Semantic Web - RDF

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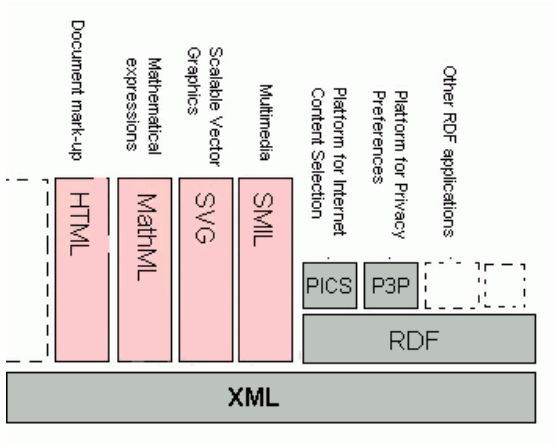
Applications and Technologies on top of XML



Outline

- Motivation: Why XML is not enough
- Introduction to RDF
  - Requirements for KR on the Web
  - The RDF Data Model
  - RDF Schema
- Extensions of RDF(S)
- Tools for RDF and RDF Schema
  - Parser, Query, and Inference Engines

Extensible Markup Language (XML) Revisited

- Key idea: separate structure from presentation
- XML DTDs or Schema define document structure
- Replace HTML with two things
  - A domain specific markup language (defined in XML)
  - A map from that markup language to HTML (defined using XSL)
- DTD enables document recipients to tell whether they've received a well-formed document
  - Gives a minimal level of validation

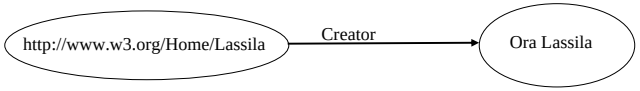
Why XML is not enough

- Only advantage of using XML is reusing the parser and document validation
- Many different possibilities to encode a domain of discourse
- Leads to difficulties when understanding of foreign documents is required

==> Next step: separate content from structure!

Encoding of Knowledge: Example

"The Creator of the Resource "http://www.w3.org/Home/Lassila" is Ora Lassila



Endless encoding possibilities in XML:

```
<Creator>
    <uri> http://www.w3.org/Home/Lassila </uri>
    <name>Ora Lassila</name>
</Creator>
```

```
<Document uri="http://www.w3.org/Home/Lassila"
    <Creator>Ora Lassila</Creator>
</Document>
```

```
<Document uri="http://www.w3.org/Home/Lassila" Creator="Ora Lassila"/>
```


Introduction to RDF

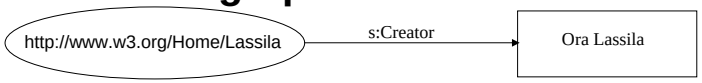
- RDF (Resource Description Framework)
  - Beyond Machine readable to *Machine understandable*
- RDF unites a wide variety of stakeholders:
  - Digital librarians, content-raters, privacy advocates, B2B industries, AI...
  - Significant (but less than XML) industrial momentum, lead by W3C
- RDF consists of two parts
  - RDF Model (a set of triples)
  - RDF Syntax (different XML serialization syntaxes)
- RDF Schema for definition of Vocabularies (simple Ontologies) for RDF (and in RDF)

RDF Data Model

- **Resources**
  - A resource is a thing you talk about (can reference)
  - Resources have URI's
  - RDF definitions are itself Resources (linkage)
- **Properties**
  - slots, defines relationship to other resources or atomic values
- **Statements**
  - "Resource has Property with Value"
  - (Values can be resources or atomic XML data)
- **Similar to Frame Systems**

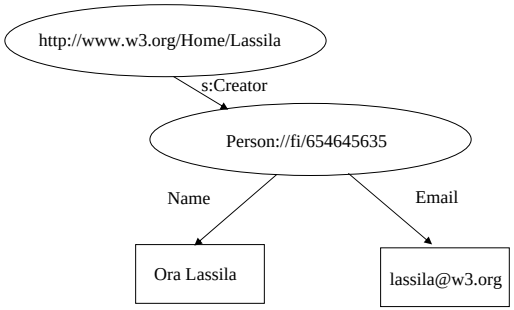
A simple Example

- **Statement**
  - "Ora Lassila is the creator of the resource http://www.w3.org/Home/Lassila"
- **Structure**
  - Resource (subject) http://www.w3.org/Home/Lassila
  - Property (predicate) http://www.schema.org/#Creator
  - Value (object) "Ora Lassila"
- **Directed graph**



Another Example

- To add properties to Creator, point through a intermediate Resource.

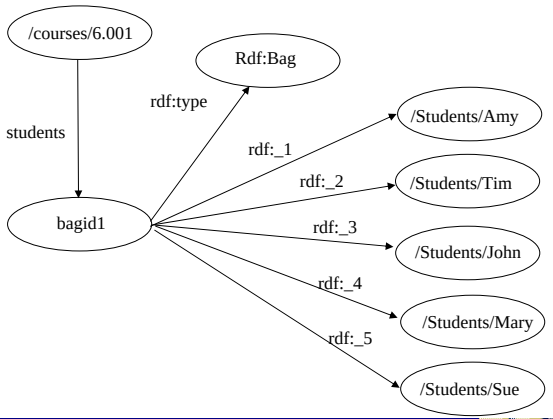


Collection Containers

- Multiple occurrences of the same PropertyType doesn't establish a relation between the values
  - The Millers own a boat, a bike, and a TV set
  - The Millers need (a car or a truck)
  - (Sarah and Bob) bought a new car
- RDF defines three special Resources:
  - **Bag** unordered values rdf:Bag
  - **Sequence** ordered values rdf:Seq
  - **Alternative** single value rdf:Alt
    - Core RDF does not enforce 'set' semantics amongst values

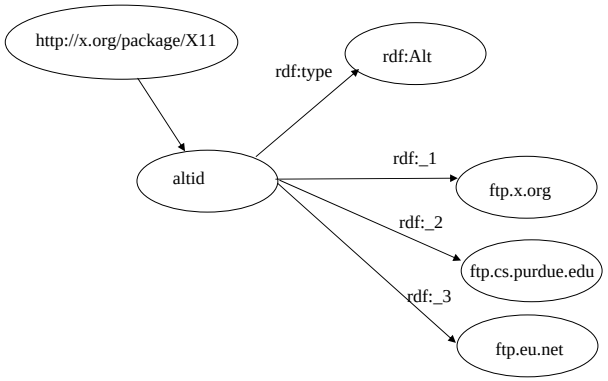
Example: Bag

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



Example: Alternative

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

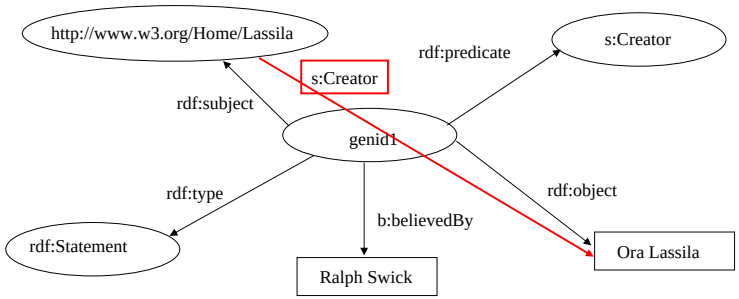


Statements about Statements (Requirement 2: Dispute Statements)

- Making statements about *statements* requires a process for transforming them into Resources
  - **subject** the original referent
  - **predicate** the original property type
  - **object** the original value
  - **type** rdf:Statement

Example: Reification

- *Ralph Swick believes that*
  - *the creator of the resource http://www.w3.org/Home/Lassila is Ora Lassila*



A Formal Model of RDF

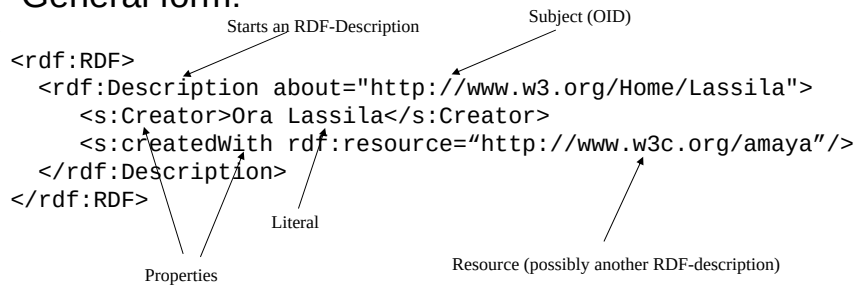
- RDF itself is mathematically straightforward:
  - Basic Definitions
    - **Resources.**
    - **Properties ⊂ Resources called**
    - **Literals**
    - **Statements = Resources × Properties ×{Resources ∪ Literals}**
  - Typing
    - **rdf:type ∈ Properties**
    - **{RDF:type, sub, obj} ∈ Statements ⇒ obj ∈Resources**

Formal Model of RDF II

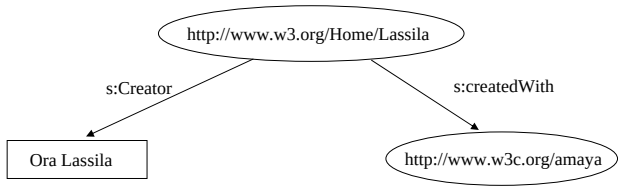
- Reification
  - **rdf:Statement ∈ Resource-Properties**
  - **{rdf:predicate, rdf:subject, rdf:object } ⊂ Properties**
  - **Reification of a triple { pred, sub, obj } of Statements is an element r of Resources representing the reified triple and the elements s1, s2, s3, and s4 of Statements such that**
    - s1: {RDF:predicate, r, pred}
    - s2: {RDF:subject, r, subj}
    - s3: {RDF:object, r, obj}
    - s4: {RDF:type, r, [RDF:Statement]}
- Collections
  - **{ RDF:Seq, RDF:Bag, and RDF:Alt } ⊂ Resources-Properties**
  - **There is a subset of Properties corresponding to the ordinals (1, 2, 3, ...) called Ord. We refer to**
  - **elements of Ord as RDF:_1, RDF:_2, RDF:_3, ...**

RDF Syntax I

- Datamodel does not enforce particular syntax
- Specification suggests many different syntaxes based on XML
- General form:

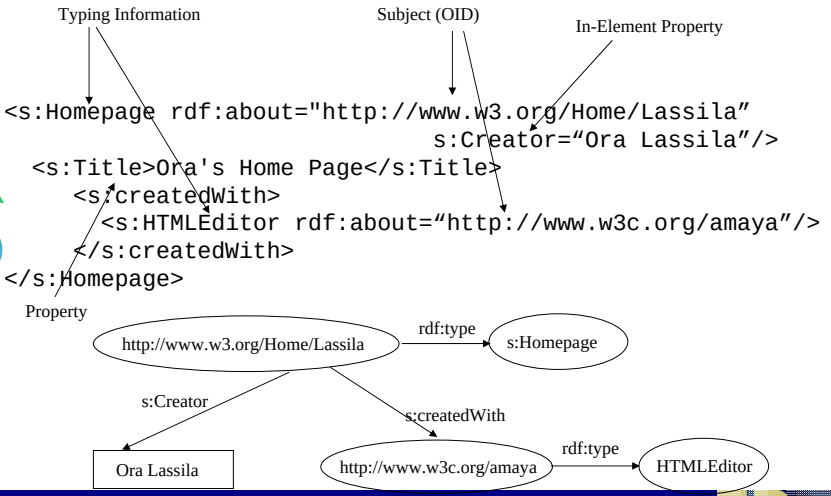


Resulting Graph




```
<rdf:RDF>
  <rdf:Description about="http://www.w3.org/Home/Lassila">
     <s:Creator>Ora Lassila</s:Creator>
     <s:createdWith rdf:resource="http://www.w3c.org/amaya"/>
  </rdf:Description>
</rdf:RDF>
```


RDF Syntax II: Syntactic Varieties



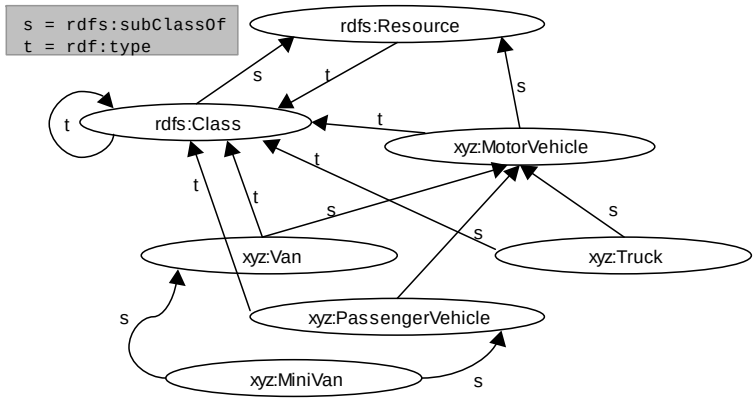
RDF Schema (RDFS)

- RDF just defines the datamodel
- Need for definition of vocabularies for the datamodel - an Ontology Language!
- RDF schemas are Web resources (and have URIs) and can be described using RDF

Most Important Modeling Primitives

- Core Classes
  - Root-Class `rdfs:Resource`
  - MetaClass `rdfs:Class`
  - Literals `rdfs:Literal`
- `rdfs:subclassOf`-property
- Inherited from RDF: properties (slots)
- `rdfs:domain` & `rdfs:range`
- `rdfs:label`, `rdfs:comment`, etc.
- Inherited from RDF: InstanceOf (`rdf:type`)

RDF-Schema: Example



Rdfs:subclassOf

```
<rdfs:description about=„Xyz:Minivan“>
    <rdfs:subclassOf about=„xyz:Van“/>
</rdfs:description>
<rdfs:description about=„myvan“>
    <rdf:type about=„xyz:MiniVan“/>
</rdfs:description>
```

Predicate Logic Consequences:

Forall X: type(X,MiniVan) -> type(X,Van).
Forall X: subclassOf(X,MiniVan) -> subclassOf(X,Van).

Rdf:property

```
<rdf:description about=„possesses“>
   <rdf:type about=„....property“/>
   <rdfs:domain about=„person“/>
   <rdfs:range about=„vehicle“/>
</rdf:description>
<rdf:description about=„peter“>
   <possesses>petersminivan</possesses>
</rdf:description>
```

Predicate Logic Consequences:

Forall X,Y: possesses (X,Y) -> (type(X,person) & type(Y,vehicle)).

More Examples...

Simplification rules

- People specifying text for arbitrary RDF processors can use any simplification
- Processors of arbitrary RDF therefore must accept all simplifications
- Special-purpose XML formats can be RDF-compliant while disallowing simplifications, requiring them, or exploiting them in specific ways

Container examples

- Bag: committee members, documents in a folder, checks in a bag
- Seq: book authors (order counts!), chapters in a book, items in an agenda
- Alt: document home and mirrors, mailing-list moderators, translations of a document

A Bag: one variant

```
<rdf:Description ID="committee">
 <rdf:type
  resource="http://www.w3.org/1999/02/22-
  rdf-syntax-ns#Bag"/>
 <rdf:_1>Jack Robinson</rdf:_1>
 <rdf:_2>John Doe</rdf:_2>
 <rdf:_3>Richard Roe</rdf:_3>
</rdf:Description>
```


A Bag: another variant

```
<rdf:Bag ID="committee">
 <rdf:li>Jack Robinson</rdf:li>
 <rdf:li>John Doe</rdf:li>
 <rdf:li>Richard Roe</rdf:li>
</rdf:Bag>
```

- Using an “rdf:Bag” element means the value of “type” is “http://www.w3.org/1999/02/22-rdf-syntax-ns#Bag”

What is the “rdf:type” property?

- It specifies a class (there may be more than one) to which the resource belongs
- Its value is always a Web resource representing the class
- It can be expressed as a “type” attribute on a Description element
- It can also be implied by using a special element instead of a Description element

Kinds of “about” attributes

- “about”: specifies the URL of the Web resource directly
- “aboutEach”: specifies the URL of a container; the properties apply to the individual members of the container
- “aboutEachPrefix”: specifies an URL prefix; the properties apply to all Web resources with that prefix

Containers vs. multiple values

- A property can appear more than once with different values
- What is true of a container isn't necessarily true of its contents and vice versa
- "aboutEach" lets us get to the contents when we already have a container
- "aboutEachPrefix" in effect manufactures a container based on URLs

Reified statements

- We reify statements so that we can talk about them rather than asserting them
- "Charles Dickens is the author of *Bleak House*" asserts a property of Charles Dickens
- "Jack believes that Charles Dickens is the author of *War and Peace*" asserts a property of Jack, not Charles Dickens

Reification properties

```
<rdf:Description about="...">
 <xx:creator>Charles Dickens</xx:creator>
</rdf:Description>
```

reifies as:

```
<rdf:Statement>
 <rdf:subject resource="..."/>
 <rdf:predicate resource="...#creator/>
 <rdf:object>Charles Dickens</rdf:object>
</rdf:Statement>
```


RDF Schemas

- Describe rules for using RDF properties
- Are expressed in RDF
- Are not to be confused with XML Schemas

RDF Classes

- Are groups of Web resources
- Have URLs to identify them
- The special class “rdfs:Literal” consists of all possible RDF string values

Property-centric classes

- In typical OO classes,each class specifies completely what properties it has and what their types are
- In RDF classes, each property specifies what classes of subjects and objects it relates
- Therefore, new properties can be added to a class without modifying the class

Specifying classes

- To specify a class, create an RDF resource of type rdfs:Class

```
<rdfs:Class id=“MyClass”>
 <rdfs:label>My Class</rdfs:label>
 <rdfs:comment>John Cowan’s demonstration
   Class</rdfs:comment>
</rdfs:Class>
```


Specifying properties

- To specify a property, create an RDF resource of type rdfs:Property

```
<rdfs:Property id=“myProperty”>
 <rdfs:comment>John Cowan’s demo
     property</rdfs:comment>
 <rdfs:domain resource=“#MyClass”/>
 <rdfs:range resource=“..#Literal”/>
<rdfs:Property>
```

Schema URIs

- Ordinary XML namespace URIs are just to guarantee uniqueness: there is no assumption that the URI refers to anything useful (or even refers at all)
- URIs for namespaces used in RDF, though, should refer to an RDF schema document

Properties (1)

- “`rdf:type`” relates any resource to its class
- “`rdfs:subClassOf`” relates a subclass to its superclass (multiple inheritance is OK)
- “`rdfs:subPropertyOf`” relates a subproperty to its superproperty

Properties (2)

- “`rdfs:seeAlso`” relates a resource to another resource explaining it (use a subproperty to specify the nature of the explanation)
- “`rdfs:isDefinedBy`” is a subproperty of “`rdfs:seeAlso`” and relates a resource to its definition, typically an RDF schema

Properties (3)

- “`rdfs:domain`” specifies the domain of a property (the classes of its subjects); if unknown, anything can be a subject
- “`rdfs:range`” specifies the range of a property (the single class of its objects); if unknown, anything can be an object

Properties (4)

- "`rdf:subject`" is the property relating a reified statement to its subject (resource)
- "`rdf:predicate`" is the property relating a reified statement to its predicate (property)
- "`rdf:object`" is the property relating a reified statement to its object (value)

Properties (5)

- "rdfs:label" specifies a human-readable name for this Class, Property, or whatever
- "rdfs:comment" specifies human-readable documentation
- Multiple values are useful for specifying multiple languages

Classes (1)

- "rdfs:Resource" is the class of all resources
- "rdfs:Literal" is the class of all strings
- "rdfs:Class" is the class of all classes
- "rdfs:Property" is the class of all properties
- "rdf:Statement" is the class of all asserted RDF statements

Classes (2)

- "rdfs:Container" is the superclass of all container classes
- "rdf:Bag", "rdf:Seq", "rdf:Alt" are the classes of Bags, Seqs, and Alts
- (Any other class that is a subclass of "rdfs:Container" can be used in RDF syntax in place of a standard container)

Dublin Core

- A set of fifteen basic properties for describing generalized Web resources
- The “obvious” mapping of Dublin Core properties into RDF properties has not yet been approved by the Dublin Core initiative, but is generally a good example

Dublin Core

- “`Title`”: the name given to the resource
- “`Creator`”: the person or organization primarily responsible for the resource
- “`Subject`”: what the resource is about
- “`Description`”: a description of the content

Dublin Core

- “`Publisher`”: the person or organization responsible for making the resource available
- “`Contributor`”: someone who has provided content to the resource other than the creator
- “`Date`”: date of creation or publication

Dublin Core

- “`Type`”: type of resource, such as home page, technical report, novel, photograph…
- “`Format`”: data format of the resource
- “`Identifier`”: URL, ISBN number, …
- “`Source`”: another resource that this resource is derived from

Dublin Core

- "`Language`": the language of the content
- "`Relation`": another resource and its relationship to this one
- "`Coverage`": the portion of time or space described by this resource (atlases, histories, etc.)

Dublin Core

- "`Rights`": the intellectual property rights adhering to this resource, or a pointer to them

Where to look next

- RDF Syntax & Model theory
  http://www.w3.org/RDF/

Extensibility of RDF

- Define an Ontology of your Language with RDF Schema (like RDF-Schema itself)
- Describe Instance Data using your new Vocabulary
- Advantage: all Languages use the same Data Model (simplifies Interoperability)

Formal Models of RDF I

- **Official Semantics: RDF Model Theory**
  [→ http://www.w3.org/TR/rdf-mt/]

Specification of a precise semantics for RDF (and RDFS), and of corresponding entailment and inference rules which are sanctioned by the semantics.

- **Earlier Proposals:**
  - RDFS(FA)
    [→ http://dl-web.man.ac.uk/rdfsfa/]
    UML-Like Stratification
  - RDF in First-Order Logic
    [→ http://nestroy.wi-inf.uni-essen.de/rdf/logical_interpretation/]
    (Outdated RDF semantics in FOL)

Formal Models of RDF II

- **RDF-MT is based on classical Tarski-style Model Theory**
- **Some Entailment rules for RDFS:**

	If E contains:	**then add:**
rdf1	xxx aaa yyy .	aaa rdf:type rdf:Property .
rdfs2	xxx aaa yyy . aaa rdfs:domain zzz .	xxx rdf:type zzz .
rdfs3	xxx aaa uuu . aaa rdfs:range zzz .	uuu rdf:type zzz .
rdfs4a	xxx aaa yyy .	xxx rdf:type rdfs:Resource
rdfs4b	xxx aaa uuu .	uuu rdf:type rdfs:Resource
rdfs5a	aaa rdfs:subPropertyOf bbb . bbb rdfs:subPropertyOf ccc .	aaa rdfs:subPropertyOf ccc

	If E contains:	**then add:**
rdfs5b	xxx rdf:type rdf:Property .	xxx rdfs:subPropertyOf xxx
rdfs6	xxx aaa yyy . aaa rdfs:subPropertyOf bbb .	xxx bbb yyy .
rdfs7a	xxx rdf:type rdfs:Class .	xxx rdfs:subClassOf rdfs:Resource .
rdfs7b	xxx rdf:type rdfs:Class .	xxx rdfs:subClassOf xxx .
rdfs8	xxx rdfs:subClassOf yyy . yyy rdfs:subClassOf zzz .	xxx rdfs:subClassOf zzz .
rdfs9	xxx rdfs:subClassOf yyy . aaa rdf:type xxx . xxx rdf:type	aaa rdf:type yyy .
rdfs10	rdfs:ContainerMembershipProperty .	xxx rdfs:subPropertyOf rdfs:member .

Formal Model of RDF III

- The entailment process terminates on any finite RDF graph
  → only finitely many possible triples can be formed from a given finite vocabulary.
- Example Graph (Single Triple): [foo bar baz].

Closure (for mentioned rules only !):

1.	foo bar baz .	Source
2.	foo rdf:type rdfs:Resource .	Rule 4a on (1)
3.	baz rdf:type rdfs:Resource .	Rule 4a on (1)
4.	bar rdf:type rdf:Property .	Rule 1 on (1)
5.	rdf:type rdf:type rdf:Property .	Rule 1 on (4)
6.	rdf:type rdfs:subPropertyOf rdf:type.	Rule 5b on (5)
7.	bar rdfs:subPropertyOf bar.	Rule 5b on (4)
8.	rdfs:subPropertyOf rdf:type rdf:Property	Rule 1 on (6)

Blank nodes

- Nodes need not be named.
- Unnamed nodes are interpreted as having unique names.
- Implication: graph matching that fulfills a particular condition becomes NP hard
- Conclusion: not so simple as it may seem!