Semantic Web Languages and Technologies

Semantic Web Technologies

- W3C "recommendations"
  - RDF, RDFS, RDFa, OWL, SPARQL, …
  - Under development: recommendations for rules, provenance, database export, etc.
- Common tools and systems -- commercial, free and open sourced
  - Ontology editors, triple stores, reasoners
- Common ontologies and data sets
  - Foaf, Dbpedia
- Infrastructure systems
  - Search, ontology metadata, linking services

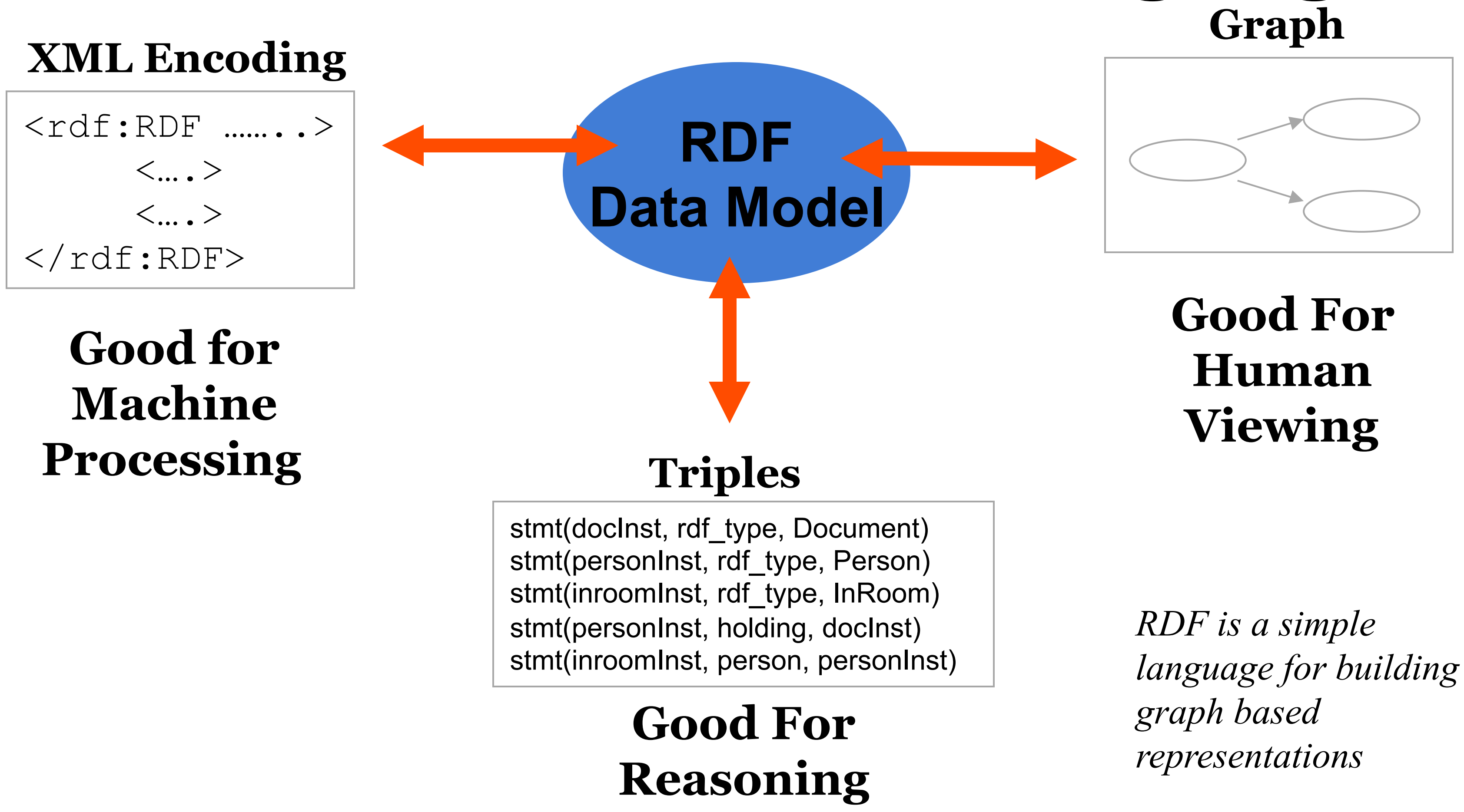
Semantic web languages today

- 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



XML Encoding

```
<rdf:RDF ……..>
     <…..>
     <…..>
</rdf:RDF>
```

Good for Machine Processing

Graph

Good For Human Viewing

Triples

```
stmt(docInst, rdf_type, Document)
stmt(personInst, rdf_type, Person)
stmt(inroomInst, rdf_type, InRoom)
stmt(personInst, holding, docInst)
stmt(inroomInst, person, personInst)
```

Good For Reasoning

RDF is a simple language for building graph based representations

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

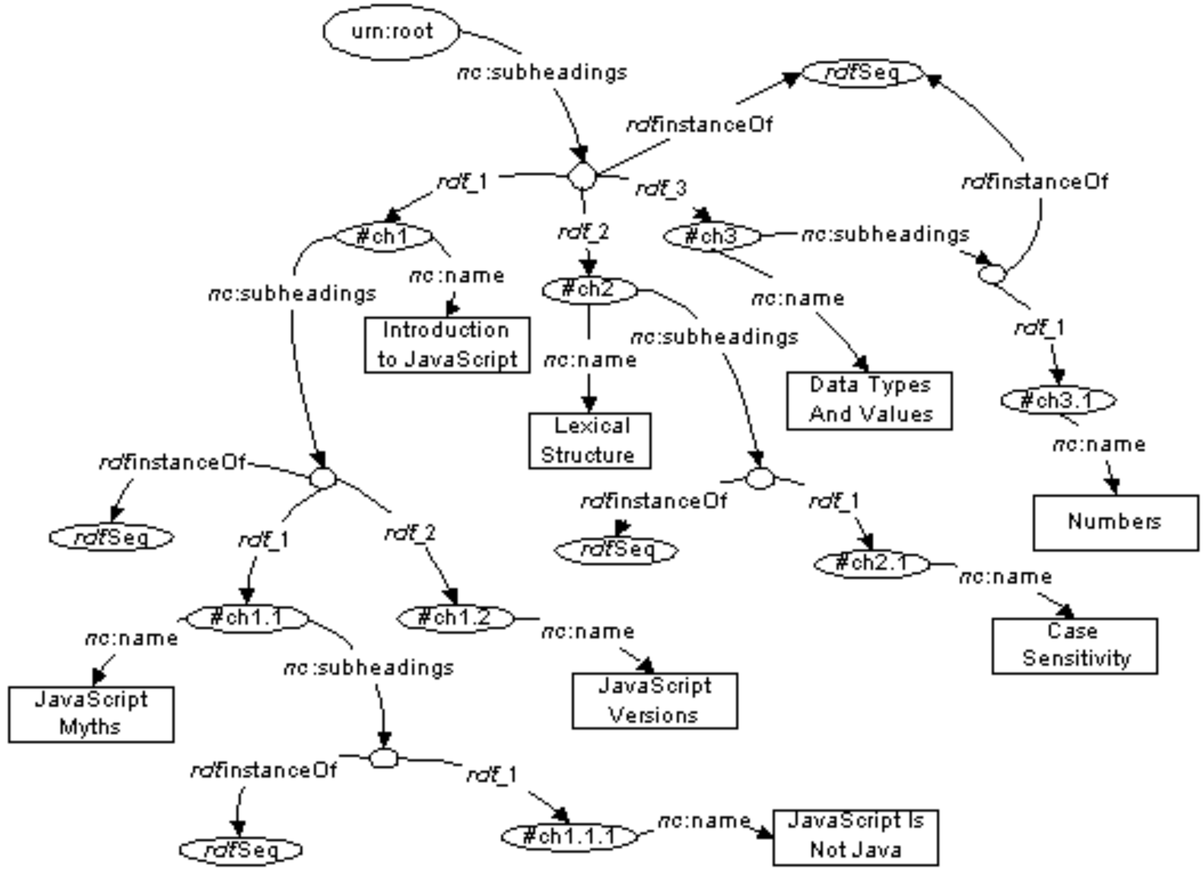
- URI = **Uniform Resource Identifier**
  - "The generic set of all names/addresses that are short strings that refer to resources"
  - URLs (Uniform Resource Locators) are a subset of URIs, used for resources that can be *accessed* on the web
- URIs look like “normal” URLs, often with fragment identifiers 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?

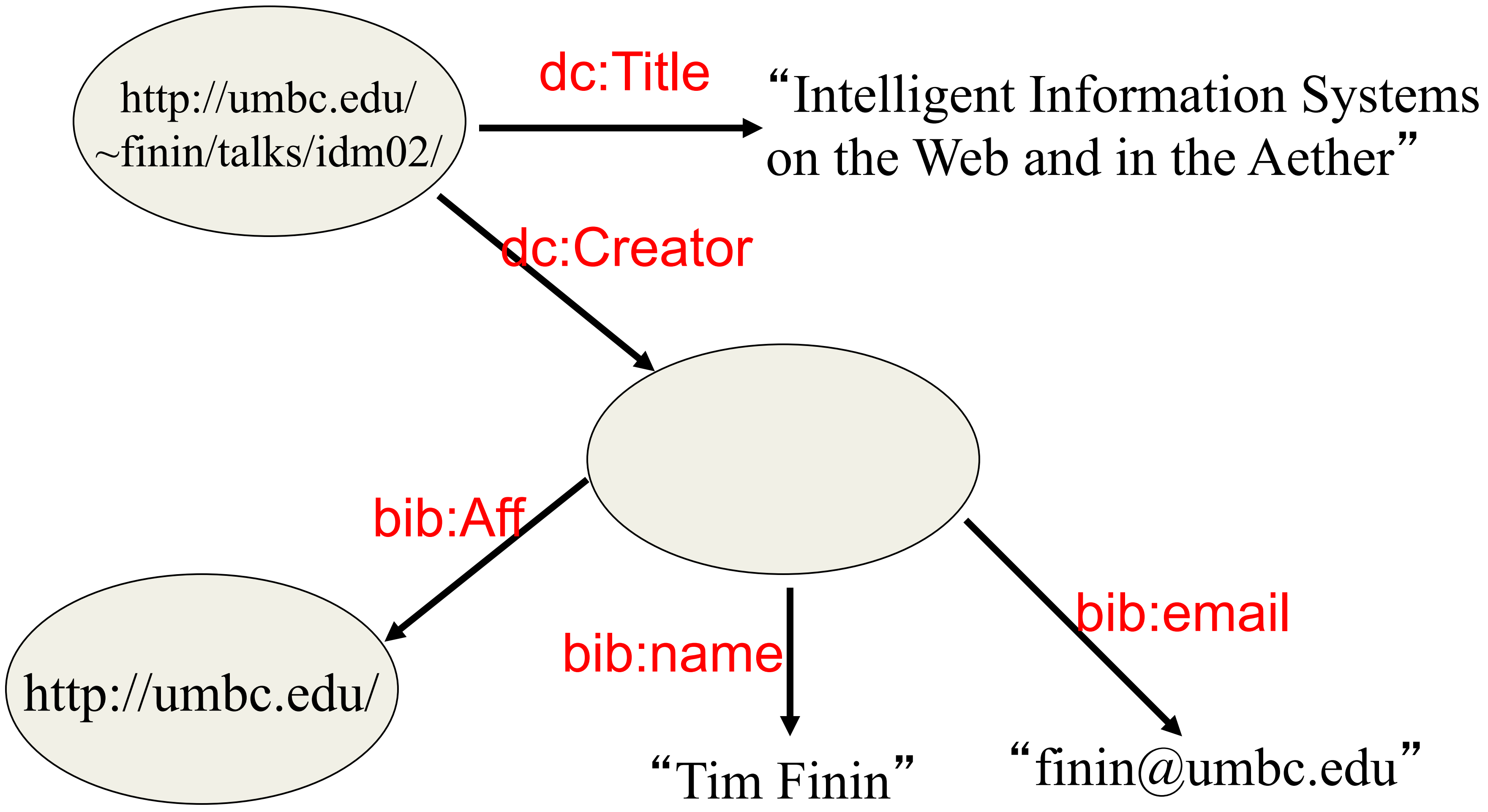
- Sometimes URIs denote a web resource
  - http://umbc.edu/~finin/finin.jpg denotes a file
  - We can use RDF to make assertions about the resource, e.g., it's an image and depicts a person with name Tim Finin, …
- Sometimes concepts in the external world
  - E.g., http://umbc.edu/ denotes a particular 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


http://umbc.edu/ ~finin/talks/idm02/
dc:Title
“Intelligent Information Systems on the Web and in the Aether”
dc:Creator
bib:Aff
http://umbc.edu/
bib:name
“Tim Finin”
bib:email
“finin@umbc.edu”

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

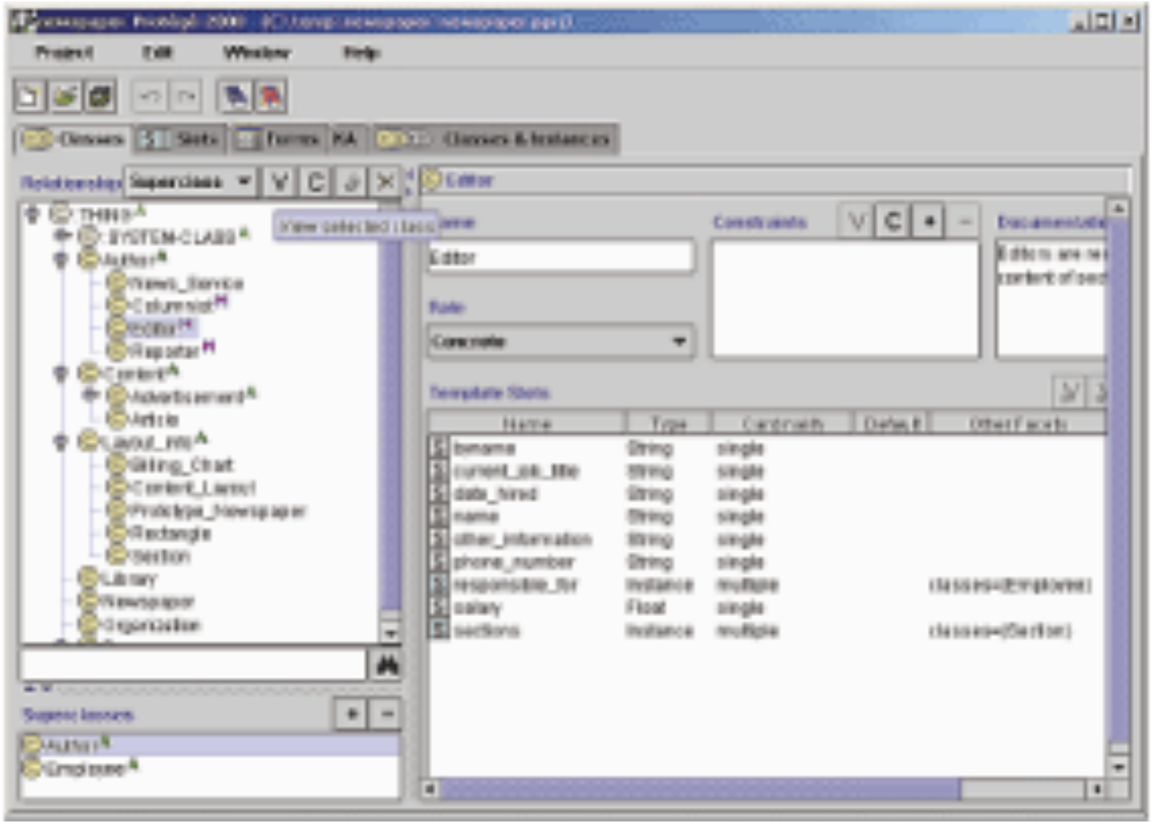
```
:john bdi:believes _:s.
_:s rdf:type rdf:Statement.
_:s rdf:subject <http://yd.example.com/catalog/
widgetX>.
_:s rdf:predicate cat:salePrice .
_:s rdf:object "19.95" .
```

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**



Name	Type	Cardinality	Default	Other Facets
byname	String	single		
current_job_title	String	single		
date_hired	String	single		
name	String	single		
other_information	String	single		
phone_number	String	single		
responsible_for	Instance	multiple		classes={Employee}
salary	Float	single		
sections	Instance	multiple		classes={Section}

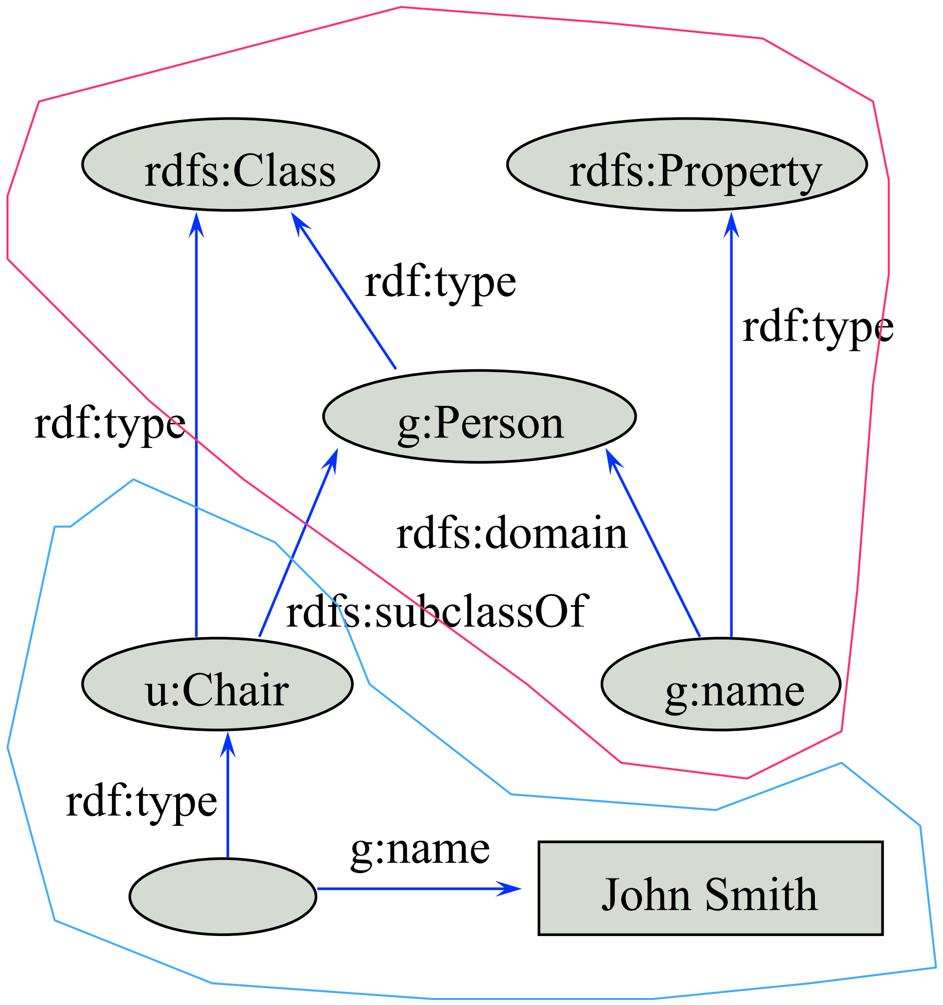
Stanford Protégé KB editor
- Java, open sourced
- extensible, lots of plug-ins
- provides reasoning & server capabilities

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: <http          /2000/01/rdf-schema#>.
@prefix : <#> .
<> rdfs:comment "This is a        3 exam
:Person a rdfs:Class.
:Woman a rdfs:Class; rdfs:subClass
:eve a :Woman; :age "100"
:sister a rdf:Property;  rdfs
        rdfs:range :Woman.
:eve :sister [a :Woman; :age 98].
:eve :believe {:eve :age "100"}.
[is :spouse of [is :sister of :eve]] :age 9
:eve.:sister.:spouse :age 99.
```

Here's how you declare a namespace.

This defin   em as referring to "this docum

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

"person is a class". The "a" syntax is sugar for rdf:type p

"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" an

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

"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

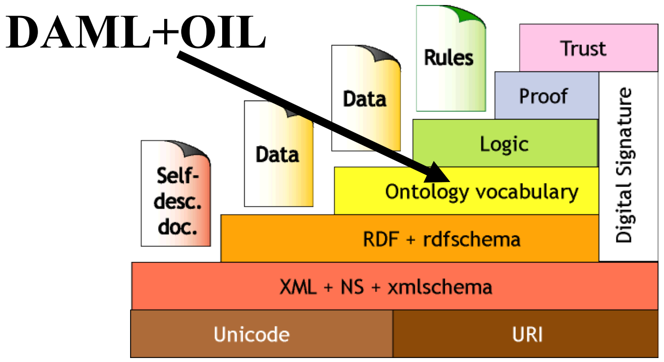
    Can’t say that the range of hasChild is person when applied to persons and elephant when applied to elephants
  - No *existence/cardinality* constraints

    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.

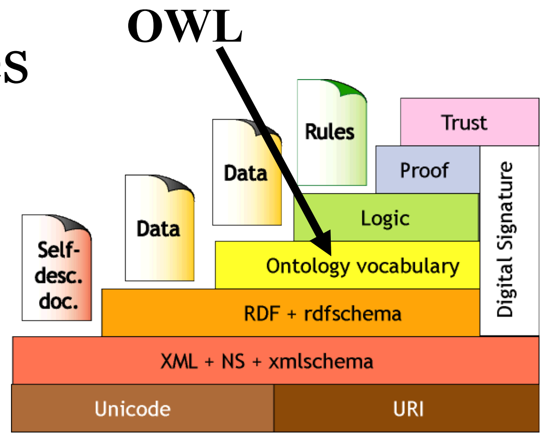
DAML+OIL = RDF + KR

- 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



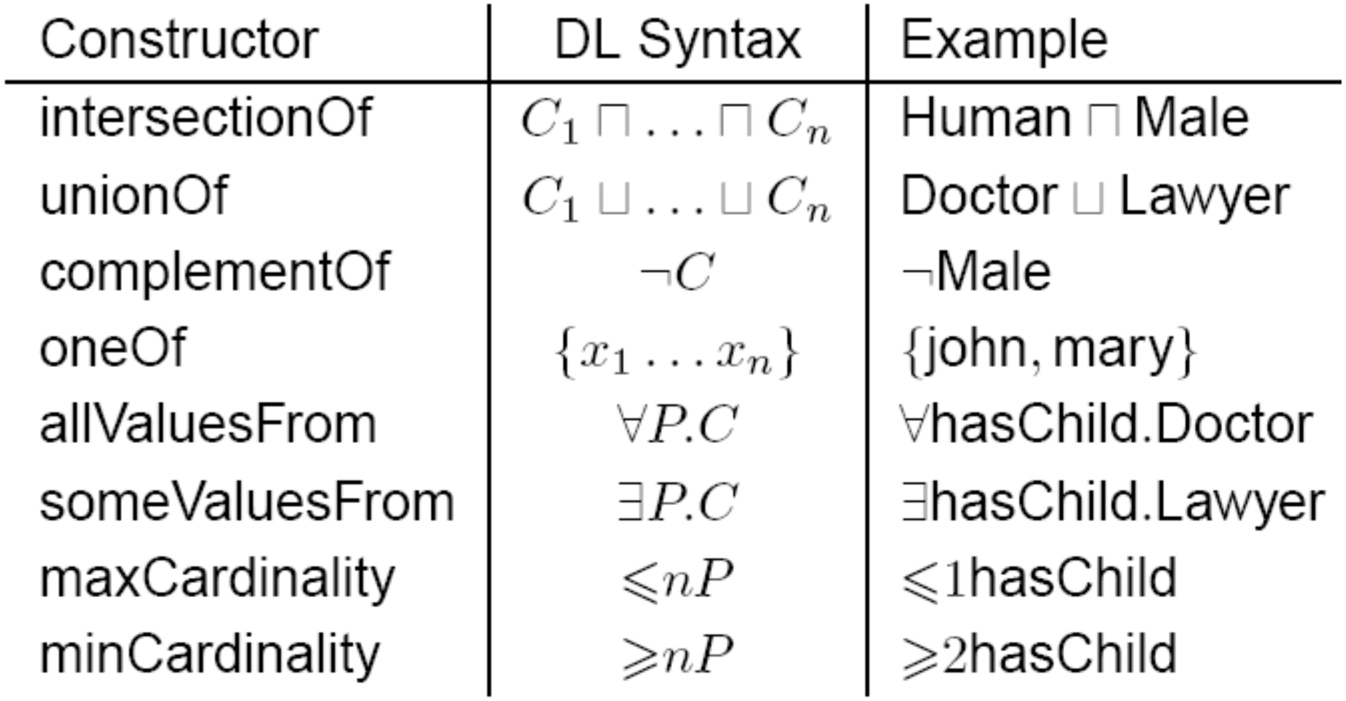
OWL ↔ RDF

- 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 $\sqcap$ Male
unionOf	$C_1 \sqcup \ldots \sqcup C_n$	Doctor $\sqcup$ Lawyer
complementOf	$\neg C$	$\neg$Male
oneOf	$\{x_1 \ldots x_n\}$	{john, mary}
allValuesFrom	$\forall P.C$	$\forall$hasChild.Doctor
someValuesFrom	$\exists P.C$	$\exists$hasChild.Lawyer
maxCardinality	$\leqslant nP$	$\leqslant$1hasChild
minCardinality	$\geqslant nP$	$\geqslant$2hasChild

borrowed from Ian Horrocks

OWL Axioms

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

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>
```

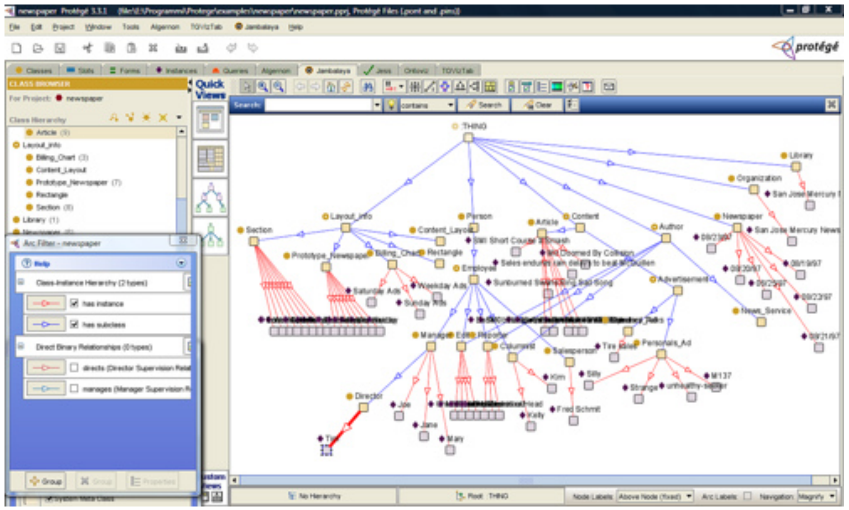
RDFa

- RDFa is a W3C recommendation for embedding SW markup in HTML as tag *attributes*
- Enables Web pages that are understandable by both people and machines

```
<p xmlns:dc="http://purl.org/dc/elements/1.1/"
  about="http://www.example.com/books/wikinomics">
In his latest book <cite property="dc:title">Wikinomics</cite>,
<span property="dc:creator">Don Tapscott</span>
explains deep changes in technology, demographics and business.
The book is due to be published in
<span property="dc:date" content="2006-10-01">October 2006
</span>. </p>
```

Ontology Editor

- There are a number of editors available for creating and editing ontologies and data
- We recommend using Protégé, a java-based free system developed at Stanford
  - Good support for reasoning
  - Lots of plugins



Triple Store

- A triple store is a database for RDF triples
- It usually has a native API and often accepts SPARQL queries
- It might do reasoning, either in an eager manner (as triples are loaded) or on demand (to answer queries), etc
- Some stores focus on scalability and others on flexibility and features
- We'll experiment with stardog

Frameworks and Libraries

- There are frameworks, libraries and packages for most programming languages
- RDFLib is a popular library for Python that we will study
- Jena is a very comprehensive Java framework originally developed by HP and now Apache