# The Semantic Web: Current Status and Future Directions

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# Talk Outline

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- *Current Status*
- *Well-Known Layer Cake*
- *Ontology = Taxonomies + Axioms*
- *The Ontology Language*
  - ✔ *RDF(S)*
  - ✔ *OWL*
- *Model Theory for Semantics*

- *Querying the Ontology*
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- *Semantic Web Rules*
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- *Future Directions*
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# Introduction

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

*–Tim Berners-Lee, James Hendler, Ora Lassila,*

*–The Semantic Web, Scientific American, May 2001*

# Introduction (conti.)

- *A new form of Web content that is meaningful to computers will unleash a revolution of new possibilities.*

- *The Semantic Web will enable machines to* comprehend *semantic documents and data, not human speech and writings.*

- *The explicit representation of the semantics of data, accompanied with domain theories (that is,* ontologies*), will enable a Web that provides a qualitatively new level of service.*

–*Tim Berners-Lee, James Hendler, and Ora Lassila*

–*The Semantic Web, Scientific American, May 2001*

# Introduction (conti.):

*Agents and the Semantic Web*

*The real power of the Semantic Web will be realized when people create many programs that collect Web content from diverse sources, process the information and exchange the results with other programs. The effectiveness of such software agents will increase exponentially as more machine-readable Web content and automated services (including other agents) become available.* $\cdots$

*–Tim Berners-Lee, James Hendler, Ora Lassila,*

*–The Semantic Web, Scientific American, May 2001*

# Current Status

- *RDF(S) and OWL are the major two ontology languages that form the ontology construct for the semantic web.*

- *The information (knowledge) query language for the RDF(S)-based ontology is in some progress but not enough. On the other hand, the query language for OWL, such as OWL-QL, is also in progress but using different approach.*

- *The semantics of the ontology languages, such as RDF(S) and OWL are defined as model theory and they are an ongoing process so need further research to complete the results.*

# Current Status (conti.)

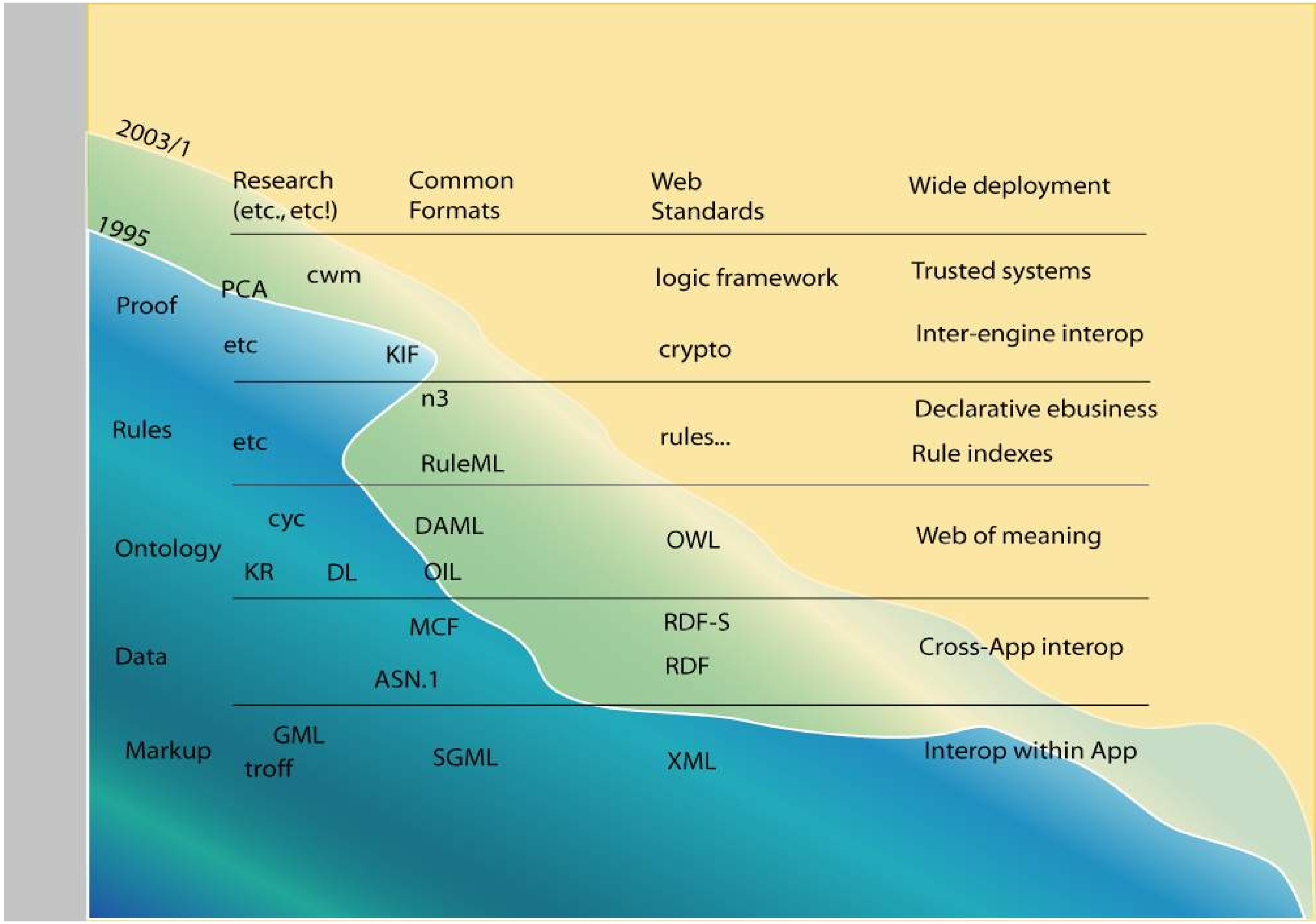
- *The supporting application development tools for the semantic web are several but they are in the very primitive stage.*

- *The semantic web services are still in progress but very slow because we need to justify why it is worthy to add the semantics in an integral web service model.*

- *The semantic p2p (peer-to-peer) computing provides a new research direction and it is only in its initial stage using very little semantic web core technologies.*

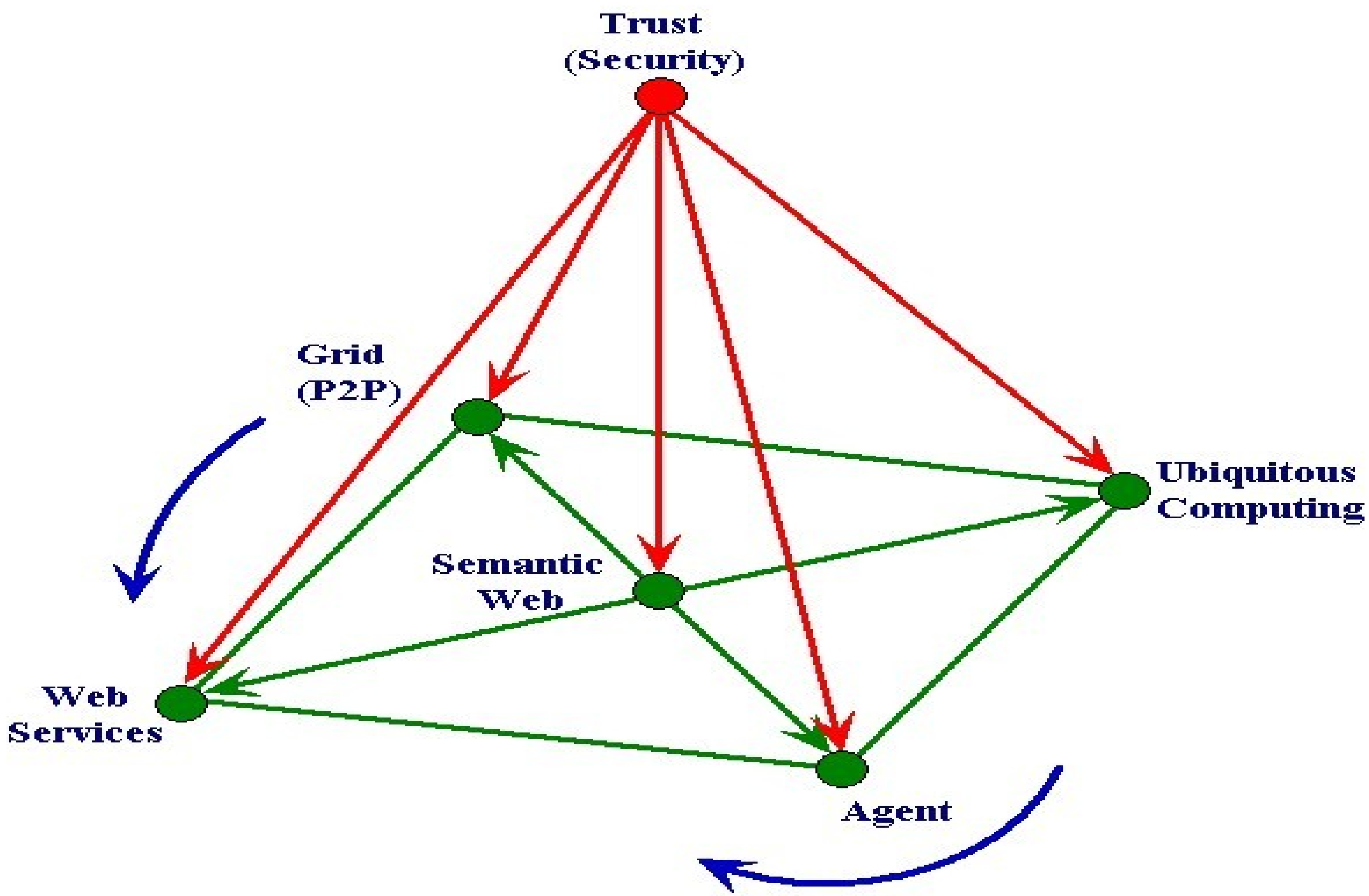
# Current Status (conti.):

*The Semantic Web Wave*

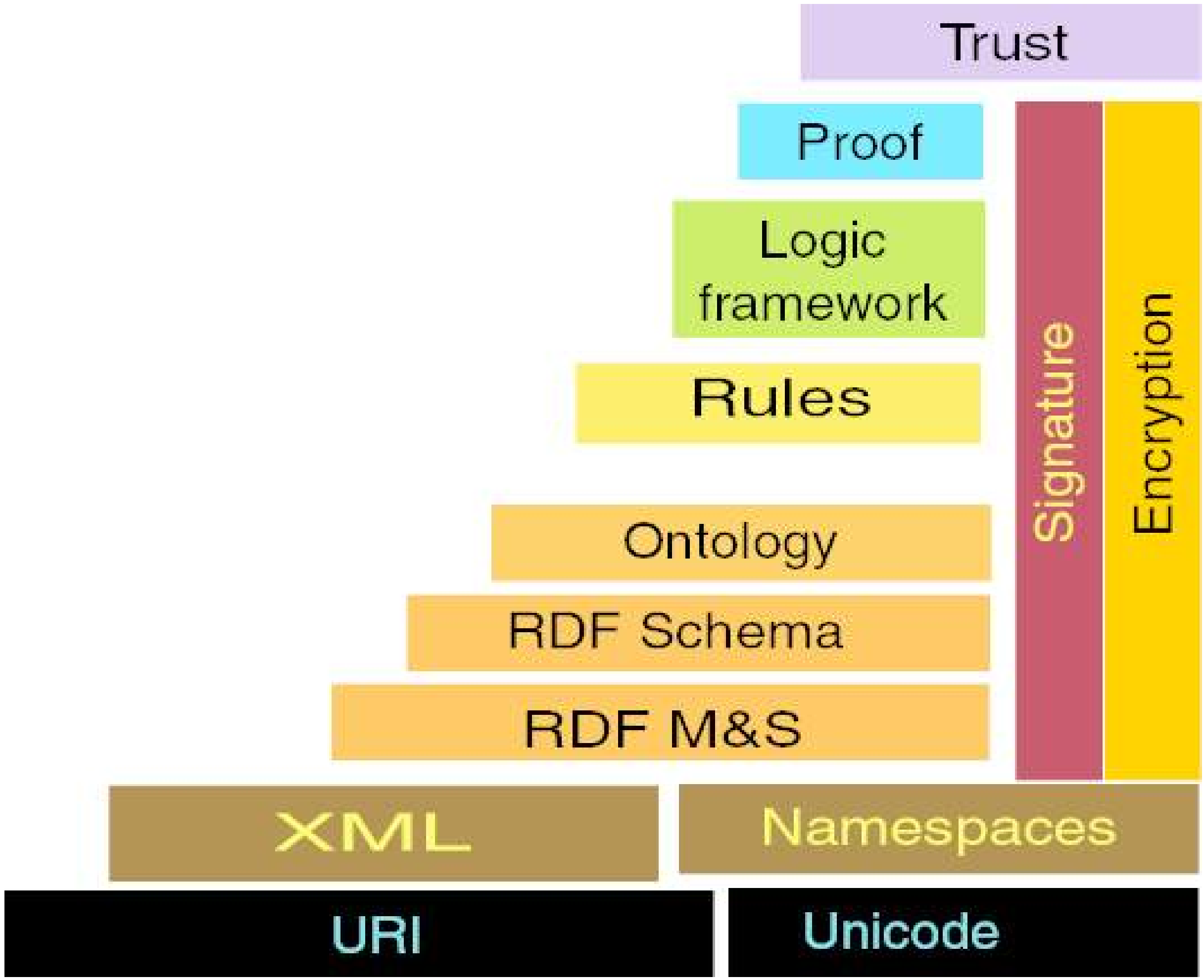


# Current Status (conti.):

*The Semantic Web Pyramid*



## Well-Known Layer Cake [Tim Berners-Lee]



# Ontology = Taxonomies + Axioms

- *An ontology is a formal, explicit specifications of a shared conceptualization[Grub:93]:*
  - *Formal refers to the fact that the ontology should be machine understandable.*
  - *Explicit means that the type of concepts used and the constraints on their use are explicitly defined.*
  - *Shared reflects the notion that an ontology captures consensual knowledge, that is, it is not restricted to some individual, but accepted by a group.*
  - *Conceptualization refers to an abstract model of some phenomenon in the world which identifies the relevant concepts of that phenomenon.*

## Ontology = Taxonomies + Axioms (conti.)

- *The ontology language for the semantic web has a taxonomy and a set of axioms. The taxonomy defines classes of objects and relations among them and axioms supply further power.*

- *Some people treat ontology as a subset of logic, some treat logic as a subset of ontological reasoning, and others consider the terms disjoint. More detailed analysis see [Gros:03].*

# Ontology = Taxonomies + Axioms (conti.)

*The axioms provide the following reasoning mechanisms:*

- ☞ *Ontology design*
  - ✔ *Check class consistency and (unexpected) implied relationships*
  - ✔ *Particularly important with large ontologies/multiple authors*
- ☞ *Ontology integration*
  - ✔ *Assert inter-ontology relationships*
  - ✔ *Reasoner computes integrated class hierarchy/consistency*

# Ontology = Taxonomies + Axioms (conti.)

- *Ontology deployment*
  - *Determine if set of facts are consistent w.r.t. ontology*
  - *Answer queries w.r.t. ontology, e.g. OWL-QL.*

# The Ontology Language[Horr:03a]

- *XML/XML Schema* $\Longleftarrow$ *Not an ontology language*
- *RDF/RDF-Schema* $\Longleftarrow$ *ontology language*
- *DAML/OIL* $\Longleftarrow$ *ontology language*
- *DAML + OIL* $\Longleftarrow$ *ontology language (replaced by OWL)*
- *OWL (Web Ontology Language)[Horr:03a] [* $\Longleftarrow$ *ontology language*
  - ✔ *OWL Lite: decidable and deterministic exponential time (EXPTIME) complexity for inference.*
  - ✔ *OWL DL (Description Logic): decidable but non-deterministic exponential time (NEXPTIME) complexity for inference.*
  - ✔ *OWL Full (OWL DL + RDF(S)): undecidable and intractable for inference.*

# The Ontology Language

*The issues of the ontology language selection when you construct domain-specific ontologies:*

- *Syntax and semantics expressive power*
- *The human readable and machine processable capacities*
- *The corresponding abstract model to represent and interpret of the real world*
- *Storing, querying, processing, exchanging, and interoperating capabilities for the underlying information (knowledge) model on the web*
- *Supporting tools for the application development*

# RDF(S): RDF and RDF Schema[Pan:03]

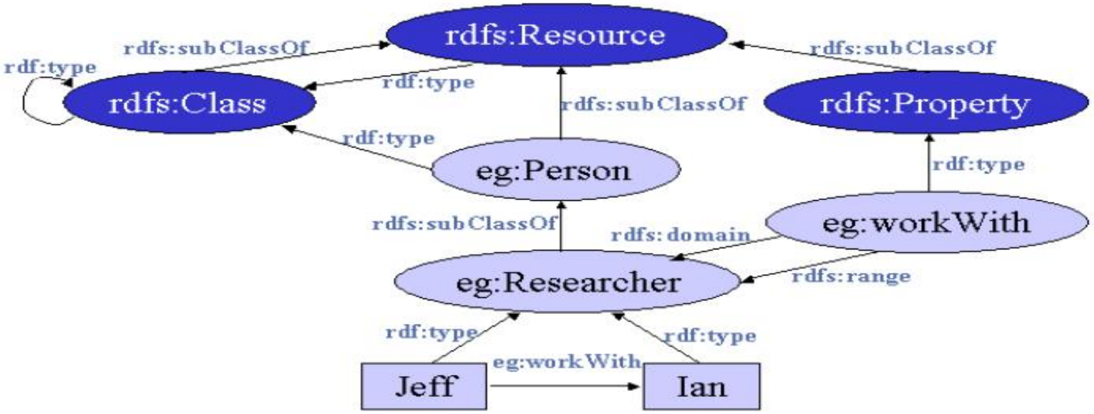



**Fig. 1.** An Example of Dual Roles in RDFS

*(i)Check RDF(S) Semantics(1)*
*(ii)Check RDF(S) Semantics(2)*

# RDF(S): Example[Staa:01]

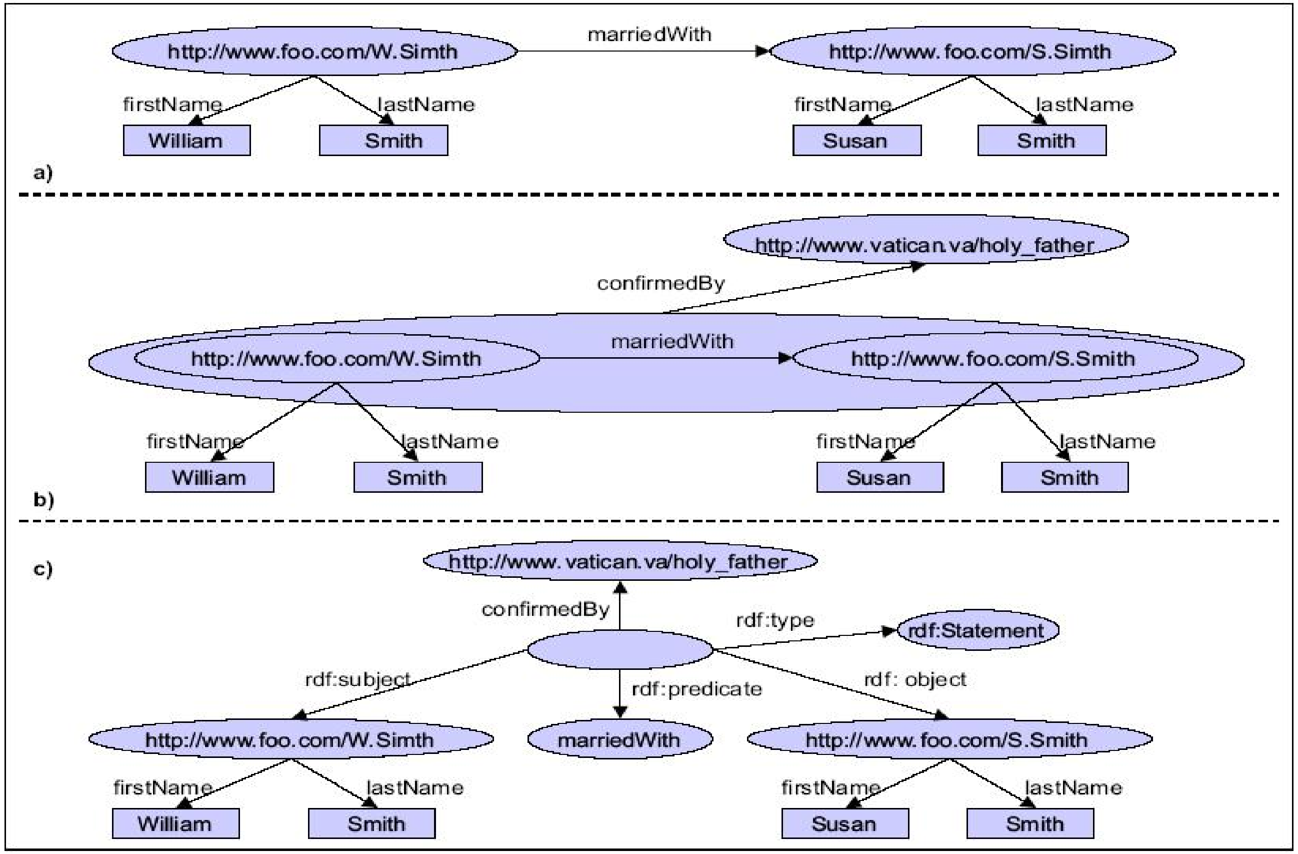



Figure 1: An example RDF data model.

# RDF(S): Example (conti.)[Staa:01]

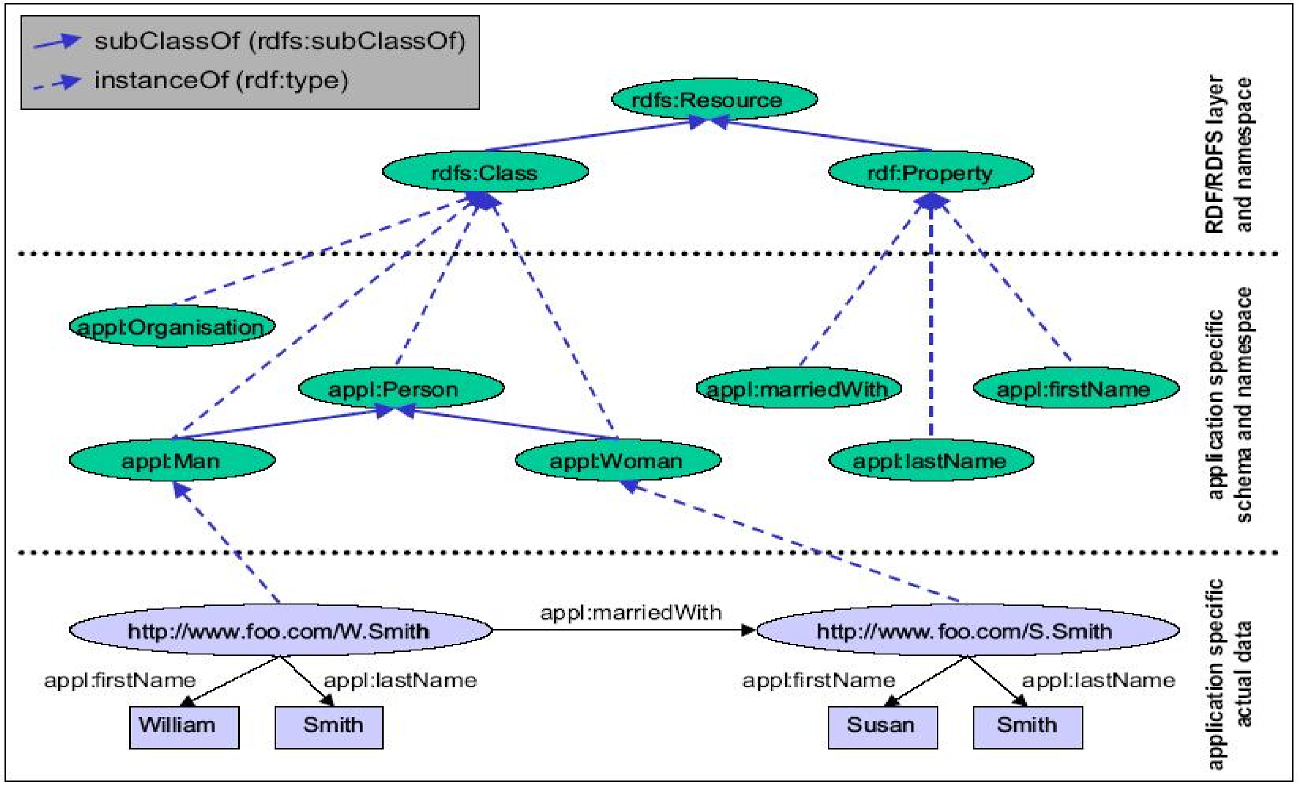



Figure 2: An example RDF schema and its embedding in RDF(S).

# RDF(S): Example (conti.)[Staa:01]

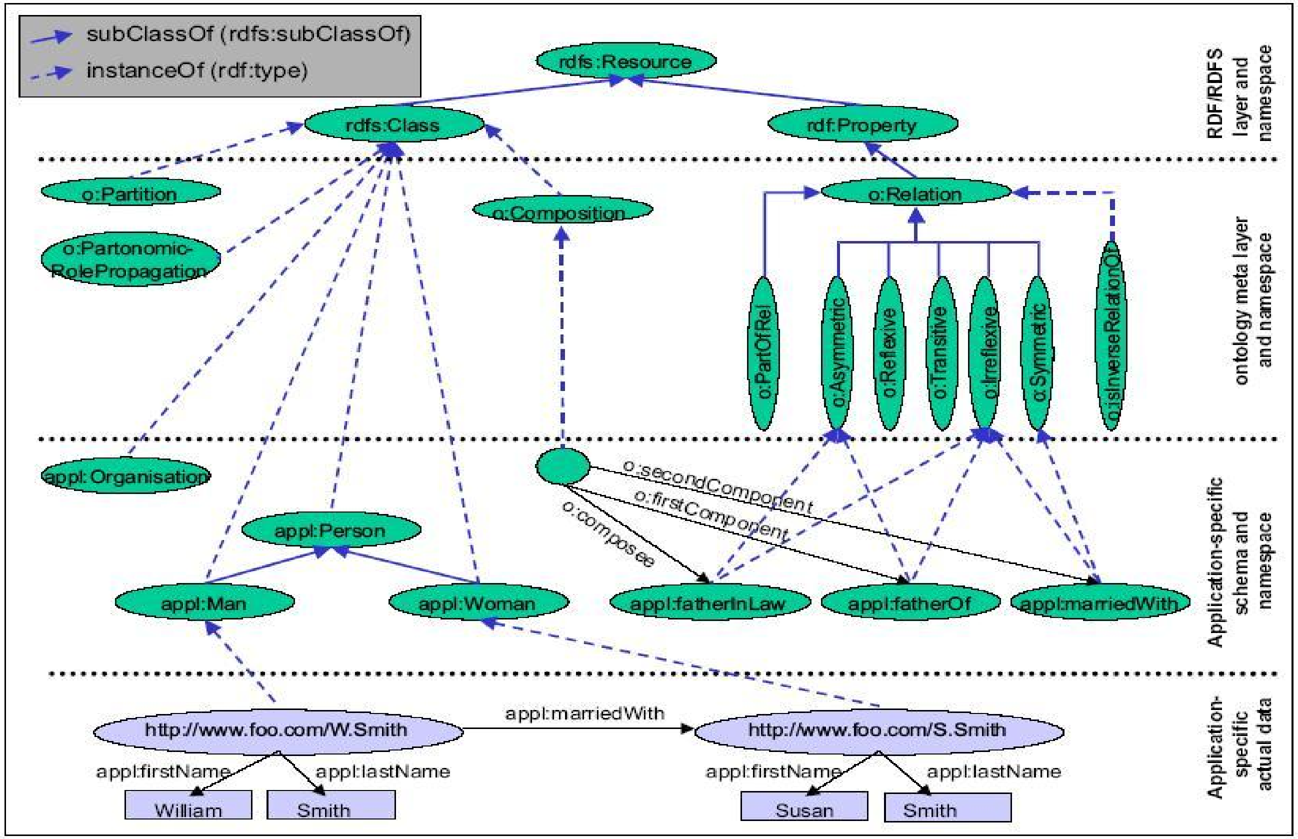



Figure 3: An excerpt of the example object model and an instantiation of classes, properties, and axioms in RDF(S)

# Expressive Power of the RDF(S)[Pan:03]

*Including the followings:*

- *Anyone can say anything about anything.*
- *RDFS has a non-standard and non-fixed layer metamodeling architecture, which makes some elements in the model appear to have multiple roles.*
- *Properties can be defined between any two resources.*
- *Any resource can be an instance of any resource (including itself).*
- *What are the motivations of the extra expressive power?*

# Limitations of the RDF(S)[Anto:03]

*Excluding the followings:*

- *Local scope of properties*
- *Disjointness of classes*
- *Boolean combinations of classes*
- *Cardinality restrictions*
- *Special characteristics of properties, such as transitive, unique, inverse, etc*

# OWL: Web Ontology Language[Anto:03]

- *OWL Full: uses all of the OWL languages primitives and also combines these primitives in arbitrary ways with RDF(S).*

- *OWL DL: sublanguage of OWL Full which restricts the way in which the constructors from OWL and RDF can be used. An RDF document will have to be extended in some ways and restricts in others before it is a legal OWL DL document.*

- *OWL Lite: limits OWL DL to a subset of the language constructors so it excludes enumerated classes, disjointness statements and arbitrary cardinality.*

## **Model Theory for Semantics**[Haye:04]

- *Model theory assumes that the language refers to a 'world' and describes the minimal conditions that a world must satisfy in order to assign an appropriate meaning for every expression in the language.*

- *A particular world is called an interpretation, so that model theory might be better called 'interpretation theory'.*

# Model Theory for Semantics[Pan:03]

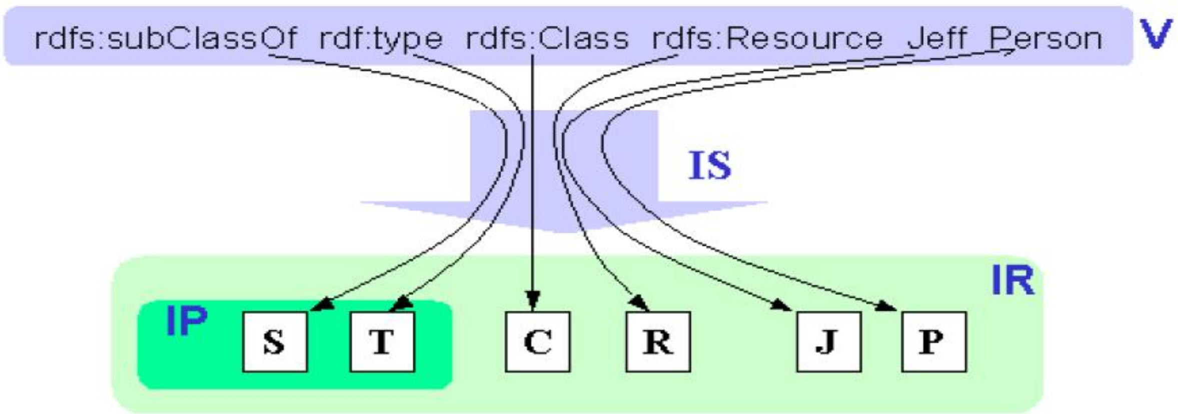



**Fig. 6.** Resources in RDF MT

*Check RDF and RDF Schema*

# Model Theory for Semantics[Pan:03]

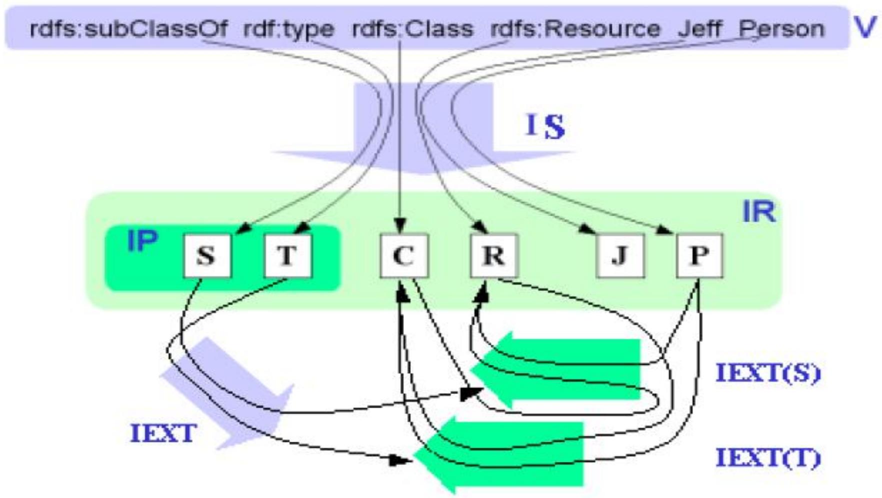



**Fig. 7.** Interpretation of RDF MT

*Check RDF and RDF Schema*

## Querying the Ontology

- *Query languages proposed for semistructure or XML data, such as XQuery, fails to interpret the semantics of ontology, such as OWL or RDF node or edge labels.*

- *The semantics for a particular ontology defined by its language's model theory must be validated before the query language can be applied for that ontology. In addition, semantics validation can be invoked explicitly on a query result or on some intermediate expression within a query.*

# The Ontology Query Language

- *XQuery* ⟸ *Not an ontology query language*

- *RQL* ⟸ *RDF(S) ontology query language*

- *OWL-QL (D-QL)* ⟸ *OWL ontology query language*

# XQuery: An XML Query Language [Cham:02]

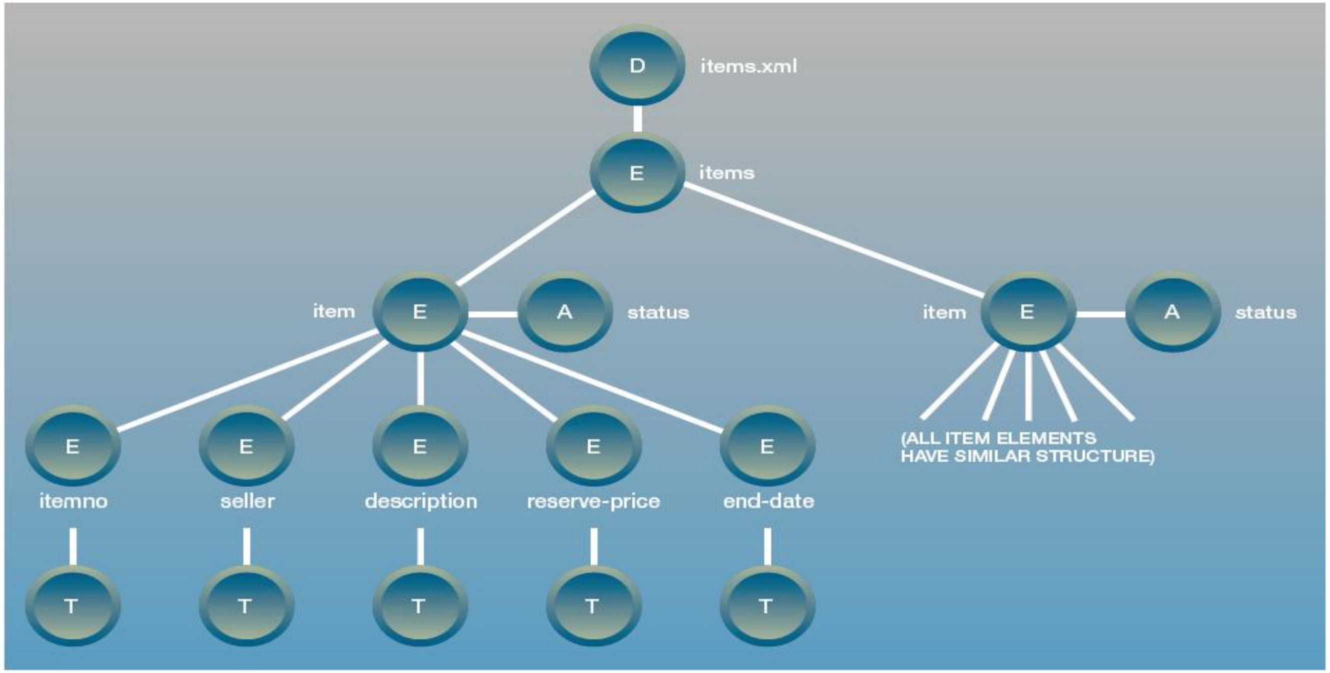
*XML data are different from relational data as:*

- ☛ *Relational data tend to have regular structure; XML data are often quite heterogeneous, and distribute their meta-data throughout the document.*
- ☛ *XML documents contain many levels of nested elements; whereas relational data are "flat".*
- ☛ *XML documents have an intrinsic order, whereas relational data are unordered.*
- ☛ *Relational data are usually "dense", and XML data are "sparse".*
- ☛ *Existing relational query languages are not directly suitable for querying XML data.*

# XQuery: An XML Query Language (conti.)[Cham:02]

*Data model representation of items.xml*

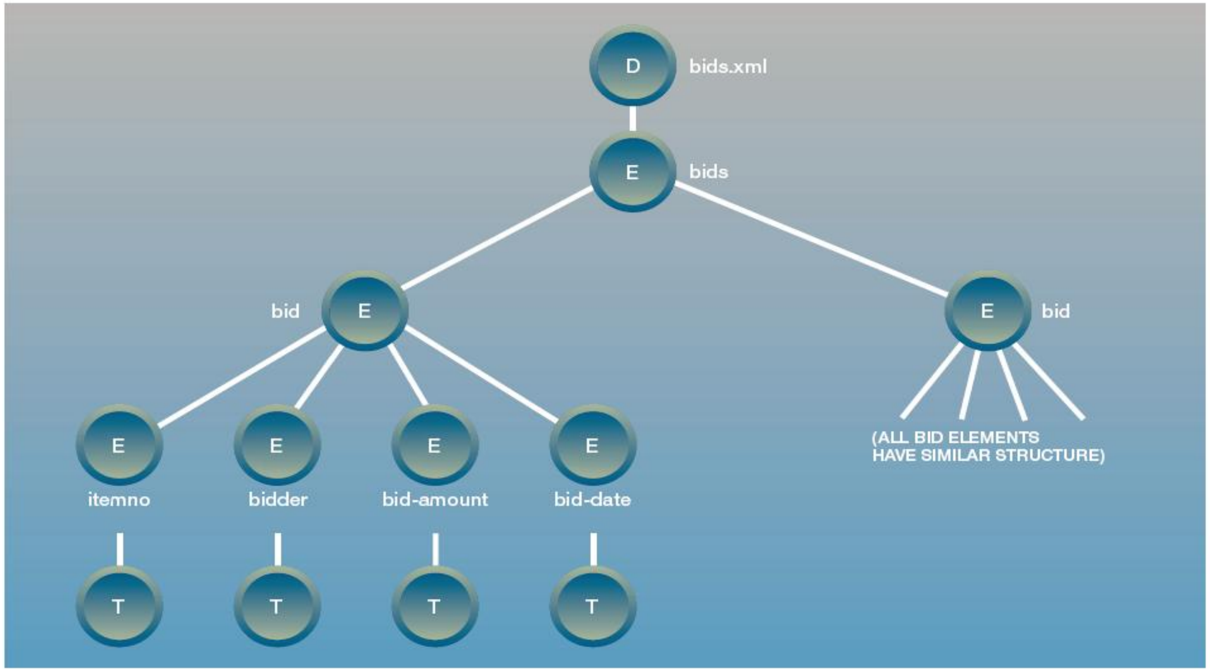
Figure 1 Data model representation of items.xml



# XQuery: An XML Query Language (conti.) [Cham:02]

*Data model representation of bids.xml*

Figure 2 Data model representation of bids.xml



# XQuery: An XML Query Language (conti.) [Cham:02]

☛ *Join Query*

*For each item that has more than ten bids, generate a popular-item element containing the item number, description, and bid count.*

```
for $i in document(‘‘items.xml")/*/item
let $b := document(‘‘bids.xml")
/*/bid[itemno = $i/itemno]
where count ($b) > 10
return

<popular-item>
  {
   $i/itemno,
   $i/description,
   <bid-count>{count ($b)}</bid-count>
  }
<popular-item>
```

## RQL: A RDF(S) Query Language [Karv:03]

- *QL queries allow us to retrieve the contents of any kind of collection with RDF data or schema information.*

- *RQL provides a* **select-from-where** *filter to iterate over these collections and introduce variables.*

- *Path expressions can be used in RQL filters to traverse RDF graphs at arbitrary depths.*

# RQL: A RDF(S) Query Language (conti.)[Karv:03]

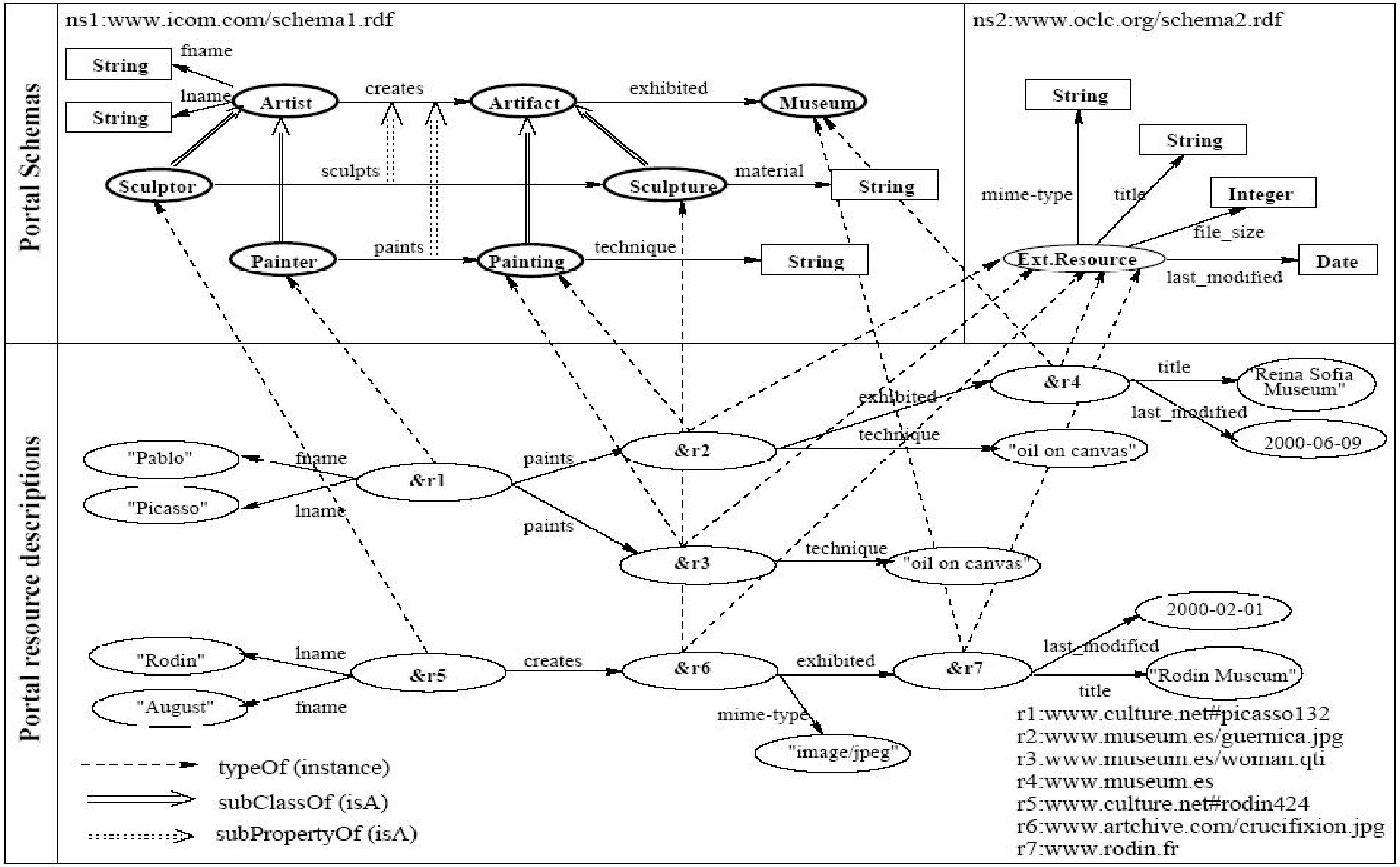



Figure 1. An example of RDF resource descriptions for a Cultural Portal

# RQL: A RDF(S) Query Language (conti.) [Karv:03]

- *Schema Queries:*
  *Which classes can appear as domain and range of the property creates?*

```
select $C1, $C2 from {$C1} creates {$C2}
```

- *Data Queries:*
  *Find the names of Artists whose Artifacts are exhibited in museums, along with the related Museum titles.*

```
select V, R,Y, Z
from {X}creates.exhibited{Y}.title{Z},
     {X}fname{V}, {X}lname{R}
```

## RQL: A RDF(S) Query Language (conti.) [Karv:03]

☛ *Combining Schema with Data Queries:*
*Find the descriptions of resources whose URI matches “www.museum.es”?*

```
select X, (select $W, (select @P, Y
                       from   {X;$W}@P{Y})
           from $W{X})
from   Resources{X}
where  X like "www.museum.es"
```

# OWL-QL (D-QL): The OWL Query Language [Fike:03b]

- *OWL-QL is a formal language and protocol for querying agent and an answering agent to use in conducting a query-answering dialogue using knowledge represented in the OWL.*
- *OWL-QL supports query-answering dialogues in which the answering agent may use automated reasoning methods to derive answers to queries.*
- *Dialogues in which the knowledge to be used in answering a query may be in multiple knowledge bases on the semantic web, and/or where those knowledge bases are not specified by the querying agent.*
- *The set of answers to a query may be unpredictable size and may require an unpredictable amount of time to compute.*

# OWL-QL (D-QL): The OWL Query Language [Fike:03b]

[2]Query: ("Who owns a red car?")
  Query Pattern: {(owns ?p ?c) (type ?c Car) (has-color ?c Red)}
  Must-Bind Variables List: (?p)
  May-Bind Variables List: ()
  Don't-Bind Variables List: ()
  Answer Pattern: {(owns ?p "a red car")}
  Answer KB Pattern: …

Answer: ("Joe owns a red car?")
  Answer Pattern Instance: {(owns Joe "a red car")}
  Query: …
  Server: …

**Figure 1. A simple OWL-QL query and answer**

# OWL-QL (D-QL): The OWL Query Language [Fike:03b]

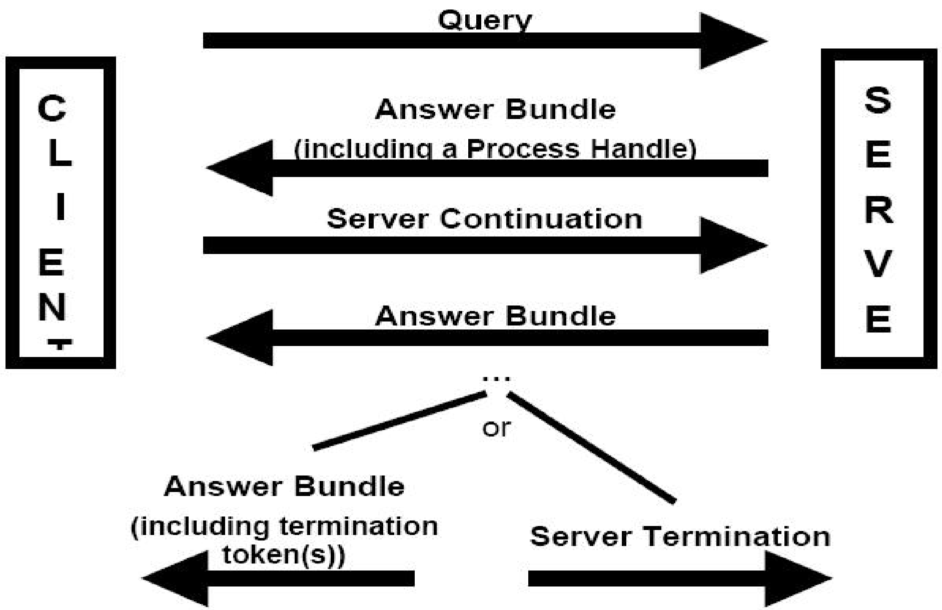



Figure 3. OWL-QL Query-Answering

# The Semantic Web Rules

- *Why the ontology language is not strong enough to express our semantic web?*

  *Some of properties expressive limitations can be overcome by the logic program based semantic web rules [Horr:04].*

- *Where are the aspects we can apply for the LP (Logic Program)-based semantic web rules?*

  *conjunctive queries, data integration, semantic web services, etc [Gros:03]*

- *A Horn clause rules extension of OWL,e.g. ORL (OWL Rules Language) with syntactically and semantically coherent manner [Horr:04].*

# Description Logic Programs (DLP) [Gros:03]

☞ *DLP-Fusion Technique:*

✔ *The bidirectional translation of premises and inferences from the DLP fragment of DL to LP, and vices versa from the DLP fragment of LP to DL.*

✔ *Build rules on top of ontologies: it enables the rule KR to have access to DL ontological definitions for vocabulary primitives (e.g., predicates and individual constants) used by the rules.*

✔ *Build ontologies on top of rules: it enables ontological definitions to be supplemented by rules, or imported into DL from rules.*

# Description Logic Programs (DLP) (conti.) [Gros:03]

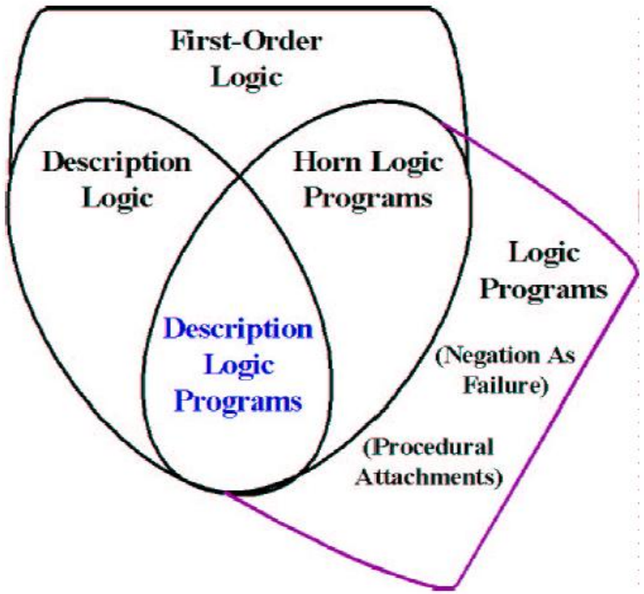



Figure 1: Expressive overlap of DL with LP.

# The Rules Language

- ☛ *RuleML (Rule Markup Language)* $\Longleftarrow$ *rule language*
- ☛ *SWRL (Semantic Web Rule Language)* $\Longleftarrow$ *ontology/rule language*
- ☛ *ORL (OWL Rules Language)* $\Longleftarrow$ *ontology/rule language*

# RuleML [Ruleml:04]

- *The RuleML Initiative is working towards an XML-based markup language that permits Web-based rule storage, interchange, retrieval, and firing/application.*

- *OWL is based on Description Logic (DL) and RuleML is based on logic programs (LP).*

- *OWL is an ontology language and RuleML is a pure rule markup language.*

- *RuleML Lite has been developed basically as a RuleML subset compatible with RDF and OWL-DL that covers webized unary and binary Datalog facts, rules, and queries.*

## SWRL: Semantic Web Rule Language [Horr:03b]

- *A combination of the OWL DL and OWL Lite with the uniary/binary Datalog RuleML sublanguages of the RuleML.*

- *SWRL includes a high-level abstract syntax for Horn-like rules in both the OWL DL and OWL Lite.*

- *A model-theoretic semantics is given to provide the formal meaning for OWL ontologies including rules written in the abstract syntax.*

- *An XML syntax based on RuleML and the OWL XML presentation syntax as well as RDF concrete syntax based on the OWL RDF/XML exchange syntax.*

# ORL: OWL Rules Language [Horr:04]

- OWL ontology language does have expressive limitions on properties.

- ORL (OWL Rules Language) is a Horn clause rules extension to OWL.

- ORL extends OWL in syntactically and semantically coherent manner.

  - ✔ The basic syntax is an extension of the abstract syntax for OWL DL and OWL Lite.

  - ✔ ORL rules XML syntax is based on the OWL XML presentation syntax

  - ✔ ORL rules mapping to RDF graphs is based on the OWL RDF/XML exchange syntax.

  - ✔ ORL semantics extend the OWL DL model-theoretic semantics.

# ORL: OWL Rules Language [Horr:02]

## *OWL (DAML+OIL) 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} |
| toClass | $\forall P.C$ | $\forall$hasChild.Doctor |
| hasClass | $\exists P.C$ | $\exists$hasChild.Lawyer |
| hasValue | $\exists P.\{x\}$ | $\exists$citizenOf.{USA} |
| minCardinalityQ | $\geqslant n P.C$ | $\geqslant$2hasChild.Lawyer |
| maxCardinalityQ | $\leqslant n P.C$ | $\leqslant$1hasChild.Male |
| cardinalityQ | $=n\, P.C$ | =1 hasParent.Female |

**Fig. 1.** DAML+OIL class constructors

# ORL: OWL Rules Language [Horr:02]

## *OWL (DAML+OIL) Axioms*

| Axiom | DL Syntax | Example |
|---|---|---|
| subClassOf | $C_1 \sqsubseteq C_2$ | Human $\sqsubseteq$ Animal $\sqcap$ Biped |
| sameClassAs | $C_1 \equiv C_2$ | Man $\equiv$ Human $\sqcap$ Male |
| subPropertyOf | $P_1 \sqsubseteq P_2$ | hasDaughter $\sqsubseteq$ hasChild |
| samePropertyAs | $P_1 \equiv P_2$ | cost $\equiv$ price |
| disjointWith | $C_1 \sqsubseteq \neg C_2$ | Male $\sqsubseteq$ $\neg$Female |
| sameIndividualAs | $\{x_1\} \equiv \{x_2\}$ | {President_Bush} $\equiv$ {G_W_Bush} |
| differentIndividualFrom | $\{x_1\} \sqsubseteq \neg\{x_2\}$ | {john} $\sqsubseteq$ $\neg${peter} |
| inverseOf | $P_1 \equiv P_2^-$ | hasChild $\equiv$ hasParent$^-$ |
| transitiveProperty | $P^+ \sqsubseteq P$ | ancestor$^+$ $\sqsubseteq$ ancestor |
| uniqueProperty | $\top \sqsubseteq \leqslant 1P$ | $\top \sqsubseteq \leqslant$1hasMother |
| unambiguousProperty | $\top \sqsubseteq \leqslant 1P^-$ | $\top \sqsubseteq \leqslant$1isMotherOf$^-$ |

**Fig. 2.** DAML+OIL axioms

# ORL: OWL Rules Language [Horr:04]

- *Extends OWL axioms by adding the production:*

```
axiom       ::= rule

rule        ::= 'Implies(' {annotation} antecedent consequent ')'
antecedent ::= 'Antecedent('{atom}')'
consequent ::= 'Consequent('{atom}')'
```

- *The rules that have the form (human readable) can not be handled by OWL ontology alone:*

$$antecedent \rightarrow consequent$$

$$parent(?a, ?b) \wedge brother(?b, ?c) \rightarrow uncle(?a, ?c)$$

$$Artist(?x) \wedge Style(?y) \wedge artistStyle(?x, ?y) \wedge creator(?x, ?z) \rightarrow style/period(?z, ?y)$$

# The Semantic Web Services

☛ *Web Services Definition [Boot:03]:*

*A Web service is a software system identified by a URI whose public interface and bindings are defined and described by XML. Its definition can be discovered by other software systems. These systems may then interact with the Web service in a manner prescribed by Internet protocols.*

# The Semantic Web Services

- *The leverages of the semantic considerations for the web services are not fully justified yet; DAML-S (OWL-S) is one of the most well-known semantic web services systems.*

- *What are the incentives for us to apply the semantic web technologies on the existing web services, such as WSDL, UDDI, BPEL4WS, etc?*

- *Where do we put the semantics (ontologies)to enhance the web services[Siva:03]?*
  - ✔ *Description Layer (WSDL): services grounding semantics*
  - ✔ *Publish and Discovery Layer (UDDI): capabilities matching semantics*
  - ✔ *Flow Layer (BPEF4WS): execution semantics*

# The Semantic Web Services (conti.) [Syca:03]

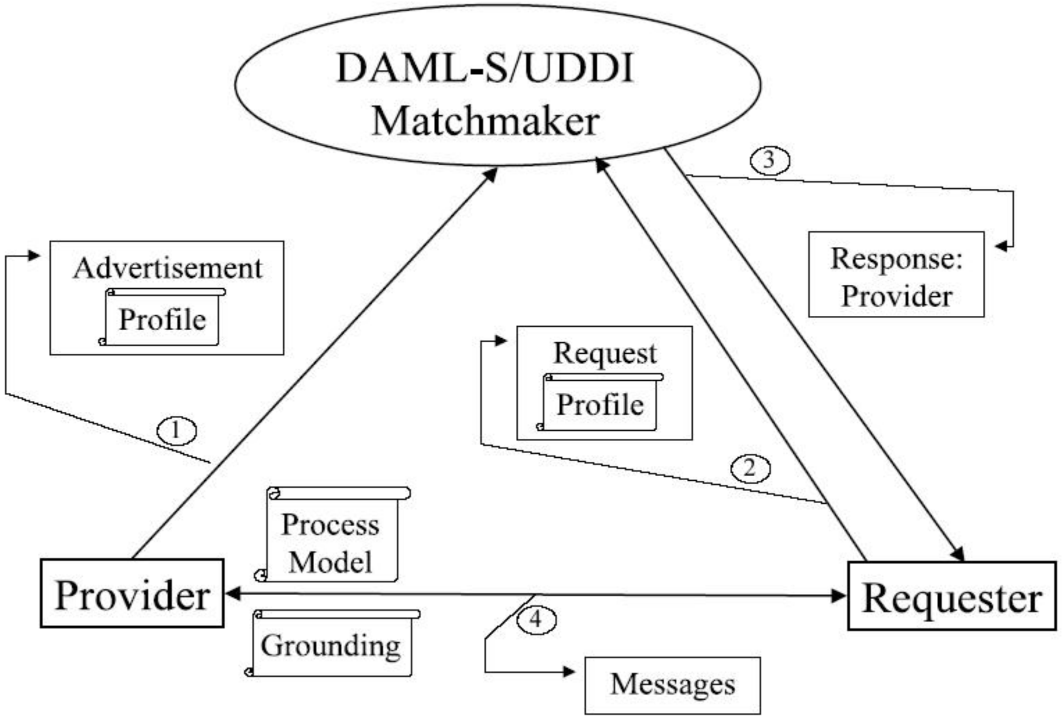



**Fig. 1.** Description of Web services Interaction

# The Semantic Web Services (conti.) [Syca:03]

*DAML-S/UDDI Matchmaker*

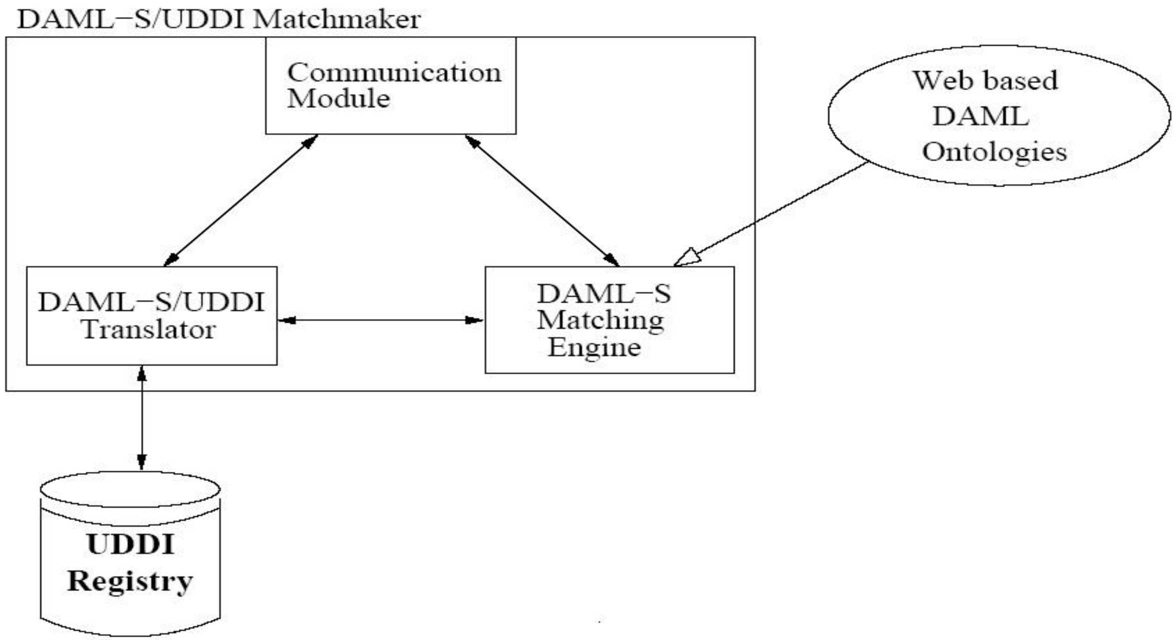



**Fig. 5.** The architecture of the DAML-S/UDDI Matchmaker

# The Semantic Web Services (conti.) [Syca:03]

*DAML-S Virtual Machine for Process Execution Control*

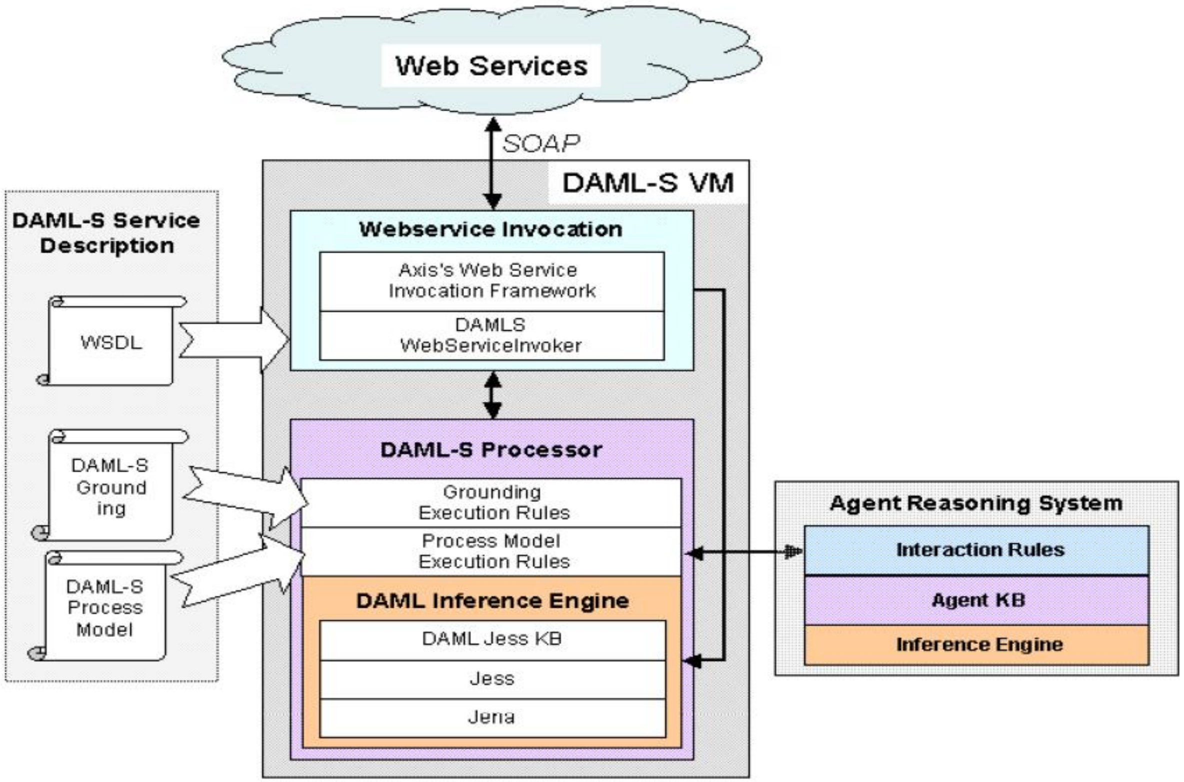



**Fig. 6.** Architecture of the DS-VM

# The Semantic P2P Computing

- *Why do we need to add semantics on the P2P computing platform?*
  *well-formed attributes and routing indices of resources for easily search, sharing, recommendation, etc.*

- *Where can we put the semantics?*
  *routing indices, resources attributes, profiles of requester and provider, dialogue session log files, resource's digital rights, etc.*

- *How can we leverage the semantic web technologies for the P2P computing? semantic overlay the P2P platform with ontology and rule mechanisms to realize the incentives of semantic search, query, process, etc.*

- *How do we justify this is worthy?*
  *simulation, field trial, analysis, etc.*

# The Semantic P2P Computing (conti.)[Nejd:03a]

*The Taxonomy of (Semantic) P2P Computing*

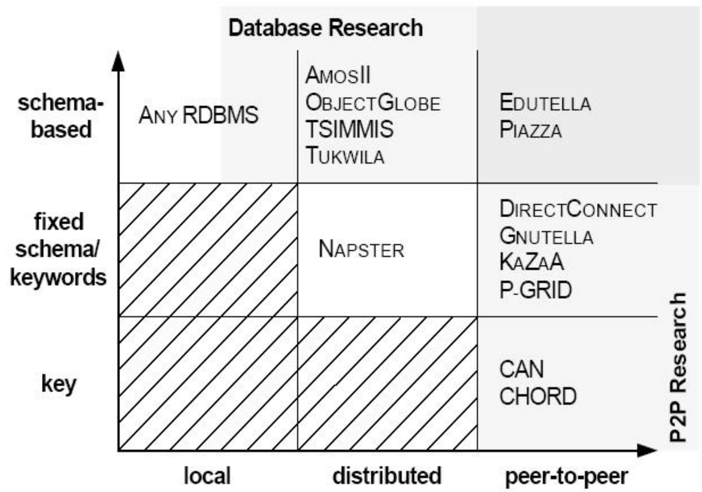



Figure 1: Schema Capabilities and Distribution

## The Semantic P2P Computing (conti.) [Nejd:03b]

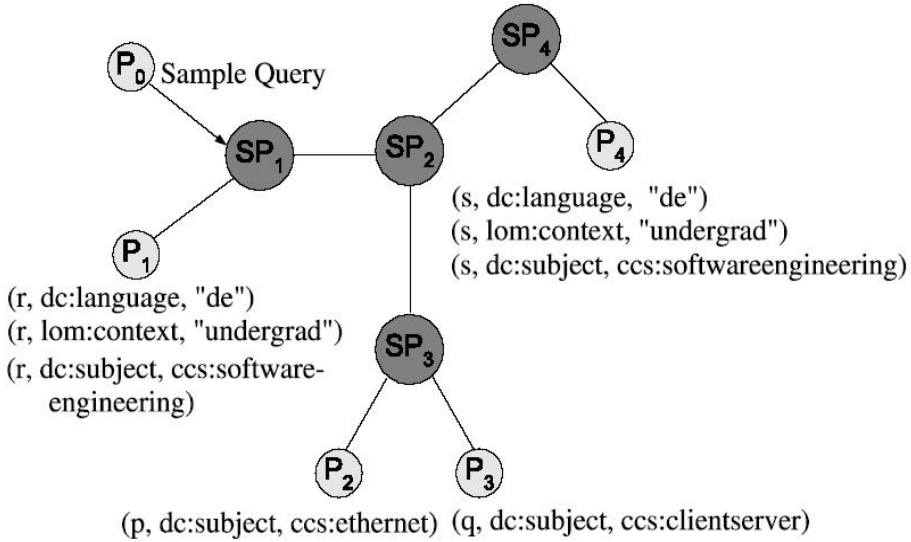
*Query the Semantic P2P Computing Schema*

- *Find lectures in German language from the area of software engineering suitable for undergraduates?*

- *Find any resource where the property dc:subject is equal to ccs:softwareengineering, dc:language is equal to "de" and lom:context is equal to "undergrad"?*

# The Semantic P2P Computing (conti.) [Nejd:03b]

*The Super-Node P2P Routing Example Network*



# Future Directions

- *Complete the rule layer and ontology layer integration with coherent model theory semantics and syntax so that the semantic web technologies can be applied to real world applications without ambiguity.*

- *Build large scale distributed multi-ontologies infrastructure with some applications on the WWW to justify the feasibility of the semantic web technologies.*

- *Deliver user friendly application development tools to allow users easily construct and propagate all kinds of possible semantic web applications.*

- *Clean up and Standardize the RDF(S) and OWL syntax and semantics comparable and interoperable issues.*

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