

The Semantic Web

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Outline

- [Foreword](#)
- [Introduction](#)
- [Concepts and Techniques](#)
- [Practical Issues](#)
- [References and Web Resources](#)
- [Discussion](#)

11/28/2001 The Semantic Web 2

Instead of trying to rebuild some aspects of a human brain, we are going to build a brain of and for humankind.

D. Fensel and M.A. Musen

The Semantic Web

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Introduction

*What we're seeing is
just the first version of the Web.*

D. Fensel and M.A. Musen

The Web Today

- The need for access to information and knowledge sources that are:
 - ✦ unstructured
 - ✦ heterogeneous
 - ✦ distributed
- The simplicity and restrictiveness of HTTP and early HTML

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3

The Web Today

- However...
 - ✦ the current state of Web technology generates serious obstacles to its further growth
 - ✦ computers themselves offer limited support in accessing and processing information
 - ✦ the main burden of extracting and interpreting information is on the human user

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4

The Needs

- Explicit representation of the *semantics* of data
- Domain theories (Ontologies)
- A Web that provides a qualitatively new level of service
- An extremely large system with various specialized reasoning services

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5

The Needs

- Access to a huge network of knowledge
 - ✦ machine-understandable and machine-processable human knowledge
- An appropriate solution for the knowledge acquisition bottleneck
- A way to pull intelligent systems out of isolation and brittleness

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6

Transforming The Web

- From the Web to the Knowledge Web (Semantic Web)
 - ✦ millions of knowledge "acquisitioners" already work on the Web nearly for free!
 - ✦ they provide up to a billion Web pages of information and knowledge!
 - ✦ using knowledge representation techniques becomes increasingly important!

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7

We are only at the beginning!

Languages for The Semantic Web

Current State of Affairs

- There are a lot of such languages around
- Most of them are based on XML, XML Schemas, RDF, and RDF Schemas

XML

- Example

```
<BOOK>
<AUTHOR> Aho, A.V. </AUTHOR>
<AUTHOR> Sethi, R. </AUTHOR>
<AUTHOR> Ullman, J.D. </AUTHOR>
<TITLE> Compilers: Principles, Techniques, and Tools </TITLE>
<PUBLISHER> Addison-Wesley </PUBLISHER>
<YEAR> 1985 </YEAR>
</BOOK>
```

XML is structure-oriented

XML Schema

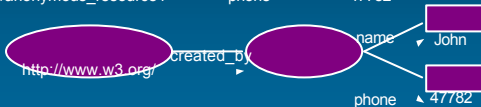
- Example

```
<xsd:schema xmlns:xsd="http://www.w3.org/1999/XMLSchema">
<xsd:element name="BOOK" type="BOOKTYPE"/>
<xsd:complexType name="BOOK_TYPE" >
<xsd:element name="AUTHOR" type="xsd:string"
minOccurs="1" maxOccurs="unbounded"/>
<xsd:element name="TITLE" type="xsd:string"/>
<xsd:element name="PUBLISHER" type="xsd:string"
minOccurs="0" maxOccurs="1"/>
<xsd:element name="YEAR" type="xsd:decimal"
minOccurs="0" maxOccurs="1"/>
<xsd:attribute name="isbn" type="xsd:string"/>
<xsd:attribute name="nickname" type="xsd:string"/>
</xsd:complexType>
</xsd:schema>
```

RDF

- Example

OBJECT	ATTRIBUTE	VALUE
http://www.w3.org/ #anonymous_resource1	created_by	#anonymous_resource1
#anonymous_resource1	name	"John"
#anonymous_resource1	phone	"47782"



RDF Schema

- Example

```
<rdfs:Class rdf:ID="herbivore">
<rdfs:subClassOf rdf:resource="#animal"/>
<rdfs:subClassOf>
...
</rdfs:subClassOf>
</rdfs:Class>
```

Ontologies


What is an ontology?

- Classic definitions (Gruber, 1993), (Guarino, 1994)
 - ⌘ a specification of a conceptualization
 - ⌘ an explicit specification of some topic
 - ⌘ a formal and declarative representation of some subject area

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What is an ontology?

- Other important definitions (Swartout and Tate, 1999)
 - ⌘ the basic structure or *armature* around which a knowledge base can be built



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What is an ontology?

- Other important definitions (Hendler, 2001)
 - ⌘ a set of knowledge terms, including the vocabulary, the semantic interconnections, and some simple rules of inference and logic for some particular topic
 - ⌘ this definition is currently predominant in The Semantic Web community

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What is an ontology?

- What does an ontology provide?
 - ⌘ the vocabulary (or names) for referring to the terms in that subject area
 - ⌘ the logical statements that describe:
 - what the terms are
 - how they are related to each other
 - how they can or cannot be related to each other

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What is an ontology?

- What does an ontology provide?
 - ⌘ rules for combining terms and relations to define extensions to the vocabulary
 - ⌘ semantics independent of reader and context
 - ⌘ a common understanding of topics that can be communicated between users and applications

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What is an ontology?

- What is the purpose of ontologies?
 - ⌘ knowledge sharing and reuse
 - ⌘ description of the concepts and relationships that can exist for an IA or a community of IAs
 - the description is like a formal specification of a program

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An Example Ontology

- The Frame ontology (Gruber, 1993)
 - ⌘ partial vocabulary of the Frame ontology
 - class relation (?relation)
 - class function (?function)
 - class class (?class)
 - relation instance-of (?individual ?class)
 - function all-instances (?class) :-> ?set-of-instances
 - function one-of (@instances) :-> ?class

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An Example Ontology

- The Frame ontology (Gruber, 1993)
 - ⌘ partial vocabulary of the Frame ontology
 - relation subclass-of (?child-class ?parent-class)
 - relation superclass-of (?parent-class ?child-class)
 - relation subrelation-of (?child-relation ?parent-relation)
 - relation direct-instance-of (?individual ?class)
 - relation direct-subclass-of (?child-class ?parent-class)

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Why Ontologies?

- The role of ontologies in the architecture of The Semantic Web
 - ⌘ to enable intelligent services
 - information brokers
 - search agents
 - information filters
 - intelligent information integration
 - knowledge management

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Why Ontologies?

- The role of ontologies in the architecture of The Semantic Web
 - ⌘ to establish further levels of interoperability (semantic interoperability) on the Web
 - syntactic interoperability: reusability in parsing the data
 - semantic interoperability: mappings between terms within the data, which requires content analysis

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Why Ontologies?

- The role of ontologies in the architecture of The Semantic Web
 - ⌘ to add a further representation and inference layer on top of the Web's current layers
 - ⌘ to enable Web-based knowledge processing, sharing, and reuse between applications

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Why Ontologies?

- Ontologies merely serve to standardize and provide interpretations for Web content
- To make content machine-understandable, Web pages must contain *semantic markup*
 - ⌘ descriptions which use the terminology that one or more ontologies define

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Tools for Building Ontologies

- XML / XMLS, RDF / RDFS, and the corresponding development tools
- Ontology representation languages (The Semantic Web languages)
- Ontology-development environments (integrated graphical tools)
- Ontology-learning tools

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Tools for Building Ontologies

- Ontology representation languages
 - ⌘ Knowledge Interchange Format (KIF)
 - ⌘ Simple HTML Ontology Extensions (SHOE)
 - ⌘ XML-based ontology-exchange language (XOL)
 - ⌘ ISO standard for describing knowledge structures (Topic Maps)
 - ⌘ DARPA Agent Markup Language (DAML)
 - ⌘ Ontology Inference Layer (OIL, DAML+ OIL)

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Tools for Building Ontologies

- The need: a standardized Web ontology language
 - ⌘ is it emerging already?
 - ⌘ OIL, DAML+ OIL, ...?
 - "OIL, a proposal for such a standard"
 - ⌘ W3C and ISO efforts?

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Ideally, we would like a universal shared knowledge-representation language to support the Semantic Web, but for a variety of pragmatic and technological reasons, this is unachievable in practice. Instead, we will have to live with a multitude of metadata representations.

S. Decker et al.

Tools for Building Ontologies

- The idea behind GFP

• The GFP provides a generic interface to underlying frame representation systems (FRS)
 • Calls to generic functions are dispatched to methods corresponding to the FRS in which the knowledge is represented
 • Applications written using the GFP are thus portable over a variety of systems and knowledge bases

11/28/2001 18

Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**

Full-fledged Web-based ontology languages (+markup)

Standard for structuring documents

HTML as an XML application

Arbitrary domain- and task-specific extensions (first step toward The Semantic Web)

Basic ontological modeling primitives

Simple model for representing semantics

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Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**

The Semantic Web "layer cake" (T. Berners-Lee, 2000)

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Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**

An OIL processor will also understand RDFS

Even simple RDF Schema agents are able to process the OIL ontologies

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Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**
 - ≅ defining an ontology in RDF means defining an RDF schema (RDFS)
 - it specifies all the concepts and relationships of the particular language
 - every ontology (RDFS) uses its own namespace (the prefix *oil* is used in OIL)
 - namespaces allow for mixing terms from different ontologies in one RDF document without confusion

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Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**
 - ≅ example


```

          <rdf:Class rdf:ID="herbivore">
            <rdf:type rdf:resource="http://www.ontoknowledge.org/oil/RDFS-schema/#DefinedClass"/>
            <rdf:subClassOf rdf:resource="#animal"/>
            <rdf:subClassOf>
              <oil:NOT>
                <oil:hasOperand rdf:resource="#carnivore"/>
              </oil:NOT>
            </rdf:subClassOf>
          </rdf:Class>
          
```

Can be captured by a pure RDFS application

11/28/2001 23

Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**
 - ≅ steps in using an ontology language *L* to extend RDF
 - step 1 - describe language *L*'s modeling primitives using RDFS
 - this step effectively means writing the meta-ontology of *L* in RDFS

11/28/2001 24

Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**

Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**

Table 2. OIL vocabulary mapping to RDF schema.

OIL original vocabulary	RDF vocabulary
Class-def	rdfs:Class
Subclass-of	rdfs:subClassOf
Slot constraint	oil:hasSlotConstraint oil:SlotConstraint
AND	oil:AND
NOT	oil:NOT
Has-value	oil:hasValue

Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**
- steps in using an ontology language *L* to extend RDF
 - step 2 - describe a specific ontology in *L* using the resulting RDFS document

11/28/2001 The Semantic Web 27

Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**

Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**
- steps in using an ontology language *L* to extend RDF
 - step 2 - describe a specific ontology in *L* using the resulting RDFS document

class-def herbivore
 subclass-of animal, NOT carnivore
 slot-constraint eats
 value-type plant
 OR (slot-constraint is-part-of has-value plant)

OIL syntax

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Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**
- Steps in using an ontology language *L* to extend RDF
 - step 3 - describe instances of the specific *L* ontology modeled in step 2 using the RDFS documents

11/28/2001 The Semantic Web 30

Tools for Building Ontologies

- **Ontology Inference Layer (OIL)**

```
<rdfs:Class rdf:ID="herbivore">
  <rdf:type rdf:resource="http://www.ontoknowledge.org/oil/
  RDFS-schema/#DefinedClass"/>
  <rdfs:subClassOf rdf:resource="#animal"/>
  <rdfs:subClassOf>
    <oil:NOT>
      <oil:hasOperand rdf:resource="#carnivore"/>
    </oil:NOT>
  </rdfs:subClassOf>
</rdfs:Class>
```

Key Application Areas

- **Where are ontologies useful? (Fikes, 1997)**

- ✧ collaboration
 • interdisciplinary teams
 • agent-agent communication
 ✧ interoperation
 • information integration
 • distributed applications

Key Application Areas

- **Where are ontologies useful? (Fikes, 1997)**

- ✧ education
 • publication medium
 • reference source
 ✧ modeling
 • reusable building blocks

Key Application Areas

- **E-commerce**

- ✧ ontologies enable machine-based communication between buyers and sellers
 ✧ vertical integration of markets
 ✧ description reuse between different marketplaces

Key Application Areas

- **Search engines**

- ✧ using ontologies to find pages with syntactically different but semantically similar words

A Vision

- **The Semantic Web's evolving infrastructure**

- ✧ not just a few large, complex, consistent ontologies that great numbers of users share
 ✧ great number of small ontological components consisting largely of pointers to each other
 ✧ Web users will develop them in much the same way that Web content is created ("anarchy")

Services on the Web

- The user's current situation
 - ✦ service discovery using a search engine
 - ✦ reading the discovered Web page
 - ✦ alternatively, executing the service to see whether it satisfies the request
 - ✦ filling in the forms of the service manually
 - ✦ composing manually the sequence of services required to complete a complex task

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Services on the Web

- The user's desired situation
 - ✦ automatic service discovery
 - using pre-provided semantic markup of Web pages
 - using ontology-enhanced search engines

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Services on the Web

- The user's desired situation
 - ✦ automatic execution of services
 - semantic markup provides declarative API for agents to execute the services
 - semantic markup tells the agent:
 - what input is necessary
 - what information will be returned
 - how to execute – and potentially interact with – the service automatically

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Services on the Web

- The user's desired situation
 - ✦ automatic service composition / interoperation
 - semantic markup of services provides the necessary information for that automation
 - the information helps select, compose, and respond to services and is encoded at the service sites
 - appropriate software manipulates the markup, together with a specification of the task's objectives

11/28/2001 The Semantic Web 10

Semantic Markup

- Ontologies merely serve to standardize and provide interpretations for Web contents
- To make content machine-understandable, Web pages must contain *semantic markup*
 - ✦ descriptions which use the terminology that one or more ontologies define

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Semantic Markup

- Objectives and effects of semantic markup of Web contents
 - ✦ semantic markup it might state that:
 - a particular entity is a member of a class
 - an entity has a particular property
 - two entities have some relationship between them
 - descriptions from different people refer to the same entity

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Semantic Markup

- Objectives and effects of semantic markup of Web contents
 - ✎ authoring tools should let the teachers/authors create markup through selections and forms
 - ✎ authors should be able to:
 - choose ontologies from a list
 - choose attributes and relations from another list
 - edit, add, remove, and merge ontologies

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Semantic Markup

- Objectives and effects of semantic markup of Web contents
 - ✎ authors need not necessarily understand the details of the markup process
 - ✎ authoring tools with semantic markup authoring capabilities must:
 - perform error checking automatically
 - make the semantic markup a regular activity

11/28/2001 The Semantic Web 14

Systems, Applications, and Projects

- UNIVERSAL Project
- OBOA/GET-BITS

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UNIVERSAL Project

- Objectives
 - ✎ facilitating an open exchange of learning resources among participating parties
 - learning resource – a form of highly specialised academic content
 - examples: a short video, a complete course,...
 - cataloguing and delivery of both live sessions and packaged content

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UNIVERSAL Project

- Objectives
 - ✎ demonstrating the feasibility of an open exchange system for course units
 - exchange between institutions of higher education across Europe

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UNIVERSAL Project

- The components
 - ✎ learning resource
 - ✎ learning object
 - ✎ delivery system
 - ✎ delivery system technology
 - ✎ taxonomy
 - ✎ anotation

- described by attributes providing hints on its usage
- can be composite (multiple learning resources which follow a common objective)

- a part of (a) learning resource(s)
- associated with a physical resource
- learning resource = several learning objects

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UNIVERSAL Project

- The components
 - ✦ offer
 - ✦ scheduling
 - ✦ higher education institution
 - ✦ alliance
 - ✦ user
 - ✦ intellectual property rights

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19

UNIVERSAL Project

- The components
 - ✦ some attributes are based on the IEEE Learning Objects Metadata (LOM) model
 - ✦ other attributes are modified and more in-depth definitions are introduced
 - ✦ implementation of this data model is based on RDF

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20

UNIVERSAL Project

- The components
 - ✦ RDF Schema for learning resources
 - ✦ RDF Schema for learning object

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21

UNIVERSAL Project

- Modularized approach
 - ✦ instances of the different components can be changed easily without affecting others
 - ✦ each component is identified by a unique ID
 - ✦ UNIVERSAL Brokerage Platform (UBP)

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22

UNIVERSAL Project

- Ontologies?
- Higher-level language?
- Markup?
- Higher-level understanding of semantics?
- Many "under construction" pages?
- Evaluation?

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23

A Web Page to Visit !

GOOD-OLD-AI

<http://good-old-ai.fon.bg.ac.yu/>
<http://good-old-ai.netfirms.com/>

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The Semantic Web

24

References and Web Resources

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11/28/2001 The Semantic Web 3

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11/28/2001 The Semantic Web 5

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11/28/2001 The Semantic Web 6

Web Resources

XML, XML Schemas, RDF, and RDF Schemas

- XML and RDF definitions - www.w3.org/XML
- www.w3.org/RDF
- Introduction to XML and XML Schemas - www.xml.com
- XML tutorial - www.hrcs.dk/~smpeller/XML/
- Tutorial on RDF and RDF Schema - www710.univ-lyon1.fr/~champion/rdf-tutorial/
- XML and related techniques - www.nasis-open.org/cover/
- "XML Bible" book - metalab.unc.edu/xml/books/bible/
- XML software and tools - xmlsoftware.com
- XML Resources - computer.org/international/xml/
- www.insead.fr/CALT/Encyclopedia/ComputerSciences/System/architecture.htm

11/28/2001 The Semantic Web 7

Web Resources

The Semantic Web

- The Semantic Web Portal - www.semanticweb.org
- The Semantic Web Activity in W3C - www.w3.org/2001/sw/Activity/
- DAML+OIL - www.daml.org/2001/03/damloil-index

11/28/2001 The Semantic Web 8

Web Resources

Ontologies

- Ontologies and Knowledge Sharing - ksl.stanford.edu/knowledgesharing/
- A Web Ontology Repository - www.daml.org/ontologies/
- OIL - www.ontoknowledge.org/oil/

11/28/2001 The Semantic Web 9