

Introduction to the Semantic Web

Semantic tecnologies – a quick overview Fulvio Corno Politecnico di Torino

Semantic Web



http://www.w3.org/2001/sw/

- Web second generation
 Web 3.0
- "Conceptual structuring of the Web in an explicit machine-readable way" (Tim Berners-Lee)
- In other words...



...let the machine do most of the work!!!

'Official' introduction (1/2)

- The Semantic Web is a web of data. There is lots of data we all use every day, and its not part of the web. I can see my bank statements on the web, and my photographs, and I can see my appointments in a calendar. But can I see my photos in a calendar to see what I was doing when I took them? Can I see bank statement lines in a calendar?
- Why not? Because we don't have a web of data. Because data is controlled by applications, and each application keeps it to itself.

'Official' introduction (2/2)

The Semantic Web is about two things. It is about common formats for integration and combination of data drawn from diverse sources, where on the original Web mainly concentrated on the interchange of documents. It is also about language for recording how the data relates to real world objects. That allows a person, or a machine, to start off in one database, and then move through an unending set of databases which are connected not by wires but by being about the same thing.



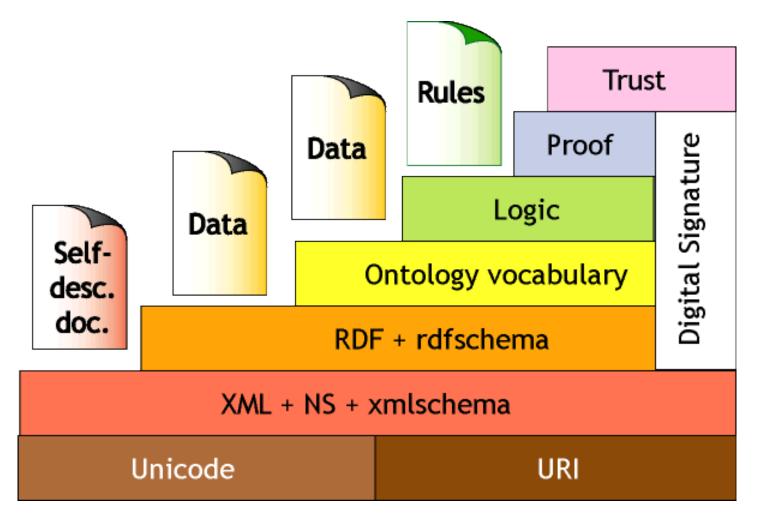
Key principles

The Semantic Web is the Web

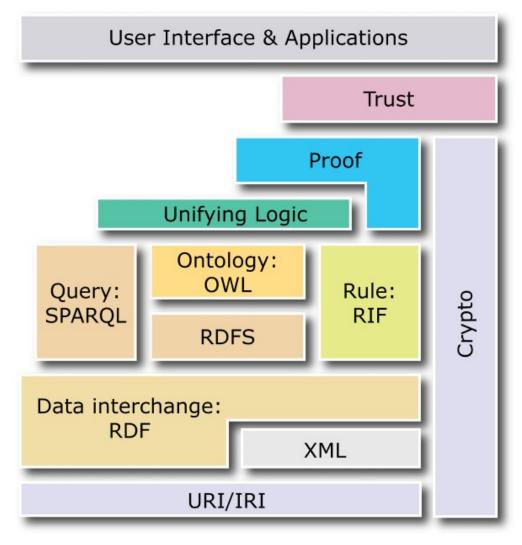
- □ Same base technologies, Evolutionary
- Decentralized (incomplete, inconsistent)
- Provide explicit statements regarding web resources
 - Authors, original information providers
 Intermediaries (humans and/or machines)
- Information consumers determine consequences of the statements
 Distributed 'reasoning'



Technology stack (old: pre-2008)

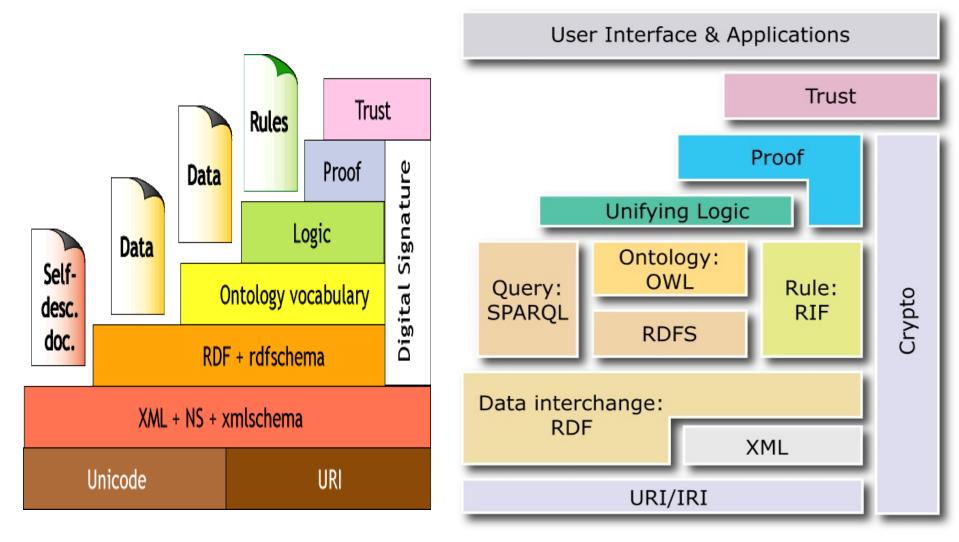


Technology stack (current: 2008)



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Comparison... current trends



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Main technologies

- Resource Description Framework (RDF) [2004]
- Gleaning Resource Descriptions from Dialects of Languages (GRDDL) [2007]
- SPARQL Query Language for RDF [2008]
- Web Ontology Language (OWL) [2004]





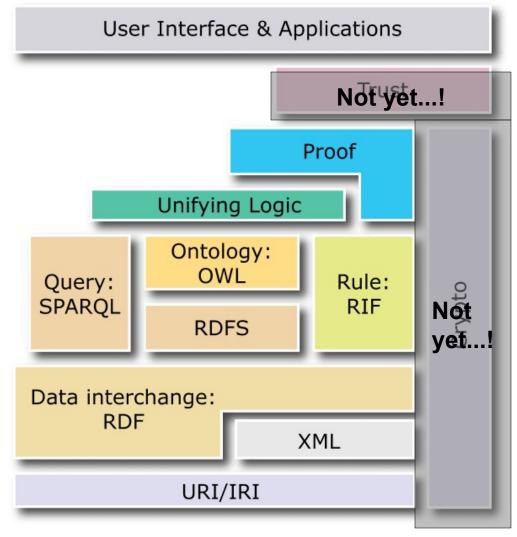




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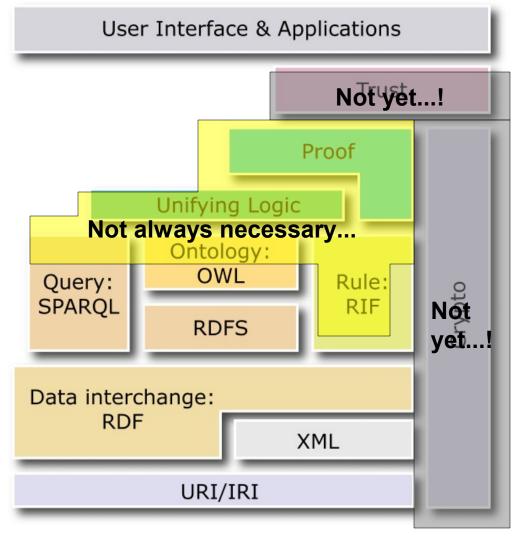


The real world...



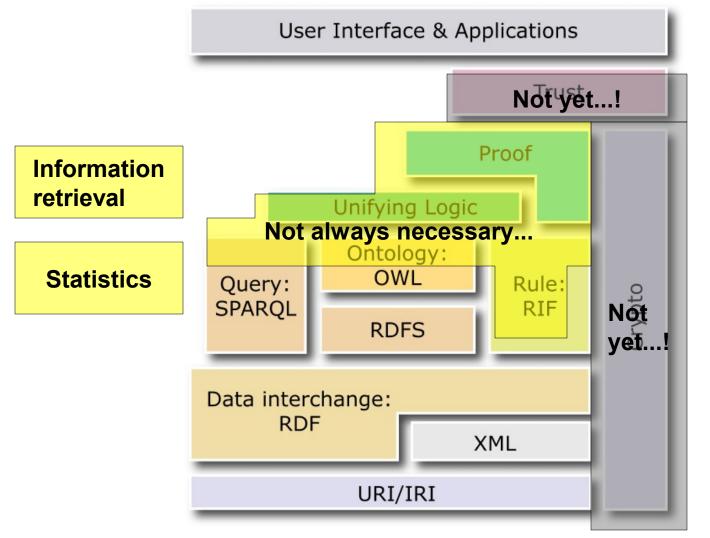


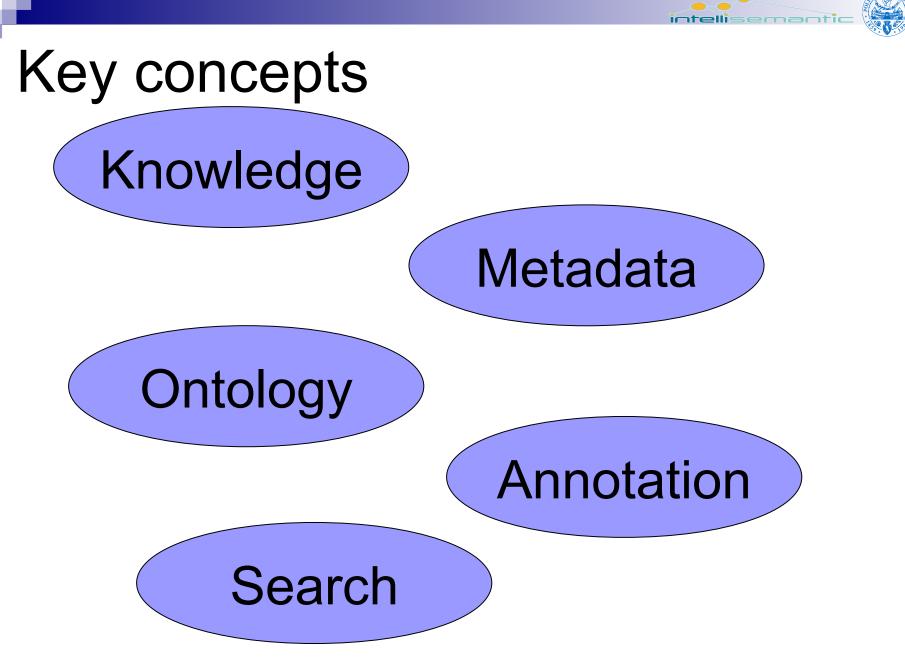
The real world...





The real world...

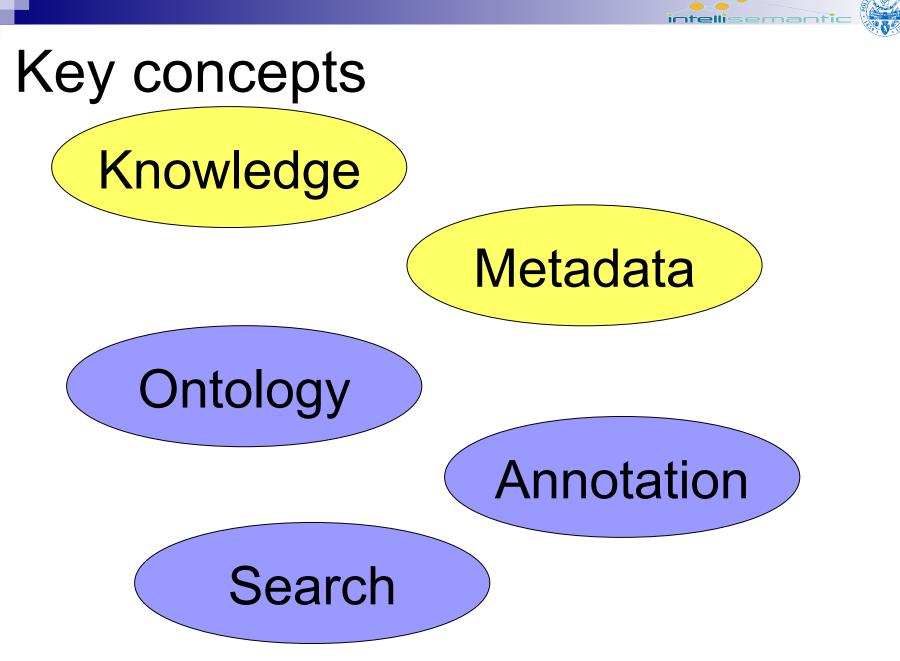






Metadata and Knowledge Representation

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Metadata

- Structured data about data
- Higher level information that describes

 - quality
 - structure
 - accessibility

□.

of a specific data set

Problems

- Even the author, sometimes, has difficulty in correctly classifying the contents
- Choice of "topics" may be done at different levels, all of them "correct"
- Choice of "keywords" is afflicted by synonyms and homonyms
- Typographical errors often appear in the original text



Classification techniques

- Controlled vocabularies
- Taxonomies
- Thesauri
- Facets
- Ontologies
- Folksonomies



Controlled vocabulary

- A closed list of named subjects, which can be used for classification
- Composed of terms [particular name for a particular concept] (similar to keywords)
- Terms are not concepts
 - A single term may be the name of one (or more) concept(s)
 - A single concept may have multiple names
 Ambiguity avoided by forbidding duplicate terms



Controlled vocabulary

Purpose:

- to avoid authors defining meaningless terms, terms which are too broad, or terms which are too narrow
- to prevent different authors from misspelling and choosing slightly different forms of the same term
- The simplest form of controlled vocabulary is simply a list of terms and nothing more.



Problems solved

Homograph

group of words that share the same spelling but have different meanings

Homonym

group of words that share the same spelling or pronunciation (or both) but have different meanings



Problems solved

Synonym

different words with identical or at least similar meanings

Polysemy

the capacity for a word to have multiple meanings



Example

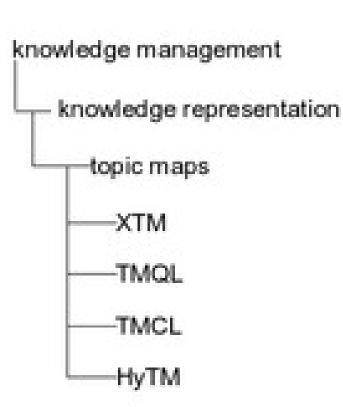
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ACM ACM Computing Classification System http://www.acm.org/class/	ΠΠΟΓΠΑLΙΟΠ	
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CAS CAS Registry Numbers http://www.cas.org/EO/regsys.html	http://www.iesi	
DDC		
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ENZYME		
Enzyme Commission Numbers http://www.chem.gmul.ac.uk/iubmb/enzyme/		
HASSET Humanities And Social Sciences Electronic Thesaurus (version 3.0) http://www.data-archive.ac.uk	/search/bassetSearch asp	
INSPEC		
Inspec Thesaurus http://www.iee.org/publish/support/inspec/document/thes/		
INSPECCN Inspec Classification http://www.iee.org/publish/support/inspec/document/class/		
JACS		
Joint Academic Coding System of the Higher Education Statistics Agency <u>http://www.hesa.ac.uk/j</u> LCC	acs/completeclassification.htm	
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http://www.iesr.ac.uk/profile/vocabs/index.html/#CtrldVocabsList

Taxonomy

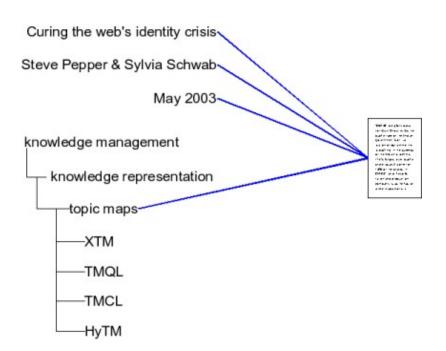
- Subject-based classification that arranges the terms in the controlled vocabulary into a hierarchy
 - Dating back to the work of Carl Linnæus in the 18th century on zoological and botanical classification and naming system for species
- Benefit: they allow related terms to be grouped together and categorized in ways that make it easier to find the correct term to use for searching or to describe an object

Taxonomy



- It is clear that "topic maps" and "XTM" are related
- Easier to classify documents
- Easier to choose search keywords

Taxonomies and metadata



- Metadata are stored as usual with the resource
- The "subject" will contain only controlled terms
- Controlled terms belong to a hierarchy, shared by all papers

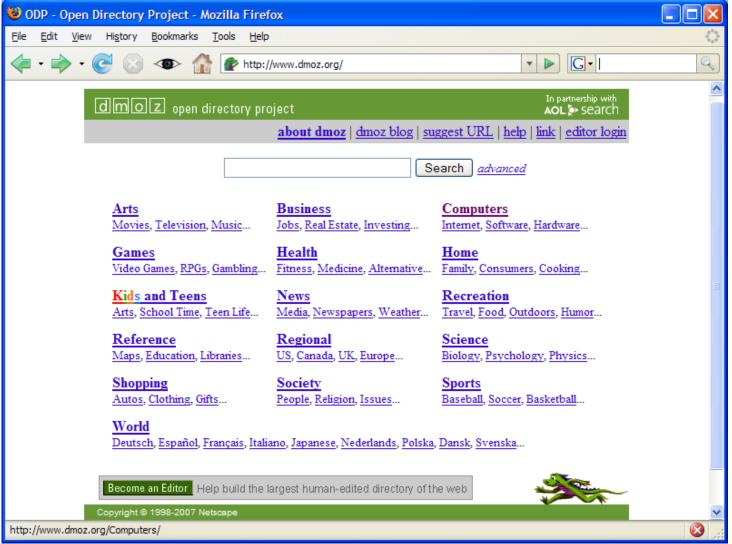


Limitations

A taxonomy may **not** express:

- □ "XML Topic Maps" is synonymous with "XTM"
- □ difference between "XTM" and "topic maps".
- "topic navigation maps" is synonymous with "topic maps", but should no longer be used\
- relationship between topic maps and subject-based classification, or the semantic web.
- relationship between XTM and XML and HyTM and SGML.
- similarity between HyTM and XTM, and their difference from TMQ





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Example

1998 ACM Computing Classification System: - Mozilla Firefox	
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ILLD.//WWW.aCM.

<u>g/ciass/1998/</u>ccs98.

The ACM Computing Classification System (1998)

- A. General Literature
 - A.0 GENERAL
 - Biographies/autobiographies
 - Conference proceedings
 - General literary works (e.g., fiction, plays)
 - A.1 INTRODUCTORY AND SURVEY
 - A.2 REFERENCE (e.g., dictionaries, encyclopedias, glossaries)
 - ◊ A.m MISCELLANEOUS
- B. Hardware
 - ◊ B.0 GENERAL
 - B.1 CONTROL STRUCTURES AND MICROPROGRAMMING (D.3.2)

m

- B.1.0 General
- B.1.1 Control Design Styles

Done

Thesaurus

- Extends taxonomies: subjects are arranged in a hierarchy
- Other statements can be made about the subjects
- Two ISO standards
 ISO2788 for monolingual thesauri
 ISO5964 for multilingual thesauri



Thesaurus relationships

- BT broader term
 - □ Refers to a term with wider or less specific meaning
 - Some systems allow multiple BTs for one term, while others do not
 - □ Inverse property: NT narrower term
 - □ A taxonomy only uses BT and NT
- SN scope note
 - □ String explaining its meaning within the thesaurus
 - Useful when the precise meaning of the term is not obvious from context.



Thesaurus relationships

USE

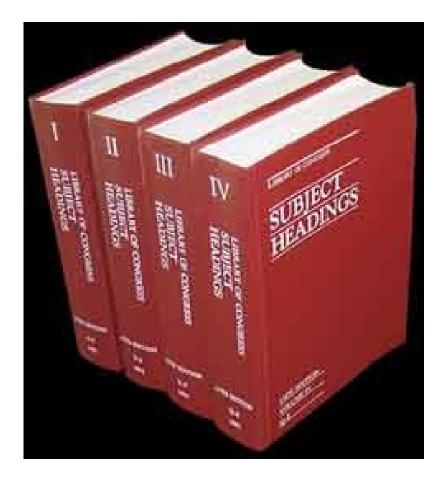
- Another term that is to be preferred instead of this term
- Implies that the terms are synonymous
- □ Inverse property: UF
- TT top term
 - □ The topmost ancestor of this term
 - □ The BT of the BT of the BT...
- RT related term
 - □ A term that is related to this term, without being a synonym of it or a broader/narrower term.

Example

😻 Records Manage	ment System - Classification Thesaurus - Mozilla Firefox
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⊔ Legislation	List of Terms
□ Management of University	0
Records Policy	
	Occupational Health and Safety (Forbidden Term)
□ TRIM Training	Use: Health and Safety.
⊐ Records Disposal	Office Accommodation (Forbidden Term)
Student Records	Use: Accommodation.
Student Operations	Office Equipment (Forbidden Term)
	Use: Equipment.
	Open Day (Descriptor)
	An organised event to allow prospective students and other clients to gain an appreciation of what the University has to offer them.
	Use: As a descriptor after the Keyword - Marketing, followed by the free text subject of the file.
	e.g. Marketing - Open Day - Swinburne at Lilydale.
	Operational Management(Keyword)
	The day-to-day and long term operations of the University. Relates to meetings, procedures, reports, strategic planning processes, and the like
Done	
vw.swinb	urne.edu.au/corporate/registrar/rms/keywords.htm Intellisemantic, Politecnico di Torino
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Example



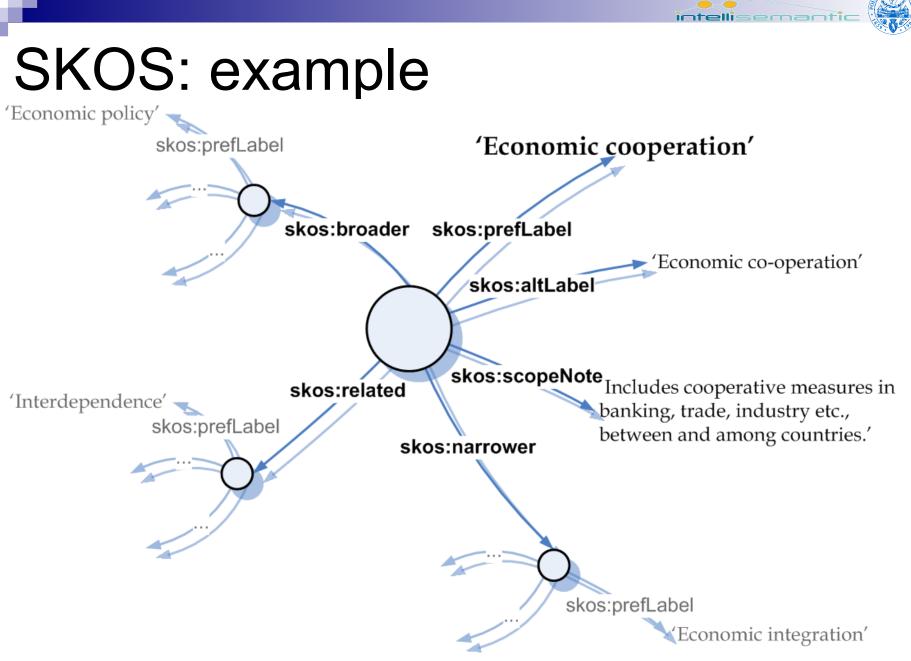
Library of Congress Subject Headings

- Since 1985 it became a taxonomy
- http://www.loc.gov/l exico/servlet/lexico/

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SKOS

- SKOS: Simple Knowledge Organization System
 - http://www.w3.org/2004/02/skos/
 - SKOS provides a standard way to represent knowledge organisation systems using the Resource Description Framework (RDF). Encoding this information in RDF allows it to be passed between computer applications in an interoperable way.»



Facets

- Proposed by S.R. Ranganathan in the 1930s
- Identifies a number of facets into which the terms are divided.
 - Facets can be thought of as different axes along which documents can be classified
 - □ Each facet contains a number of terms
 - Usually with at thesaurus-like organization
 - A term is only allowed to belong to a single facet
- A document is classified by picking one term from each facet to describe the document along all the different axes



Advantages

- Multi-dimensionality
- Persistence
- Scalability
- Flexibility

http://flamenco.berkeley.e du/

Example

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Argentina (5)	China (2)	YEAR		
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03/07/2008

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Ontology

- Model for describing the world that consists of a set of types, properties, and relationships
- Extends the other subject-based classification approaches
 - Has open vocabularies
 - □ Has open relationship types
 - Not just BT/NT + USE/UF

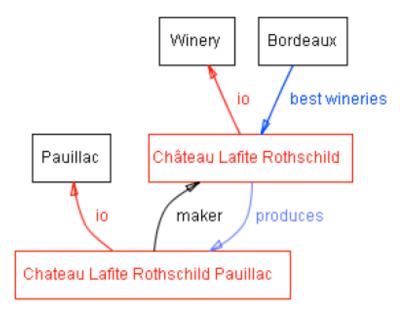


Ontology structure

Concepts
 Relationships

 Is-a
 Other

 Instances



http://onto.stanford.edu.8080/wino/ind ex.jsp

Example

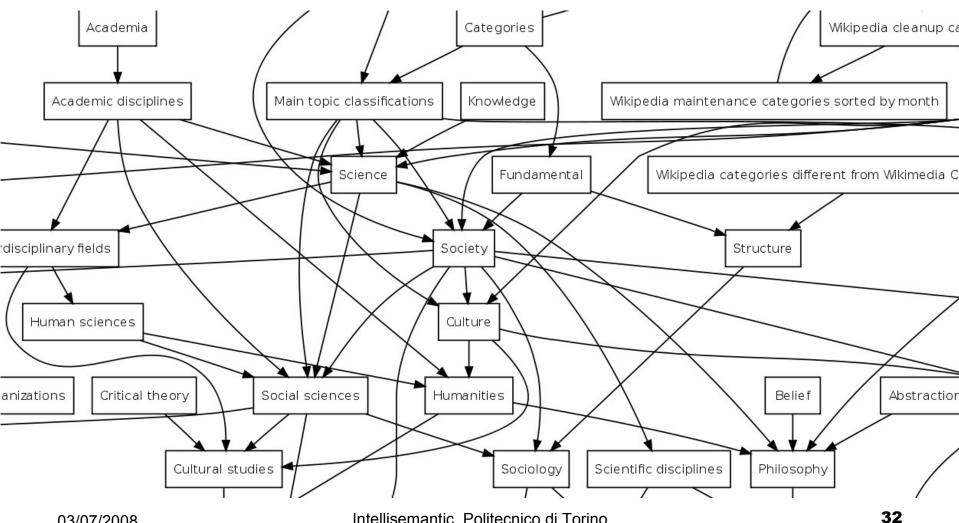
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Poultry: Rotisserie chicken - Roast duck - Roast goose - Roast turkey							
Meat: Grilled T-Bone steak - 10 oz. Prime rib - Garlicky roast beef tenderloin - Grilled veal chops - Grilled pork chops - Lamb curry							
Pasta: Spaghetti with tomato sauce - Fetuccine Alfredo - Fra Diavolo - Linguine with white clam sauce							

Folksonomy

- Internet-mediated social environments
- Collaboratively generated, open-ended labeling system that enables Internet users to categorize content such as Web pages, online photographs, and Web links
- Users can discover who created a given folksonomy tag, and see the other tags that this person created
 - reward: better user's capacity to find related content



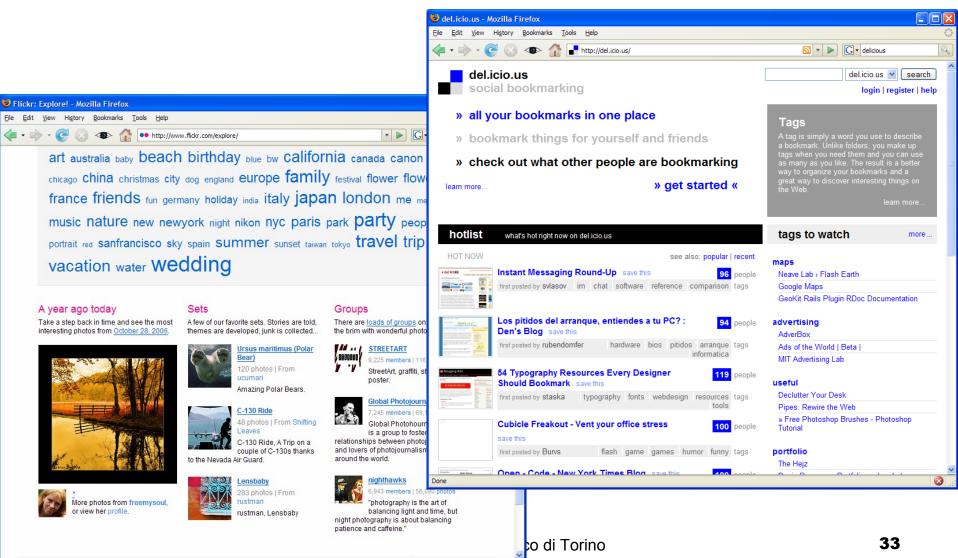
Example (wikipedia)



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Example (flickr - del.icio.us)



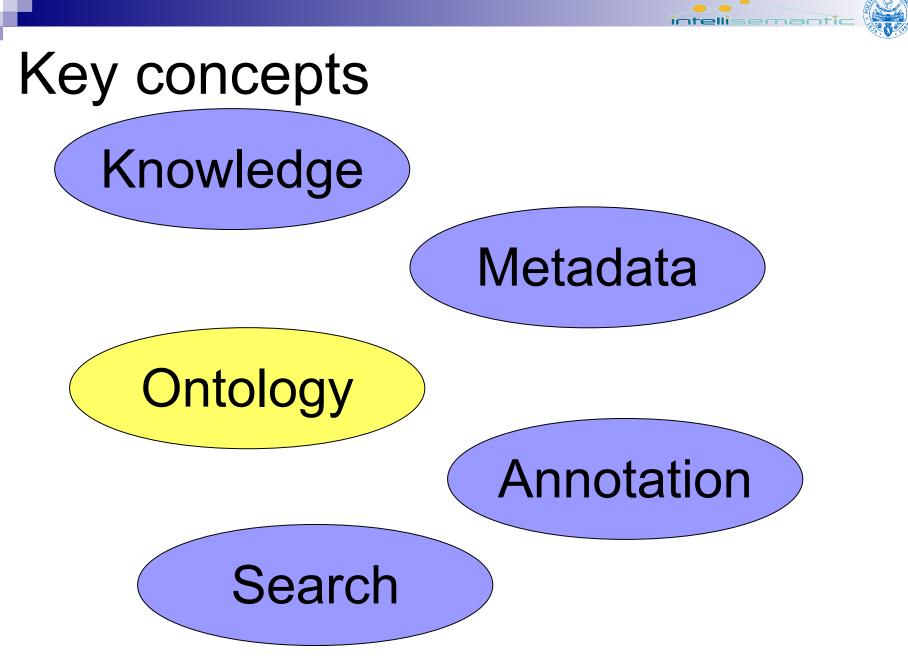
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References

- http://www.controlledvocabulary.com/links.html
- http://en.wikipedia.org/wiki/Controlled_vocabulary
- http://www.ontopia.net/topicmaps/materials/tm-vsthesauri.html
- http://www.w3.org/2004/02/skos/
- http://en.wikipedia.org/wiki/SKOS



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What are the problems?

- People, Organizations, Software Systems must communicate
 - Among themselvesTo the others
- Obstacles
 - □ Different needs
 - Different background
 - Different viewpoints
 - Different assumptions

How to solve them?

- resolve terminological confusion
- resolve conceptual confusion
- come to a shared understanding
- A shared understanding serves for:
 - providing a unifying framework for different viewpoints
 - providing the basis for communication between different people from different contexts



Ontologies: summary

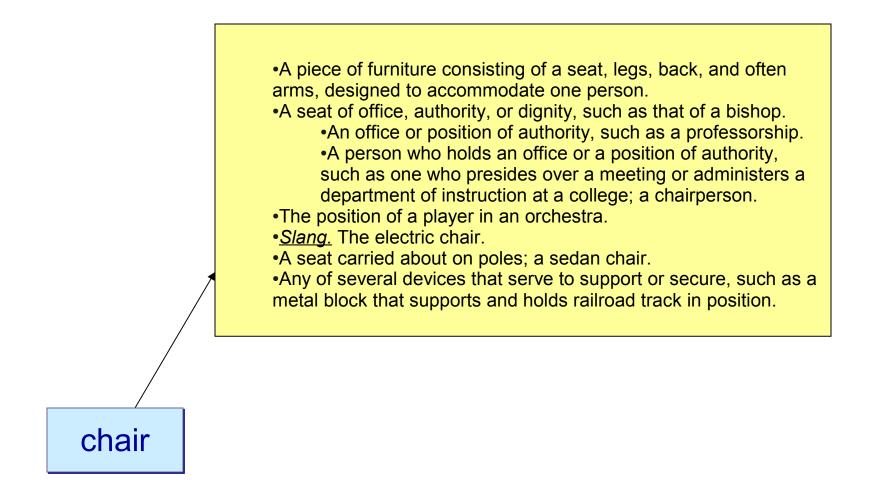
- An ontology is an explicit description of a domain
 - \Box concepts
 - properties and attributes of concepts
 constraints on properties and attributes
 individuals (often, but not always)
- An ontology defines

 a common vocabulary
 a shared understanding



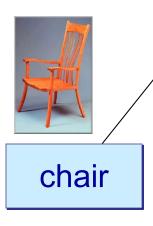








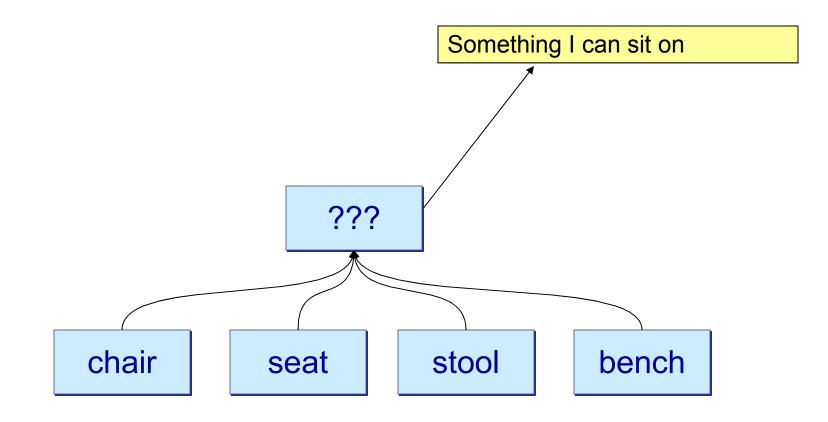
A piece of furniture consisting of a seat, legs, back, and often arms, designed to accommodate one person.



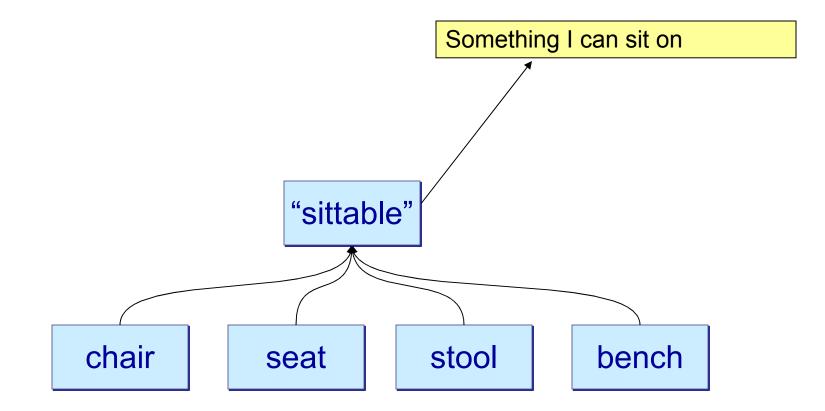






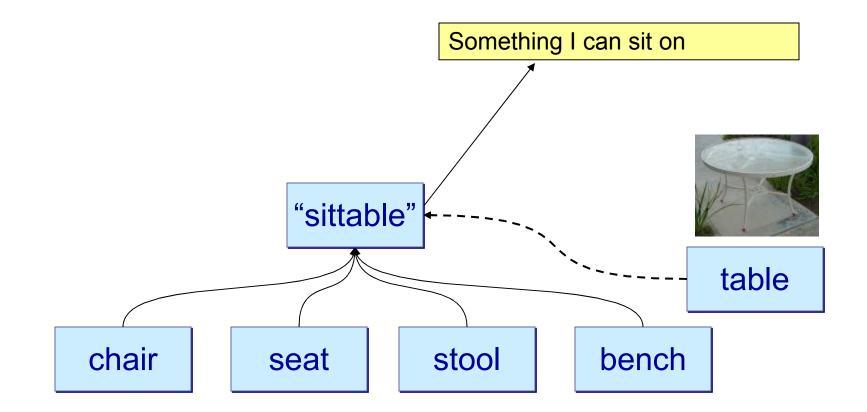






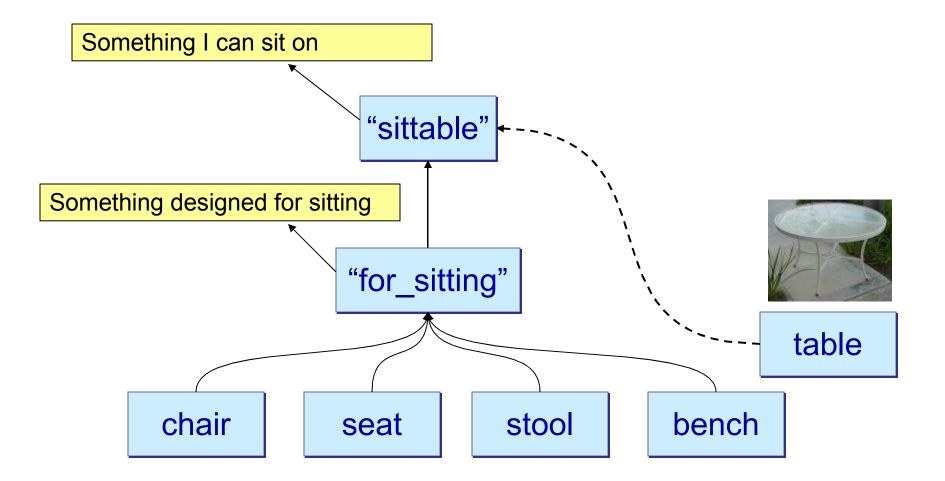
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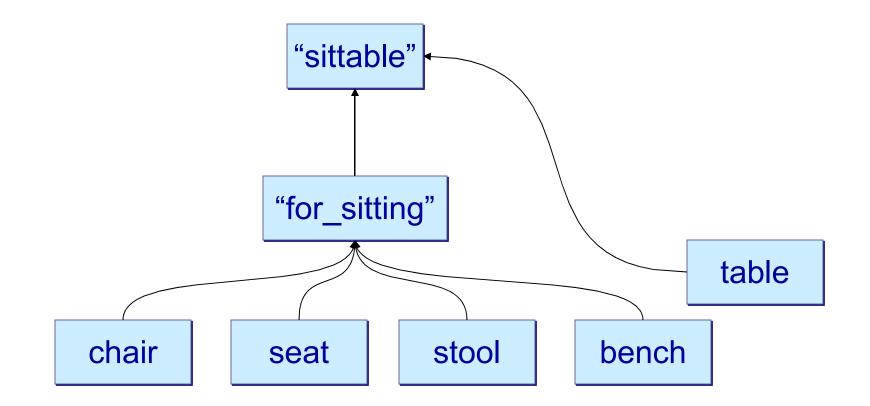




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Ontology structure





Ingredients

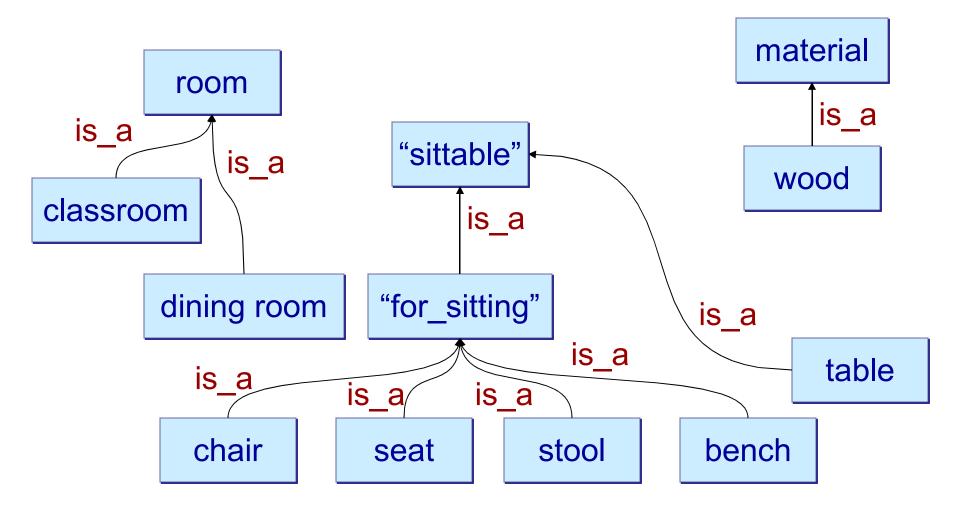
Concepts

shorthand name (internal use)

- □ synthetic title (to be displayed)
- □ definition (real unambiguous shared definition)
- Relationships among concepts
 - □is_a
 - other

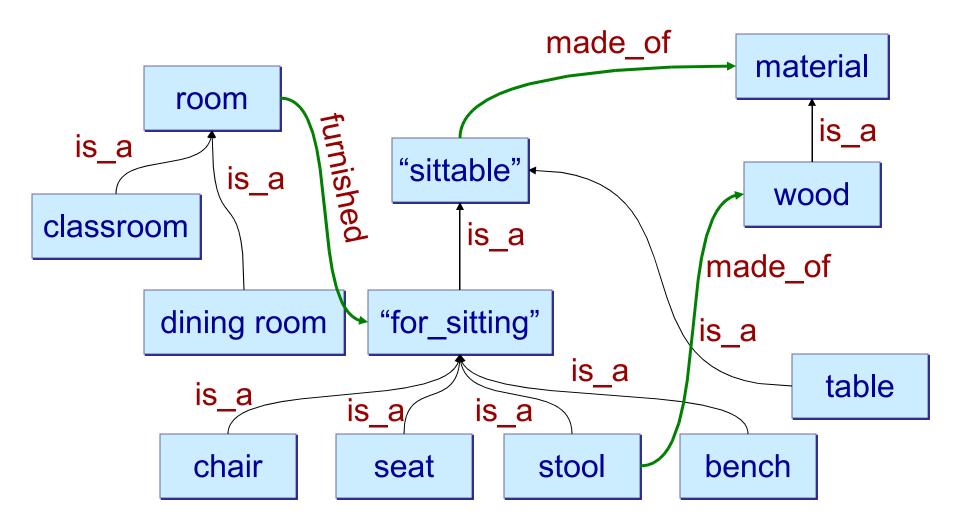
Annotations

Relationships



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Relationships



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Ontology building blocks

Ontologies generally describe: Individuals

the basic or "ground level" objects

sets, collections, or types of objects

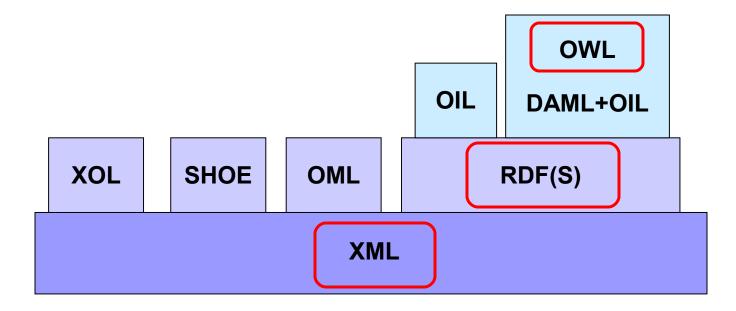
- Attributes
 - properties, features, characteristics, or parameters that objects can have and share

Relationships

ways that objects can be related to one another



Ontology languages



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RDF

- Resource Description Framework
 Resource = URI (retrievable, or not)
- RDF is structured in statements
- A statement is a **triple**:
 - Subject predicate object
 - Subject: a resource
 - Predicate: a verb / property / relationship
 - Object: a resource, or a literal string

RDF examples

- http://elite.polito.it/people#FulvioCorno http://purl.org/vocab/relationship/employed By http://www.polito.it
- http://elite.polito.it/people#FulvioCorno hasProfession http://reliant.teknowledge.com/DAML/Midlevel-ontology.owl#Professor



RDF in XML

```
<rdf:RDF

xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"

xmlns:dc="http://purl.org/dc/elements/1.1/">

<rdf:Description

rdf:about="http://en.wikipedia.org/wiki/Tony_Benn">

<dc:title>Tony Benn</dc:title>

<dc:publisher>Wikipedia</dc:publisher>

</rdf:Description>

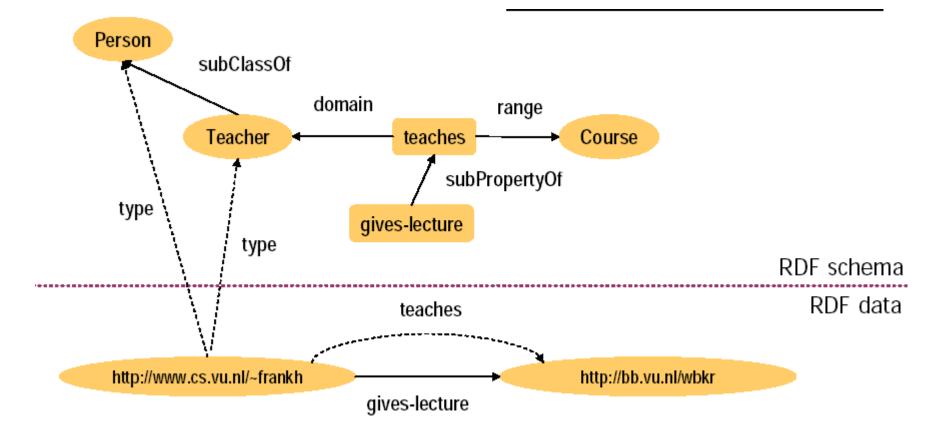
</rdf:RDF>
```

RDF from multiple dictionaries

<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#" xmlns:foaf="http://xmlns.com/foaf/0.1/" xmlns:dc="http://purl.org/dc/elements/1.1/"> <rdf:Description rdf:about="http://en.wikipedia.org/wiki/Tony Benn"> <dc:title>Tony Benn</dc:title> <dc:publisher>Wikipedia</dc:publisher> <foaf:primaryTopic> <foaf:Person> <foaf:name>Tony Benn</foaf:name> </foaf:Person> </foaf:primaryTopic> </rdf:Description> </rdf:RDF>



RDF and **RDF** schema



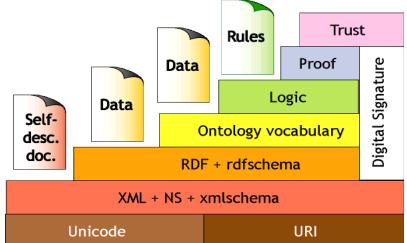


Formal ontologies

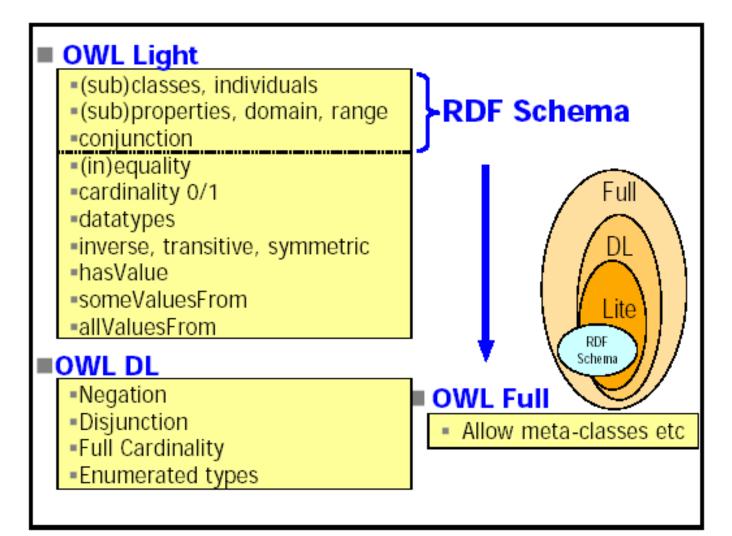
- A formal ontology
 - is defined using a language with a formal semantics
 - well defined meaning of the language constructs
 - well known rules to combine them
 - □ is bound to a given logic theory
 - first-order logic
 - description logic

OWL - Introduction

- 4th level on the semantic web cake
- built on top of XML
 - □RDF/S
- Three versions
 Lite
 DL (maps to Description Logic)
 Full (not fully tractable)
 Serializable as XML



OWL: Ontology Web Language



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OWL-DL

Based on Description Logic

Well defined formal semantics

- well defined rules to treat sentence meaning
- well defined assumptions on the world being modeled
- Well known reasoning/inferencing algorithms
 - tractable, conclusions can be derived in finite time
- Widely available reasoning systems no need to re-invent the wheel



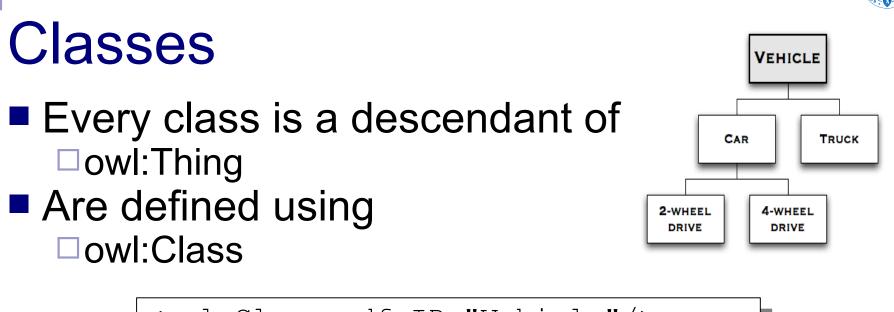
Building blocks in OWL

Ontology declaration (XML syntax)

<rdf:RDF xmlns:owl =http://www.w3.org/2002/07/owl#" xmlns:rdf ="http://www.w3.org/1999/02/22-rdf-syntax-ns#" xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#" xmlns:xsd ="http://www.w3.org/2001/XMLSchema#">

Ontology metadata (information about the ontology)

```
<owl:Ontology rdf:about="">
    <rdfs:comment>An example OWL ontology</rdfs:comment>
    <owl:priorVersion
    rdf:resource="http://www.mydomain.org/uni-ns-old"/>
    <owl:imports
    rdf:resource="http://www.mydomain.org/persons"/>
    <rdfs:label>University Ontology</rdfs:label>
</owl:Ontology>
```



<owl:Class rdf:ID="Vehicle"/>

Equivalence owl:equivalentClass

```
<owl:Class rdf:ID="Car">
```

```
<owl:equivalentClass
rdf:resource="#Automobile"/>
```

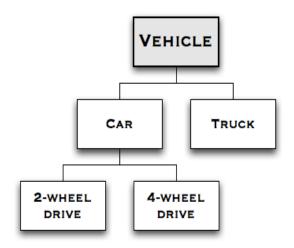
```
</owl:Class>
```

03/07/2



Subsumption

Provided by Owl:subClassOf



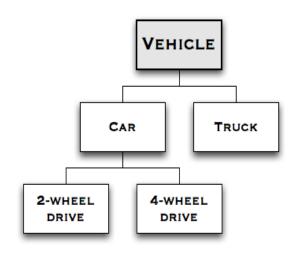
<owl:Class rdf:ID="2-Wheel-Drive">

<rdfs:subClassOf rdf:resource="#Car"/>

</owl:Class>

Partitions

Disjoint partition owl:disjointWith



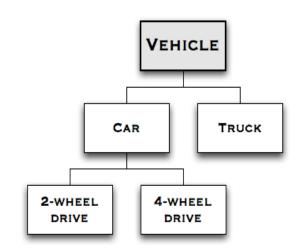
<owl:Class rdf:about="#2-Wheel-Drive">

```
<owl:disjointWith
rdf:resource="#4-Wheel-Drive"/>
```

```
</owl:Class>
```

Partitions

Exhaustive partition owl:oneOf



<owl:Class rdf:ID="Car">
 <owl:oneOf rdf:parseType="Collection">
 <owl:Thing rdf:about="#2-Wheel-Drive"/>
 <owl:Thing rdf:about="#4-Wheel-Drive"/>
 </owl:oneOf>
</owl:Class>



Attributes

Known as "properties"

Subdivided in

- □ Datatype properties
 - Attributes that specify a class features by means of data (XSD datatype)
 - phone, title, age
- Object properties
 - Attributes that define relationships between classes (Relations)
 - isTaughtBy(Class(course), Class(professor))



Attributes - datatypeProperties

- Allow to describe a specific aspect of a concept
 - □ Based on XSD data types
 - □ The range specifies the data type
 - The domain specifies the class to which the property is referred

```
<owl:DatatypeProperty rdf:ID="age">
```

```
<rdfs:domain rdf:resource="#Person"/>
```

```
<rdfs:range rdf:resource="http://www.w3.org/
2001/XMLSchema#nonNegativeInteger"/>
```

```
</owl:DatatypeProperty>
```



Relationships

- Directed (from one concept to another, no viceversa)
- Defined through object properties
 - domain
 - the class(es) from which the relation departs
 - □range
 - the relation destination(s)
- Subsumption between relationships is possible



Relationships Example

```
<owl:ObjectProperty rdf:ID="isTaughtBy">
```

```
<rdfs:domain rdf:resource="#course"/>
```

```
<rdfs:range
rdf:resource="#academicStaffMember"/>
```

<rdfs:subPropertyOf rdf:resource="#involves"/>

</owl:ObjectProperty>



Instances (Individuals)

No unique name assumption

if two instances have a different name or ID this does not imply that they are different individuals.



Advanced constructs

OWL supports several advanced constructs to define classes and relationships

Intensional definition of classes

 by defining constraints on attribute values (either object or datatype properties)

```
<owl:Class rdf:about="#academicStaffMember">
    <rdfs:subClassOf>
        <owl:Restriction>
        <owl:onProperty rdf:resource="#teaches"/>
        <owl:someValuesFrom
        rdf:resource="#undergraduateCourse"/>
        </owl:Restriction>
        </rdfs:subClassOf>
</owl:Class>
```



Advanced constructs

Cardinality

- Used to fix the number of instances that can be related
- □example:
 - A department should have at least 10 members

```
<owl:Class rdf:about="#department">
  <rdfs:subClassOf>
    <owl:Restriction>
    <owl:onProperty rdf:resource="#hasMember"/>
    <owl:minCardinality
    rdf:datatype="&xsd;nonNegativeInteger">
    10
    </owl:minCardinality>
    </owl:minCardinality>
    </owl:Restriction>
    </rdfs:subClassOf>
</owl:Class>
```



Special properties (1/2)

 owl:TransitiveProperty
 defines a transitive property, such as "has better grade than", "is taller than", or "is

ancestor of".

owl:SymmetricProperty

defines a symmetric property, such as "has same grade as" or "is sibling of".

owl:FunctionalProperty

defines a property that has at most one value for each object, such as "age", "height", or "directSupervisor".



Special properties (2/2)

owl:InverseFunctionalProperty defines a property for which two different objects cannot have the same value

- □example
 - the property "isTheSocialSecurityNumberFor"
 - a social security number is assigned to one person only.



OWL class constructors

Constructor	DL Syntax	Example	Modal Syntax
intersectionOf	$C_1 \sqcap \ldots \sqcap C_n$	Human ⊓ Male	$C_1 \wedge \ldots \wedge C_n$
unionOf	$C_1 \sqcup \ldots \sqcup C_n$	Doctor ⊔ Lawyer	$C_1 \vee \ldots \vee C_n$
complementOf	$\neg C$	¬Male	$\neg C$
oneOf	$\{x_1\} \sqcup \ldots \sqcup \{x_n\}$	{john} ⊔ {mary}	$x_1 \vee \ldots \vee x_n$
allValuesFrom	$\forall P.C$	∀hasChild.Doctor	[P]C
someValuesFrom	$\exists P.C$	∃hasChild.Lawyer	$\langle P \rangle C$
maxCardinality	$\leqslant nP$	≤1hasChild	$[P]_{n+1}$
minCardinality	$\geqslant nP$	≥2hasChild	$\langle P \rangle_n$

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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	$\{x_1\} \sqsubseteq \neg \{x_2\}$	${\rm john} \sqsubseteq \neg {\rm peter}$
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	$P^+ \sqsubseteq \tilde{P}$	ancestor+ ⊑ ancestor
functionalProperty	$\top \sqsubseteq \leqslant 1P$	$\top \sqsubseteq \leqslant 1$ hasMother
inverseFunctionalProperty	$\top \sqsubseteq \leqslant 1P^-$	$\top \sqsubseteq \leq 1$ hasSSN ⁻

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Open questions...

Reasoning is only feasible for OWL-DL limitations

- vocabulary partition
 - a resource can only be a class, an object property, a datatype property (a class cannot be at same time an individual)
- explicit typing
 - partitioning must be stated explicitly
- no transitive cardinality restrictions
 - □ transitive properties cannot have cardinality restrictions

Some semantics is still missing

e.g. how to define what a given relation means?



SWRL (quick glance)

SWRL

□ Semantic Web Rule Language

- Can be used to define new relationships (thus provides their operational semantics)
- Builds on top of RDF

Example:

- □ Base predicates
 - Father(?x,?y)
 - Mother(?x,?z)
- □New relations (defined through SWRL)
 - Father(?x, ?y) → Parent(?x, ?y)
 - Mother(?x, ?z) \rightarrow Parent(?x, ?y)



SWRL (quick glance)

Example 2

DomoMLPlus:Room(?x) ^ DomoMLPlus:hasWall(?x, ?z) ^ DomoMLPlus:hasWallOpening(?z, ?y) ^ DomoMLPlus:Window(?y)→ DomoMLPlus:hasWindows(?x, true)



No ontology, no semantics

- Reuse of existing taxonomies as ontologies
- Publicly available ontologies
 - Horizontal ontologies (SUMO, MILO, WordNet, ...)
 - □ Vertical ontologies (domain-specific)
- Semi-automatic ontology learning from resources
- Manual development / enrichment