Semantic Web:
Overviews and Applications

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Contents

- Semantic Web in General
- Roles of XML and RDF in Semantic Web
- Ontologies
- Web Ontology Language (OWL)
- Semantic Web Applications
- Trends

Current Web is for Humans

- The current Web is for humans
  - The current Web represents information using
    - Natural language
    - Graphics, multimedia, page layout, etc.
  - Humans can process this easily
    - Can deduce facts from partial information
    - Can create mental association
    - Are used to various sensory information
  - Tasks often require to *combine* data on the Web
    - Hotel and travel info may come from different sites
    - Searches in different digital libraries
  - Again, humans combine these information easily

Current Web is *Not* for Machines

- Machines are ignorant
  - Partial information is unusable
  - Difficult to make sense from, eg, an image
  - Drawing analogies automatically is difficult
  - Difficult to combine information
    - Is `<foo:creator>` same as `<bar:author>` ?
    - How to combine different XML hierarchies?
- Problems
  - Search engines generates too many false hits
  - Web service is only described in terms of input and output : necessary to characterize the service in terms of *semantics*
  - Etc.

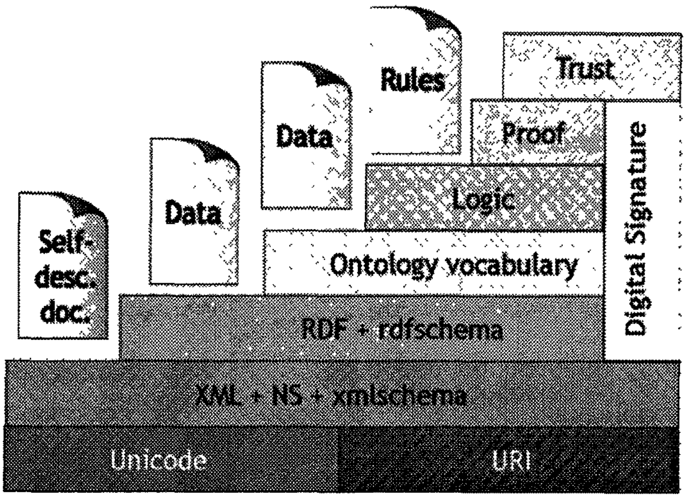
What is Needed?

- A resource should provide information about itself, called *metadata*
  - Metadata should be in a machine processable format
  - Agents should be able to *reason* about (meta)data
  - Metadata vocabularies should be defined
- To make metadata machine processable, we need
  - Unambiguous names for resources (URIs)
  - A common data model for expressing metadata (RDF)
    - .. and ways to access the metadata on the Web
  - Common vocabularies (Ontologies)

Nature of the Semantic Web

- What is the Semantic Web?
  - *A metadata based infrastructure for reasoning on the Web*
  - It *extends* the current Web (and does not replace it)
  - Information is given *well-defined meaning*
- Goals of the Semantic Web
  - To develop enabling *standards* and *technologies* designed to help machines understand more information on the Web
  - To support richer discovery, data integration, navigation, and automation of tasks

Semantic Web Layers



How XML Fits into the Semantic Web?

- XML characteristics
  - XML has a standard syntax for metadata
  - XML has a standard structure for both documents and data
- XML is the *syntactical foundation layer* of Semantic Web

```
<note>
<date>12/11/99</date>
<to>Tove</to>
<from>Jani</from>
<heading>Reminder</heading>
<body>Don't forget me this weekend!</body>
</note>
```

XML is *Not* Enough

- Limitations of XML
  - Many ways to say the same thing
    - Multiple valid structures for the same data

```
<note>
<date>
 <day>12</day>
 <month>11</month>
 <year>99</year>
</date>
<to>Tove</to>
<from>Jani</from>
<heading>Reminder</heading>
<body>Don't forget me this weekend!</body>
</note>
```

  - Not impose a common interpretation of a data
    - heading vs. title
    - price vs. cost

RDF (Resource Description Framework)

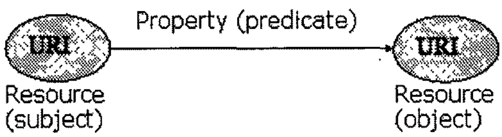
- RDF is an infrastructure that enables *the encoding, exchange and reuse of structured metadata*
- RDF is a foundation for processing metadata
  - Provides interoperability between applications that exchange machine-understandable information on the Web
- RDF is the *semantic foundation layer* of Semantic Web

RDF Model

- The metadata is a set of *statements*
- Statements can be modeled with:
  - *Resources*: an element, a URI, a literal, ...
  - *Properties*: directed relations between two resources
  - *Statements*: "triples" of two resources bound by a property
    - Usual terminology: (s,p,o) for subject, property, object
- RDF is a general model for such statements
  - ...with machine readable formats (e.g., RDF/XML, n3, Turtle, RXR)
  - RDF/XML is the official W3C format

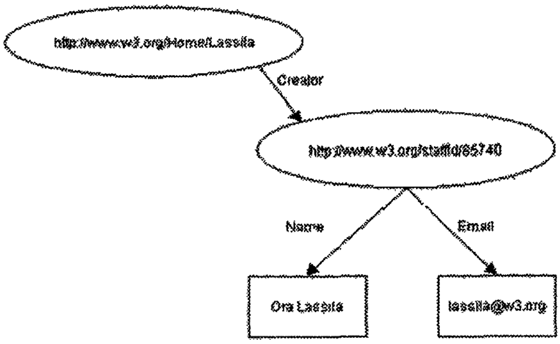
RDF is a Graph

- An (s,p,o) triple can be viewed as a labelled edge in a graph
  - A set of RDF statements is a *directed, labelled graph*
  - Both "objects" and "subjects" are the graph nodes
  - "properties" are the edges
- One should "think" in terms of graphs
  - XML or n3 syntax are only the tools for practical usage!
  - The term "serialization" is often used for encoding



RDF Graph Example

"The individual referred to by employee id 85740 is named Ora Lassila
and has the email address lassila@w3.org.
The resource http://www.w3.org/Home/Lassila was created by this individual."



Structured value with identifier

RDF/XML Serialization

"The individual referred to by employee id 85740 is named Ora Lassila
and has the email address lassila@w3.org.
The resource http://www.w3.org/Home/Lassila was created by this individual."

```
<rdf:RDF>
  <rdf:Description about="http://www.w3.org/Home/Lassila">
    <s:Creator>
      <rdf:Description about="http://www.w3.org/staffId/85740">
        <v:Name>Ora Lassila</v:Name>
        <v:Email>lassila@w3.org</v:Email>
      </rdf:Description>
    </s:Creator>
  </rdf:Description>
</rdf:RDF>
```

Containers

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- For referring to a collection of resources
  - E.g, to say that a work was created by more than one person, or to list the students in a course, or the software modules in a package
- Three types of container objects in RDF
  - Bag, Sequence, Alternative
- RDF representation of a collection of resources
  - RDF uses an additional resource that identifies the specific collection.
  - This resource must be declared to be an instance of one of the container object types, using the *type* property.
  - The membership properties are named simply "_1", "_2", "_3", etc.

Bag Example

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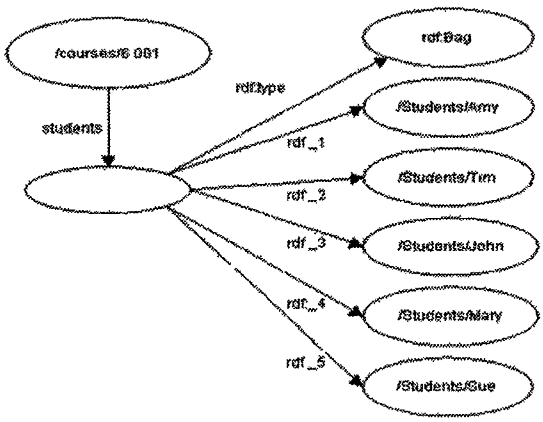
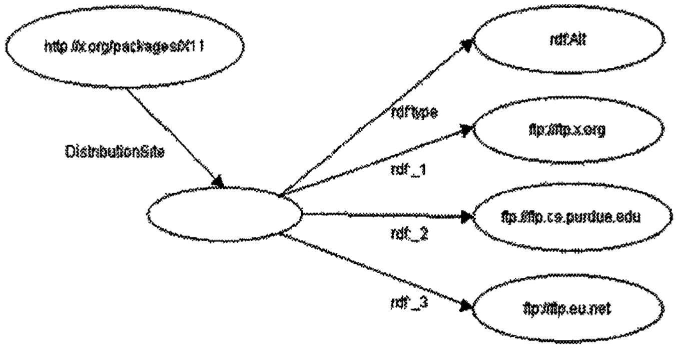
"The students in course 6.001 are Amy, Tim, John, Mary, and Sue."



Alternative Example

"The source code for X11 may be found at ftp.x.org, ftp.cs.purdue.edu, or ftp.eu.net."

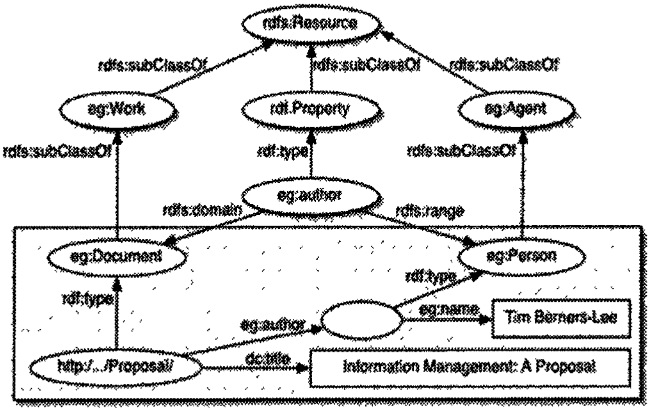


RDF Schema (RDFS)

- RDF Schemas are used to declare vocabularies
  - A schema defines the terms that will be used in RDF statements and gives specific meanings to them.
  - RDF Schema: officially "RDF Vocabulary Description Language"
- Provides a basic *type system* for use in RDF models
  - Defines resources and properties such as `Class` and `subClassOf` that are used in specifying application-specific schemas
  - A bit like defining record type for a database

RDFS Example

This example illustrates the use of the RDF Schema vocabulary for describing classes and properties, and the connection to application-level data



Ontology

- Why Ontology?
  - RDFS is useful, but does not solve all the issues
  - Complex applications may want more possibilities
  - Can a program *reason* about some terms?
    - "if <A> is left of <B> and <B> is left of <C>, is <A> left of <C>?"
    - obviously true for humans, not obvious for a program..
    - programs should be able to *deduce* such statements
  - If somebody else defines a set of terms: are they the same?
  - *Construct* classes, not just name them
  - Restrict a property range *when used for a specific class*

Ontology Definition

- An ontology is a formal, explicit specification of a shared conceptualization.
  (by T. Gruber, 1993, Studer et. al. 1998)
  - Conceptualization: an abstract model of how people think about things in the world, usually restricted to a particular subject area
  - Explicit specification: the type of concepts used and the constraints on their use are explicitly defined
  - Formal: the ontology should be machine understandable
  - Shared: an ontology captures consensual knowledge; it is not restricted to some individual but is accepted by a group

Web Ontology Language

- The Semantic Web needs a support of ontologies
  - Defines the *concepts* and *relationships* used to describe and represent an area of knowledge
  - The most typical kind of ontology for the Web has a *taxonomy* and a set of *inference rules*
- We need a *Web Ontology Language* to define
  - The terminology used in a specific context
  - More constraints on properties
  - The logical characteristics of properties
  - The equivalence of terms across ontologies
  - Etc.

OWL : W3C's Ontology Language

- A layer *on top* of RDFS with additional possibilities
- Outcome of various projects:
  - DARPA project: DAML
  - EU project: OIL
  - An attempt to merge the two: DAML+OIL
  - The latter was submitted to W3C
  - Lots of coordination with the core RDF work
  - Recommendation since early 2004

Classes in OWL

- In RDFS, you can subclass existing classes .. but, otherwise, that is all you can do
- In OWL, you can *construct* classes from existing ones:
  - Enumerate its content
  - Through intersection, union, complement
  - Through property restrictions
- To do so, OWL introduces its own `Class`.. and `Thing` to differentiate the *individuals* from the *classes*

Classes can be Enumerated

- Possible content is explicitly listed

```
<owl:Class rdf:ID="WineColor">
  <rdfs:subClassOf rdf:resource="#WineDescriptor"/>
  <owl:oneOf rdf:parseType="Collection">
    <owl:Thing rdf:about="#White"/>
    <owl:Thing rdf:about="#Rose"/>
    <owl:Thing rdf:about="#Red"/>
  </owl:oneOf>
</owl:Class>
```

Union Of Classes

- Essentially, set-theoretical union

```
<owl:Class rdf:ID="Fruit">
  <owl:unionOf rdf:parseType="Collection">
    <owl:Class rdf:about="#SweetFruit" />
    <owl:Class rdf:about="#NonSweetFruit" />
  </owl:unionOf>
</owl:Class>
```

- Other possibilities:
  - `complementOf`, `intersectionOf`

Property Restrictions

- (Sub)classes can be created by restricting the behaviour of a property *on that class*
- Restriction may be by:
  - Value constraints (i.e. further restrictions on the range)
    - *All* values must be from a class
    - *At least one* value must be from a class
  - Cardinality constraints (i.e., how many times the property can be used on an instance?)
    - Minimum, maximum, exact cardinality
  - `owl:Restriction` defines a blank node with restrictions
    - Refer to the property that is constrained
    - Define the restriction itself

Cardinality Restriction Example

```
<owl:Class rdf:ID="Vintage">
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#hasVintageYear"/>
      <owl:cardinality rdf:datatype="&xsd;nonNegativeInteger">1</owl:cardinality>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

Property Characterization

- In RDFS, properties are constrained by domain and range
- In OWL, one can also characterize their *behaviour*
  - Symmetric, transitive, functional, etc
- OWL separates data properties
  - "datatype property" means that its range are *typed* literals

Transitive Property Example

```
<owl:ObjectProperty rdf:ID="locatedIn">
  <rdf:type rdf:resource="&owl;TransitiveProperty" />
  <rdfs:domain rdf:resource="&owl;Thing" />
  <rdfs:range rdf:resource="#Region" />
</owl:ObjectProperty>

<Region rdf:ID="SantaCruzMountainsRegion">
  <locatedIn rdf:resource="#CaliforniaRegion" />
</Region>

<Region rdf:ID="CaliforniaRegion">
  <locatedIn rdf:resource="#USRegion" />
</Region>
```

Term Equivalence/Relations

- For classes:
  - `owl:equivalentClass`: two classes have the same individuals
  - `owl:disjointWith`: no individuals in common
- For properties:
  - `owl:equivalentProperty`: equivalent in terms of classes
  - `owl:inverseOf`: inverse relationship
- For individuals:
  - `owl:sameAs`: two URI refer to the same individual (e.g., concept)
  - `owl:differentFrom`: negation of `owl:sameAs`

Ontologies are Hard

- A full ontology-based application is a very complex system
  - In fact, it is turning mathematical logic into a program
- Hard to implement, heavy to run ..
- .. and not all applications may need it!
- Three layers of OWL are defined: Lite, DL, Full
  - Increasing level of complexity and expressiveness
  - "Full" is the whole thing
  - "DL (Description Logic)" restricts Full in some respects
  - "Lite" restricts DL even more

OWL Full

- No constraints on the various constructs
  - `owl:Class` is equivalent to `rdfs:Class`
  - `owl:Thing` is equivalent to `rdfs:Resource`
- This means that:
  - `Class` can also be an individual
    - It is possible to talk about class of classes, etc.
  - One can make statements on RDFS constructs
    - Declare `rdf:type` to be functional..
  - Etc..
- A real superset of RDFS

OWL Description Logic (DL)

- OWL DL characteristics
  - `owl:Class`, `owl:Thing`, `owl:ObjectProperty`, and `owl:DatatypeProperty` are *strictly separated*
    - A class *cannot* be an individual of another class
  - No mixture of `owl:Class` and `rdfs:Class` in definitions
    - Essentially: use OWL concepts only!
  - No statements on RDFS resources
  - No characterization of datatype properties possible
  - No cardinality constraint on transitive properties
  - *GOAL: maximal subset of OWL Full for which a decidable reasoning procedure is realizable*

OWL Lite

- OWL Lite characteristics
  - All of DL's restrictions, plus some more:
    - Class construction can be done only through:
      - intersection
      - property constraints
  - *GOAL: provide a minimal useful subset, easily implemented*
    - Simple class hierarchies can be built
    - Property constraints and characterizations can be used

Description Logic

- DL characteristics
  - An area in knowledge representation
  - Express and reason with complex definitions of, and relations among, objects and classes
  - Designed to focus on categories and their definitions
  - Inference Tasks
    - ***Subsumption***: checking if one category is a subset of another based on their definitions
    - ***Classification***: checking if an object is a subset of another based on their definitions
  - OWL DL is an embodiment of a Description Logic

Some Tools

- (Graphical) Editors
  - IsaViz
  - Protégé 2000
  - Further info on OWL tools at: http://www.w3.org/2001/sw/WebOnt/impls
- Programming environments
  - Jena 2: OWL reasoning
  - SWI-Prolog: RDF/OWL framework in Prolog
- Validators
  - For RDF: http://www.w3.org/RDF/Validator/
  - For OWL: http://owl.bbn.com/validator/

Semantic Web Applications

- Large number of applications emerge
  - Some applications use RDF only
  - Others use ontologies, too
    - Huge number of ontologies exist, using proprietary formats
    - Converting them to RDF/OWL will be a major task
    - But it will be worth it!
- SWAD-Europe survey:
  - URI: http://www.w3.org/2003/11/SWApplSurvey
  - Lists more than 50 applications in 12 categories..

SW Application Examples

- Dublin Core
  - Vocabularies for distributed Digital Libraries
  - One of the first metadata vocabularies in RDF
  - URI: http://www.dublincore.org
- Data integration
  - Achieve semantic integration of corporate resources or different databases
  - RDF/RDFS/OWL based vocabularies as an "interlingua" among system components
  - Boeing example: http://www.cs.rutgers.edu/~shklar/www11/final_submissions/paper3.pdf
  - Similar approaches: Artiste project, MITRE Corp.,...

SW Application Examples (cont.)

- Sun's SwordFish
  - Sun provides assisted support for its products, handbooks, etc
  - Public queries go through an internal RDF engine for:
    - Sun's White Papers collection (http://www.sun.com/servers/wp.html/)
    - Sun's System Handbooks collection (http://sunsolve.sun.com/handbook_pub)
- XMP
  - Adobe's tool to add RDF-based metadata to *all* their file formats
    - Eg, Photoshop in Creative Suite
    - http://www.adobe.com/products/xmp/main.html

SW Application Examples (cont.)

- Web Content Syndication (RSS)
  - Can be used to specify the *important* content of a page
  - There is a Yahoo discussion group and (non-W4C) working group
  - URI: http://purl.org/rss
  - Widely used in the weblog world!

SW Application Examples (cont.)

- Web Services Descriptions
  - Mapping of WSDL1.2 to RDF
  - Web Choreography development in terms of RDF/OWL
    - Initiative already exist, e.g., OWL-S or WSMO
- Gene Ontology Consortium
  - Controlled vocabularies to describe aspects of gene products
  - URI: http://www.geneontology.org
- OntoWeb
  - Ontology-based information exchange for knowledge management and electronic commerce
  - URI: http://ontoweb.aifb.uni-karlsruhe.de

SW Application Examples (cont.)

- Baby CareLink
  - Center of information for the treatment of premature babies
  - Provides an OWL service *as a Web Service*
    - Combines disparate vocabularies like medical, insurance, etc
    - Users can add new entries to ontologies
    - Complex questions can be asked through the service
  - ***Perfect example for the synergy of Web services and the Semantic Web!***

Semantic Web Trends

- DAML+OIL is already the most used ontology language ever!!
  - 3.5M statements on 25,000 web pages
- Gaining acceptance by web players
  - Semantic Web Track being offered at WWW 2002
  - 3x more people attended WWW2002 Developer Day on SW than attended KR
- Significant (international) government support
  - US DARPA/NSF; EU IST Framework 5,6
  - Japan, Germany, Australia considering significant investments
  - US National Cancer Institute to publish cancer vocabulary in DAML+OIL

Conclusions

- It is no longer a question of whether the semantic web will come into being, it is already here!
- We're already well past the starting gate
  - Web ontologies, term languages, "shims" to DB and services, research in proofs/rules/trust
  - Standardization providing a common denominator for KR researchers as well as web developers
  - Small companies starting to form, Big companies starting to move
- The current environment is open, encouraging, moving fast, and exciting