TECHNISCHE UNIVERSITÄT DRESDEN

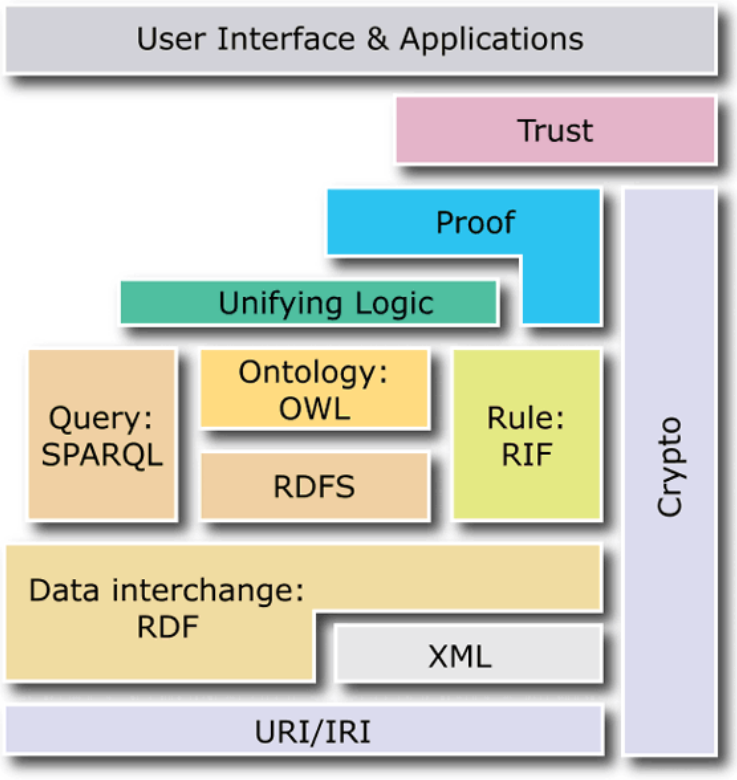
# FOUNDATIONS OF SEMANTIC WEB TECHNOLOGIES

## Introduction to RDF

**Sebastian Rudolph**

DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

# Introduction to RDF



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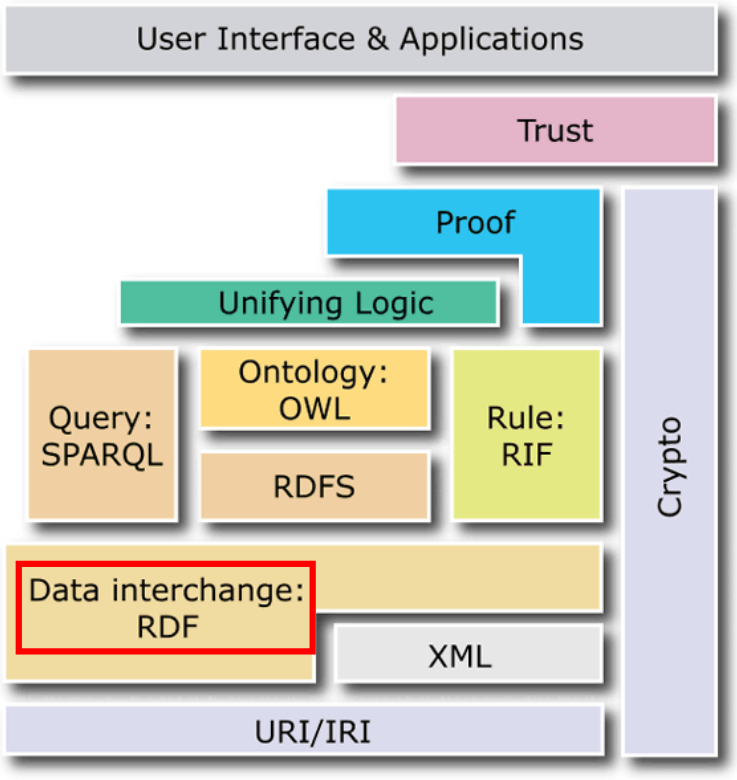

# Agenda

- Motivation
- RDF data model
- Syntax for RDF: Turtle and XML
- Datatypes
- Multi-Valued Relationships
- Blank Nodes
- Lists
- Graph Definitions
- RDF in Practice

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# Disadvantages of XML

- tag names ambiguous (can be tackled by name spaces and IRIs)
- tree structure not optimal for
  - intuitive description of the data
  - information integration
- Example: how to encode in a tree the sentence:
  “The book ‘Semantic Web – Grundlagen’ was published by Springer-Verlag.”

# Modeling Problems in XML

"The book 'Semantic Web – Grundlagen' was published by Springer-Verlag."

# Modeling Problems in XML

"The book 'Semantic Web – Grundlagen' was published by Springer-Verlag."

```
<Published>
  <Publisher>Springer-Verlag</Publisher>
  <Book>Semantic Web -- Grundlagen</Book>
</Published>
```

# Modeling Problems in XML

"The book 'Semantic Web – Grundlagen' was published by Springer-Verlag."

```
<Published>
  <Publisher>Springer-Verlag</Publisher>
  <Book>Semantic Web -- Grundlagen</Book>
</Published>
```

```
<Publisher Name="Springer-Verlag">
  <Published Book="Semantic Web -- Grundlagen"/>
</Publisher>
```

# Modeling Problems in XML

"The book 'Semantic Web – Grundlagen' was published by Springer-Verlag."

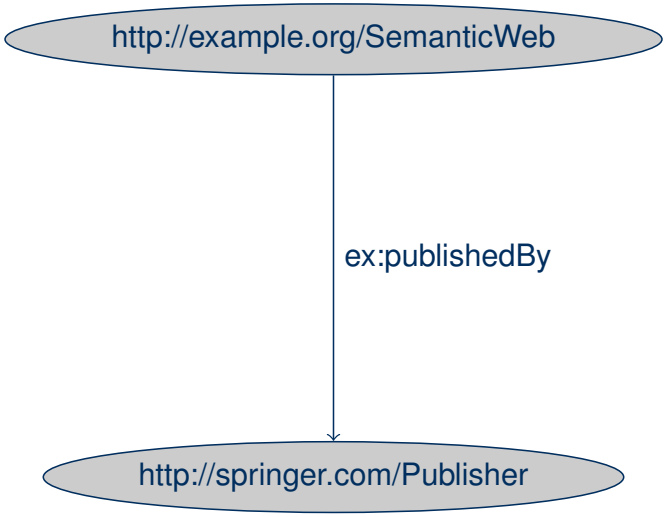
```
<Published>
  <Publisher>Springer-Verlag</Publisher>
  <Book>Semantic Web -- Grundlagen</Book>
</Published>
```

```
<Publisher Name="Springer-Verlag">
  <Published Book="Semantic Web -- Grundlagen"/>
</Publisher>
```

```
<Book Name="Semantic Web -- Grundlagen">
  <Publisher Publisher="Springer-Verlag"/>
</Book>
```

# RDF: Graphs instead of Trees

## Solution: Representation as (directed) Graphs



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# General Remarks about RDF

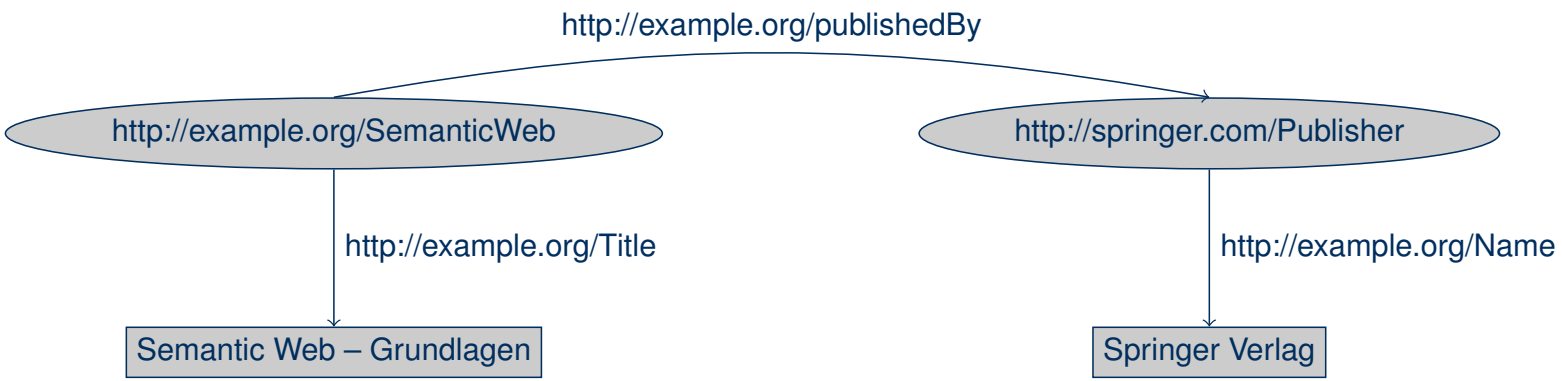
- “Resource Description Framework”
- W3C Recommendation (http://www.w3.org/RDF)
- currently being revised
- RDF is a data model
  - originally: assign metadata to Web resources, later more general usage
  - encodes structured information
  - universal, machine-readable exchange format

# Constituents of RDF Graphs

- IRIs
  - for uniquely referencing resources
  - (already discussed at XML lecture)
- literals
  - describe data values that do not have an independent existence
- blank nodes
  - allow for stating the existence of some individual (and describing its properties) without giving it a name

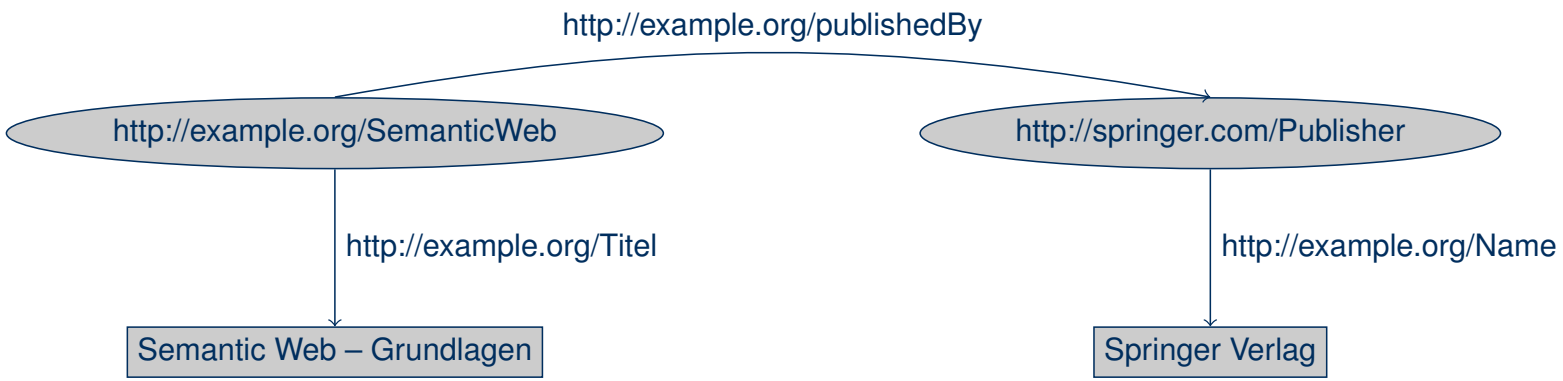
# Literals

- for representing data values
- noted as strings
- interpreted by an associated datatype
- literals without datatype are treated like strings



# Graph as a Set of Triples

- there are several different ways to represent graphs
- we use list of (node-edge-node) triples



# RDF Triple

Constituents of an RDF triple


- inspired by linguistic but not always an exact match
- permitted occurrences of constituents:
  subject : IRI or blank node
  predicate: IRI (also called properties)
  object: IRI or blank node or literal
- node and edge labels are unique, thus the original graph can be reconstructed from the list of triples

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# Simple Syntax for RDF

- direct enumeration of triples:
  - N3: “Notation 3” – comprehensive formalism
  - N-Triples: fraction of N3
  - Turtle: extension of N-Triples (by abbreviations)
- Turtle syntax:
  - IRIs in angular brackets
  - literals in quotes
  - tripels terminated by full stop
  - spaces and line breaks outside such delimiters are ignored

# Turtle Syntax: Abbreviations

## Example

```
<http://ex.org/SemanticWeb> <http://ex.org/publishedBy>
  <http://springer.com/Publisher> .
<http://ex.org/SemanticWeb> <http://ex.org/Titel>
  "Semantic Web -- Grundlagen" .
<http://springer.com/Verlag> <http://ex.org/Name>
  "Springer Verlag" .
```

## In Turtle we can define prefix abbreviations:

```
@prefix ex:  <http://ex.org/> .
@prefix springer:  <http://springer.com/> .
ex:SemanticWeb ex:publishedBy springer:Publisher .
ex:SemanticWeb ex:Title "Semantic Web -- Grundlagen" .
springer:Publisher ex:Name "Springer Verlag" .
```

# Turtle Syntax: Abbreviations

Multiple triples with the same subject can be grouped:

```
@prefix ex:  <http://ex.org/> .
@prefix springer:  <http://springer.com/> .

ex:SemanticWeb     ex:publishedBy springer:Publisher ;
                   ex:Title       "Semantic Web -- Grundlagen" .
springer:Publisher ex:Name        "Springer Verlag" .
```

# Turtle Syntax: Abbreviations

Multiple triples with the same subject can be grouped:

```
@prefix ex:  <http://ex.org/> .
@prefix springer:  <http://springer.com/> .

ex:SemanticWeb     ex:publishedBy springer:Publisher ;
                   ex:Title       "Semantic Web -- Grundlagen" .
springer:Publisher ex:Name        "Springer Verlag" .
```

likewise triples with coinciding subject and predicate:

```
@prefix ex:  <http://ex.org/> .

ex:SemanticWeb ex:Author ex:Hitzler, ex:Krötzsch,
                         ex:Rudolph, ex:Sure ;
               ex:Titel  "Semantic Web -- Grundlagen" .
```

# XML Syntax of RDF

- Turtle intuitively understandable, machine-processable
- yet, better tool support and available libraries for XML
- thus: XML syntax more wide-spread

# XML Syntax of RDF

- like in XML, name spaces are used in order to disambiguate tag names
- RDF-specific tags have a predefined name space, by convention abbreviated with 'rdf'

```
<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF
 xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
 xmlns:ex="http://example.org/">

 <rdf:Description rdf:about="http://example.org/SemanticWeb">
  <ex:publishedBy>
   <rdf:Description rdf:about="http://springer.com/Publisher"/>
  </ex:publishedBy>
 </rdf:Description>

</rdf:RDF>
```

# XML Syntax of RDF

- the rdf:Description element encodes the subject (the IRI of which is stated as the value of the associated rdf:about attribute)
- every element directly nested into an rdf:Description element denotes a predicate (the IRI of which is the element name),
- predicate elements in turn contain the triple's object as rdf:Description element

```
:
:
 <rdf:Description rdf:about="http://example.org/SemanticWeb">
  <ex:publishedBy>
   <rdf:Description rdf:about="http://springer.com/Publisher"/>
  </ex:publishedBy>
 </rdf:Description>
:
```

# XML Syntax of RDF

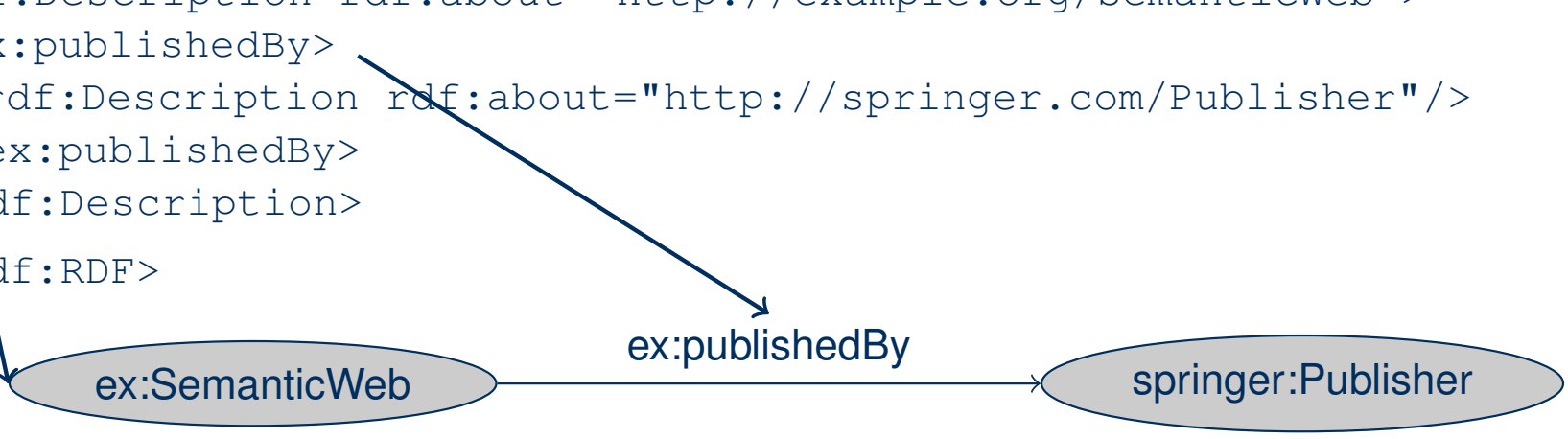
```
<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:ex="http://example.org/">
<rdf:Description rdf:about="http://example.org/SemanticWeb">
 <ex:publishedBy>
  <rdf:Description rdf:about="http://springer.com/Publisher"/>
 </ex:publishedBy>
</rdf:Description>
</rdf:RDF>
```

# XML Syntax of RDF

```
<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:ex="http://example.org/">
<rdf:Description rdf:about="http://example.org/SemanticWeb">
 <ex:publishedBy>
  <rdf:Description rdf:about="http://springer.com/Publisher"/>
 </ex:publishedBy>
</rdf:Description>
</rdf:RDF>
```

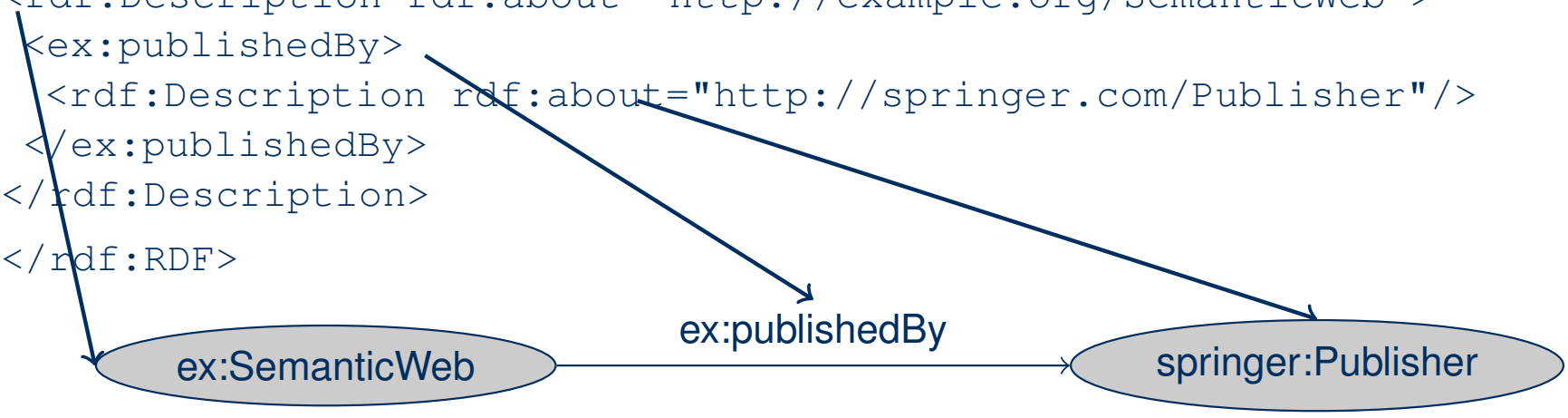
# XML Syntax of RDF

```
<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:ex="http://example.org/">
<rdf:Description rdf:about="http://example.org/SemanticWeb">
 <ex:publishedBy>
  <rdf:Description rdf:about="http://springer.com/Publisher"/>
 </ex:publishedBy>
</rdf:Description>
</rdf:RDF>
```



# XML Syntax of RDF

```
<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:ex="http://example.org/">
<rdf:Description rdf:about="http://example.org/SemanticWeb">
 <ex:publishedBy>
  <rdf:Description rdf:about="http://springer.com/Publisher"/>
 </ex:publishedBy>
</rdf:Description>
</rdf:RDF>
```



# XML Syntax of RDF

- untyped literals can be included as free text into the predicate element
- condensed forms admissible:
  - one subject containing several property elements
  - one object description serves as subject for another triple

```
<rdf:Description rdf:about="http://example.org/SemanticWeb">
 <ex:Title>Semantic Web -- Grundlagen</ex:Title>
 <ex:publishedBy>
  <rdf:Description rdf:about="http://springer.com/Publisher"/>
   <ex:Name>Springer Verlag</ex>Name>
  </rdf:Description>
 </ex:publishedBy>
</rdf:Description>
```

# XML Syntax of RDF

- alternative (but semantically equivalent) representation of literals as XML attributes
- property IRIs are then used as attribute names
- object IRIs can be given as value of the rdf:resource attribute inside a property tags

```
<rdf:Description rdf:about="http://example.org/SemanticWeb"
                 ex:Title="Semantic Web -- Grundlagen">
 <ex:publishedBy rdf:resource="http://springer.com/Publisher"/>
</rdf:Description>
<rdf:Description rdf:about="http://springer.com/Verlag"
                 ex:Name="Springer Verlag"/>
```

# RDF/XML Syntax: Complications

- name spaces are needed (not just for abbreviation reasons), because colons inside XML elements and attributes are always interpreted as name space delimiters
- problem: in XML, no name spaces in attribute values allowed (would be interpreted as IRI schema), thus we cannot write:
  `rdf:about="ex:SemanticWeb"`
- “work around” via XML entities:
  Declaration:
  `<!ENTITY ex 'http://example.org/'>`
  Usage:
  `rdf:resource="&ex;SemanticWeb"`

# RDF/XML Syntax: Base IRIs

- usage of base IRIs:

```
<rdf:RDF
 xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
 xmlns:base="http://example.org/">

 <rdf:Description rdf:about="SemanticWeb">
  <ex:publishedBy rdf:resource="http://springer.com/Publisher"/
 </rdf:Description>

</rdf:RDF>
```

- relative IRIs (i.e. those that are to be preceded by the given base IRI) are recognized by the absence of a schema part

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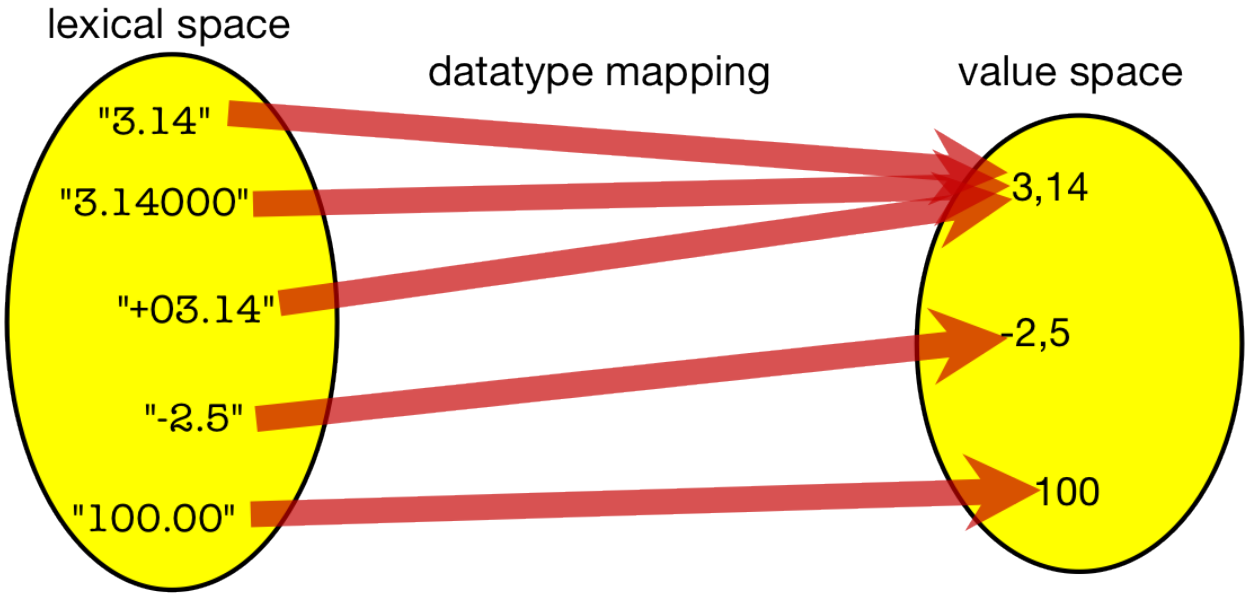
# Datatypes

Example: `xsd:decimal`



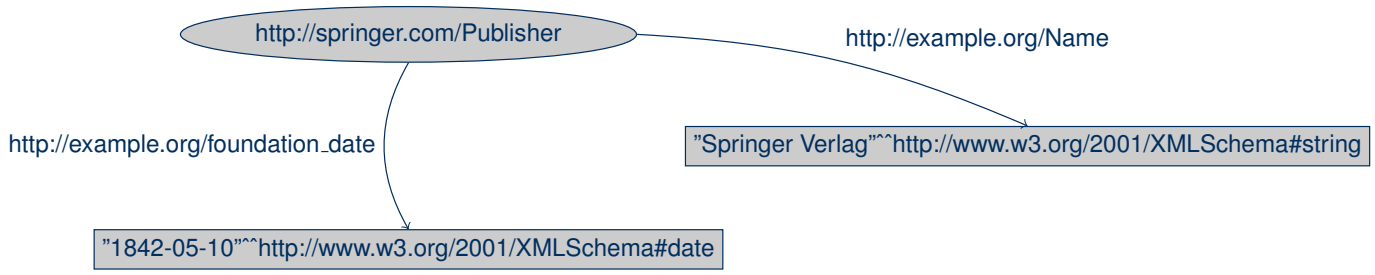

For xsd:decimal holds ”3.14”=”+03.14”
But not for xsd:string !

# Datatypes in RDF

- by now: untyped literals, treated like strings (e.g.: ”02”<”100”<”11”<”2”)
- typing allows for a better (more semantic = meaning-adequate) handling of values
- datatypes are themselves denoted by IRIs and can essentially be freely chosen
- common: usage of xsd datatypes
- syntax:
  ”datavalue”^^datatype_IRI

# Datatypes in RDF – Example

Graph:




Turtle:

```
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
<http://springer.com/Publisher>
   <http://example.org/Name> "Springer Verlag"^^xsd:string ;
   <http://example.org/foundation\_date> "1842-05-10"^^xsd:date .
```

XML:

```
<rdf:Description rdf:about="http://springer.com/Publisher">
 <ex:Name rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
    Springer Verlag
 </ex:Name>
 <ex:foundation\_date rdf:datatype="http://www.w3.org/2001/XMLSchema#date">
    1842-05-10
 </ex:foundation\_date>
</rdf:Description>
```

# XML Schema – Canonical Values

- there may be several lexical forms for one value
- one of these is picked as the value's canonical form
- useful to detect equivalence between different notations of the same values
- the following lexical forms of the datatype `decimal` represent the same value: 100.5, +100.5, 0100.5, 100.50, 100.500, 100.5000, the canonical variant is: 100.5

# The Predefined Datatype

- rdf:XMLLiteral is the only datatype that is pre-defined within the RDF standard
- denotes arbitrary balanced XML snippets
- in RDF/XML special syntax for unambiguous representation:

```
<rdf:Description rdf:about="http://example.org/SemanticWeb">
 <ex:Titel rdf:parseType="Literal">
    <b>Semantic Web</b><br />
    Grundlagen
 </ex:Titel>
</rdf:Description>
```

# Language Information and Datatypes

- language information can only be provided for untyped literals
- Example:

XML:

```
<rdf:Description rdf:about="http://springer.com/Publisher">
 <ex:Name xml:lang="de">Springer Verlag</ex:Name>
 <ex:Name xml:lang="en">Springer Science+Business
                        Media</ex:Name>
</rdf:Description>
```

Turtle:

```
<http://springer.com/Publisher> <http://example.org/Name>
"Springer Verlag"@de, "Springer Science+Business Media"@en .
```

# Language Information and Datatypes

According to the spec, the following literals are all different from each other:

```
@prefix xsd: <http://www.w3.org/2001/XMLSchema#>
<http://springer.com/Verlag> <http://example.org/Name>
"Springer Verlag", "Springer Verlag"@de,
"Springer Verlag"^^xsd:string .
```

In practice they are, however, often implemented as equal.

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# Multi-Valued Relationships

- Cooking with RDF:
  “For the preparation of Chutney, you need 1 lb green mango, a teaspoon Cayenne pepper, . . . ”
- first modeling attempt:

```
@prefix ex: <http://example.org/> .
ex:Chutney ex:hasIngredient "1lb green mango",
                            "1 tsp. Cayenne pepper",
                            ...
```

- Not satisfactory: ingredients plus amounts encoded as one string. Search for recipes containing green mango not possible (or difficult).

# Multi-Valued Relationships

- Cooking with RDF:
  “For the preparation of Chutney, you need 1 lb green mango, a teaspoon Cayenne pepper, . . . ”
- second modeling attempt:

```
@prefix ex: <http://example.org/> .
ex:Chutney ex:hasIngredient ex:greenMango;
           ex:amount "1 lb";
           ex:hasIngredient ex:CayennePepper;
           ex:amount "1 tsp.";
           ...
```

- Even worse: no unique assignment of ingredient and amounts possible.

# Multi-Valued Relationships

- Problem: we have a proper three-valued (aka: ternary) relationship (cf. databases)

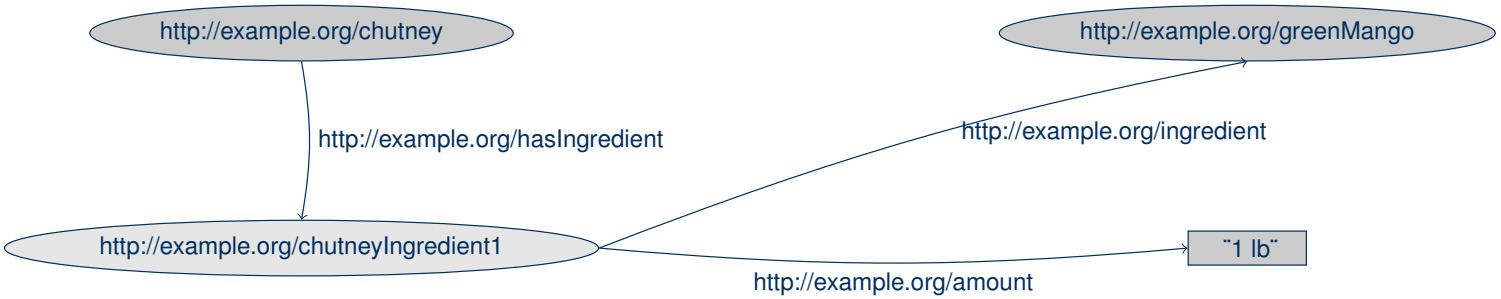
| dish | ingredient | amount |
|---|---|---|
| chutney | green mango | 1 lb |
| chutney | Cayenne pepper | 1 tsp. |

- direct representation in RDF not possible
- solution: introduction of auxiliary nodes

# Multi-Valued Relationships

auxiliary nodes in RDF:

- as graph




- Turtle syntax (using rdf:value for the primary component)

```
@prefix ex: <http://example.org/> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
ex:chutney                ex:hasIngredient ex:chutneyIngredient1 .
ex:chutneyIngredient1     rdf:value        ex:greenMango;
                          ex:amount        "1 lb" .
...
```

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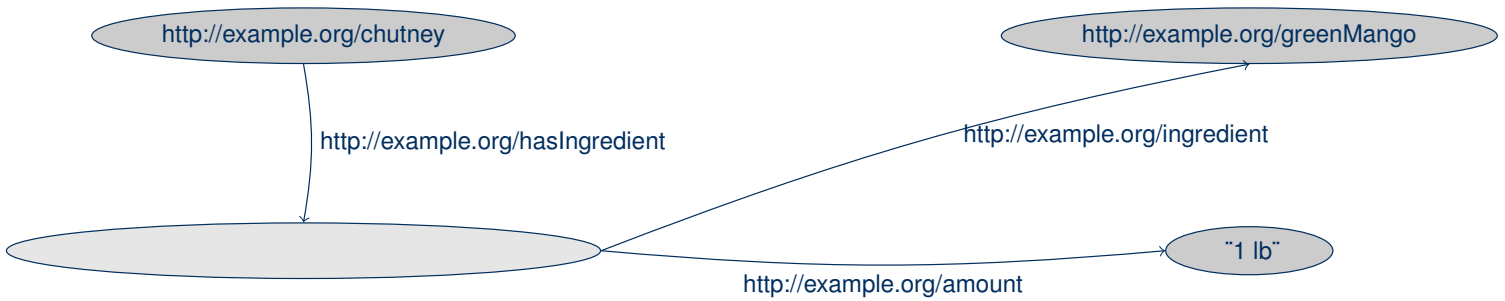
# Blank Nodes

auxiliary nodes in RDF:

- blank nodes (aka bnodes) can be used for resources that need not be named (e.g. auxiliary nodes)
- can be interpreted as existential statement
- syntax (as graph):



# Blank Nodes

RDF/XML-Syntax:

```
<rdf:Description rdf:about="http://example.org/chutney">
  <ex:hasIngredient rdf:nodeID="id1" />
</rdf:Description>
<rdf:Description rdf:nodeID="id1">
  <ex:ingredient rdf:resource="http://example.org/greenMango" />
  <ex:amount>1 lb<ex:amount/>
</rdf:Description>
```

abbreviated:

```
<rdf:Description rdf:about="http://example.org/chutney">
  <ex:hasIngredient rdf:parseType="Resource">
    <ex:ingredient rdf:resource="http://example.org/greenMango" />
    <ex:amount>1 lb<ex:amount/>
  </ex:hatsIngredient>
</rdf:Description>
```

# Blank Nodes

Turtle syntax:

```
@prefix ex: <http://example.org/> .
ex:chutney ex:hasIngredient  _:id1 .
_:id1      ex:ingredient     ex:greenMango ;
           ex:amount         "1 lb" .
```

abbreviated:

```
@prefix ex: <http://example.org/> .
ex:chutney ex:hasIngredient [
           ex:ingredient ex:greenMango ;
           ex:amount     "1 lb" ] .
```

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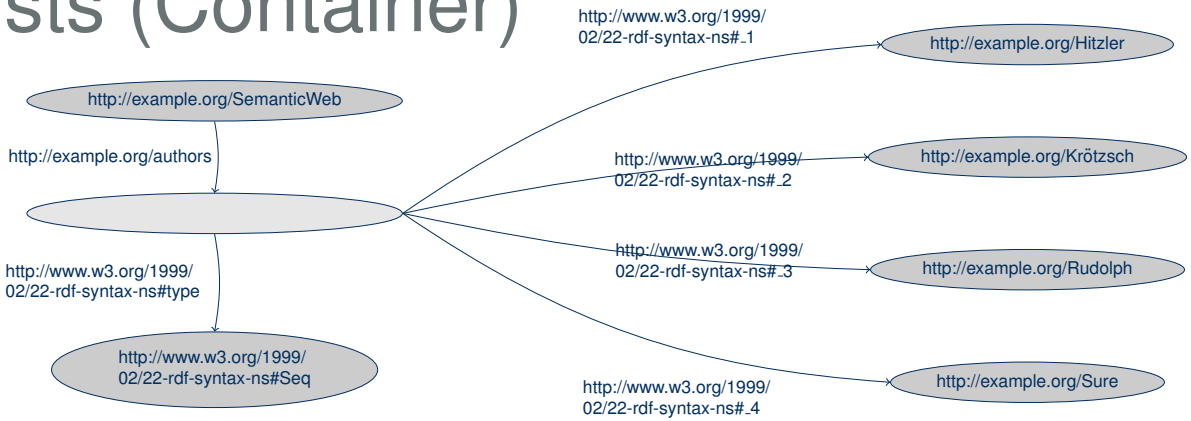
# Lists

- General data structures for enumerating arbitrary many resources (where order is relevant), e.g. autors of a book
- distinction between
  - open lists (container)
    new entries can be added
  - closed lists (collections)
    new entries can not be added
- These structures are modeled using the already discussed means of representation, i.e. no additional expressivity!

# Open Lists (Container)

graph:




abbreviated in RDF/XML:

```
<rdf:Description rdf:about="http://example.org/SemanticWeb">
  <ex:authors>
    <rdf:Seq>
      <rdf:li rdf:resource="http://example.org/Hitzler />
      <rdf:li rdf:resource="http://example.org/Krötzsch />
      <rdf:li rdf:resource="http://example.org/Rudolph />
      <rdf:li rdf:resource="http://example.org/Sure />
    </rdf:Seq>
  </ex:authors>
</rdf:Description>
```

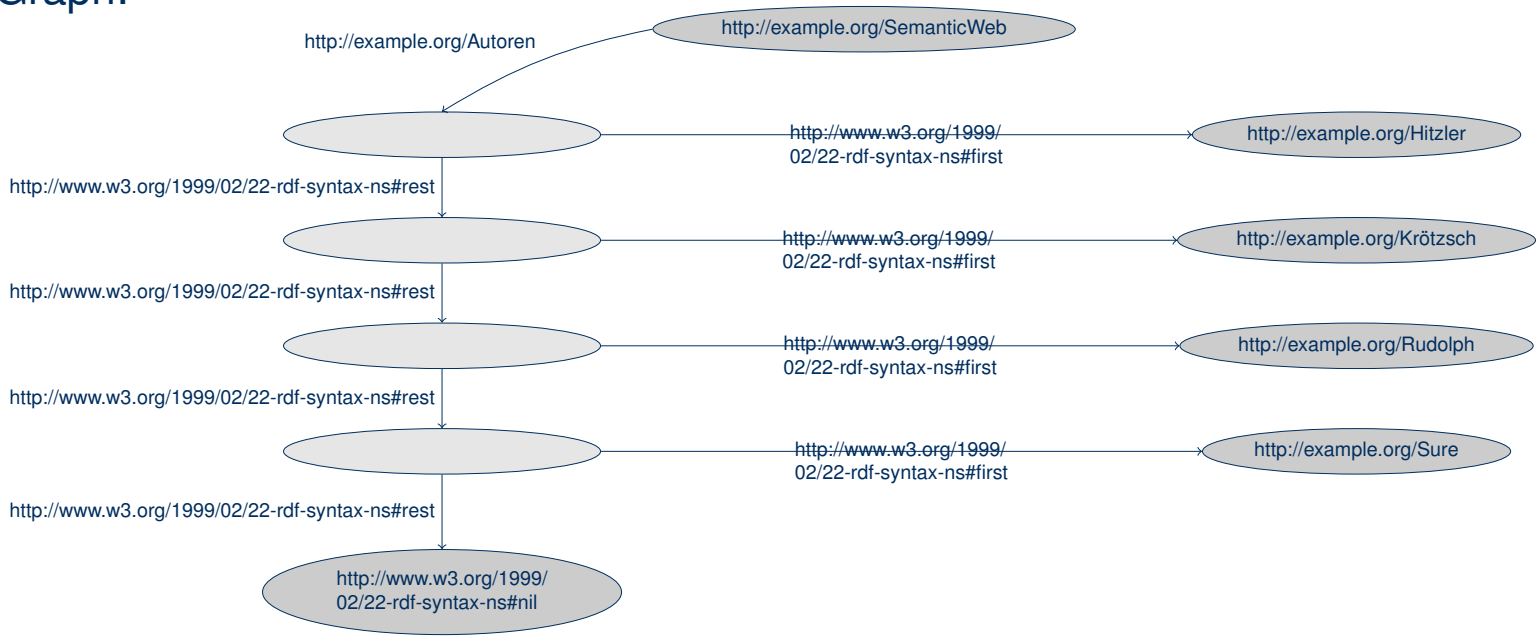
# Types of Open Lists

Via `rdf:type` the a list type is assigned to the root node of the list:

- rdf:Seq
  ordered list (sequence)
- rdf:Bag
  unordered set
  indicates that the encoded order is irrelevant
- rdf:Alt
  set of alternatives
  normally only one entry will be relevant

# Closed Lists (Collections)

Graph:




underlying idea: recursive deconstruction of the list into head element and (possibly empty) rest list

# Closed Lists (Collections)

## RDF/XML-Syntax

```
<rdf:Description rdf:about="http://example.org/SemanticWeb>
  <ex:authors rdf:parseType="Collection">
    <rdf:Description rdf:about="http://example.org/Hitzler />
    <rdf:Description rdf:about="http://example.org/Krötzsch />
    <rdf:Description rdf:about="http://example.org/Rudolph />
    <rdf:Description rdf:about="http://example.org/Sure />
  </ex:authors>
</rdf:Description>
```

## Turtle

```
@prefix ex: <http://example.org/> .
ex:SemanticWeb ex:authors
  ( ex:Hitzler ex:Krötzsch ex:Rudolph ex:Sure ) .
```

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# Graph Definitions

- An RDF triple consists of three components:
  1. the subject, which can be an IRI or a bnode,
  2. the predicate, which has to be an IRI, and
  3. the object, which can be an IRI, a bnode or a Literal.
- The predicate is also denoted as property.
- An RDF graph (or simply graph) is a set of RDF triples. The graph nodes are the subjects and objects of these triples.
- A (proper) subgraph of an RDF graph is a (proper) subset of its triples.
- A ground graph is an RDF graph without bnodes.

# Graph Definitions

- A name is an IRI or a literal.
- A typed literal comprises two names: the literal itself and its type reference (IRI)
- A set of names is referred to as a vocabulary.
- The vocabulary of a graph is the set of all names occurring as subject, predicate or object in one of its triples.
- Remark: The IRIs which only occur inside the typed literals do not belong to the graph's vocabulary.

# Graph Definitions

- Let $M$ be a mapping from bnodes to a set of literals, bnodes and IRIs. We denote $M$ as instance mapping.
- Every graph $G'$ obtained by substituting (some or all) bnodes $\ell$ in $G$ by $M(\ell)$, is an instance of $G$.
- An instance with respect to a vocabulary $V$ is an instance in which all names replacing bnodes are from $V$.
- A proper instance of a graph is an instance wherein at least one bnode has been replaced by a name or identified with another bnode.
- Graphs that only differ in the labels of their bnodes are considered equivalent.

# Graph Definitions

- An RDF graph is lean if it does not have an instance that is a proper subgraph of it.

$\rightsquigarrow$ Non-lean graphs are internally redundant.

```
{ex:a ex:p _:x .  _:y ex:p _:x .}        (1)
{ex:a ex:p _:x .  _:x ex:p _:x .}        (2)
```

# Graph Definitions

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```

- (1) is not lean, but (2) is

# Graph Definitions

The merge of two RDF graphs $G_1$ and $G_2$ is defined as follows:

- if $G_1$ and $G_2$ do not have common bnodes, the merge is the union $G_1 \cup G_2$
- otherwise, the merge of $G_1$ and $G_2$ is the union of $G_1'$ und $G_2'$, where $G_1'$ and $G_2'$ are equivalent to $G_1$ and $G_2$, respectively, but do not have blank nodes in common
- if this renaming of variables is carried out, one usually says “blank nodes have been are standardized apart”

# Agenda

- Motivation
- RDF data model
- Syntax for RDF: Turtle and XML
- Datatypes
- Multi-Valued Relationships
- Blank Nodes
- Lists
- Graph Definitions
- RDF in Practice

# Popularty of RDF

- today, a plethora of RDF tools exists
- there are libraries for virtually all programming languges
- freely available systems to work with large RDF data sets (so-called RDF Stores or Triple Stores)
- also commercial players (like Oracle) support RDF
- RDF is basis for other data formats: RSS 1.0, XMP (Adobe), SVG (vector graphics)

# Assessment of RDF

- widely supported standard for data storage and interchange
- enables syntax-independent representation of distributed information via a graph-based data model
- pure RDF very oriented toward idividuals
- few possibilities to encode schema knowledge
- $\rightarrow$ RDF Schema (next lecture)

# RDFa – RDF-in-attributes

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML+RDFa 1.0//EN"
    "http://www.w3.org/MarkUp/DTD/xhtml-rdfa-1.dtd">
<html xmlns="http://www.w3.org/1999/xhtml"
    xmlns:foaf="http://xmlns.com/foaf/0.1/"
    xmlns:dc="http://purl.org/dc/elements/1.1/"
    version="XHTML+RDFa 1.0" xml:lang="en">
  <head>
    <title>John's Home Page</title>
    <base href="http://example.org/john-d/" />
    <meta property="dc:creator" content="Jonathan Doe" />
    <link rel="foaf:primaryTopic"
        href="http://example.org/john-d/#me" />
  </head>
```

# RDFa – RDF-in-attributes

```
  <body about="http://example.org/john-d/#me">
    <h1>John's Home Page</h1>
    <p>My name is <span property="foaf:nick">John D</span>
       and I like <a href="http://www.neubauten.org/"
       rel="foaf:interest" xml:lang="de">Einstürzende
       Neubauten</a>.
    </p>
    <p>
      My <span rel="foaf:interest"
      resource="urn:ISBN:0752820907">favorite book is the
      inspiring <span about="urn:ISBN:0752820907"><cite
      property="dc:title">Weaving the Web</cite> by
      <span property="dc:creator">Tim Berners-Lee</span>
      </span>
     </span>
    </p>
  </body>
</html>
```

# RDFa – RDF Version

```
<?xml version="1.0" encoding="UTF-8"?>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:foaf="http://xmlns.com/foaf/0.1/"
    xmlns:dc="http://purl.org/dc/elements/1.1/">
  <rdf:Description rdf:about="http://example.org/john-d/">
    <dc:creator xml:lang="en">Jonathan Doe</dc:creator>
    <foaf:primaryTopic>
      <rdf:Description rdf:about="http://example.org/john-d/#me">
        <foaf:nick xml:lang="en">John D</foaf:nick>
        <foaf:interest rdf:resource="http://www.neubauten.org/"/>
        <foaf:interest>
          <rdf:Description rdf:about="urn:ISBN:0752820907">
            <dc:creator xml:lang="en">Tim Berners-Lee</dc:creator>
            <dc:title xml:lang="en">Weaving the Web</dc:title>
          </rdf:Description>
        </foaf:interest>
      </rdf:Description>
    </foaf:primaryTopic>
  </rdf:Description>
</rdf:RDF>
```

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