, t**hat is, ***M*** satisfies that the conditions stated in Definition 2.5. Assume that each class *C* in ***V*** is associated with a namespace prefix*.*

Table 2 shows the transformation rules *induced* by the correspondence assertions in ***M***. For example, the rule on the right-hand side of Line 5 indicates that, for each tuple *t* of *R* such that *t.A* is not null: (1) one should compute *s*, the URI of the instance of domain *D* of *P* that *t* represents, using the class correspondence assertion *ΨD*; (2) translate the value of *A* in tuple *t*, generating the literal *v*; (3) associate *v* as the value for property *P* of *s*

**Table .** Built-in predicates

|  |  |
| --- | --- |
| **Built-in predicate** | **Intuitive definition** |
| *nonNull(v)* | *nonNull(v)* holds iff value *v* is not null |
| *RDFLiteral(u, A, R, v)* | Given a value *u*, an attribute *A* of *R*, a relation name *R*,  and a literal *v*,*RDFLiteral(u, A, R, v)* holds iff  *v* is the literal representation of *u*, given the type of *A* in *R* |
| *HasReferencedTuples[ϕ](t,u)*  where *ϕ* is a path from *R* to *T* | Given a tuple *t* of *R* and tuple *u* of *T*,  *HasReferencedTuples[ϕ](t,u)* holds iff  *u* is referenced by *t* through path *ϕ* |
| *HasURI[Ψ](t,s)*  where *Ψ* is a CCA for a class *C* of ***V***, using attributes *A1,...,An* of *R* | Given a tuple *t* of *R*, *HasURI[Ψ](t,s)* holds iff  *s* is the URI obtained by concatenating the namespace prefix for *C* and the values of *t.A1,...,t.An* |
| *concat([v1,.., vn],v)* | Given a list *[v1,.., vn]* of string values,  *concat([v1,.., vn],v)* holds iff  *v* is the string obtained by concatenating *v1,..,vn* |

**Table .** Mapping Rules

|  |  |  |
| --- | --- | --- |
|  | **Correspondence Assertion** | **Mapping Rule** |
| 1 | *Ψ: C* ≡ *R[A1,...,An]* | *C(s)* ← *R(t), HasURI[Ψ](t,s)* |
| 2 | *Ψ: C* ≡ *R[A1,...,An]σ* | *C(s)* ← *R(t), HasURI[Ψ](t,s),σ(t)* |
| 3 | *Ψ: O* ≡ *R*  where:  - ***M*** has a CCA *ΨD*that matches the domain *D* of *O*  with *R* and *ΨD*has mapping rule *D(s)←R(t),BD[t,s]*  - ***M*** has a CCA *ΨN* that matches the range *N* of *O*  with *R* and *ΨN* has mapping rule *N(o)←R(t),BN[t,o]* | *P(s,o)* ← *R(t), BD[t,s], BN[t,o]* |
| 4 | *Ψ: O* ≡ *R / ϕ*  where:  - *ϕ* is a path of *R* to *T*  - ***M*** has a CCA *ΨD*that matches the domain *D* of *O*  with *R* and *ΨD*has mapping rule *D(s)←R(t),BD[t,s]*  - ***M*** has a CCA *ΨN* that matches the range *N* of *O*  with *T* and *ΨN* has mapping rule *N(o)←T(u),BN[u,o]* | *P(s,o)* ←  *R(t), BD[t,s],*  *HasReferencedTuples[ϕ](t,u),*  *T(u), BN[u,o]* |
| 5 | *Ψ: P* ≡ *R / A*  where:  - ***M*** has a CCA *ΨD*that matches the domain *D* of *P*  with *R* and *ΨD*has mapping rule *D(s)←R(t),BD[t,s]*  - *A* is an attribute of *R* | *P(s,v)* ← *R(t), BD[t,s],*  *nonNull(t.A)*  *RDFLiteral(t.A,“A”,“R”,v)* |
| 6 | *Ψ: P* ≡ *R / ϕ / A*  where:  - *ϕ* is a path of *R* to *T*  - ***M*** has a CCA *ΨD*that matches the domain *D* of *P*  with *R* and *ΨD*has mapping rule *D(s)←R(t),BD[t,s]*  - *A* is an attribute of *T* | *P(s,v)* ← *R(t), BD[t,s],*  *HasReferencedTuples[ϕ](t,u),*  *nonNull(u.A),*  *RDFLiteral(u.A,“A”,“T”,v)* |
| 7 | *Ψ: P* ≡ *R / {A1,...,Am}*  where:  - ***M*** has a CCA *ΨD*that matches the domain *D* of *P*  with *R* and *ΨD*has mapping rule *D(s)←R(t),BD[t,s]*  - *A1,...,Am* are attributes of *R* | *P(s,v)* ← *R(t), BD[t,s],*  *nonNull(t.A1),…,nonNull(t.Am),*  *RDFLiteral(t.A1,“A1”,“R”,v1),*  *…,*  *RDFLiteral(t.Am,“Am”,“R”,vm),*  *concat([v1,..,vm],v)* |
| 8 | *Ψ: P* ≡ *R / ϕ / {A1,...,Am}*  where:  - *ϕ* is a path of *R* to *T*  - ***M*** has a CCA *ΨD*that matches the domain *D* of *P*  with *R* and *ΨD*has mapping rule *D(s)←R(t),BD[t,s]*  - *A1,...,Am* are attributes of *T* | *P(s,v)* ← *D(t), BD[t,s],*  *HasReferencedTuples[ϕ](t,u),*  *nonNull(u.A1),…,nonNull(u.Am)*  *RDFLiteral(u.A1,“A1”,“T”,v1),*  *…,*  *RDFLiteral(u.Am,“Am”,“T”, vm),*  *concat([v1,..,vm],v)* |

1. Running Example

In this Section, we present the example we will use in the rest of the paper.

Figure 1 depicts the relational schema *ISWC\_REL*, which represents authors and their publications, organizations which authors are affiliated to, topics referenced by publications and conferences which publications were submitted to. Each table has a distinct primary key, whose name ends with 'ID', and which is of type integer. Tables *Persons* and *Papers* represent the main concepts. The attribute *conference* of table *Papers* is a foreign key to table *Conferences*. Table *Rel\_Person\_Paper* represents an 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 four well-known vocabularies: *FOAF* (Friend of a Friend), *SKOS* (Knowledge Organization System), *VCARD* and *DC* (Dublin Core). We use the prefix “*conf”* for the new terms defined in the *CONF\_OWL* ontology.

Table 3 shows a set of correspondence assertions that specifies a mapping between *CONF\_OWL* and *ISWC\_REL*, obtained with the help of the tool described in [] .

We now discuss the transformation rules induced by some of the CAs in Table 3.

### *CCA1* specifies that each tuple *t* in *Persons* produces one RDF triple (we omit the translations from attribute values to RDF literals for simplicity):

*<http://example.com/person/t.perID> rdf:type*  *foaf:Person*.

* *DCA1* specifies that each tuple *t* in *Persons* produces one RDF triple:

*<<http://example.com/person/t.perID>>* *foaf:name*

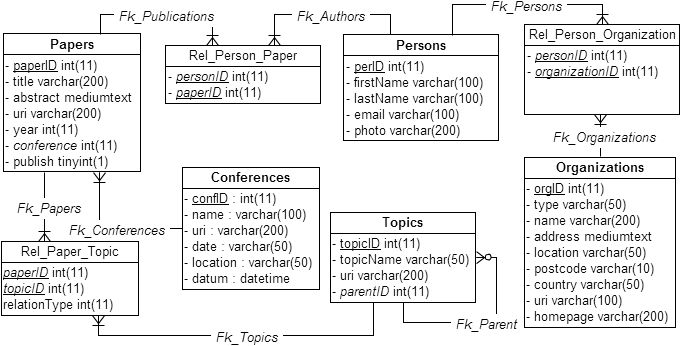
*concat(t.firstname, t.lastname)*.

* *DCA2* specifies that each tuple *t* in *Persons* produces one RDF triple:

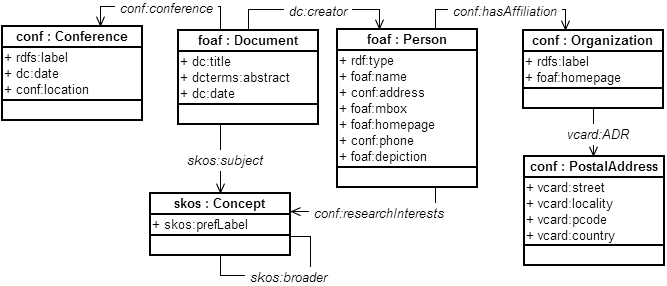
*<http://example.com/person/t.perID>* *foaf:mbox " t.email".*

* *OCA2* specifies that, for each tuple *t* in *Person*, for each tuple *t’* in *Topics* such that *t’* is referenced by *t* through path *[Fk\_Authors, Fk\_Publications, Fk\_Papers, Fk\_Topics]*, one triple of the form is generated:

*<http://example.com/person/t.perID> conf:ResearchInterests http://example.com/org/t’.topicID.*



**Fig. .** ISWC\_REL Database Schema



**Fig. .** CONF\_OWL Target Ontology

**Table .** Correspondence Assertions

|  |  |
| --- | --- |
| *CCA1* | *foaf:Person*  *Persons[perID]* |
| *CCA2* | *foaf:Document*  *Papers[paperID]* |
| *CCA3* | *conf:Organization*  *Organizations[orgID]* |
| *CCA4* | *conf:PostalAddress*  *Organizations[orgID]* |
| *CCA5* | *conf:Conference*  *Conferences[confID]* |
| *CCA6* | *skos:Concept*  *Topics[topicID]* |
| *OCA1* | *conf:hasAffiliation*  *Persons / [Fk\_Persons, Fk\_Organizations]* |
| *OCA2* | *conf:researchInterests*  *Persons / [Fk\_Authors, Fk\_Publications, Fk\_Papers, Fk\_Topics ]* |
| *OCA3* | *vcard:ADR*  *Organizations* |
| *OCA4* | *skos:subject*  *Papers / [Fk\_Papers, Fk\_Topics]* |
| *OCA5* | *conf:conference*  *Papers / Fk\_Conferences* |
| *OCA6* | *skos:broader*  *Topics / Fk\_Parent* |
| *DCA1* | *foaf:name*  *Persons / { firstName, lastName }* |
| *DCA2* | *foaf:mbox*  *Persons / email* |
| *DCA3* | [*rdfs:label*](conf:Organization/rdfs:label) *Organization / name* |
| *DCA4* | *foaf:homepage*  *Organization / homepage* |
| *DCA5* | [*vcard:Street*](conf:PostalAddress/vcard:Street) *Organizations / address* |
| *DCA6* | *vcard:locality*  *Organizations / location* |
| *DCA7* | *vcard:Pcode*  *Organizations / postcode* |
| *DCA8* | *vcard:country*  *Organizations /country* |
| *DCA9* | *dc:title*  *Papers / title* |
| *DCA10* | *dcterms:abstract*  *Papers / abstract* |
| *DCA11* | *dc:date*  *Papers / year* |
| *DCA12* | *skos:prefLabel*  *Topics / topicName* |
| *DCA13* | *rdfs:label*  *Conferences / name* |
| *DCA14* | *dc:date*  *Conferences / date* |
| *DCA15* | *conf:location*  *Conferences / location* |

1. A Strategy for R2RML Mapping Generation
   1. R2RML Mapping Language

An *R2RML mapping* refers to logical tables to retrieve data from the input database. A *logical table* is a base table, a view or a valid SQL query (called an *R2RML view*). Each logical table is mapped to RDF using a *triples map*, which has a *subject map* and multiple *predicate-object maps*. The subject map generates the subject of the RDF triples. The predicate-object maps consist of *predicate maps* and *object maps* (or *referencing object maps*). Triples are created by combining the subject map with a predicate map and an object map, and by applying such maps to the logical table rows.

The use of views in R2RML mappings facilitates the definition of complex mappings. For example, the object map for the object property *conf:researchInterests* shown in Table 7 refers to an R2RML view. The object map in lines 8-14 maps tuples of the R2RML view, defined in lines 3-6, to triples of the object property *conf:researchInterests*.

**Table 4.** Triples map generated from *OCA2*

|  |  |
| --- | --- |
| 1 | <#ResearchInterestsTriplesMap> |
| 2 | rr:logicalTable [ |
| 3 | rr:sqlQuery """ |
| 4 | SELECT pe.perID as id, rpt.topicID as idTopic |
| 5 | FROM Persons as pe, Rel\_Person\_Paper as rpp,  Papers as pa, Rel\_Paper\_Topic as rpt |
| 6 | WHERE pe.perID = rpp.personID and rpp.paperID = pa.paperID and  pa.paperID = rpt.paperID]; |
| 7 | rr:subjectMap [rr:template "http://example.com/person/{id}"; |
| 8 | rr:predicateObjectMap [ |
| 9 | rr:predicate conf:researchInterests; |
| 10 | rr:objectMap [rr:template [http://example.com/topic/{ idTopic }](http://example.com/topic/%7b%20idTopic%20%7d) ]; ]; |

* 1. Overview of the strategy

In this section, we present our approach for generation of customized R2RML mappings. The process inputs are:

* ***D*** = *(VD,CD)*: the target ontology
* ***S***: the data source schema that must be mapped to ***D***
* ***A***: a set of correspondence assertions between ***S*** and ***D***

In our approach, we use a three-level architecture for mapping RDB to RDF, which is depicted in Figure 3. The exported ontology (***EO***) models the RDF view exported by the data source. The vocabulary of the exported ontology is a subset of the target ontology vocabulary. The middle layer consists of a set of relational view schemas ***VS***, where ***VS*** is a direct transformation for the exported ontology ***E.*** The view schemas in ***VS*** can be implemented as relational views or R2RML views [xxx].

In our framework, the use of the middle layer ***VS***, help breaking the definition of the mappings into two stages: the definition of the *SQL mappings* and the definition of the *R2RML mappings*. The R2RML mapping from the views to the exported ontology is in fact one-to-one and is automatically generated based on ***VS***. Also, it simplifies maintaining the R2RML mapping to reflect changes to the database schemas.

The mapping generation process consists of three main steps. The first step involves the design of the *exported ontology* ***EO***. The second step involves the design of a set of a relational view schemas ***V*** and a set of direct correspondence assertions between VS and EO. The third step generates the R2RML mapping ***M*** which maps ***VS*** to ***EO***.

|  |  |
| --- | --- |
| **Fig. .** 3-Level Schema Architecture | **Fig. .** ISWC\_RDF Exported Ontology Schema |

* 1. Step 1: Design of the Exported Ontology

The design of the exported ontology depends on what we require from the data exported by the data source. As proposed in [5], we require the exported ontology be an open or a closed fragment of the target ontology.

Again, let ***D*** = *(VD,CD)* denote the target ontology and ***E*** = *(VE,CE)* denote the exported ontology. Assume that *VE* is a subset of *VD*. Then, ***E*** = *(VE,CE)* can be automatically generated, based on the correspondence assertions between the ***D*** and ***S***[7]. Briefly, a term *T* (class or property) of *VD* is in *VE* if and only if there is a matching assertion for *T* in ***A***. The constraints *CE* are generated using the procedure **openFragment** introduced in [5].

Consider, for example, the ISWC\_REL database schema in Figure 1, the CONF\_OWL Domain Ontology in Figure 2 and the correspondence assertions in Table 3. Figure 4 shows the exported ontology ISWC\_RDF. The vocabulary of ISWC\_RDF contains all the elements of the CONF\_OWL ontology that matches an element of ISWC\_REL.

* 1. Step 2: Design of relational view schemas

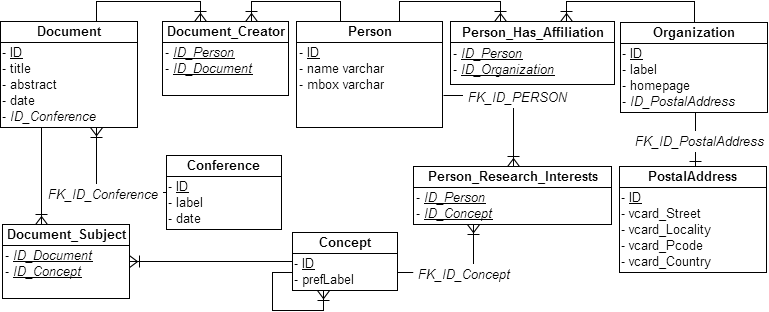
Table 8 shows Algorithm 1, which automatically generates the relational view schemas for a given exported ontology ***EO*** = *(VE,CE )* a set of direct correspondence assertions between VS and EO. The algorithm has 3 main steps:

* Step 1: For each class in *VE*, create a relational view and the CCA that matches the class with the view.
* Step 2: Deals with datatype properties in *VE*. Two cases are possible:
* Case 2.1. If the datatype property has maxcardinality equal to 1, generate an attribute and a simple DCA that matches the datatype property with the attribute.
* Case 2.2. If the datatype property has maxcardinality greater than1, generate a link relation with a foreign key and an attribute, and generate a direct DCA that matches the datatype property with a path composed by the foreign key and the attribute.
* Step 3: Deals with object properties in *VE*. Two cases are possible:
* Case 3.1. If the object property has maxcardinality equal to 1, generate a foreign key and a direct OCA that matches the object property with the foreign key.
* Case 3.2. If the object property has maxcardinality greater than1, generate a link relation with two foreign keys and a direct OCA that matches the object property with a path composed by the two foreign keys.

Figure 5 depicts *ISWC\_Views*, the relational view schemas for the exported ontology *ISWC\_RDF*, and Table 9 contains some of the CAs between the *ISWC\_RDF* vocabulary and *ISWC\_Views*. In Figure 5, the relations *Conference*, *Person*, *Document,* *Concept*, *Organization* and *PostalAddress* are generated for the classes in *ISWC\_RDF*; and the link relations *Document\_Creator*, *Document\_Subject*, *Person\_Research\_Interests*, *Person\_Has\_Afilliation* are generated for the object properties *creator*, *subject*, *researchInterests*, *hasAfilliation* respectively.

**Table 8.** Algorithm 1

|  |
| --- |
| Step 1: **For each** class *prefixC:C* in *VE* **do**  Create a relational view *C*;  Create attribute *ID* as primary key of *C*;  Create CCA *prefixC:C* ≡*C[ID];* |
| Step 2: **For each** datatype property *prefixP:P* in *VE* **do**  Let *prefixD:D* be the domain of *prefixP:P*;  Case 2.1: *prefixP:P* has maxCardinality equal to 1.  Create attribute *P* in view *D* whose type is defined according to range of *prefixP:P*;  Create DCA *prefixP:P* ≡*D*/*P*;  Case 2.2: *prefixP:P* has maxCardinality greater than 1.  Create intermediate relational view *D\_P*;  Create attribute *ID\_D* in *D\_P* whose type is defined according to attribute ID of D;  Create foreign key *FK\_ID\_D(D\_P:{ID\_D},D:{ID})*  Create attribute *P* in *D\_P* whose type is defined according to range of *prefixP:P*;  Create DCA *prefixP:P* ≡*D/[ FK\_ID\_D]/P*; |
| Step 3: **For each** object property *prefixP:P* in *VE* **do**  Let *prefixD:D* and *prefixR:R* be the domain and range of *prefixP:P*, respectively;  Case 3.1: *prefixP:P* has maxCardinality equal to 1.  Create attribute *ID\_R* in view *D* whose type is defined according to attribute *ID* of *R*.  Create foreign key *FK\_ID\_R(D:{ID\_R},R:{ID})*  Create OCA *prefixP:P* ≡*D/[ FK\_ID\_R];*  Case 3.2: *prefixP:P* has maxCardinality greater than 1.  Create intermediate table *D\_P*;  Create attribute *ID\_D* in *D\_P* whose type is defined according to attribute ID of D;  Create attribute *ID\_R* in *D\_P* whose type is defined according to attribute ID of R;  Create foreign key *FK\_ID\_D(D\_P:{ID\_D},D:{ID})*  Create foreign key *FK\_ID\_R(D\_P:{ID\_R}, R:{ID})*  Create OCA *prefixP:P* ≡*D/[FK\_ID\_D, FK\_ID\_R];* |



**Fig. .** ISWC\_View Schemas

**Table 9.** Simple Correspondence Assertions between *ISWC\_RDF* and *ISWC\_Views*

|  |  |
| --- | --- |
| *CCA1* | *foaf:Person*  *Person[ID]* |
| *CCA2* | *foaf:Document*  *Document[ID]* |
| *CCA3* | *conf:Organization*  *Organization[ID]* |
| *CCA4* | *conf:PostalAddress*  *PostalAddress[ID]* |
| *CCA5* | *conf:Conference*  *Conference[ID]* |
| *CCA6* | *skos:Concept*  *Concept[ID]* |
| *OCA1* | *conf:conference*  *Document / [FK\_ID\_Conference]* |
| *OCA2* | *conf:researchInterests*  *Person /[FK\_ID\_Person, FK\_ID\_Concept]* |
| *OCA3* | *vcard:ADR*  *Organization /[FK\_ID\_PostalAddress]* |
| *OCA4* | *skos:subject*  *Document /[FK\_ID\_Document, FK\_ID\_Concept]* |
| *DCA1* | *foaf:name*  *Person / name* |
| *DCA2* | *foaf:mbox*  *Person / mbox* |
| *DCA3* | *skos:prefLabel*  *Concept / prefLabel* |

* 1. Step 3: Generation of R2RML mappings

This section shows how to translate direct correspondence assertions to R2RML mappings. In order to translate direct correspondence assertions to R2RML mappings, a subject map should be defined for each CCA, a predicate map for each DCA, and an object map for each OCA.

Table 9 shows the templates to translate simple correspondence assertions to R2RML mappings. The parameters are in bold and they are preceded by ‘$’ character. Line 1 shows the CCA direct template. ***$C*** is the class name that is the same name of the view generated after the algorithm execution. Thus, ***$C*** is used to define mapping name, table name, uri template and class name. ***$attList*** is the list of view *C* key attributes (*A1,...,An*) and the each attribute into this list is used to build the URI of the class. Line 2 depicts the DCA simple template. ***$p*** is the prefix of datatype property ***$P***. As this is a simple assertion, ***$P*** also represents the name of the column defined in view *C*. Line 3 shows the DCA simple template with a foreign key (fk). The existence of the fk tells us that the maxCardinality of the datatype property is greater than one. So the algorithm has created a view for this property and this view is used as the logical table of the subject map. This is the solution for this special case of triples generation where the cardinality of the object is greater than one. Line 4 exposes the OCA simple template with just one foreign key (*fk*) into the path **$*ϕ***. ***$p*** is the prefix of object property ***$P***. The length of **$*ϕ*** equals to one indicates that the maxCardinality of ***$P*** is also one, so the algorithm has not created a new view for this object property. The object map refers the triples map defined to ***$P*** range class and for each pair of *fk* matching attributes a join condition is created. By the end, Line 5 depicts the OCA simple template with more than one fk into the path **$*ϕ***. So the object property has maxCardinality greater than one and the algorithm has created a view for this property. Similarly to the explanation of Line 3, we have to create a new triples map. The detail here is the creation of join conditions. Our solution considers just the attributes of the last FK to build the join conditions. This happens because the view created by the algorithm already includes the joins through the whole path and projects just the key attributes of the last relation referenced by the last FK.

**Table 9.** Templates to translate simple correspondence assertions to R2RML mappings

|  |  |
| --- | --- |
| 1 | *Ψ: prefix:C* ≡ *C[A1,...,An]* |
|  | <#**$C**TriplesMap>  rr:logicalTable [ rr:tableName "**$C**" ];  rr:subjectMap [  rr:template "**$C**/ #foreach ($att in **$attList**) {$att}/ #end";  rr:class **$p**:**$C**;  ]; |
| 2 | *Ψ: p:P ≡ C / P, where P is a datatype property* |
|  | rr:predicateObjectMap [  rr:predicate **$p**:**$P**;  rr:objectMap [ rr:column "**$P**" ];  ]; |
| 3 | *Ψ: p:P ≡ C / ϕ / B, where ϕ has only one foreign key (fk)* |
|  | <#**$C\_$P**TriplesMap>  rr:logicalTable [ rr:tableName "**$C\_$P**" ];  rr:subjectMap [  rr:template "**$C**/{ID\_**$C**}";  rr:class **$p**:**$C**;  ];  rr:predicateObjectMap [  rr:predicate **$p**:**$P**;  rr:objectMap [ rr:column "**$B**" ];  ]; |
| 4 | *Ψ: p:O ≡ C /ϕ, where ϕ has only one foreign key (fk) and P is an object property* |
|  | rr:predicateObjectMap [  rr:predicate **$p**:**$O**;  rr:objectMap [  rr:parentTriplesMap <**$O.rangeClass()**TriplesMap>;  #foreach ($pair in **$*ϕ****.get*Fk())  rr:joinCondition [  rr:child “$pair.childAtt”;  rr:parent “$pair.parentAtt”;  ];  #end  ];  ]; |
| 5 | *Ψ: p:O* ≡ *R / ϕ , where ϕ is an associated path with two foreign keys* |
|  | <#**$C\_$P**TriplesMap>  rr:logicalTable [ rr:tableName "**$C\_$P**" ];  rr:subjectMap [  rr:template "**$C**/{ID\_**$C**}";  rr:class **$p**:**$C**;  ];  rr:predicateObjectMap [  rr:predicate **$p**:**$O**;  rr:objectMap [  rr:parentTriplesMap <**$O.rangeClass()**TriplesMap>;  #foreach ($pair in **$*ϕ****.getLast*Fk())  rr:joinCondition [  rr:child “$pair.childAtt”;  rr:parent “$pair.parentAtt”;  ];  #end  ];  ]; |

Table 10 contains some of the R2RML mappings automatically generated from the direct CAs in Table 9, using the templates in Table 9.

**Table 10.** R2RML Mapping Generated from ACs in Table 9

|  |
| --- |
| <#PersonTriplesMap> # **R2RML mappings generated from *CCA1* and *DCA1***  rr:logicalTable [ rr:tableName "Person" ];  rr:subjectMap [  rr:template "[*person*](http://example.com/person/t.perID)/{ID}";  rr:class foaf:Person; ]; |
| rr:predicateObjectMap [  rr:predicate foaf:name;  rr:objectMap [ rr:column "name" ]; ] . |
| **...** |
| <#ConceptTriplesMap> # **R2RML mapping generated from *CCA6***  rr:logicalTable [ rr:tableName "Concept" ];  rr:subjectMap [  rr:template "*concept*/{ID}";  rr:class skos:Concept; ] . |
| **...** |
| <#Person\_researchInterestsTriplesMap> # **R2RML mappings generated from *OCA2***  rr:logicalTable [rr:tableName “Person\_researchInterests”];  rr:subjectMap [  rr:template "[*person*](http://example.com/person/t.perID)/{ID\_Person}";  rr:class foaf:Person; ];  rr:predicateObjectMap [  rr:predicate conf:researchInterests;  rr:objectMap [  rr:parentTriplesMap <ConceptTriplesMap>;  rr:joinCondition [  rr:child “ID\_Concept”;  rr:parent “ID”;  ]; ]; ] . |

1. Conclusion and Future Work

Motivated by the need to develop tools that facilitate the deployment of mappings using R2RML, we first introduced correspondence assertions to specify the mapping between a target vocabulary and a base RDB schema. We then proposed an approach to automatically generate R2RML mappings, based on a set of correspondence assertions. The approach uses relational views as a middle layer, which facilitates the R2RML generation process, and improves the maintainability of the mapping.

We introduced correspondence assertions in earlier papers [15] to investigate XML views. Therefore, it would be natural to adopt the same approach to address RDB-to-RDF mappings. In fact, the latter problem proved to be much simpler than the former, since XML views are fairly complex.

  As for the immediate future, we are extending the D2R Server to process R2RML mappings as a basis for the mapping implementation. The extension supports the mapping generation process described in Section 5.

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