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

Graph

Good For Machine Processing

XML Encoding

<rdf:RDF ....>
  ....
</rdf:RDF>

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)

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 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://umbe.edu/~finin/cv.html
  - a book in the library, a real person (?)
  - isbn://5031-4444-3333
  - ...
- Properties themselves are also resources (URIs)

UIRIs 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
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://daml.umbc.edu/ontologies/bib/Name> "Tim Finin" .
<http://umbc.edu/~finin/talks/idm02/> <http://daml.umbc.edu/ontologies/bib/Email> "finin@umbc.edu" .
<http://umbc.edu/~finin/talks/idm02/> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <Description> .
<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)

• 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"

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

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, star signs, ...
- 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

```xml
<rdf:RDF
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
  xmlns:gen="http://schema.org"
  xmlns:u="http://schema.org/univ">
  <g:Person rdf:ID="john">
    <g:name>John Smith</g:name>
  </g:Person>
</rdf:RDF>
```
RDFS supports simple inferences

- 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.w3.org/2000/01/rdf-schema#>.
@prefix : <genesis.n3>.
parent rdfs:domain person; rdfs:range person.
mother rdfs:subProperty parent; rdfs:domain woman; rdfs:range person.
eve mother cain.
```

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.

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**OWL Class Constructors**

<table>
<thead>
<tr>
<th>Constructor</th>
<th>DL Syntax</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>intersectionOf</td>
<td>$C_1 \cap \ldots \cap C_n$</td>
<td>Human ⊑ Male</td>
</tr>
<tr>
<td>unionOf</td>
<td>$C_1 \cup \ldots \cup C_n$</td>
<td>Doctor ⊑ Lawyer ⊑ Male</td>
</tr>
<tr>
<td>complementOf</td>
<td>$\neg C$</td>
<td>(John, Mary)</td>
</tr>
<tr>
<td>oneOf</td>
<td>${x_1, \ldots, x_n}$</td>
<td>hasChild, Doctor</td>
</tr>
<tr>
<td>allValuesFrom</td>
<td>$\forall P . C$</td>
<td>hasChild, Lawyer</td>
</tr>
<tr>
<td>someValuesFrom</td>
<td>$\exists P . C$</td>
<td>hasChild, Lawyer</td>
</tr>
<tr>
<td>maxCardinality</td>
<td>$\leq n P$</td>
<td>hasChild, Doctor</td>
</tr>
<tr>
<td>minCardinality</td>
<td>$\geq n P$</td>
<td>hasChild, Doctor</td>
</tr>
</tbody>
</table>

*borrowed from Ian Horrocks*

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**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 Axioms**

<table>
<thead>
<tr>
<th>Axiom</th>
<th>DL Syntax</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>subClassOf</td>
<td>$C_1 \sqsubseteq C_2$</td>
<td>Human ⊑ Animal ⊑ Biped</td>
</tr>
<tr>
<td>equivalentClass</td>
<td>$C_1 \equiv C_2$</td>
<td>Man ⊑ Human ⊑ Male</td>
</tr>
<tr>
<td>disjointWith</td>
<td>$C_1 \sqsubseteq \neg C_2$</td>
<td>Male ⊑ Female</td>
</tr>
<tr>
<td>sameIndividualAs</td>
<td>${x_1, x_2} \sqsubseteq {x_3, x_4}$</td>
<td>(President, Bush) = (G_W, Bush)</td>
</tr>
<tr>
<td>differentFrom</td>
<td>${x_1} \sqsubseteq {x_2}$</td>
<td>(John) ≠ (Peter)</td>
</tr>
<tr>
<td>subPropertyOf</td>
<td>$P_1 \sqsubseteq P_2$</td>
<td>hasDaughter ⊑ hasChild</td>
</tr>
<tr>
<td>equivalentProperty</td>
<td>$P_1 \equiv P_2$</td>
<td>hasChild = hasParent</td>
</tr>
<tr>
<td>inverseOf</td>
<td>$P_1 \sqsubseteq P_2$</td>
<td>hasChild = hasParent</td>
</tr>
<tr>
<td>transitiveProperty</td>
<td>$P^n \sqsubseteq P$</td>
<td>ancestor ⊑ ancestor</td>
</tr>
<tr>
<td>functionalProperty</td>
<td>$\top \sqsubseteq P$</td>
<td>⊢ ⊑ hasMother</td>
</tr>
<tr>
<td>inverseFunctionalProperty</td>
<td>$\top \sqsubseteq (P^n)^*$</td>
<td>⊢ ⊑ hasSSN</td>
</tr>
</tbody>
</table>

*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 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 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 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

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

URIs are a W3C standard generalizing URLs

everything has a URI

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


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