

# Improving Programmability of Linked Data Sources

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**Abstract.**

## 1 TODO: Proposals for title

Some ideas for the title:

- Towards a Data-oriented Type System in Programming Environments
- A type Bridging technique for RDF data sources
- Adapter Layer for Web data integration
- Connected Programming

## 2 Introduction

Publishing linked (open) data on the Web has become a success story during the last years. RDF as the underlying representation formalism allows for flexible modeling of data such that users are able to easily share, distribute and interconnect their own data all over the world. Publishing and representing data on the Web is one side of the coin, but writing programs and applications that access and smoothly integrate RDF data is another, rather challenging issue.

One key problem is the fundamental gap how data is processed in both areas. RDF representation benefits from the flexible data model, while software engineering environments and programming languages rely on powerful typing mechanisms that guide programmers in their development by intelligent IDE support and avoid run-time exceptions that might be caused by incompatible types.

The integration of large external data into programs and programming environments has already been investigated by dynamically typed programming languages. However, as it is in the nature of these languages, without type support when writing program code. Some initially approaches use adapter mechanism to integrate large data sources into statically typed programs. They rely on a rigid and well-known schema of the data source. Given such schema information, these approaches have led to good principles and toolins to allow for a smooth integration of data.

Looking into linked data, the question arises whether a smooth integration is even possible for RDF data sources. In particular, we are faced with the following problems. First, schema information might be partially unknown and even incomplete when data are accessed. Instead, the structure among individuals, which is given in terms of properties between individuals, might be used for a data access with respect to a certain structure. Second, while the schema is rather fix, the underlying data tend to change rather often. Thus, programs at run time might incorporate such aspects. Third, the sheer size of data sources (like DBpedia) might lead to a large number of types and accordingly to high type generation effort, while the program and system execution only need a part of the generated types. Thus, in an extreme case, this might even make the use of statically typed languages impossible.

In this paper, we present an integration and type bridge from RDF data sources to statically typed programming languages. We adopt the principles of *type provider* to define an adapter in terms of a library (i.e., a dll-file) for statically typed programming languages. This adapter can be loaded in a program to access an arbitrary RDF data source that offers a SPARQL endpoint.

### 3 What does programming Linked Data mean?

The RDF data model is basically a graph, which is constituted of a set of subject-predicate-object triples. This graph covers both the schema in terms of classes and the data in terms of individuals. The usage of certain predicates like `rdf:type`, `rdfs:domain` and `rdfs:range` and classes like `rdf:Class` indicate that certain entities in the graph are classes. Thus, this is an evidence for a schema.

When writing programs and Web applications, programmers use programming languages and environments like IDEs to write their code. Programming languages typically rely on some kind of schema or types where types (or classes) serve as containers to manage data. The organization of types in a so-called type system is an essential benefit of statically typed languages where a powerful type system supports programmers during the program design and ensures type correctness in program execution. In particular, statically typed programming languages provide the following benefits:

1. **Design Time Assistance:** The programming environment provides support for programmers when writing code by context-sensitive auto-completion, interactive type checking (so called red squiggles) and quick information display like mouse-hover and detailed documentation (e.g., by pressing F1 button). All these interactive features help programmers in writing their code and give early feedback (at design time) about program correctness.
2. **Run Time Assistance:** When a statically typed program is compiled, type definitions and their usage in programs are checked. Thus, at run time, we can rely on a proper type system that offers features like type casts, type checking and type inference. Run time errors and exceptions during program execution based on incorrect type usage and type mismatch are already detected.

during design and compilation, and thus, might not cause errors at run time. Types can be even used to optimize type interpretations. *comment Gerd: I can't remember what the last sentence about optimize / drive interpretations mean.*

While these benefits of statically typed programming languages are obvious, the key question is how can such features be achieved when we access and integrate RDF data sources, i.e., types in our type system refer to RDF classes and collections of individuals. This means, that types are used in the usual programming manner, for instance RDF individuals have all properties that are defined by the RDF classes. This is illustrated in the following example. In each step, we see the corresponding requirement that has to be addressed by a type bridge. We can distinguish between *navigation requirement (NR)* and *typing requirement (TR)*.

Assume a developer is programming an application for a mobile phone that accesses data about movies, retrieved from RDF data sources like DBpedia<sup>1</sup> via a SPARQL endpoint, e.g., as provided by DBpedia<sup>2</sup>.

**Step 1: Find a Class.** First of all, the programmer decides to use DBpedia as a data source since it is well connected to other data sources. As a first step, the programmer has to look for a dedicated class for “movie” in the data source. For this purpose, the data source must be explored, e.g., by starting from a top RDF class and moving downwards the class hierarchy.

**NR 1:** Thus, we need means to explore a data source and find the dedicated class.

**Step 2: Define a Class / Type for a class.** Once, a class for a “movie” is found, e.g., <http://dbpedia.org/ontology/movie>, the programmer has to define this class in the program.

**Listing 1.1.** Type Definition for RDF Class “Movie”

```
1 // The "Movie" Type
2 type Movie = {
3   id : URI
4   rdfs:label "Movie"
5 }
6
```

**TR 1:** The problem we have to solve here is to map the RDF class description into a type definition in the program code.

**Step 3: Define Related Types / Classes.** Looking into the RDF class, we see that “Movie” is a subclass of “Work” (<http://dbpedia.org/dbpedia-owl/Work>). Hence, if we want to reflect this characteristic, we need to define a type for class “Work” as well.

<sup>1</sup> DBpedia: <http://dbpedia.org>

<sup>2</sup> DBpedia SPARQL Endpoint: <http://dbpedia.org/sparql>

**Listing 1.2.** Type Definition for RDF Class “Movie” and “Work”

```
1 // The "Work" Type
2 type Work = {
3   id : URI
4   rdfs:label "Work"
5 }
6
7 // Again the "Movie" Type as Subclass of "Work"
8 type Movie = {
9   inherit Work
10  id : URI
11  rdfs:label "Movie"
12 }
13
```

Obviously, besides the “Work” class, other class might be created as Movie is related to them. This procedure might even continue since these other classes like “Work” can depend on other classes.

Given the sheer size of linked data sources (or even the linked data cloud), the key *problem* is which classes need to be integrated in a program, i.e., for which RDF classes is a type definition necessary. Building types for all classes of a data source is definitely not scalable, and even not needed since a particular application might only need a part of the classes.

**TR 2:** Thus, the question is whether it is possible to build types only *on demand*.

**Step 4: Define individuals of classes.** In our application, we want to manage concrete movies, which can be derived from the data sources, as individuals of this class. Using a SPARQL query we can retrieve all individuals of class “Movie”. For instance, we get the individual <http://dbpedia.org/page/Skyfall> for the movie “Skyfall”. Accordingly, we can build an instance of movie.

**Listing 1.3.** Individual of “Movie”

```
1 let skyfall = Movie('http://dbpedia.org/page/Skyfall')
```

**TR 3** Types are used to instantiate individuals.

**Step 5: Incorporate Properties of Individuals.** It is in the nature of the flexible RDF model that properties can be defined for individuals without explicit definition of these properties for classes.

**NR 2:** Navigation along properties must be able for individuals.

### 3.1 Contribution

We distinguish between challenges and our corresponding contributions that are related to (i) the programming environment, (ii) the mapping from schema and data requests to SPARQL queries and (iii) the Semantic Web and linked data oriented investigations.

## Programming Language and Environment

We present a type bridge / adapter in order to create types for RDF classes that are retrieved from linked data sources. In particular, this includes the following aspects.

*comment Gerd: Here we need a description of type provider features.*

**Type Integration and Type Inference.** When deriving RDF data from external data sources, the key problem is how to integrate such types into the host programming schema.

**Contribution:** Types are built based on the schema information that is obtained from the RDF data source.

**Type Definition on Demand — Scalability.** As data sources on the Web tend to be huge, it is not a promising idea to build the types for all classes of a data source. Obviously, types are only needed if particular applications need to access them. **Contribution:** on demand typing based on the current element.

**Incorporate Data Changes.** It is obvious that RDF data change rather frequently, while the schema remains stable. Thus, it is meaningful to build types wrt. schema (at design time) and populate these types at run time.

**Contribution:** Types are built wrt. the schema (class definitions in RDF). Classes are populated by individuals at run time. This implicitly also takes changes of the data (individuals) into account.

## Semantic Web and Linked Data

While our type bridge is built to access and integrate RDF data into programs, we also use Semantic Web technologies and built the data access upon these existing means. In particular, we apply SPARQL queries, the SPARQL entailment regime, which includes RDF(S) entailment, and we actually rely on best practices for publishing linked data.

**Derive fine-grained Schema from RDF Data.** Hierarchies of classes and also properties in RDF data can be quite extensive. Besides this, domain and range restrictions of properties that entities can be classes in case this is not explicitly stated.

**Contribution:** We incorporate RDF entailment regime, which is supported by SPARQL 1.1 in order to derive a fine-grained type system / schema.

**Navigation on Class vs. Instance level.** In RDF data sources, property specifications at the class level are often rare, for instance in DBpedia classes have only three or four properties and these are actually quite generic one, derived from super-classes. Instead, the most interesting way for navigating is at the instance level. But, how can we cover properties if their corresponding class in the programming language does not have this property. We can even not assume this property for the class since the individuals do not necessarily share their properties.

**Contribution:** We offer a two-layered navigation in RDF sources

**Property-based Classes.** RDF data have type statements that assign data (individuals) to classes. However, it has been shown that besides the type statements properties of individuals are an essential means to group individual to a kind of classes instead of only relying on explicitly specified types.

**Contribution:** We allow the specification of types as a set of properties.

**Set-based Classes.** Following the OWL-based set semantics, classes in the RDF sense can be considered as unions or intersections of RDF classes.

**Contribution:** We allow the specification of types as a unions and intersection of existing types.

### 3.2 Semantic Web and Linked Data

*comment Gerd: not sure, whether the mapping to SPARQL is worth to mention.*

## 4 Foundations

An RDF<sup>3</sup> data source consists of at least one RDF graph, which is a set of RDF triples  $(s, p, o)$  that consists of subject (s), predicate or (p) and object (cf. Def. 2).

**Definition 1 (RDF Graph).** Let  $U$  be a set of URIs,  $L$  a set of literals and  $B$  a set of blank nodes, with  $U \cap L \cap B = \emptyset$ .

An RDF graph is defined as:  $G = \{(s, p, o) \in (U \cup B) \times U \times (U \cup L \cup B)\}$ .

SPARQL<sup>4</sup> is a query language for RDF graphs with **select**, **from** and **where** clauses. Like an RDF graph, the graph pattern of the **where** clause consists of RDF triples, in which variables are allowed as subjects, predicates and objects of triples. The result of a query is a binding of the variables in the **select** clause, while the binding is determined by matching of triples from the **where** clause to triples in the RDF graph  $G$ .

In SPARQL 1.1, which we are referring to in this paper, the graph matching principle between triples in the query and the data source is extended by entailment relations, as defined by the SPARQL entailment regimes<sup>5</sup>. Among

<sup>3</sup> RDF Primer: <http://www.w3.org/TR/rdf-primer>

<sup>4</sup> SPARQL 1.1 Query Language: <http://www.w3.org/TR/sparql11-query>

<sup>5</sup> SPARQL 1.1 Entailment Regimes: <http://www.w3.org/TR/sparql11-entailment>

others, the entailment regimes contain RDF and RDFS entailment rules. Thus, triple matching is extended to triples that can be derived from an RDF graph  $G$ . Formally, we denote this extended set of triples, which can be derived by RDF(S) entailment as Materialized Graph (cf. Def. ??). (The symbol  $\models_{\mathcal{T}}$  denotes RDF(S) entailment.)

We use a distinction between classes (schema) and data in the RDF graph. We refer an entity  $C$  (subject or predicate in a triple) as a class (or RDF class). This is described by the second part of Def. 2.

**Definition 2 (Materialized RDF Graph and RDF Classes).**

1. Let  $G$  be an RDF graph. A materialized graph  $\hat{G}$  is defined as follows:  

$$\hat{G} = \{(s, p, o) \in (U \cup B) \times U \times (U \cup L \cup B) \mid G \models_{\mathcal{T}} (s, p, o)\}.$$
2.  $C$  is referred to as a class (or RDF class) if one of the following conditions hold: (i) there is a type statement  $(s \text{ rdf:type } C) \in \hat{G}$ , (ii) there is a domain restriction  $(s \text{ rdfs:domain } C) \in \hat{G}$  or (iii) there is a range restriction  $(s \text{ rdfs:range } C) \in \hat{G}$  and  $C$  is not a datatype.

Foundations: F# and Type Provider

**Definition 3 (Type System).** A type system is a tuple  $(\Gamma, \mathcal{T})$ . Let  $\Gamma$  be a domain,  $\mathcal{T}$  a set of type expressions (or types for short).  $\top \in \mathcal{T}$  is the most general type expression that is a super-type of all other types.

For each element in the domain  $e \in \Gamma$  there is a type  $\tau \in \mathcal{T}$  such that  $e$  is an individual of type  $\tau$ :  $e : \tau$

**Definition 4 (Class-Type Mapping).** An RDF graph  $G$  is mapped to a type system  $(\Gamma, \mathcal{T})$  by a class-type mapping  $m$ . Each (named) RDF class  $C$  is mapped to a type  $\tau \in \mathcal{T}$ . Each property is mapped to a type tuple  $(\tau_1, \tau_2) \in \mathcal{T} \times \mathcal{T}$ .<sup>6</sup>

## 5 A Type Bridge for RDF

comment Gerd: not sure we use ‘bridge’, ‘adapter’ or ‘type provider’?

comment Gerd: we have to make the distinction clear: (i) the work we did (meta-level) and (ii) how the TP is used as a library (run time)

Our goal is to build an integration bridge for arbitrary RDF data sources with a SPARQL endpoint in order to access and integrated RDF data into a statically typed program on demand. When using these bridge, it should not be part of the actual developed application, instead it is just used as a library. In the following, we will see some technical details how the bridge is developed.

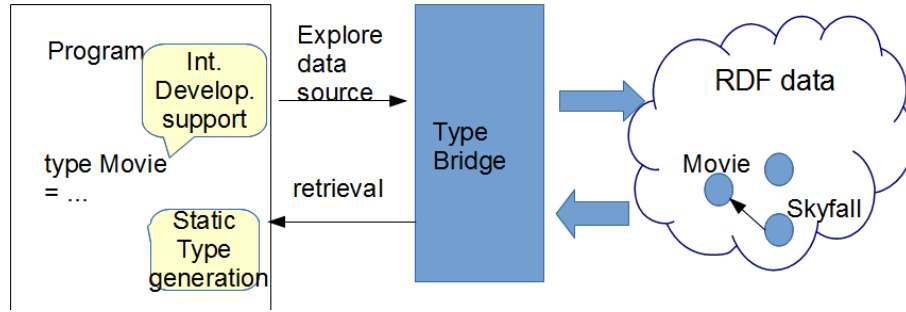
<sup>6</sup> Note: If the domain or range class of a property is unknown, the corresponding types are  $\top$ .

## 5.1 Features of the Type Bridge

According to Sect. 3, we aim at achieving two groups of requirements: navigation requirements (NR) and typing requirements (TR). Navigation is needed since the an RDF graph does not explicitly distinguish between schema and data, as for instance in relational databases. Thus, the navigation is used to find those elements in the graph that should be integrated as types and their corresponding data (individuals) in a program. Aspects of the integration into the programming type system are reflected by the typing requirements (TR).

In order to meet the requirements, the type bridge has to provide the following functionality. First, the exploration of an RDF graph must be supported. Thus, we need to be able to hook into the graph and then follow the properties from one entity to the next one. While this is possible for RDF classes and individuals. Second, the retrieval of the currently explored entity and its properties must be supported.

The type bridge, its features and its context of use is illustrated in Fig. 1. The design and implementation of the type bridge is described in the next part of this section.



**Fig. 1.** Functionality and Context of the Type Bridge

## 5.2 Type Definitions

Our type bridge is a compile time component. It has static parameters like the address (URI) of the SPARQL endpoint. The type bridge consists of two components: (i) the data source *connector* and (ii) the *type generation description*. The latter one is a kind of compile-time meta-programming construct. In the following, we consider both components in detail.

The connector establishes a connection to the SPARQL endpoint. It serves as a mediator between the type generation description and the external data source. The connector gets as an argument the URI of the SPARQL endpoint in order to establish a connection to the SPARQL endpoint.



The connector consists of functions that are used by the type generation description to navigate in the data source and to retrieve data. Internally, these functions encode SPARQL queries to implement both tasks the navigation and the retrieval.

The type generation description defines how types with their parameters, properties and methods are built.

The first part is the definition of the type itself, which requires at least the name of the type and its erasure, i.e., the type this type can be erased to.

Let  $C$  be the class, which is retrieved by a SPARQL query. The type generation description in  $F\#$  is as follows:

**Listing 1.4. Type Rule:** Type Generation Description for RDF Class  $C$

```
1 t = ProvidedTypeDefinition(cName, baseType=Some typeof<obj>)
```

In Listing 1.4, `cName` denotes the name of class  $C$ , e.g., the URI of  $C$ . The `baseType` gives the “super-type” from which the generated type  $t$  inherits from. As an example, assume we specify a type generation description for RDF classes. Its description, which is a compile-time meta-programming construct, is used to build RDF classes, e.g., the “Movie” class in our example.

Types can have properties, accordingly if a type will be created, the corresponding properties have to be created too. These properties are obtained from the RDF data source and should be directly reflected in the source code that will specify the type. Accordingly, the type generation description describes how to obtain properties and to generate the properties of these types.

**Listing 1.5. Property Rule:** Add Property for Class  $C$

```
1 let p = ProvidedProperty(pName, typeof<string>,
2   GetterCode = (fun args ->
3     <@@(%%(args.[0]):obj) :?> string @@>))
4   // add this property (delayed)
5   t.AddMemberDelayed(p)
```

In Listing 1.5, `pName` denotes the name of the property (e.g., the URI), `typeof` gives the super-type (string in this case) and `GetterCode` is a so-called quotation that specifies the result of a property selection at run time. In this simple case, the string representation of the property itself is the meaning of the property. In the second line, the property is “added” to the type. Note, this this depends on the concrete generated type when the bridge is used in a concrete program. For instance, if a type for RDF class “Movie” is created (according to the rule in Listing 1.4), the properties (predicates in the RDF graph) of “Movie” are generated and added (according to the property rule in Listing ??).

Finally, individuals can be added to classes according to Listing 1.6. For this, a new type will be created with the name of the class (denoted by `cName`) and the suffix “Individuals”. This type is added to `t`. In this collection, all individuals are contained.

**Listing 1.6. Individual Rule:** Add Individuals (set / collection) to Class  $C$

```

1 let individuals =
2     ProvidedTypeDefinition(cname+"Individuals", Some typeof<obj>)
3     \\ add these individuals
4     individuals.AddMembersDelayed()
5     \\ add individual collection to type
6     t.AddMemberDelayed(individuals)

```

### 5.3 Additional Constructs

According to the integration principle, types are created when a certain entity is retrieved from the graph. While this entity is reached by navigation along the graph. Thus, we can also have some cycles in the exploitation. In order to achieve scalability in statically typed languages, it has to be ensured that a type for entity is only created once. To do this, we use dictionaries in the type dictionaries (hash maps) to ensure that types are unique and to avoid infinite loops.

## 6 Linked Data Programming — Type Bridge in-use

The type generation definition, as presented in Sect. 5, can be applied for arbitrary RDF data sources. The usage in two steps. First, when writing a program, e.g., an application for a mobile phone (cf. Sect. 3), gets the full support from the underlying static type system. Second, when the application is used at run-time, these generated types are treated as basic .NET types in F#.

Consider again the program development from the original example in Sect. 5.

*Navigation Principle* The navigation uses the usual dot-operator, as it is also used in other type bridges in F#. The navigation works as follows:

- The top-level element is the data source, e.g., DBpedia. This is represented by the type `http://dbpedia.org`. When pressing the dot we get a list of all classes.
- 
- design time: intellisense, autocompleting, when designing types
- run time: lazy typing

## 7 Evaluation

## 8 Related Work

Related work can be distinguished into two groups: the exploration of data sources (data access) and the integration into programming environments.

Several related approaches study the exploration and visualization of Web data sources. The aim of this work is to allow users without SPARQL experiences an easy means to get information from linked data sources. tFacet [1] and gFacet [2] are tools for faceted exploration of linked data sources via SPARQL endpoints. fFacet provides a tree view for navigation, while gFacet has a graph facet for browsing. The navigation of RDF data for the purpose of visualizing parts of the data source is studied in [3], but with the focus on visualization aspects like optimization of the displayed graph area. In contrast our work, these approaches do not consider any kind of integration aspects like code generation and typing. Furthermore, the navigation is rather restricted to a simple hierarchical top-down navigation.

Data<sup>7</sup> provides a protocol to query and update external data via RESTful service. OData contains a data model, logically based on an ER model, such that the protocol can describe both data (called entities) and types (entity types). Some implementations provide access from OData applications to SPARQL endpoints<sup>8</sup>.

## References

1. Brunk, S., Heim, P.: tFacet: Hierarchical Faceted Exploration of Semantic Data Using Well-Known Interaction Concepts. In: International Workshop on Data-Centric Interactions on the Web (DCI 2011). Volume 817 of CEUR-WS.org. (2011) 31–36
2. Heim, P., Ziegler, J., Lohmann, S.: gFacet: A Browser for the Web of Data. In: International Workshop on Interacting with Multimedia Content in the Social Semantic Web (IMC-SSW 2008). Volume 417 of CEUR-WS. (2008) 49–58
3. Dokulil, J., Katreniaková, J.: Navigation in RDF Data. In: 12th International Conference on Information Visualisation, IEEE Computer Society (2008) 26–31

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<sup>7</sup> OData (Open Data Protocol): <http://www.odata.org/>

<sup>8</sup> OData SPARQL: <https://github.com/BrightstarDB/odata-sparql> last visit 2013-05-07