Introduction to the Semantic Web

Questions

- What is the Semantic Web?
- Why do we want it?
- How will we do it?
- Who will do it?
- When will it be done?

"XML is Lisp's bastard nephew, with uglier syntax and no semantics. Yet XML is poised to enable the creation of a Web of data that dwarfs anything since the Library at Alexandria."

-- Philip Wadler, *Et tu XML? The fall of the relational empire*, VLDB, Rome, September 2001.

"The web has made people smarter. We need to understand how to use it to make machines smarter, too."

-- Michael I. Jordan, paraphrased from a talk at AAAI, July 2002 by Michael Jordan (UC Berkeley)

"The Semantic Web will globalize KR, just as the WWW globalize hypertext"

-- Tim Berners-Lee

"The multi-agent systems paradigm and the web both emerged around 1990. One has succeeded beyond imagination and the other has not yet made it out of the lab."

-- Anonymous, 2001

IOHO

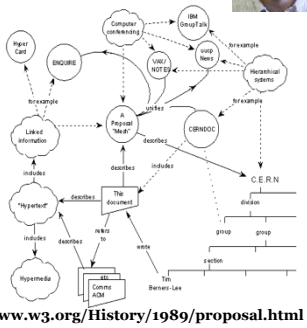
- The web is like a universal acid, eating through and consuming everything it touches.
  - Web principles and technologies are equally good for wireless/ pervasive computing
- The semantic web is our first serious attempt to provide semantics for XML sublanguages
- It will provide mechanisms for people and machines (agents, programs, web services) to come together.
  - In all kinds of networked environments: wired, wireless, ad hoc, wearable, etc.

Origins

Tim Berners-Lee's original 1989 WWW proposal described a web of relationships among named objects unifying many info. management tasks.

Capsule history

- Guha's MCF (~94)
- XML+MCF=>RDF (~96)
- RDF+OO=>RDFS (~99)
- RDFS+KR=>DAML+OIL (00)
- W3C's SW activity (01)
- W3C's OWL (03)



http://www.w3.org/History/1989/proposal.html

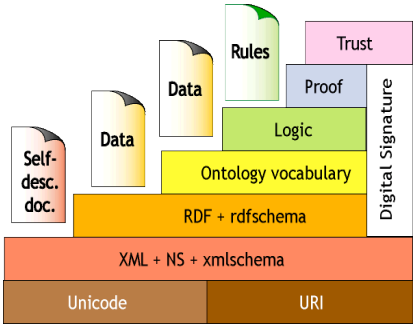
W3C's Semantic Web Goals

Focus on machine consumption:

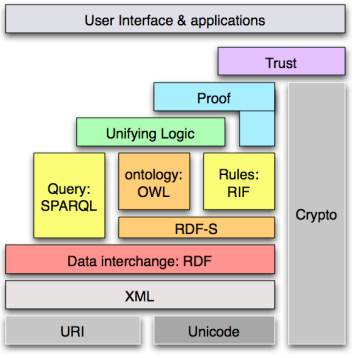
"The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation."

-- Berners-Lee, Hendler and Lassila, The Semantic Web, Scientific American, 2001

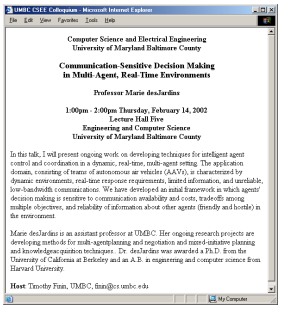
TBL's semantic web vision



Semantic web stack 2006



Why is this hard?



Computer Science and Electrical Engineering
University of Maryland Baltimore County

Communication-Sensitive Decision Making in Multi-Agent, Real-Time Environments

Professor Marie desJardins

1:00pm - 2:00pm Thursday, February 14, 2002
Lecture Hall Five
Engineering and Computer Science
University of Maryland Baltimore County

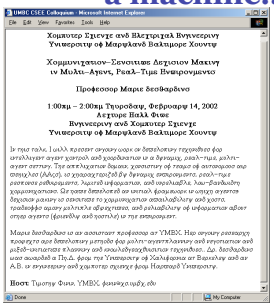
In this talk, I will present ongoing work on developing techniques for intelligent agent control and coordination in a dynamic, real-time, multi-agent setting. The application domain, consisting of teams of autonomous air vehicles (AAVs), is characterized by dynamic environments, real-time response requirements, limited information, and unreliable, low-bandwidth communications. We have developed an initial framework in which agents' decision making is sensitive to communication availability and costs, trade-offs among multiple objectives, and reliability of information about other agents (friendly and hostile) in the environment.

Marie desJardins is an assistant professor at UMBC. Her ongoing research projects are developing methods for multi-agent planning and negotiation and mixed-initiative planning and knowledge-acquisition techniques. Dr. desJardins was awarded a Ph.D. from the University of California at Berkeley and an A.B. in engineering and computer science from Harvard University.

Host: Timothy Finin, UMBC, finin@cs.umbc.edu

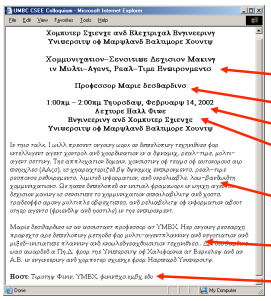
after Frank van Harmelen and Jim Hendler

What a web page looks like to a machine…



after Frank van Harmelen and Jim Hendler

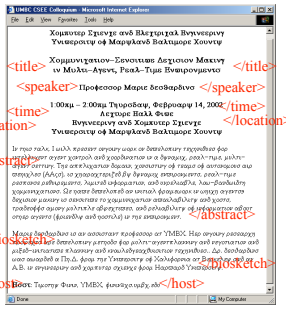
OK, so HTML is not helpful



Maybe we can tell the machine what the different parts of the text represent?

title
speaker
time
location
abstract
biosketch
host

XML to the rescue?

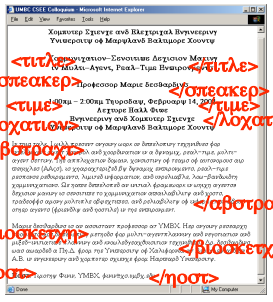


XML fans propose creating a XML tag set to use for each application.

For talks, we can choose <title>, <speaker>, etc.

after Frank van Harmelen and Jim Hendler

XML ≠ machine accessible meaning



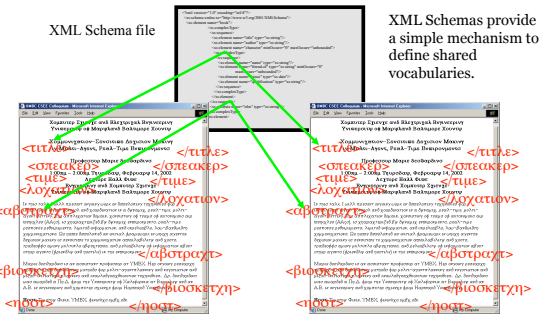
But, to your machine, the tags still look like this….

The tag names carry no meaning.

XML DTDs and Schemas have little or no semantics.

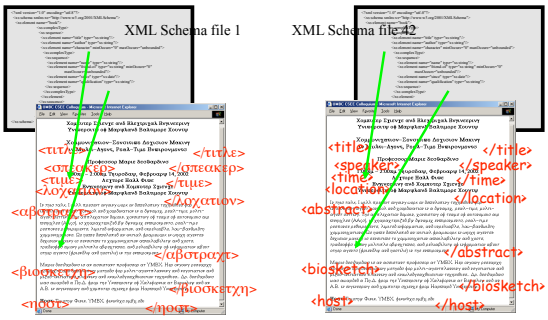
after Frank van Harmelen and Jim Hendler

XML Schema helps



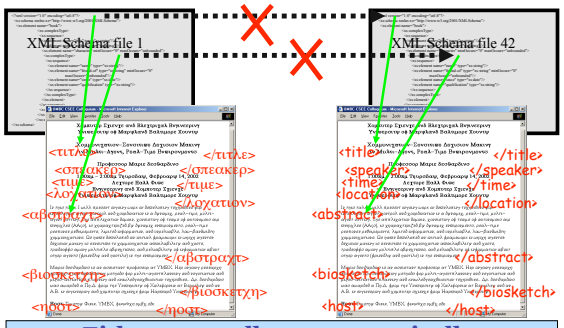
after Frank van Harmelen and Jim Hendler

But there are many schemas



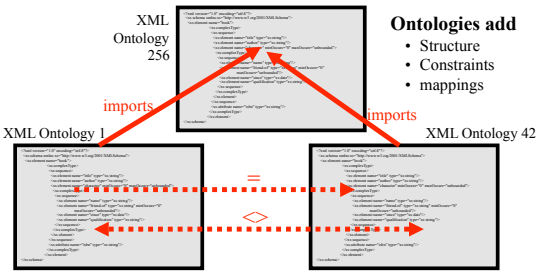
after Frank van Harmelen and Jim Hendler

There's no way to relate schema



Either manually or automatically.
XML Schema is weak on semantics.

An Ontology level is needed



We need a way to define ontologies in XML
So we can relate them
So machines can understand (to some degree) their meaning

Today and tomorrow

- Simple ontologies like FOAF & DC in use today
  - We've crawled more than 3M FOAF RDF files
- We hope to be able to make effective use ontologies like Cyc in the coming decade
  - There are skeptics …
  - It's a great research topic …
- The SW community has a roadmap and some experimental languages …
- Industry is still holding back…
  - They are being conservative
- We need more experimentation and exploration

Semantic Web Languages

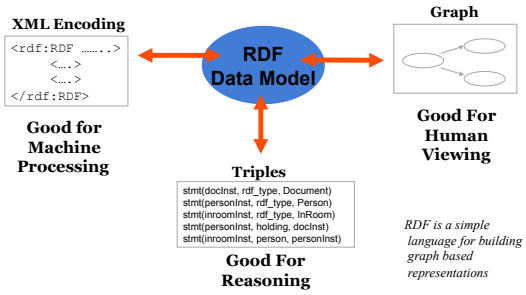
Semantic web languages today

- Today there are, IOHO, two semantic web languages
  - **RDF** – Resource Description Framework http://www.w3.org/RDF/
  - **DAML+OIL** – Darpa Agent Markup Language http://www.daml.org/ (deprecated)
  - **OWL** – Ontology Web Language http://www.w3.org/2001/sw/
- **Topic maps** (http://topicmaps.org/) are another species, not based on RDF
- Microformats, Common Logic, etc. offer other possibilities

Two Semantic Web Notions

- **The semantic web**
  - The idea of a web of machine understandable information
  - Agnostic about the technology used to support it
  - May involve more AI (e.g., NLP)
  - Human end users in the center
- **The Semantic Web**
  - The current vision of a semantic web as defined by the W3C community: a web of data
  - Using W3C supported standards (i.e., RDF, OWL, SPARQL, XML, RIF, etc.
  - By machines for machines with human oriented applications on top.

RDF is the first SW language



The RDF Data Model

- An RDF document is an unordered collection of statements, each with a **subject**, **predicate** and **object** (aka **triples**)
- A triple can be thought of as a labelled arc in a graph
- Statements describe properties of web **resources**
- A resource is any object that can be pointed to by a **URI**:
  - a document, a picture, a paragraph on the Web, …
  - E.g., http://umbc.edu/~finin/cv.html
  - a book in the library, a real person (?)
  - isbn://5031-4444-3333
  - …
- Properties themselves are also resources (URIs)

URIs are a foundation

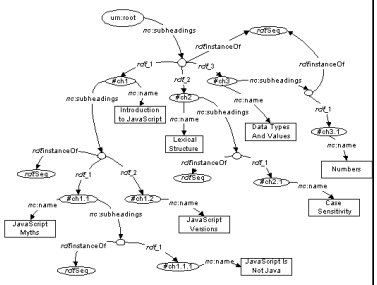
- URI = **Uniform Resource Identifier**
  - "The generic set of all names/addresses that are short strings that refer to resources"
  - URLs (Uniform Resource Locators) are a subset of URIs, used for resources that can be *accessed* on the web
- URIs look like "normal" URLs, often with fragment identifiers to point to a document part:
  - http://foo.com/bar/mumble.html#pitch
- URIs are unambiguous, unlike natural language terms
  - the web provides a global **namespace**
  - We assume references to the same URI are to the same thing

What does a URI mean?

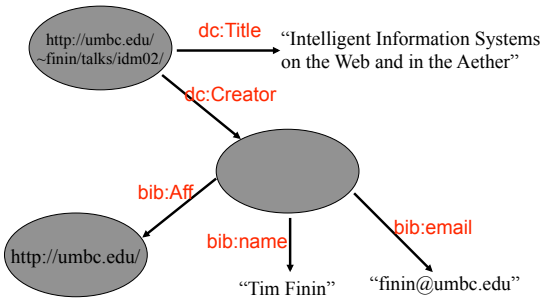
- Sometimes URIs denote a web resource
  - http://umbc.edu/~finin/finin.jpg denotes a file
  - We can use RDF to make assertions about the resource, e.g., it's an image and depicts a person with name Tim Finin, …
- Sometimes concepts in the external world
  - E.g., http://umbc.edu/ denotes a particular University located in Baltimore
  - This is done by social convention
- Cool URIs don't change
  - http://www.w3.org/Provider/Style/URI

The RDF Graph

- An RDF document is an unordered collection of triples
- The subject of one triple can be the object of another
- So the result is a directed, labelled graph
- A triple's object can also be a literal, e.g., a string.



Simple RDF Example



XML encoding for RDF

```
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:dc="http://purl.org/dc/elements/1.1/"
   xmlns:bib="http://daml.umbc.edu/ontologies/bib/">
<description about="http://umbc.edu/~finin/talks/idm02/">
  <dc:title>Intelligent Information Systems on the Web and in the
 Aether</dc:Title>
  <dc:creator>
    <description>
      <bib:Name>Tim Finin</bib:Name>
      <bib:Email>finin@umbc.edu</bib:Email>
      <bib:Aff resource="http://umbc.edu/" />
    </description>
  </dc:Creator>
</description>
</rdf:RDF>
```

N triple representation

- RDF can be encoded as a set of **triples**.
  <subject> <predicate> <object> .

```
<http://umbc.edu/~finin/talks/idm02/> <http://purl.org/dc/elements/1.1/
  Title>
      "Intelligent Information Systems on the Web and in the Aether" .
_:j10949 <http://daml.umbc.edu/ontologies/bib/Name> "Tim Finin" .
_:j10949 <http://daml.umbc.edu/ontologies/bib/Email> "finin@umbc.edu" .
_:j10949 <http://daml.umbc.edu/ontologies/bib/Aff> <http://umbc.edu/> .
_:j10949 <http://www.w3.org/1999/02/22-rdf-syntax-ns#type><Description> .
<http://umbc.edu/~finin/talks/idm02/> <http://purl.org/dc/elements/1.1/
  Creator> _:j10949 .
<http://umbc.edu/~finin/talks/idm02/> <http://www.w3.org/1999/02/22-rdf-
  syntax-ns#type> <Description> .
```

Note the gensym for the anonymous node _:j10949

Triple Notes

- **RDF triples have one of two forms:**
  - <URI> <URI> <URI>
  - <URI> <URI> <quoted string>
- **Triples are also easily mapped into logic**
  - <subject> <predicate> <object> becoming:
    - <predicate>(<subject>,<object>)
    - With type(<S>,<O>) becoming <O>(<S>)
  - Example:
    - subclass(man,person)
    - sex(man,male)
    - domain(sex,animal)
    - man(adam)
    - age(adam,100)

; Note: we're not
; showing the actual
; URIs for clarity

- **Triples are easily stored and managed in DBMS**
  - Flat nature of a triple a good match for relational DBs

N3 notation for RDF

- N3 is a compact notation for RDF that is easier for people to read, write and edit.
- Aka Notation 3, developed by TBL himself.
- Translators exist between N3 and the XML encoding, such as the web form on
  - http://www.w3.org/DesignIssues/Notation3.html
- So, it's just "syntactic sugar"
- But, XML is largely unreadable and even harder to write

N3 Example

```
@prefix rdf: http://www.w3.org/1999/02/22-rdf-syntax-ns# .
@prefix dc: http://purl.org/dc/elements/1.1/ .
@prefix bib: http://daml.umbc.edu/ontologies/bib/ .
<http://umbc.edu/~finin/talks/idm02/>
   dc:title "Intelligent Information Systems on the Web
             and in the Aether" ;
 dc:creator
    [ bib:Name "Tim Finin";
      bib:Email "finin@umbc.edu"
      bib:Aff: "http://umbc.edu/" ] .
```

A usecase: FOAF

- FOAF (Friend of a Friend) is a simple ontology to describe people and their social networks.
  - See the foaf project page: http://www.foaf-project.org/
- We recently crawled the web and discovered over 1,000,000 valid RDF FOAF files.
  - Most of these are from the http://liveJournal.com/ blogging system which encodes basic user info in foaf
  - See http://apple.cs.umbc.edu/semdis/wob/foaf/

```
<foaf:Person>
   <foaf:name>Tim Finin</foaf:name>
   <foaf:mbox_sha1sum>2410…37262c252e</foaf:mbox_sha1sum>
   <foaf:homepage rdf:resource="http://umbc.edu/~finin/" />
   <foaf:img rdf:resource="http://umbc.edu/~finin/images/passport.gif" />
</foaf:Person>
```

FOAF Vocabulary

Basics
Agent
Person
name
nick
title
homepage
mbox
mbox_sha1sum
img
depiction (depicts)
surname
family_name
givenname
firstName

Personal Info
weblog
knows
interest
currentProject
pastProject
plan
based_near
workplaceHomepage
workInfoHomepage
schoolHomepage
topic_interest
publications
geekcode
myersBriggs
dnaChecksum

Documents & Images
Document
Image
PersonalProfileDocument
topic (page)
primaryTopic
tipjar
sha1
made (maker)
thumbnail
logo

Online Accts
OnlineAccount
OnlineChatAccount
OnlineEcommerceAccount
OnlineGamingAccount
holdsAccount
accountServiceHomepage
accountName
icqChatID
msnChatID
aimChatID
jabberID
yahooChatID

Projects & Groups
Project Organization
Group member
membershipClass fundedBy
theme

FOAF: why RDF? Extensibility!

- FOAF vocabulary provides 50+ basic terms for making simple claims about people
- FOAF files can use other RDF terms too: RSS, MusicBrainz, Dublin Core, Wordnet, Creative Commons, blood types, starsigns, …
- RDF guarantees freedom of independent extension
  - OWL provides fancier data-merging facilities
- **Result:** Freedom to say what you like, using any RDF markup you want, and have RDF crawlers merge your FOAF documents with other's and know when you're talking about the same entities.

After Dan Brickley, danbri@w3.org

No free lunch!

Consequence:

- We must plan for lies, mischief, mistakes, stale data, slander
- Dataset is out of control, distributed, dynamic
- Importance of knowing who-said-what
  - Anyone can describe anyone
  - We must record data provenance
  - Modeling and reasoning about trust is critical
- Legal, privacy and etiquette issues emerge
- Welcome to the real world

After Dan Brickley, danbri@w3.org

More RDF Vocabulary

- RDF has terms for describing lists, bags, sequences, etc.
- RDF also can describe triples through reification
- Enabling statements about statements

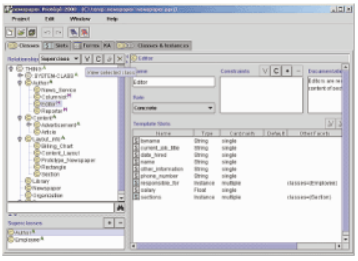
```
:john bdi:believes _:s.
_:s rdf:type rdf:Statement.
_:s rdf:subject <http://yd.example.com/catalog/widgetX>.
_:s rdf:predicate cat:salePrice .
_:s rdf:object "19.95" .
```

RDF is being used!

- **RDF has a solid specification**
- **RDF is being used in a number of web standards**
  - CC/PP (Composite Capabilities/Preference Profiles)
  - P3P (Platform for Privacy Preferences Project)
  - RSS (RDF Site Summary)
  - RDF Calendar (~ iCalendar in RDF)
- **And in other systems**
  - Netscape's Mozilla web browser, open directory (http://dmoz.org/)
  - Adobe products via XMP (eXtensible Metadata Platform)
  - Web communities: LiveJournal, Ecademy, and Cocolog
  - In Microsoft's VISTA: Connected Services Framework uses an RDF database and SPARQL

RDF Schema (RDFS)

- **RDF Schema adds taxonomies for classes & properties**
  - subClass and subProperty
- **and some metadata.**
  - domain and range constraints on properties
- **Several widely used KB tools can import and export in RDFS**



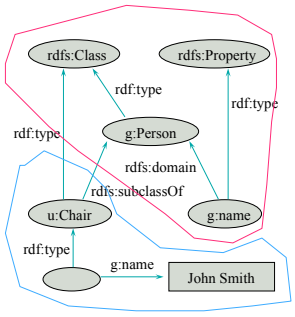
Stanford Protégé KB editor
- Java, open sourced
- extensible, lots of plug-ins
- provides reasoning & server capabilities

RDFS Vocabulary

RDFS introduces the following terms and gives each a meaning w.r.t. the rdf data model

- Terms for classes
  - rdfs:Class
  - rdfs:subClassOf
- Terms for properties
  - rdfs:domain
  - rdfs:range
  - rdfs:subPropertyOf
- Special classes
  - rdfs:Resource
  - rdfs:Literal
  - rdfs:Datatype
- Terms for collections
  - rdfs:member
  - rdfs:Container
  - rdfs:ContainerMembershipProperty
- Special properties
  - rdfs:comment
  - rdfs:seeAlso
  - rdfs:isDefinedBy
  - rdfs:label

RDF and RDF Schema




```
<rdfs:Property rdf:ID="name">
   <rdfs:domain rdf:resource="Person">
</rdfs:Property>

<rdfs:Class rdf:ID="Chair">
   <rdfs:subclassOf  rdf:resource=
      "http://schema.org/gen#Person">
</rdfs:Class>
```

```
<rdf:RDF
    xmlns:g="http://schema.org/gen"
    xmlns:u="http://schema.org/univ">
  <u:Chair rdf:ID="john">
    <g:name>John Smith</g:name>
  </u:Chair>
</rdf:RDF>
```

RDFS supports simple inferences

New and Improved! 100% Better than XML!!

- An RDF ontology plus some RDF statements may imply additional RDF statements.
- This is not true of XML.
- Note that this is **part of the data model** and not of the accessing or processing code.

```
@prefix rdfs: <http://www.....>.
@prefix : <genesis.n3>.
      parent rdfs:domain person;
               rdfs:range person.
      mother rdfs:subProperty parent;
               rdfs:domain woman;
               rdfs:range person.
      eve mother cain.
```

⇒

```
parent a property.
person a class.
woman subClass person.
mother a property.
eve a person;
      a woman;
      parent cain.
cain a person.
```

N3 example

```
@prefix rdf: <h                                  -ns#>.
@prefix rdfs: <h                                 ema#>.
@prefix : <#>
<> rdfs:comment "This i          N3 exa
:Person a rdfs:Class.
:Woman a rdfs:Class; rdfs:subCl
:eve a :Woman; :age "100".
:sister a rdf:Property; rdfs:domai
      rdfs:range :Woman.
:eve :sister [a :Woman; :age 98].
:eve :believe {:eve :age "100".
[is :spouse of [is :sister of :eve]] :age
:eve.:sister.:spouse :age 99.
```

Here's how you declare a namespace.

This defines <> referring to "this document".

<> Is an alias for the URI of this document.

"person is a class" sugar for rdf:type

The "a" syntax is

"Woman is a class and a subclass of person". Note the ; syntax.

"eve is a woman whose age is 100."

"sister is a property from person to woman"

"eve has

woman

"eve believes that her age is 100". The braces introduce a

"the spouse of the sister of eve is 99".

"the spouse of the sister of eve is 99".

Is RDF(S) better than XML?

Q: For a specific application, should I use XML or RDF?
A: It depends…

- XML's model is
  - a tree, i.e., a strong hierarchy
  - applications may rely on hierarchy position
  - relatively simple syntax and structure
  - not easy to *combine* trees
- RDF's model is
  - a *loose* collections of relations
  - applications may do "database"-like search
  - not easy to recover hierarchy
  - easy to combine relations in one big collection
  - great for the integration of heterogeneous information

From where will the markup come?

- A few authors will add it manually.
- More will use annotation tools.
  - SMORE: Semantic Markup, Ontology and RDF Editor
- Intelligent processors (e.g., NLP) can understand documents and add markup (hard)
  - Machine learning powered information extraction tools show promise
- Lots of web content comes from databases & we can generate SW markup along with the HTML
  - See http://ebiquity.umbc.edu/

From where will the markup come?

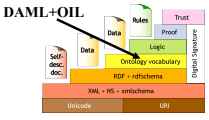
- In many tools, part of the metadata information is present, but thrown away at output
  - e.g., a business chart can be generated by a tool…
  - …it "knows" the structure, the classification, etc. of the chart
  - …but, usually, this information is lost
  - …storing it in metadata is easy!
- So *"semantic web aware"* tools can produce lots of metadata
  - E.g., Adobe's use of its XMP platform

Problems with RDFS

- RDFS **too weak** to describe resources in sufficient detail, e.g.:
  - -No *localised range and domain* constraints
    Can't say that the range of hasChild is person when applied to persons and elephant when applied to elephants
  - -No *existence/cardinality* constraints
    Can't say that all *instances* of person have a mother that is also a person, or that persons have exactly 2 parents
  - -No *transitive, inverse or symmetrical* properties
    Can't say that isPartOf is a transitive property, that hasPart is the inverse of isPartOf or that touches is symmetrical
- We need RDF terms providing these and other features.

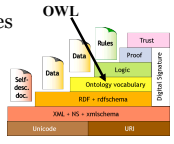
DAML+OIL = RDF + KR

- DAML = Darpa Agent Markup Language
  - DARPA program with 17 projects & an integrator developing language spec, tools, applications for SW.
- OIL = Ontology Inference Layer
  - An EU effort aimed at developing a layered approach to representing knowledge on the web.
- Process
  - Joint Committee: US DAML and EU Semantic Web Technologies participants
  - DAML+OIL specs released in 2001
  - See http://www.daml.org/
  - Includes model theoretic and axiomatic semantics



W3C's Web Ontology Language (OWL)

- DAML+OIL begat OWL.
- OWL released as W3C recommendation 2/10/04
- See http://www.w3.org/2001/sw/WebOnt/ for OWL overview, guide, specification, test cases, etc.
- Three layers of OWL are defined of decreasing levels of complexity and expressiveness
  - **OWL Full** is the whole thing
  - **OWL DL** (Description Logic) introduces restrictions
  - **OWL Lite** is an entry level language intended to be easy to understand and implement



OWL ↔ RDF

- An OWL ontology is a set of RDF statements
  - OWL defines semantics for certain statements
  - Does **NOT** restrict what can be said -- documents can include arbitrary RDF
  - But no OWL semantics for non-OWL statements
- Adds capabilities common to description logics:
  - cardinality constraints, defined classes (=> classification), equivalence, local restrictions, disjoint classes, etc.
- More support for ontologies
  - Ontology imports ontology, versioning, ...
- But not (yet) variables, quantification, & rules
- A complete OWL reasoning is significantly more complex than a complete RDFS reasoner.

Owl is based on Description Logic

- DL is a family of KR languages that might be described as **"Logic meets Objects"**
- A DL is characterized by a set of constructors that allow one to build complex **concepts** and **roles** from atomic ones
  - **Concepts** correspond to classes; interpreted as sets of objects
  - **Roles** correspond to relations; interpreted as binary relations on objects
- Axioms assert **facts** about concepts, roles and **individuals**
- Distinguished by:
  - Formal semantics for a decidable fragment of FOL
  - Sound and complete decision procedures for key problems
  - Many implemented systems, some highly optimized

OWL Class Constructors

Constructor	DL Syntax	Example
intersectionOf	$C_1 \sqcap \ldots \sqcap C_n$	Human ⊓ Male
unionOf	$C_1 \sqcup \ldots \sqcup C_n$	Doctor ⊔ Lawyer
complementOf	$\neg C$	¬Male
oneOf	$\{x_1 \ldots x_n\}$	{john, mary}
allValuesFrom	$\forall P.C$	∀hasChild.Doctor
someValuesFrom	$\exists P.C$	∃hasChild.Lawyer
maxCardinality	$\leqslant nP$	⩽1hasChild
minCardinality	$\geqslant nP$	⩾2hasChild

borrowed from Ian Horrocks

OWL Axioms

Axiom	DL Syntax	Example
subClassOf	$C_1 \sqsubseteq C_2$	Human ⊑ Animal ⊓ Biped
equivalentClass	$C_1 \equiv C_2$	Man ≡ Human ⊓ Male
disjointWith	$C_1 \sqsubseteq \neg C_2$	Male ⊑ ¬Female
sameIndividualAs	$\{x_1\} \equiv \{x_2\}$	{President_Bush} ≡ {G_W_Bush}
differentFrom	$\{x_1\} \sqsubseteq \neg\{x_2\}$	{john} ⊑ ¬{peter}
subPropertyOf	$P_1 \sqsubseteq P_2$	hasDaughter ⊑ hasChild
equivalentProperty	$P_1 \equiv P_2$	cost ≡ price
inverseOf	$P_1 \equiv P_2^-$	hasChild ≡ hasParent⁻
transitiveProperty	$P^+ \sqsubseteq P$	ancestor⁺ ⊑ ancestor
functionalProperty	$\top \sqsubseteq \leqslant 1P$	⊤ ⊑ ⩽1hasMother
inverseFunctionalProperty	$\top \sqsubseteq \leqslant 1P^-$	⊤ ⊑ ⩽1hasSSN⁻

borrowed from Ian Horrocks

OWL Language

- Three species of OWL
  - *OWL Full* is union of OWL syntax and RDF
  - *OWL DL* restricted to FOL fragment (≅ DAML+OIL)
  - *OWL Lite* is "simpler" subset of OWL DL
- Semantic layering
  - OWL DL ≅ OWL full within DL fragment
- OWL DL based on SHIQ Description Logic
- OWL DL Benefits from many years of DL research
  - Well defined semantics
  - Formal properties well understood (complexity, decidability)
  - Known reasoning algorithms
  - Implemented systems (highly optimised)

OWL Lite Features

- **RDF Schema Features**
  - *Class, rdfs:subClassOf , Individual*
  - *rdf:Property, rdfs:subPropertyOf*
  - *rdfs:domain , rdfs:range*
- **Equality and Inequality**
  - *sameClassAs , samePropertyAs , sameIndividualAs*
  - *differentIndividualFrom*
- **Restricted Cardinality**
  - *minCardinality, maxCardinality (restricted to 0 or 1)*
  - *cardinality (restricted to 0 or 1)*
- **Property Characteristics**
  - *inverseOf , TransitiveProperty , SymmetricProperty*
  - *FunctionalProperty(unique) , InverseFunctionalProperty*
  - *allValuesFrom, someValuesFrom (universal and existential local range restrictions)*
- ***Datatypes***
  - *Following the decisions of RDF Core.*
- ***Header Information***
  - *imports , Dublin Core Metadata , versionInfo*

OWL Features

- **Class Axioms**
  - *oneOf* (enumerated classes)
  - *disjointWith*
  - *sameClassAs* applied to class expressions
  - *rdfs:subClassOf* applied to class expressions
- **Boolean Combinations of Class Expressions**
  - *unionOf*
  - *intersectionOf*
  - *complementOf*
- **Arbitrary Cardinality**
  - *minCardinality*
  - *maxCardinality*
  - *cardinality*
- **Filler Information**
  - *hasValue* Descriptions can include specific value information

OWL Ontologies

- The owl:Ontology class describes an ontology
- An ontology file should be one instance of owl:Ontology
- Ontology properties include
  - owl:imports, owl:versionInfo, owl:priorVersion
  - owl:backwardCompatibleWith, owl:incompatibleWith
  - rdfs:label, rdfs:comment can also be used
- Deprecation control classes:
  - owl:DeprecatedClass, owl:DeprecatedProperty types

OWL in One Slide

OWL is built on top of XML and RDF

It allows the definition, sharing, composition and use of ontologies

OWL is ~= a frame based knowledge representation language

It can be used to add metadata about anything which has a URI.

URIs are a W3C standard generalizing URLs

everything has a URI

```
<rdf:RDF xmlns:rdf ="http://w3.org/22-rdf-syntax-ns#"
   xmlns:rdfs=http://w3.org/rdf-schema#>
   xmlns:owl="http://www.w3.org/2002/07/owl#">
<owl:Ontology rdf:about="">
   <owl:imports rdf:resource="http://owl.org/owl+oil"/>
</owl:Ontology>
<owl:Class rdf:ID="Person">
  <rdfs:subClassOf rdf:resource="#Animal"/>
  <rdfs:subClassOf>
   <owl:Restriction>
     <owl:onProperty rdf:resource="#hasParent"/>
     <owl:allValuesFrom rdf:resource="#Person"/>
   </owl:Restriction>
  </rdfs:subClassOf>
  <rdfs:subClassOf>
   <owl:Restriction owl:cardinality="1">
     <owl:onProperty rdf:resource="#hasFather"/>
   </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
<Person rdf:about="http://umbc.edu/~finin/">
  <rdfs:comment>Finin is a person.</rdfs:comment>
</Person>
```