Knowledge Representation and Semantic Technologies

Introduction to the Semantic Web

Riccardo Rosati

Corso di Laurea Magistrale in Ingegneria Informatica
Sapienza Università di Roma
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What is the Semantic Web?

- “The Semantic Web is a Web of actionable information—information derived from data through a semantic theory for interpreting the symbols.”
- “The semantic theory provides an account of ‘meaning’ in which the logical connection of terms establishes interoperability between systems”

(Shadbot, Hall, Berners-Lee, The Semantic Web revisited, IEEE Intelligent Systems, May 2006)

The Semantic Web: why?

- search on the Web: problems...
- ...due to the way in which information is stored on the Web
- **Problem 1**: web documents do not distinguish between information content and presentation (“solved” by XML)
- **Problem 2**: different web documents may represent in different ways semantically related pieces of information
- this leads to hard problems for “intelligent” information search on the Web

Separating content and presentation

Problem 1: web documents do not distinguish between information content and presentation

- problem due to the HTML language
- problem “solved” by current technology
  - stylesheets (HTML, XML)
  - XML
- stylesheets allow for separating formatting attributes from the information presented

Separating content and presentation

- XML: eXtensible Mark-up Language
- XML documents are written through a user-defined set of tags
- tags are used to express the "semantics" of the various pieces of information

XML: example

HTML:

```
<H1>Seminari di Ingegneria del Software</H1>
  <UL>
    <LI>Teacher: Giuseppe De Giacomo
    <LI>Room: 7
    <LI>Prerequisites: none
  </UL>
```

XML:

```
<course>
  <title>Seminari di Ingegneria del Software
  </title>
  <teacher>Giuseppe De Giacomo</teacher>
  <room>1AI, 1I</room>
  <prereq>none</prereq>
</course>
```

Limitations of XML

XML does not solve all the problems:

- legacy HTML documents
- different XML documents may express information with the same meaning using different tags

The need for a “Semantic” Web

Problem 2: different web documents may represent in different ways semantically related pieces of information

- different XML documents do not share the “semantics” of information
- idea: annotate (mark-up) pieces of information to express the “meaning” of such a piece of information
- the meaning of such tags is shared!

$\Rightarrow$ shared semantics

The Semantic Web initiative

viewpoint:

the Web = a web of data

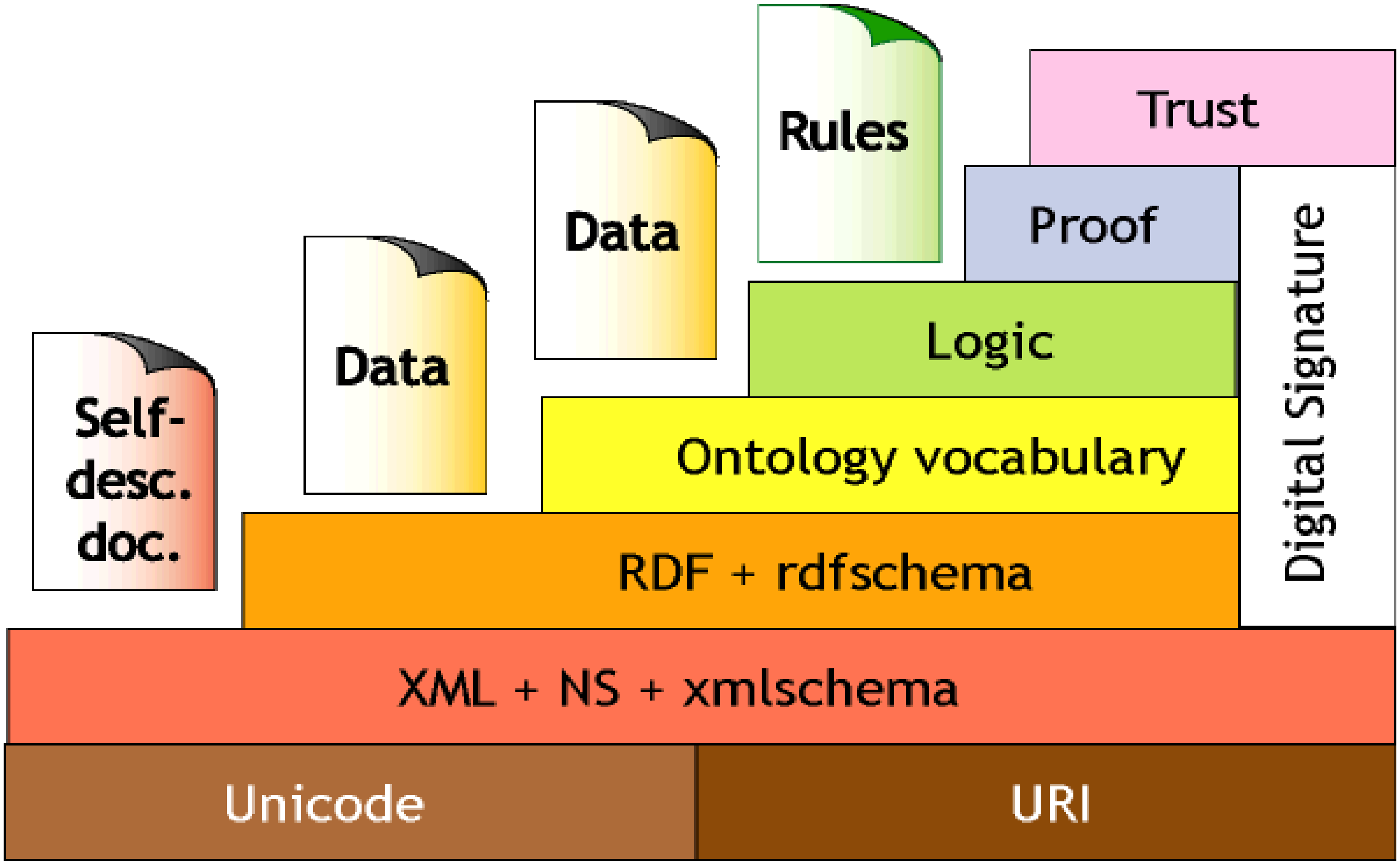
goal:

to provide a common framework to share data on the Web across application boundaries

main ideas:

- ontology
- standards
- “layers”

The Semantic Web Tower



The Semantic Web Layers

- XML layer
- RDF + RDFS layer
- Ontology layer
- Proof-rule layer
- Trust layer

The XML layer

- XML (eXtensible Markup Language)
  - user-definable and domain-specific markup
- URI (Uniform Resource Identifier)
  - universal naming for Web resources
  - same URI = same resource
  - URIs are the “ground terms” of the SW

- W3C standards

The RDF + RDFS layer

RDF = a simple conceptual data model

W3C standard (1999)

RDF model = set of RDF triples

triple = expression (statement)

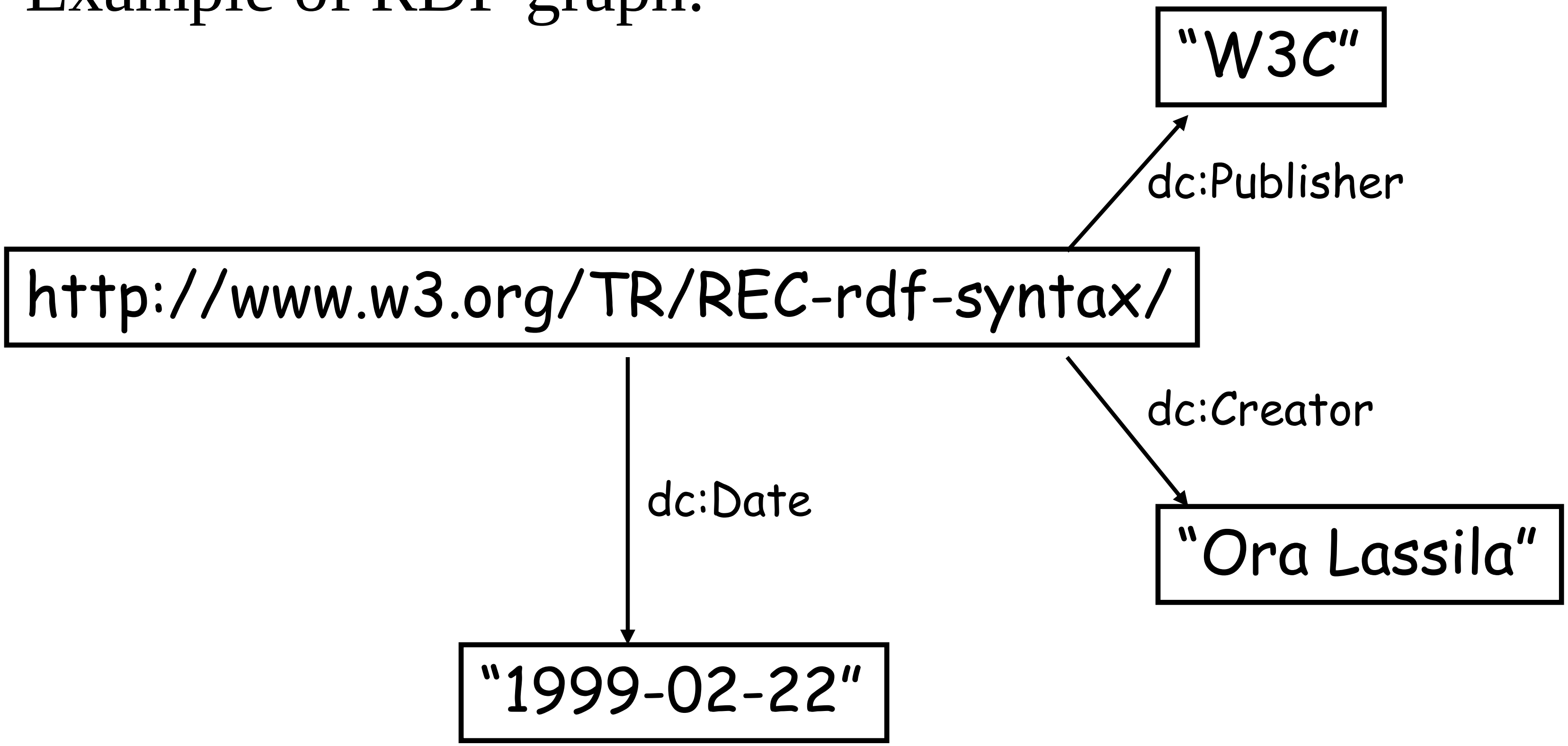
(subject, predicate, object)

- subject = resource
- predicate = property (of the resource)
- object = value (of the property)

=> an RDF model is a **graph**

The RDF + RDFS layer

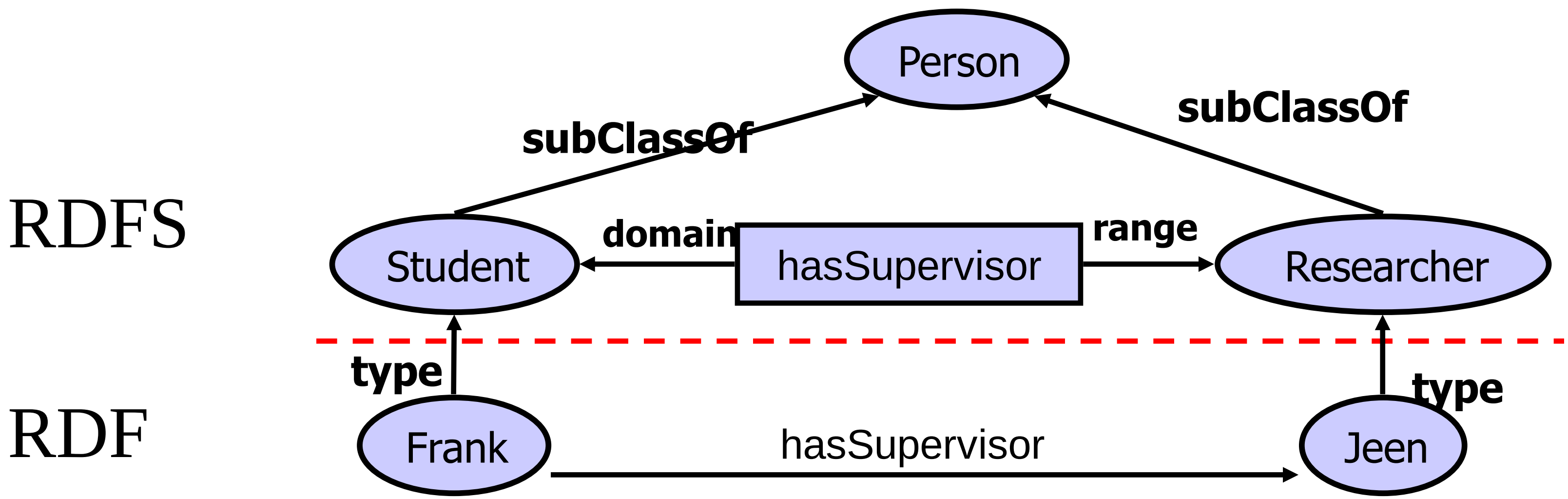
Example of RDF graph:



The RDF + RDFS layer

- RDFS = RDF Schema
- “vocabulary” for RDF
- W3C standard (2004)

example:



The Ontology layer

ontology = shared conceptualization

$\Rightarrow$ conceptual model

(more expressive than RDF + RDFS)

$\Rightarrow$ expressed in a true knowledge representation language

OWL (Web Ontology Language) = standard language for ontologies

The proof/rule layer

beyond OWL:

- proof/rule layer
- rule: informal notion
- rules are used to perform inference over ontologies
- rules as a tool for capturing further knowledge (not expressible in OWL ontologies)

The Trust layer

- SW top layer:
- support for provenance/trust
- provenance:
  - where does the information come from?
  - how this information has been obtained?
  - can I trust this information?
- largely unexplored issue
- no standardization effort

The Semantic Web: main ingredients

- underlying web layer (URI, XML)
  - reusing and extending web technologies
- basic conceptual modeling language (RDF)
- ontology language (OWL)
- rules/proof
- reusing and extending AI technologies
  - knowledge representation
  - automated reasoning
- ...and database technologies
  - data integration

The notion of ontology

- ontology = shared conceptualization of a domain of interest
- shared vocabulary => simple (shallow) ontology
- (complex) relationships between “terms” => deep ontology
- AI view:
  - ontology = logical theory (knowledge base)
- DB view:
  - ontology = conceptual model

Ontologies: example

```
class-def animal                          % animals are a class
class-def plant                           % plants are a class
  subclass-of NOT animal                  % that is disjoint from animals
class-def tree
  subclass-of plant                       % trees are a type of plants
class-def branch
  slot-constraint is-part-of              % branches are parts of some tree
     has-value tree
     max-cardinality 1
class-def defined carnivore               % carnivores are animals
  subclass-of animal
  slot-constraint eats                    % that eat any other animals
     value-type animal
class-def defined herbivore               % herbivores are animals
  subclass-of animal, NOT carnivore % that are not carnivores, and
  slot-constraint eats                      % they eat plants or parts of plants
     value-type plant OR (slot-constraint is-part-of has-value plant)
```

Ontologies: the role of logic

- ontology = logical theory
- why?
  - declarative
  - formal semantics
  - reasoning (sound and complete inference techniques)
- well-established correspondence between conceptual modeling formalisms and logic

Ontologies and Description Logics

- OWL is based on a fragment of first-order predicate logic (FOL)
- Description Logics (DLs) = subclasses of FOL
  - only unary and binary predicates
  - function-free
  - quantification allowed only in restricted form
  - (variable-free syntax)
  - decidable reasoning
- DLs are one of the most prominent languages for Knowledge Representation

Ontologies and Description Logics

- expressive abilities of DLs have been widely explored
- reasoning in DLs has been extensively studied
- DL reasoners have been developed and optimized

$\Rightarrow$ DLs as a central technology for the SW

Rule-based formalisms

- Prolog
- Logic programming
- Constraint (logic) programming
- Production rules
- Datalog
- ...

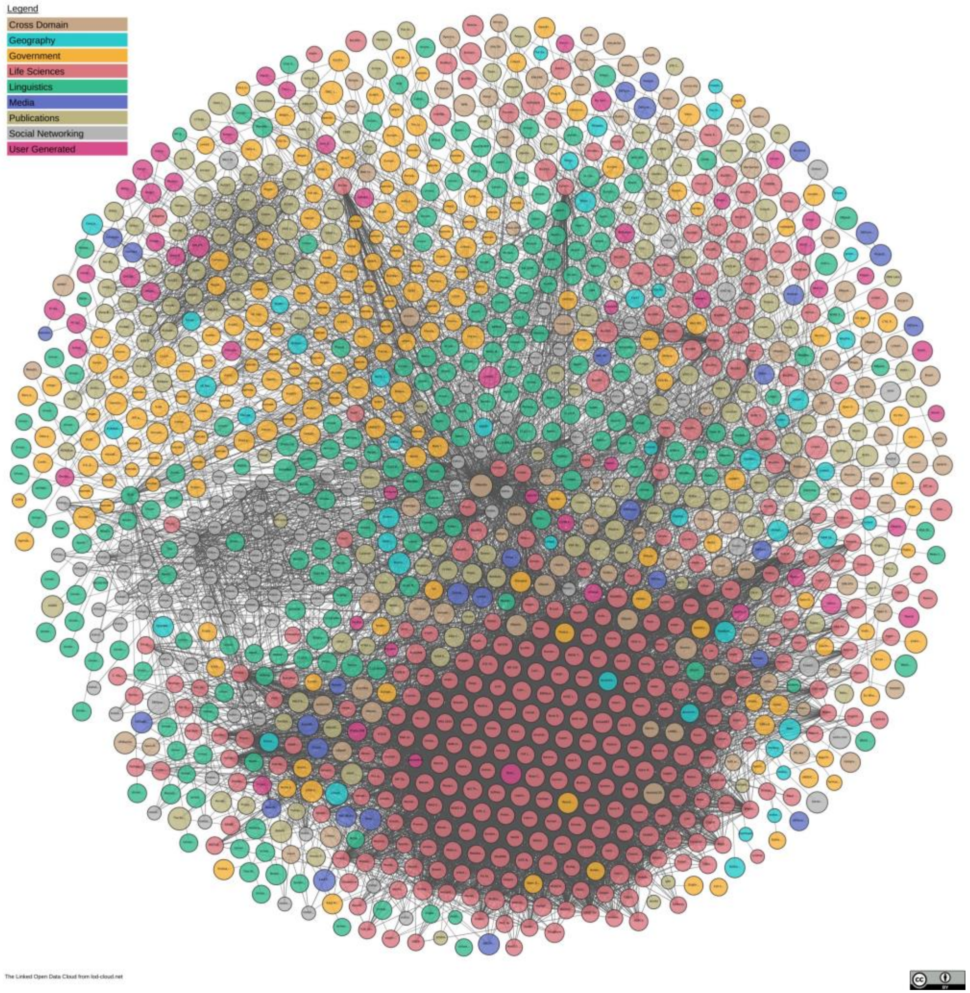
RIF (Rule Interchange Format): W3C recommendation (2010)

Linked Data

Linked Data: a recommended best practice for exposing, sharing, and connecting pieces of data, information, and knowledge on the Semantic Web using URIs and RDF

Linking Open Data (LOD): “The goal of the W3C SWEO Linking Open Data community project is to **extend the Web with a data commons by publishing various open data sets as RDF on the Web** and by **setting RDF links between data items from different data sources**.
RDF links enable you to navigate from a data item within one data source to related data items within other sources using a Semantic Web browser.
As query results are structured data and not just links to HTML pages, they can be used within other applications.”

The LOD cloud diagram



The Linked Open Data cloud diagram as in March 2019, from lod-cloud.net