The Semantic Web: Myths and Reality

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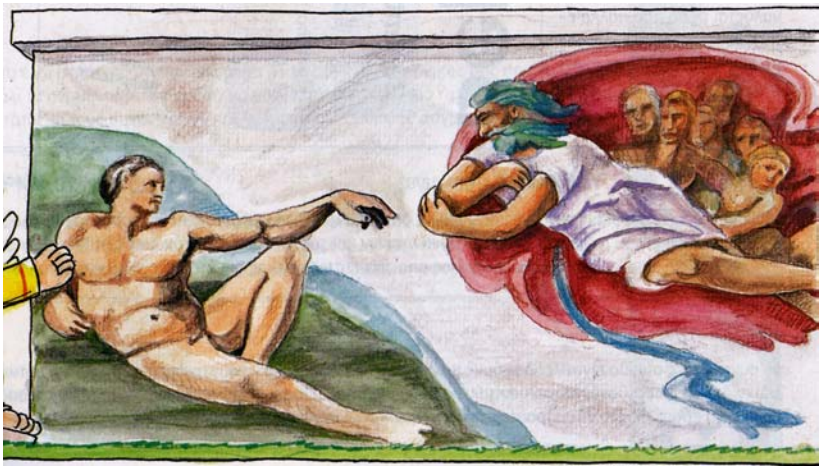
This Talk is not about Myths !

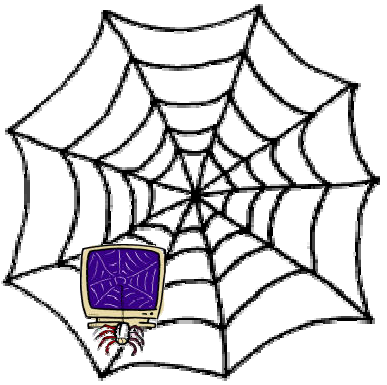
Is about Reality !!!



www.arkas.gr

How the Web is Today ?

- Information and its presentations are mixed up in the form of HTML documents
  - all intended for human consumption
  - many generated automatically by applications
- Easy to fetch any Web page, from any server, any platform
  - access through a uniform interface



The Secrets of HTML Success

- Everybody can write it:
  - HTML is simple
  - HTML is textual: it is human readable, you can use any editor, ...
- Everybody can read it:
  - HTML is portable on any platform
  - The browser is the universal application
- Everybody can search it:
  - Keyword-based Search Engines: high recall, low precision
- It connects pieces of information together
  - Through hypertext links

What's Wrong with HTML

- If written properly, normal HTML markup may reflect document presentation, but it cannot adequately represent the semantics & structure of data

Artist Name

Artifact Title

Date

Dimensions

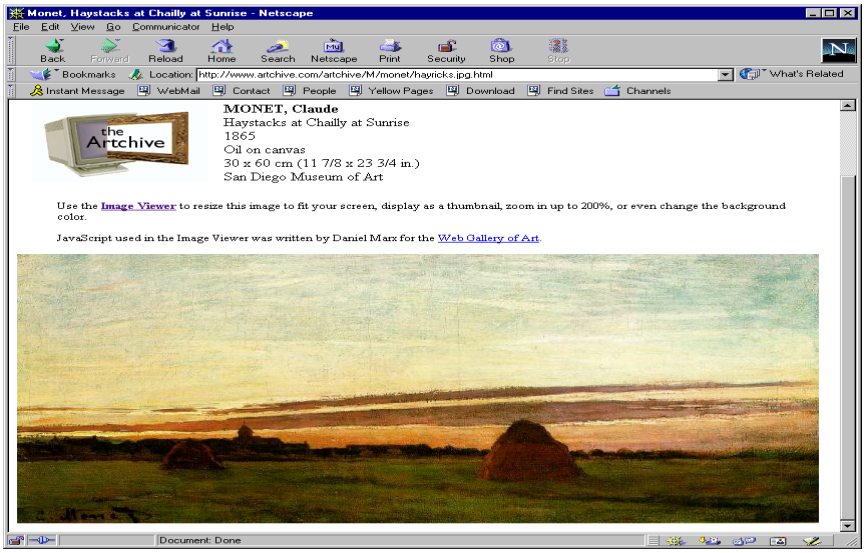
Material

Image Reference

Museum

```
<B>MONET, Claude<B><BR>
Haystacks at Chailly at Sunrise<BR>
1865<BR>
Oil on canvas<BR>
30 x 60 cm (11 7/8 x 23 3/4 in.)<BR>
San Diego Museum of Art <BR>
<P>
<IMG SRC="http://192.41.13.240/artchive/
m/monet/hayricks.jpg">
```

HTML Document Presentation



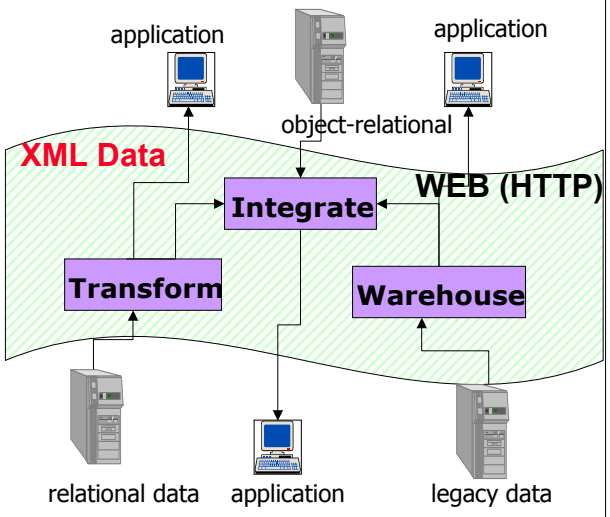
But Modern Web Applications Need More!

- Infomediaries:
  - Community Web Portals
  - Digital Museums & Libraries
- Electronic commerce:
  - On-line Catalogs & Procurement
  - Comparison Shoppers
  - Market Places
  - Virtual Enterprises
- Scientific applications:
  - E-learning
  - Data & Knowledge Grids
- Advanced Information Management
  - finding,
  - extracting,
  - representing,
  - interpreting,
  - maintaining
- Flexible, Quick Interoperation: the ability to uniformly share, interpret and manipulate heterogeneous information
  - applications cannot consume HTML

More than HTML documents: Data on the Web
More than Web browsers: Web-enabled Applications

Paradigm Shift on the Web

- New Web standard XML:
  - XML generated by applications
  - XML consumed by applications
- Data exchange:
  - across platforms
  - across organizations
- Web: from collection of documents to Web data published as documents

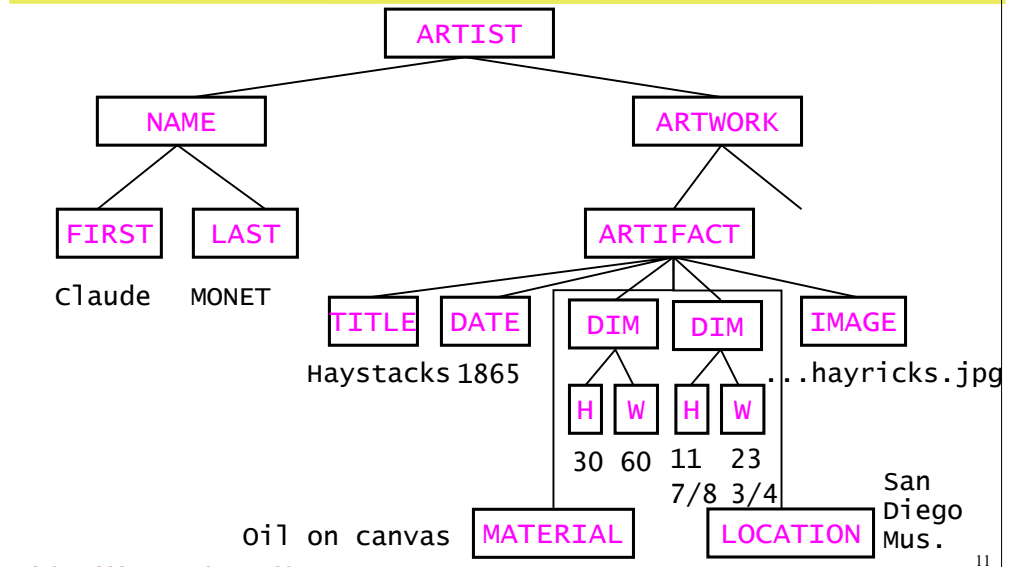


XML Data Representation: The Document View

```
<ARTIST>
  <NAME>
    <FIRST>Claude</FIRST> <LAST>Monet</LAST>
  </NAME>
  <ARTWORK>
    <ARTIFACT>
      <TITLE>Haystacks at Chailly at Sunrise</TITLE>
      <DATE>1865</DATE>
      <MATERIAL>Oil on canvas</MATERIAL>
      <DIM Metric='cm'>
       <HEIGHT>30</HEIGHT><WIDTH>60</WIDTH></DIM>
      <DIM Metric='in'>
       <HEIGHT>11 7/8</HEIGHT><WIDTH>23 3/4</WIDTH></DIM>
      <LOCATION>San Diego Museum of Art</LOCATION>
      <IMAGE File='http://192.41.13.240/artchive/m/monet/hayricks.jpg'/>
    </ARTIFACT>
  </ARTWORK>
</ARTIST>
```

Element Name
Element Content
Attribute Name
Attribute Value
Empty Element

XML Data Representation: The Database View



The Secrets of XML Popularity

- It looks like HTML...
  - Simple, familiar, easy to learn, human-readable
  - Universal and portable
  - Supported by the W3C: trusted and quickly adopted by the industry
- …but it's more than HTML!
  - flexible: you can represent any information
  - extensible: you can represent it the way you want!
- Increasing precision in XML specifications
  - Well-Formed: already better than plain text
  - Valid: Structure conforms to a DTD or an XML Schema

Well-Formed XML

- An object is said to be a well-formed XML document if it meets all the well-formedness constraints (WFCs) of the XML syntax:
  - tags (etc.) are syntactically correct
  - every tag has an end-tag
  - tags are properly nested
  - there exists a root
- By definition if a document is not well-formed, it is not XML
  - This means that there is no an XML document which is not well-formed, and XML processors are not required to do anything with such documents

Valid XML

- A well-formed document is valid only if it contains a proper DTD (or Schema) and if the document obeys the constraints of that DTD (or Schema) and therefore the XML Validity Constraints (VCs)
  - only declared tags (element or attribute names) are used
  - all tag occurrences conform to specified content models
- Examples:
  - The following XML Document is well-formed but not valid

```
<ARTIST>Claude Monet</ARTIST>
```

  - The following XML Document is not even well-formed

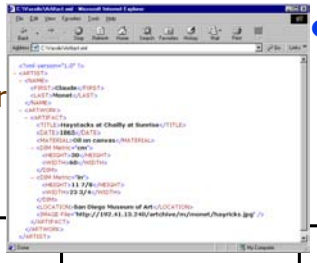
```
<FIRST>Claude</FIRST><LAST>Monet</LAST>
```

XML Document Type Definition (DTD)

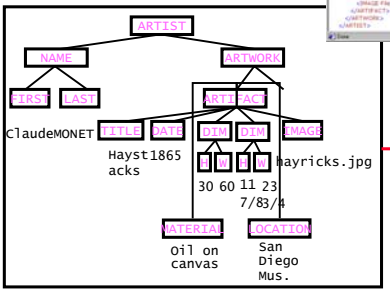
```
<!DOCTYPE artist [
<!ELEMENT artist (name, born, death, artwork, nationality?,
                  influences)>
<!ATTLIST artist oid ID #REQUIRED>
<!ELEMENT name      (first, last)>
<!ELEMENT first     (#PCDATA)>
<!ELEMENT last      (#PCDATA)> ...
<!ELEMENT artwork   (artifact+)>
<!ELEMENT artifact (title, date, material, dim*, location, image)>
<!ELEMENT title     (#PCDATA)> ...
<!ELEMENT dim       (height, width)>
<!ATTLIST dim metric (cm | in) 'cm'>
<!ELEMENT location (#PCDATA)>
<!ELEMENT image EMPTY>
<!ATTLIST image file ENTITY #REQUIRED>
<!ELEMENT influences (PCDATA | aref)*>
<!ELEMENT aref EMPTY>
<!ATTLIST aref oref IDREF #IMPLIED>
]>
```


Is XML the Solution to Interoperability?

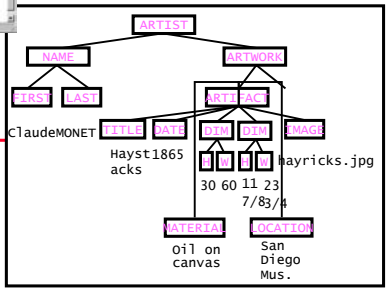
Document = medium for exchanging information



- Still need to agree on:
  - DTDs or Schemas
  - Meaning of tags
  - "Operations" on data
  - Meaning of operations



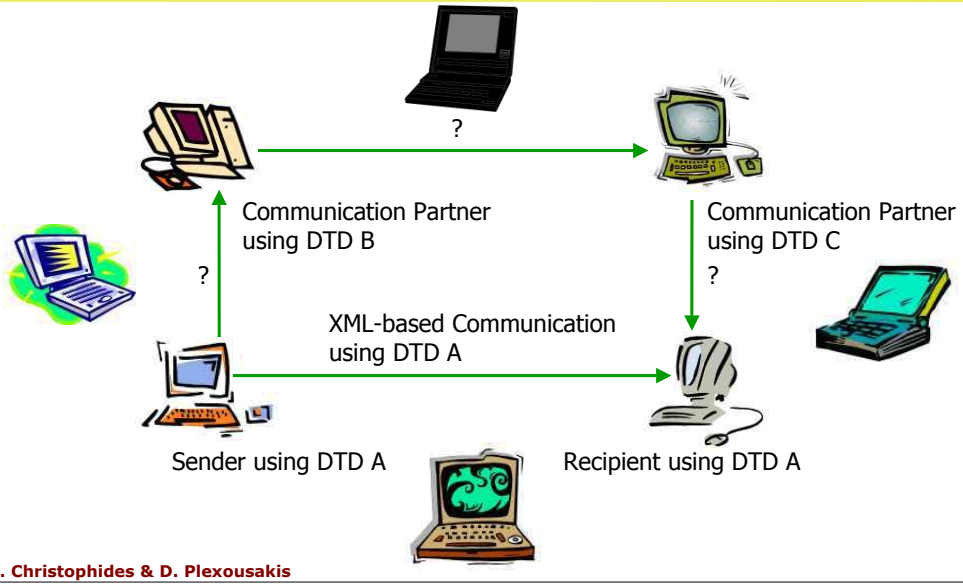
Communication



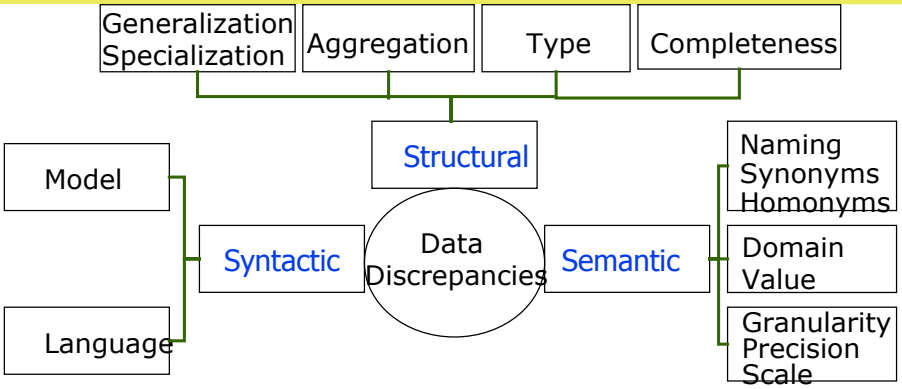
Application 1

Application 2

Large Scale Interoperation on the Web



Recall Data Heterogeneity



- XML is a Universal Format capturing data from different Models
  - Relational or Object DBMS
  - Document and File Repositories
- Semantic (and structural) heterogeneity occurs when there is a disagreement about the meaning, interpretation, or intended use of the same or related data

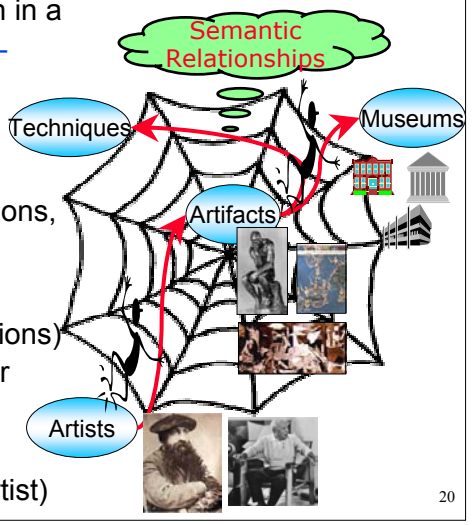
Interoperability is still an Open Issue !

- Semantic discrepancies :
  - Synonymy & Polysemy & Taxonomy
    - <ARTIFACT> vs. <ARTEFACT>
    - is <ARTWORK> paintings or songs ?
    - how < … Style='Impressionism'> is related to < … Style='Pointillism'> ?
- Structural discrepancies :
  - Aggregation
    - <NAME><FIRST>Claude</FIRST><LAST>Monet</LAST></NAME> vs <NAME>Claude Monet</NAME>
  - Type
    - <ARTIFACT Kind='Painting'> ... </ARTIFACT> vs <PAINTING>Claude Monet</PAINTING>
- Syntactic discrepancies :
  - <ARTIST Name='Claude Monet'> ... </ARTIST> vs <ARTIST> <NAME>Claude Monet</NAME> ... </ARTIST>

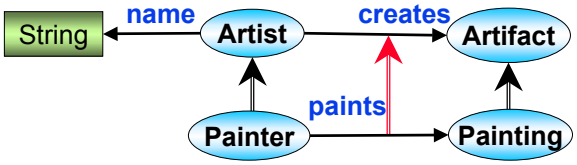
More than Web Data: Semantics on the Web
More than Web Applications: Web Services

The Semantic Web Vision: A Web of Meaning

- The "Next Generation Web" aims to provide infrastructure for expressing information in a precise, human-readable, and machine-interpretable form
- Enable both syntactic and semantic/ structural interoperability among independently-developed Web applications, allowing them to efficiently perform sophisticated tasks for humans
- Enable Web resources (data & applications) to be accessible by their meaning rather than by keywords and syntactic forms
  - Conceptual Navigation & Querying
  - Inference Services (Picasso is an Artist)



A First Step Towards the SW: RDF and RDFS

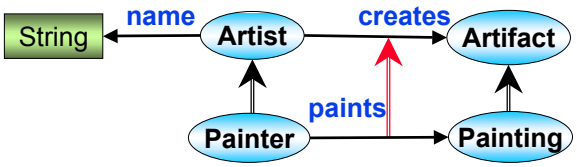



```
<Artist rdf:about="picasso132">
  <name>Pablo Picasso</name>
  <creates>
    <Artifact rdf:about=
    http://www.artchive.com/woman.jpg/>
  </creates>
</Artifact>
```

```
<Artist rdf:about="picasso132"
        name ="Pablo Picasso">
  <creates Artifact =
    http://www.artchive.com/woman.jpg/>
</Artifact>
```

```
<Painter rdf:about="picasso132">
  <name>Pablo Picasso </name>
  <paints>
   <Painting rdf:about=
   "http://www.artchive.com/woman.jpg"/>
 </paints>
 <paints>
   <Painting rdf:about="http://
    museoreinasofia.mcu.es/guernica.gif">
    </Painting>
 </paints>
</Painter>
```


A First Step Towards the SW: RDF and RDFS




```
<rdfs:Class rdf:ID="Artist"/>

<rdfs:Class rdf:ID="Artifact"/>

<rdfs:Class rdf:ID="Painter">
 <rdfs:subClassOf rdf:resource="#Artist"/>
</rdfs:Class>

<rdfs:Class rdf:ID="Painting">
 <rdfs:subClassOf rdf:resource="#Artifact"/>
</rdfs:Class>

<rdf:Property rdf:ID="name">
 <rdfs:domain rdf:resource="#Artist"/>
 <rdfs:range rdf:resource="http://www.w3.org/
                  rdf-datatypes.xsd#String"/>
</rdf:Property>
```

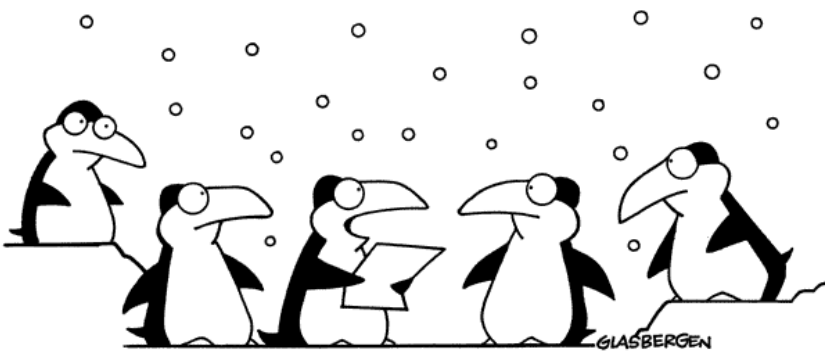
```
<rdf:Property rdf:ID="creates">
 <rdfs:domain rdf:resource="#Artist"/>
 <rdfs:range rdf:resource="#Artifact"/>
</rdf:Property>

<rdf:Property rdf:ID="paints">
 <rdfs:domain rdf:resource="#Painter"/>
 <rdfs:range rdf:resource="#Painting"/>
 <rdfs:subPropertyOf
              rdf:resource="#creates"/>
</rdf:Property>

<rdf:Property rdf:ID="created">
 <rdfs:domain rdf:resource="#Painting"/>
 <rdfs:rangerdf:resource="http://www.w3.org/
                  rdf-datatypes.xsd#Date"/>
</rdf:Property>
```

Is RDF/S the Solution to Interoperability?

- RDF/S abstracts from the syntactic discrepancies of XML data (elements vs attributes)
  - but it introduce new ones, related to its own model & syntax (classes vs properties, unique identifiers of resources)
  - ➔we can't read arbitrary XML data and interpret them as RDF!
- RDF/S provides core primitives for modeling the semantics of data in a domain of discourse (extended ER models)
  - however application data reside in autonomous sources, structured according to different schemas
  - ➔we can't expect that all existing data will be published on the SW as RDF/S data committing to one commonly agreed ontology (schema)!
- We still need expressive languages for mapping ontologies as well as translate accordingly the data from one application to another
  - finding semantic mappings is now the bottleneck!
  - ➔largely done by hand, labor intensive & error prone !

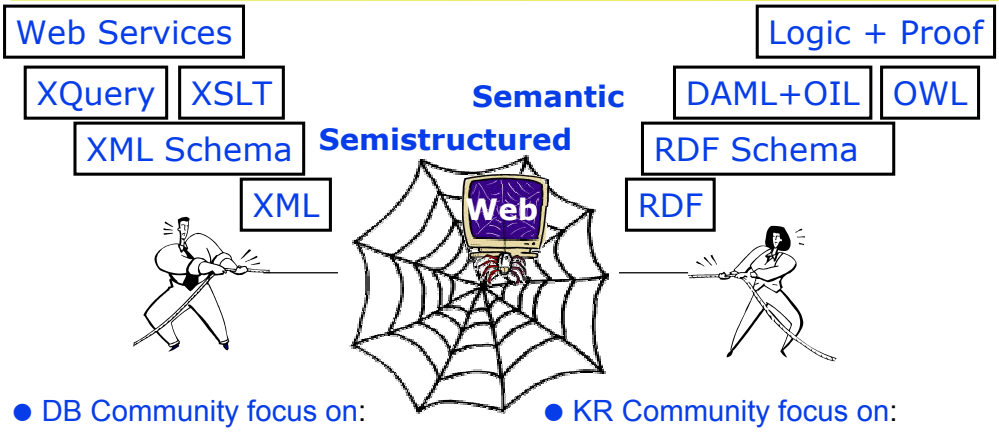
Diversity is a Feature!

- Semantic/Structural heterogeneity is not a drawback, but a feature of large scale distributed systems in a dynamic and open information universe



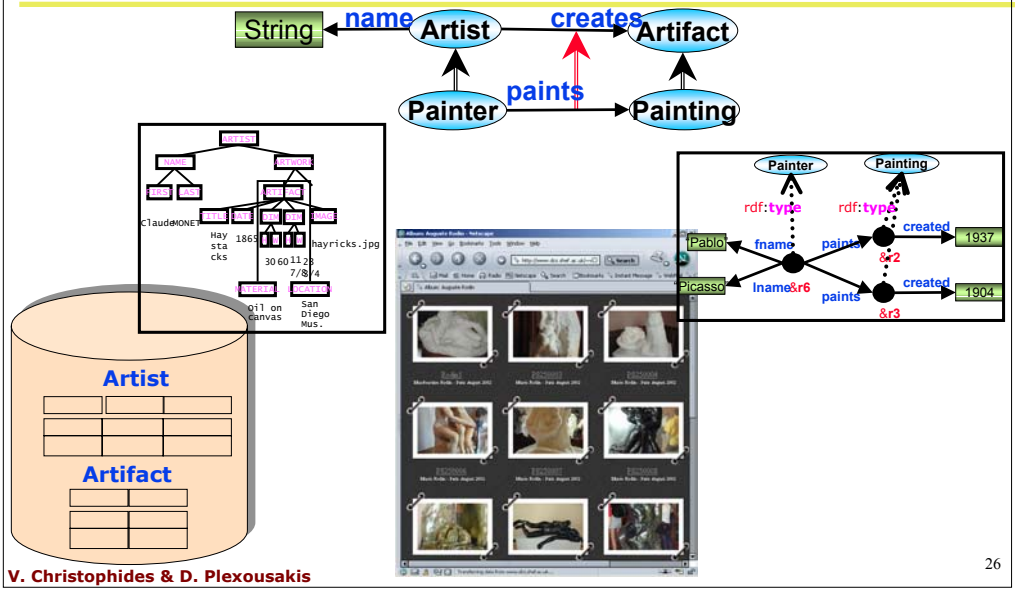
"They say we're not placing enough emphasis on diversity."

Two Cultures on the Future Web: DB vs KR

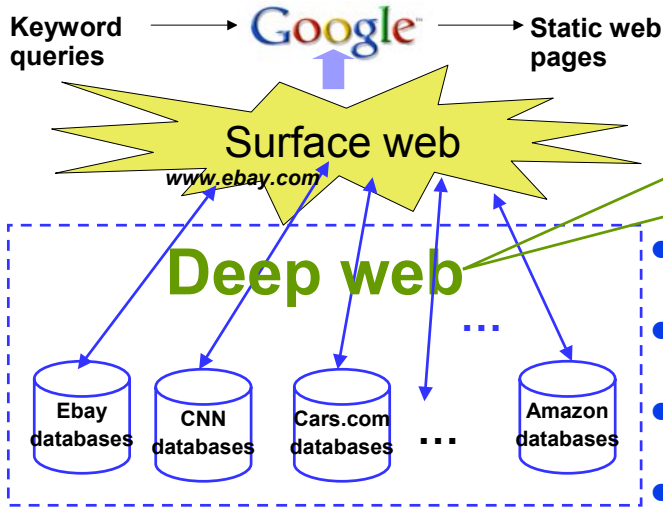


- DB Community focus on:
  - XML Data Semantics (Typing, Constraints)
  - XML Data Manipulation Languages (Querying, Views, Programming)
- KR Community focus on:
  - Ontology Languages (Frame / Description Logics)
  - Reasoners and Theorem Provers

Similar Motivations but different Application Contexts!



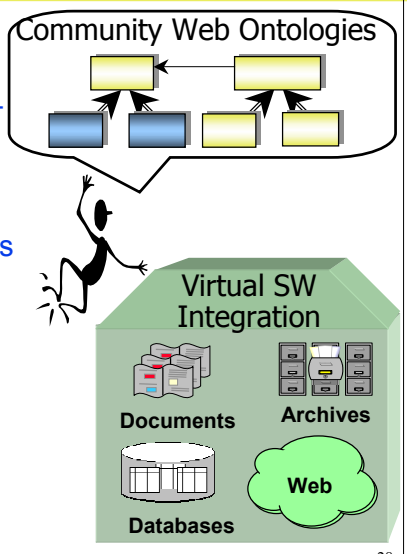
Visible (Surface) vs Invisible (Deep) Web



- Variety of Data formats & search mechanisms
- Accessible from specific HTML pages
- Higher Quality Information
- Not indexed by Google or other major search engines

Our Vision: Combine DB and KR Approaches

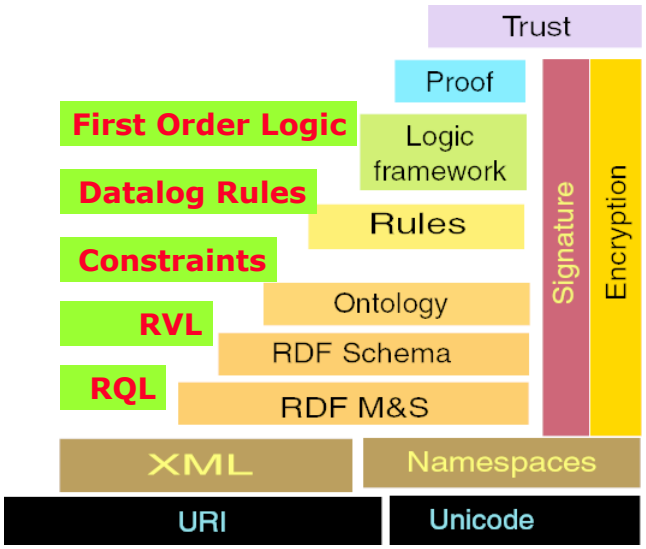
- Provide a useful, comprehensive, and high-level access to community resources
  - Ontologies as shared, formal conceptualizations of particular domains
- Build scalable technologies for managing semantically rich data and metadata
  - Declarative Querying/Viewing Languages
  - Efficient Storage for Voluminous Descriptive Information
- Support an expressive SW Integration Middleware
  - Establish Mapping/Translation Rules
  - Reformulate Conceptual Queries
  - Exploit data semantics for Query Optimization and Consistency Checking



W3C Semantic Web Activity

- Semantic Web Activity (http://www.w3.org/2001/sw/)
  - "Established to serve a leadership role, in both the design of enabling specifications and the open, collaborative development of technologies that support the automation, integration and reuse of data across various applications"
  - Successor to the W3C Metadata Activity
- RDF Core Working Group (http://www.w3.org/2001/sw/RDFCore/)
  - Responsible for the Resource Description Framework (RDF)
- Web Ontology Working Group (http://www.w3.org/2001/sw/WebOnt/)
  - Charter: Build upon the RDF Core work a language for defining structured web based ontologies which will provide richer integration and interoperability of data among descriptive communities
  - Developing Ontology Web Language (OWL)
    - Based on DAML+OIL, developed in DARPA's Agent Markup Language program

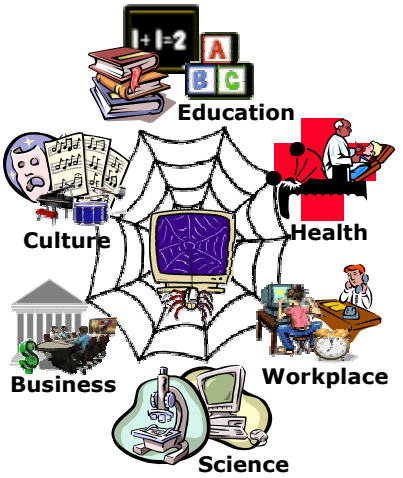
SW Layer Cake and ICS-FORTH Vision



Resource Description Framework (RDF)

RDF Objectives

- Enables communities to define their own descriptive semantics of Web resources
  - we can disagree about semantics, but share the same infrastructure (editors, query languages, databases, etc.)
- Imposes some structural constraints on the encoding of resource descriptions
  - for consistent exchange and processing of metadata on the Web
- Facilitates the development of descriptive vocabularies without central coordination
  - mechanisms for reusing and refining concepts, properties, etc.
  - mechanisms for extending resource descriptions in a peer-to-peer fashion



What is a Resource Description ?

Resource Description

author

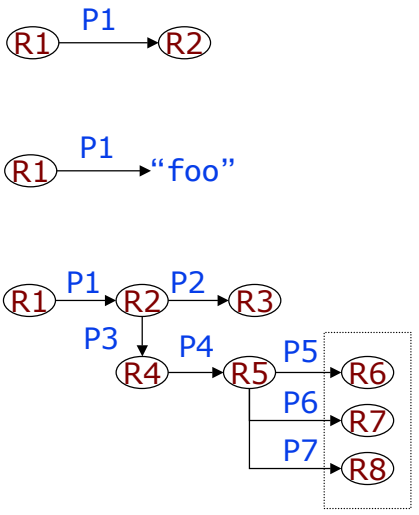
title

publisher

Resource

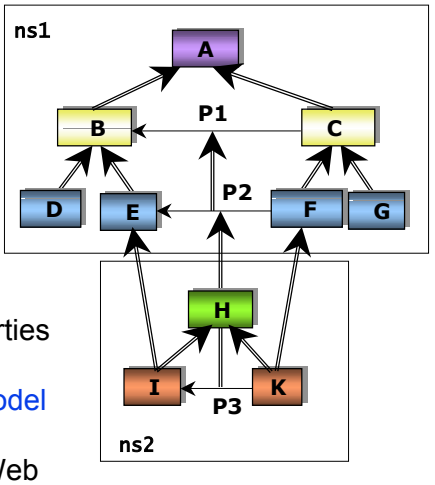
The Core RDF Data Model

- RDF: enables communities to describe their resources in a quite natural and flexible way
  - Data Model: Directed Labeled Graphs
    - Nodes: Resources (URIs) or Literals
    - Edges: Properties – Attributes or Relationships
    - Statement: assertion of the form *resource, property, value*
    - Description: set of statements concerning a resource
  - XML syntax



The Core RDFS Data Model

- RDFS: enables communities to share machine readable tokens and define human readable labels
  - Node labels (types) are defined as classes
    - XML Schema Literal data types
  - Edge labels (predicates) are defined as properties of these classes
    - domain and range constraint
  - Subsumption of both classes & properties (simple & multiple *is_A*)
- RDFS is expressible in the basic RDF model and syntax
  - vocabularies can be also viewed as Web resources identified by a namespace URI

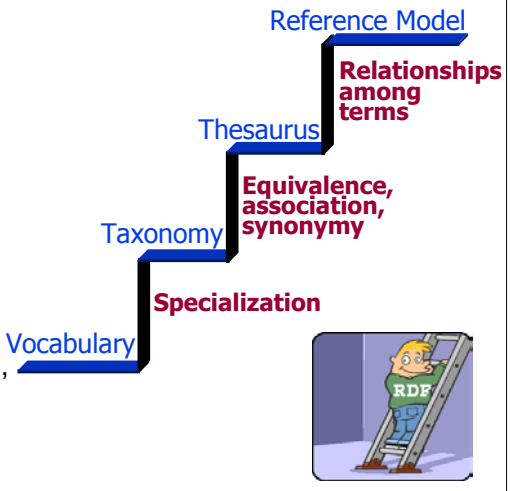


Looking at Existing RDF Applications

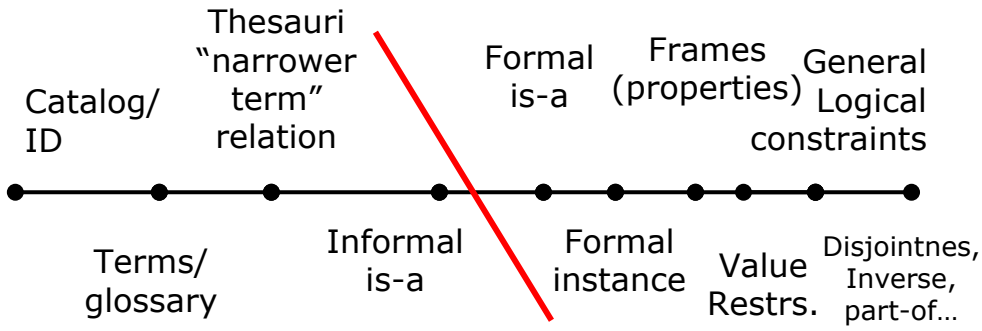
- Cultural Heritage/ Archives/ Libraries
- Educational/ Academic /Learning
- Publishing/ News
- Audio-Visual
- Geospatial/ Environmental
- Biology/ Medicine
- E-Commerce
- Ubiquitous/ Mobile/ Grid Computing
- Cross-Domain

What Descriptive Semantics RDF/S can capture?

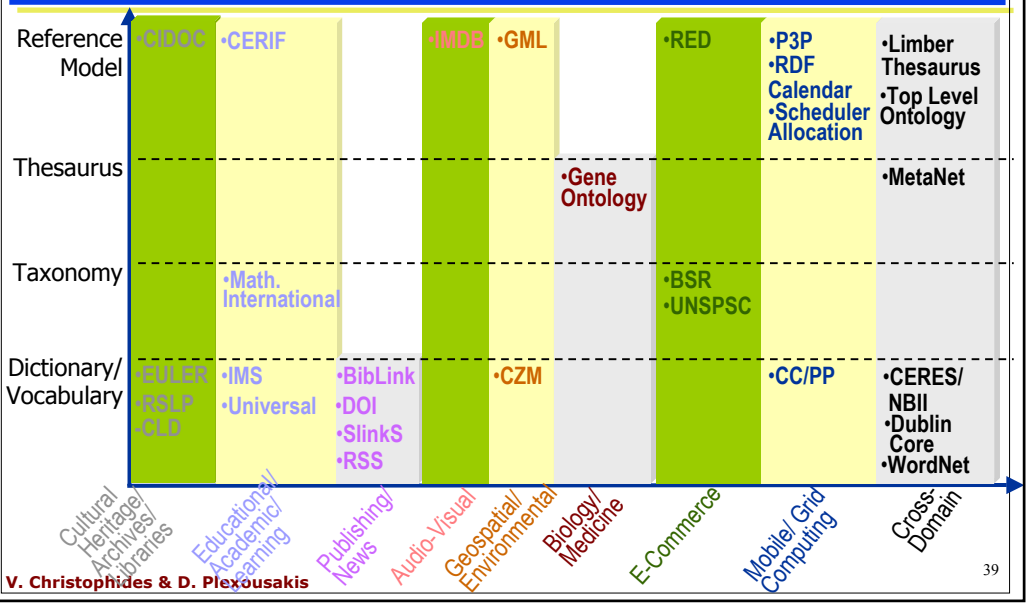
- Dictionaries/ Vocabularies
  - simple lists of terms and their definitions
- Taxonomies
  - Specialization between terms
- Thesauri
  - Broader/narrower terms, equivalence, association and synonymy relations
- Reference Models
  - A representation vocabulary of the concepts in the subject area, the relations among the terms and the way the terms can or cannot be related to each other



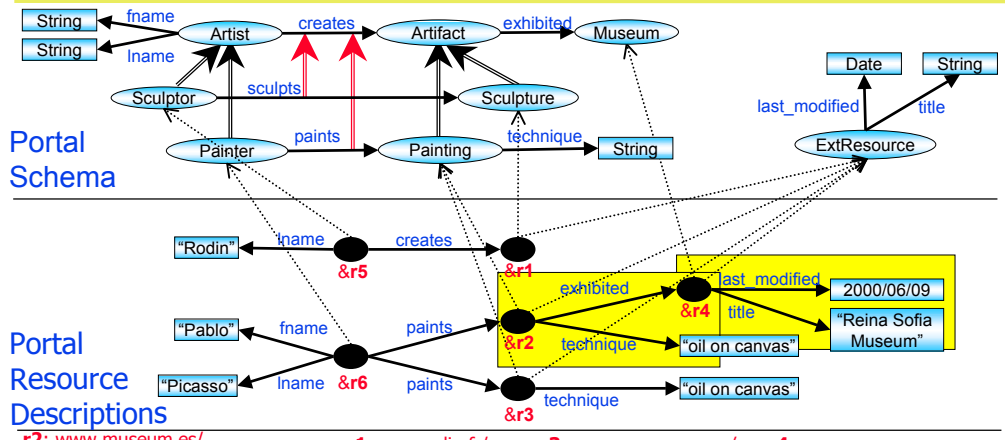
Ontologies - What Are They?



A First Categorization of existing RDF Schemas



A Cultural Community Web Portal in RDF



Web Resources

r2: www.museum.es/ guernica.jpg

r1:www.rodin.fr/ thinker.gif

r3:www.museum.es/ woman.qti

r4:www.museum.es

Advantages of RDF/S vs. Well-Known Formalisms

- Relational or Object Database Models (ODMG, SQL)
  - Instances may be associated with different properties
  - Heterogeneous Collections
- Semistructured or XML Data Models (OEM, UnQL, YAT, XML Schema)
  - Labels on both nodes or edges
  - Both class and property subsumption
- Knowledge Representation Languages (Telos, DL, F-Logic)
  - Supports complex values (bags, sequences)

Why a Formal Data Model for RDF ?

- As support for physical/logical independence
  - RDF can be stored in files, a native repository, a relational database
  - RDF can be virtual, as a view of a repository, integrated sources
  - RDF can be in memory, using data structures in C, C++, Java, etc
  - RDF can be streamed between processes
- To describe information content of RDF statements
  - to agree and reason about information content, preservation
- To define semantics of a data manipulation language:
  - A query language describes in a declarative fashion, the mapping between an input instance of the data model to an output instance of the data model

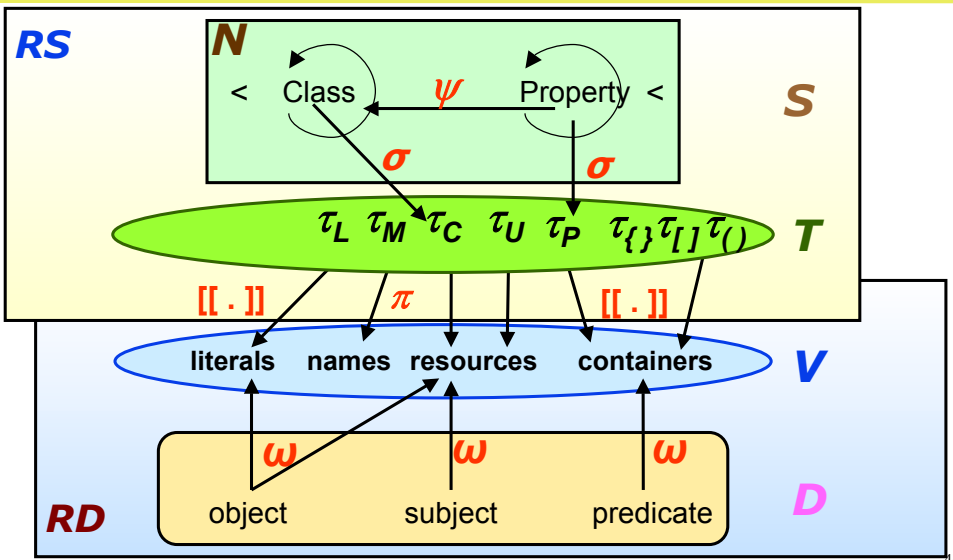
Why a Type System for RDF ?

- For error detection & safety:
  - to correctly understand statements of interest
    - e.g., don't confuse resource URIs with class/property names!
  - to enforce safety of operations
    - e.g., don't do float arithmetic on classes!
  - to check valid compositions of operations
    - e.g., don't ask the subproperties of the range of a class!

- For performance:
  - to design better storage (improving clustering, etc.)
  - to efficiently process queries (rewriting path expressions, etc.)

- We need a full-fledged Data Definition Language for RDF !
  - RDF Schema is viewed more as an ontology & modeling tool

A Formal Data Model for RDF/S



A Formal Data Model for RDF/S

- Type System:

  $\tau = \tau_L \mid \tau_U \mid \tau_M \mid \tau_C \mid \tau_P[\tau_1, \tau_2] \mid \{\tau\} \mid [1{:}\tau + 2{:}\tau + \ldots + n{:}\tau] \mid (1{:}\tau + 2{:}\tau + \ldots + n{:}\tau)$

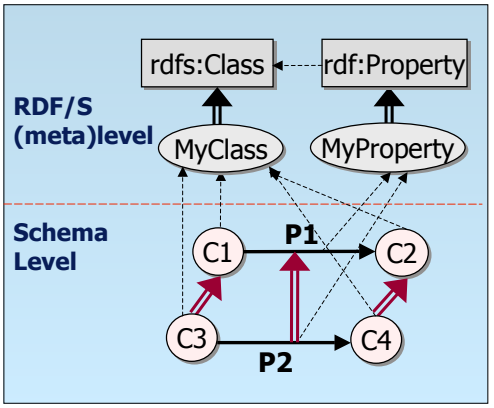
- Interpretation Function:
  - Literal types: $[[\ \tau_L\ ]] = dom(\tau_L)$
  - Resource types: $[[\ \tau_u\ ]] = u \in U$
  - MetaClass types: $[[\ \tau_M\ ]] = \{v \mid v \in \pi^*(m)\}$
  - Class types: $[[\ \tau_C\ ]] = \{v \mid v \in \pi^*(c)\}$
  - Property types: $[[\ \tau_p[\tau_1, \tau_2]\ ]] = \{ [v_1, v_2] \mid v_1 \in [[\tau_1]],\ v_2 \in [[\tau_2]] \} \cup \{[[\ \tau_p[\tau'_1, \tau'_2]\ ]] = \{ [v'_1, v_2] \mid v'_1 \in [[\tau'_1]],\ v'_2 \in [[\tau'_2]] \}\ p' < p\}$
  - Bag types: $[[\ \{\tau\}\ ]] = \{ \{v_1, \ldots, v_j\} \mid j > 0,\ \forall\ i \in [1..j]\ v_i \in [[\ \tau\ ]] \}$
  - Seq types: $[[\ [\tau]\ ]] = \{ [1{:}v_1, 2{:}v_2, \ldots, n{:}v_n] \mid n > 0,\ \forall\ i \in [1..n]\ v_i \in [[\ \tau_i\ ]] \}$
  - Alt types: $[[\ (1{:}\tau_1 + 2{:}\tau_2 + \ldots + n{:}\tau_n)\ ]] = \{i{:}v_i \mid,\ \forall\ i \in [1..n]\ v_i \in [[\ \tau_i\ ]] \}$

A Formal Data Model for RDF/S

- An RDF schema is a tuple: S = (RS, σ)
  - RS = (V_S, E_S, H, ψ, λ, N, <) is a valid RDF Schema
  - σ is a type function: N $\rightarrow$ **T**
- An RDF description base, instance of a schema S, is a tuple: D = (RD,ω)
  - RD=(RS, V_D, E_D, ψ, λ) is a set of valid resource descriptions
  - ω is a valuation function: $V_D \cup E_D \rightarrow$ **V** such that:
    - $\forall$ n $\in V_D$, ω (n) $\in$ [[σ (λ (n))]]
    - $\forall$ p $\in E_D$ from node n to n', [ω(n), ω(n')] $\in$ [[p]]

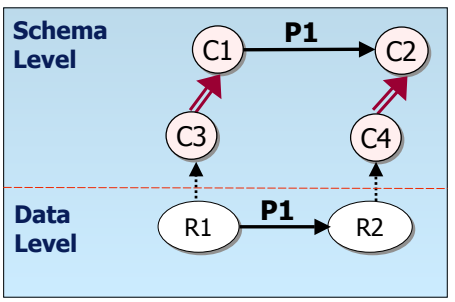
Imposed Constraints (1)

- For a valid RDF/S schema:
  - The domain and range of a property must be unique and always defined
  - The domain (range) of a sub-property must be subsumed by the domain (range) of the super-property
  - A subsumption hierarchy can be defined only among names of the same type (metaclasses, classes and properties)
  - No cycles in the subsumption hierarchies



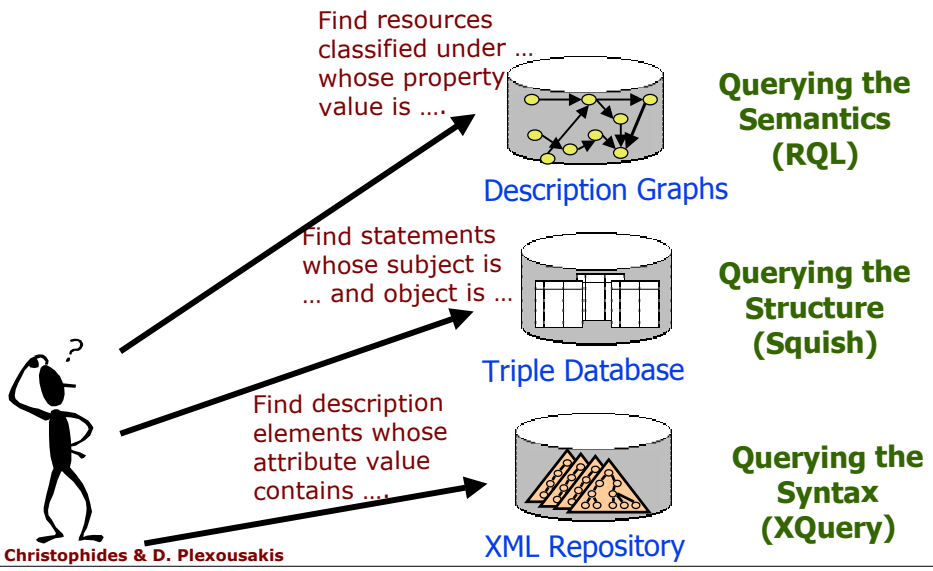
Imposed Constraints (2)

- For a valid RDF/S description base:
  - A literal value is instance of one and only one literal type
  - A resource is always instance of the most "specialized" class w.r.t the subsumption hierarchy
  - The resources connected by a property at data level must be instances of classes equal or subsumed by the property domain and range



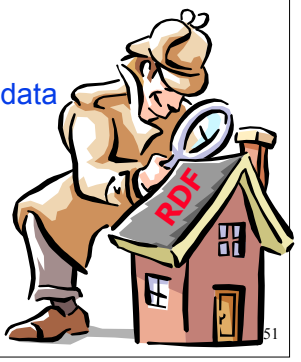
Querying and Viewing RDF/S

The RDF Query Language



The RDF Query Language: RQL

- Declarative query language for RDF description bases
  - relies on a typed data model (literal & container types + union types)
  - follows a functional approach (basic queries and filters)
  - adapts the functionality of semistructured or XML query languages to RDF, but also:
    - treats properties as first-class citizens
    - exploits taxonomies of node and edge labels
    - allows querying of schemas as semistructured data



Using Names to Access RDF Schema/Data Graphs

- Querying the RDF/S (or user-defined) meta-schema names
  - **Class**
  - **Property**
  - **Literal**

Includes Painter & Sculptor

- Querying the RDF/S user-defined schema names
  - Artist
  - creates

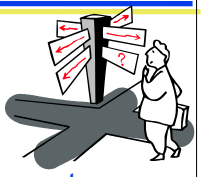
Includes paints & sculpts

- The Namespace Clause
  - ns1:ExtResource
    using namespace ns1= &ns2:www.oclc.org/schema.rdf

Querying Large RDF Schemas with RQL

- Basic Class Queries
  - subclassof(Artist)
  - subclassof^(Artist)
  - superclassof(Painter)
  - superclassof^(Painter)
  - topclass
  - leafclass
  - nca(Sculptor,Painting)
- Basic Property Queries
  - subpropertyof(creates)
  - subpropertyof^(creates)
  - superpropertyof(paints)
  - superpropertyof^(paints)
  - topproperty
  - leafclass
  - nca(paints,sculpts)
- Basic Class and Property Queries
  - domain(creates)
  - range(creates)

Class & Property Querying



- Find the domain and range of the property creates

  seq (**domain**(creates), **range**(creates))

- Which classes can appear as domain and range of property creates

  select **$X**, **$Y** from {**$X**}creates{**$Y**} or

  select **X**, **Y** from **Class**{**X**}, **Class**{**Y**}, {;**X**}creates{;**Y**}

- Find all properties defined on class Painting and its superclasses

  select **@P, range**(**@P**) from {;Painting}**@P** or

  select **P, range**(**P**)
  from **Property**{**P**}
  where **domain**(**P**) **>=** Painting

RQL Query Result

property exhibited	class Museum
property technique	literal string

```
<?xml version="1.0" encoding="ISO-8859-1" ?>
- <RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#">
  - <rdf:Bag ID="bag177976867">
    - <rdf:li>
      - <rdf:Seq>
          <rdf:li rdf:type="property" rdf:resource="exhibited" />
        - <rdf:li>
          - <rdf:Alt>
              <rdf:li rdf:type="class" rdf:resource="Museum" />
            </rdf:Alt>
          </rdf:li>
        </rdf:Seq>
      </rdf:li>
    - <rdf:li>
      - <rdf:Seq>
          <rdf:li rdf:type="property" rdf:resource="technique" />
        - <rdf:li>
          - <rdf:Alt>
              <rdf:li rdf:type="literal" rdf:resource="string" />
            </rdf:Alt>
          </rdf:li>
        </rdf:Seq>
      </rdf:li>
    </rdf:Bag>
</RDF>
```


Schema Navigation using RQL

- Iterate over the subclasses of class Artist

  select **$X** from Artist{**$X**} or
  select **X** from subclassof(Artist){**X**}

- Find the ranges of the property exhibited which can be reached from a class in the range of property creates

  select **$Y**, **$Z** from creates{**$Y**}.exhibited{**$Z**} or
  select **$Y**, **$Z** from creates{**$Y**}, exhibited{**$Z**}
  where **$Y** <= domain(exhibited)

- Find the properties that can be reached from a range class of property creates, as well as, their respective ranges

  select * from creates{**$Y**}.@P{**$$Z**} or
  from **Class**{**Y**}, (**Class union Literal**){**Z**}, creates{;**Y**}.@P{;**Z**}

Exporting Schemas using RQL Queries

- Find all schema information (i.e., group related superclasses and properties for each schema class)

```
select C, superclassof^(C),
       (select P, range(P), superpropertyof^(P)
        from   Property{P}
        where domain(P) = C)
from Class{C}
```

- Find schema properties having as domain or range a meta-class

```
select $$C, superclassof^($$C),
       (select  P, range(P), superpropertyof^(P)
        from   Property{P}
        where domain(P) = $$C or range(P) = $$C)
from Class{$$C}
```


Querying Complex Portal Descriptions with RQL

- Find all resources

Resource

Multiply classified resources

- Find the resources of type ExtResource and Sculpture

ExtResource **intersect** Sculpture
ExtResource **minus** Sculpture
ExtResource **union** Sculpture

- Count the total number of Painter resources

count(Painter)

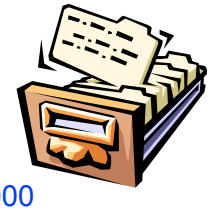
Aggregate functions

Filtering RDF Descriptions with RQL

- Find the file size of the resource with URI "www.artchive.com/rembrandt/abraham.jpg"

```
select X
from {X}file_size{Y}
where X = &www.artchive.com/rembrandt/abraham.jpg
```

Conditions on URIs



- Find the resources that have been modified after year 2000

```
select X
from {X}last_modified{Y}
where Y >= 2000-01-01
```

Conditions on Dates

Navigating in Description Graphs using RQL

- Find the Museum resources that have been modified (i.e., data path with node and edge labels)

```
select X
from Museum{X}.last_modified{Y}
```

- Find the resources that have been created and their respective titles (i.e., data path using only edge labels)

```
select X, Z from creates{Y}.title{Z}
```

- Find the titles of exhibited resources that have been created by a Sculptor (i.e., multiple data paths)

```
select Z, W
from Sculptor.creates{Y}.exhibited{Z}, {Z}title{W}
```

Using Schema to Filter Resource Descriptions

- Find the schema properties and their values of resources classified under the class Artist or its subclasses (i.e., restrict property source values using node labels)

```
select X, @P , Y
from {X}@P{Y}
where domain(@P) <= Artist
```

- Find modified resources which can be reached by a property applied to the class Painting and its superclasses (i.e., restrict property source values using edge labels)

```
select @P, Y, Z
from {;Painting}@P.{Y}last_modified{Z}
```


Using Schema to Filter Resource Descriptions

- Find the properties emanating from ExtResources and their source and target values

```
select  x , @P , y
from    {x;ExtResource}@P{y}
```

Data paths foreseen in the schema

- Find the properties applied on instances of the class ExtResource and their source and target values

```
select  x, @P, y
from    ExtResource{x}.@P{y}
```

Data paths not foreseen in the schema

Notice the difference

resource	property	resource
http://www.museum.es/guernica.jpg	exhibited	http://www.museum.es

resource	property	string
http://www.museum.es/guernica.jpg	technique	oil on canvas

resource	property	string
http://www.museum.es/woman.qti	technique	oil on canvas

resource	property	string
http://www.museum.es	title	Reina Sofia Museum

resource	property	date
http://www.museum.es	last_modified	2000-06-09T12:30:34+00:00

Discover the Schema of RDF Descriptions

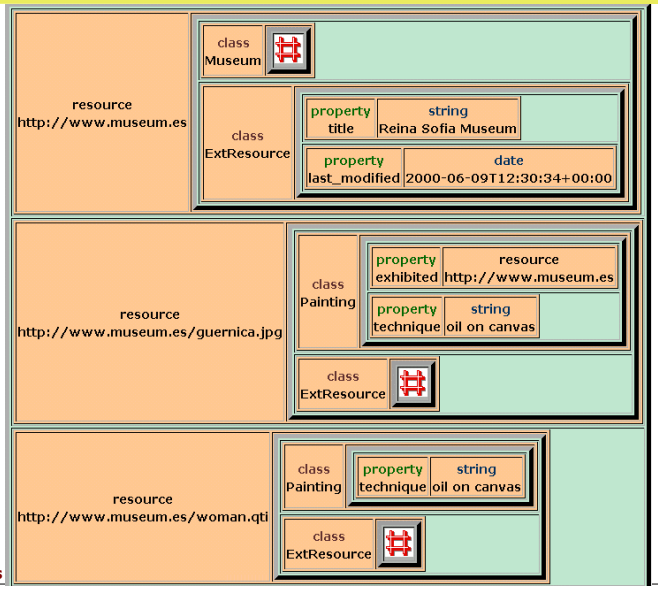
- Find the classes under which is classified the resource with URL "www.museum.es"

typeof (&www.museum.es)

- Find the description of resources whose URI match "www.museum.es"

```
select $C,  (select @P, Y
             from {Z ; $Z} @P {Y}
             where X = Z and $C = $Z)
from $C {X}
where X like "*http://www.museum.es*"
```

RQL Query Result



And if you still like triples …

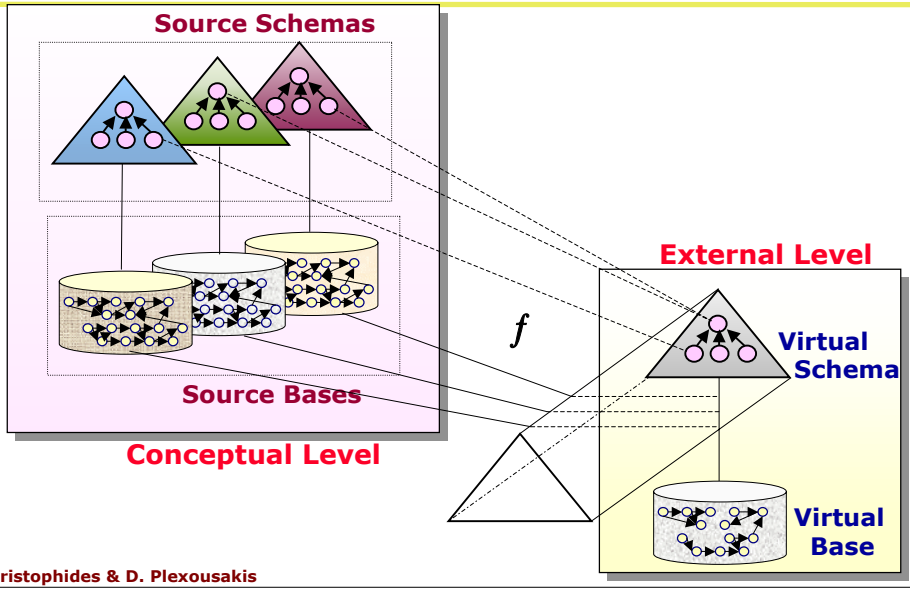
- Find the description of resources which are not of type ExtResource

```
(
  (select X, @P, Y from {X} @P {Y})
   union
  (select X, type, $X from $X {X})
)
minus
(
  (select X, @P, Y from {X:ExtResource}@P{Y})
   union
  (select X, type, ExtResource from ExtResource {X})
)
```

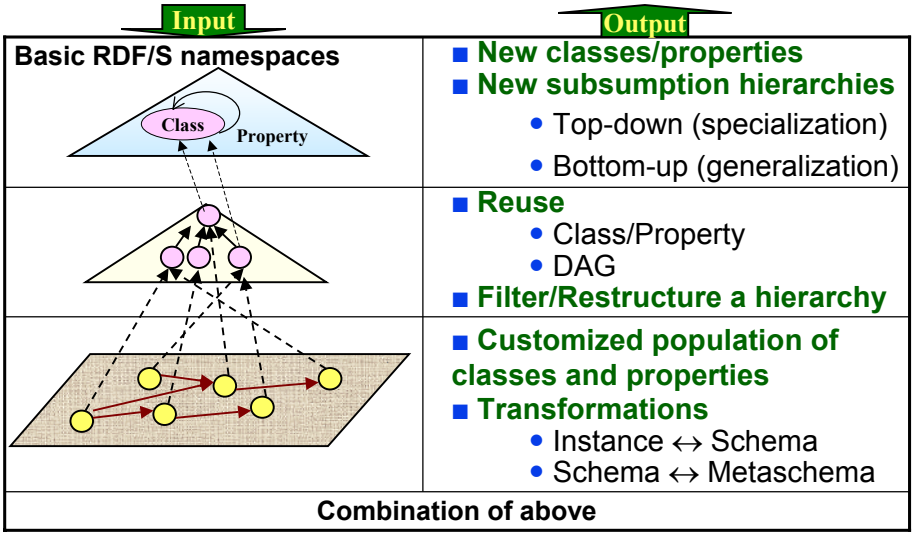
The RDF View Language: RVL

- Declarative view definition language for virtual RDF description bases and schemas
  - relies on the RQL typed data model
  - follows also a functional approach (object construction operators)
  - ensures logical data independence
    - view specifications are independent from those of the source schemas and bases,
    - the semantics of existing virtual schemas is not be altered by the definition of new ones
  - supports object-preserving and object-generating views
  - provides heavy data restructuring facilities
  - allows users to query and create views using both source and virtual schemas

The RVL Approach



The RVL Functionality



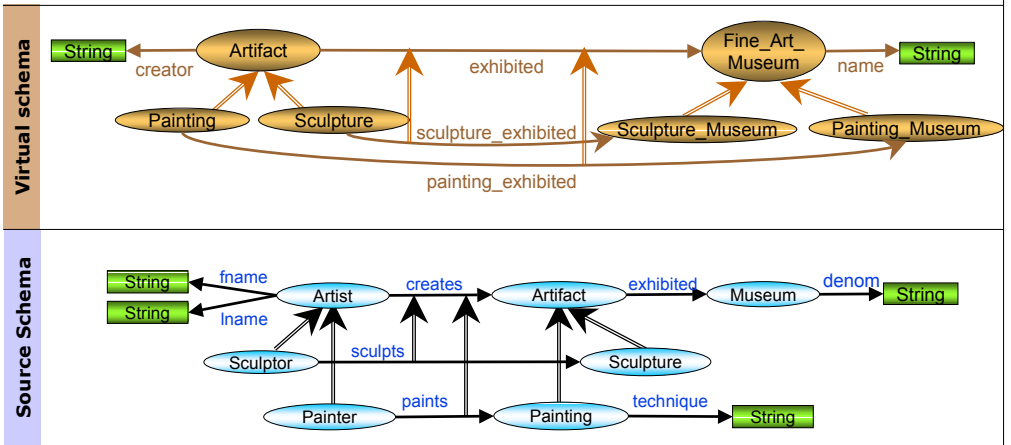
The RVL Syntax

```
[ VIEW operator
  FROM RQL_path_expression
  WHERE filtering_conditions
  USING NAMESPACE source_schema_namespace]
.....
.....
.....
CREATE NAMESPACE RVL_view_namespace
```

The RVL Operators

- Instantiation Operator
  - Creates virtual (meta)classes and properties
  - Populates virtual (meta)classes and properties
  - Up(Down)grades the abstraction level of a source entity
- Subsumption Operator
  - Creates new subsumption hierarchies of virtual (meta)classes and properties
  - Reorganizes source subsumption hierarchies of (meta)classes and properties

An RVL virtual RDF/S schema and base



An RVL virtual RDF/S schema and base

- CREATE NAMESPACE myview=&http://www.ics.forth.gr/mycult.rdf#
- VIEW Class("Fine_Art_Museum"), Class("Painting_Museum"),
  Class("Sculpture_Museum"), Class("Artifact"),
  Class("Painting"), Class("Sculpture")
- VIEW Property("name", Fine_Art_Museum, xsd:string),
  Property("title", Artifact, xsd:string),
  Property("creator", Artifact, xsd:string),
  Property("exhibited", Artifact, Fine_Art_Museum),
  Property("sculpture_exhibited",Sculpture, Sculpture_Museum),
  Property("painting_exhibited", Painting, Painting_Museum)
- VIEW Fine_Art_Museum<Sculpture_Museum>,
  Fine_Art_Museum<Painting_Museum>,
  Artifact<Painting>, Artifact<Sculpture>
  exhibited<sculpture_exhibited>,
  exhibited<painting_exhibited>

An RVL virtual RDF/S schema and base

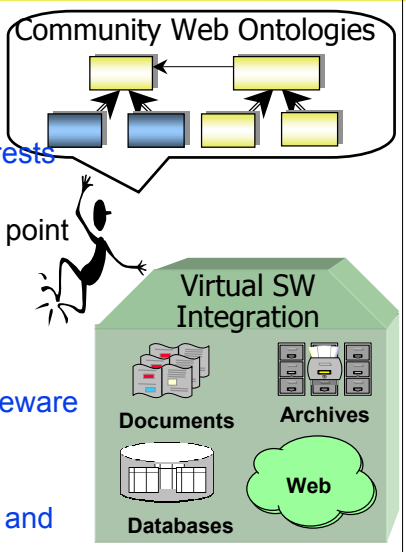
- VIEW Painting(X), painting_exhibited(X,Y), Painting_Museum(Y),
  name(Y,W), title(X,K), creator(X,Z)
  FROM {Z}n1:creates{X; n1:Painting}.n1:exhibited{Y}.n1:denom{W},
  {X}n1:title{K}
  USING NAMESPACE n1=&http://www.culture.mus/cult.rdf#

- VIEW Sculpture(X), sculpture_exhibited(X,Y), Sculpture_Museum(Y),
  name(Y,W), title(X,K), creator(X,Z)
  FROM {Z}n1:creates{X; n1:Sculpture}.n1:exhibited{Y}.n1:denom{W},
  {X}n1:title{K}
  USING NAMESPACE n1=&http://www.culture.mus/cult.rdf#

Semantic Interoperability: the role of Semantic Web Middleware

Our Vision for the SW: Community Webs

- What is a Community Web?
  - A group of people sharing a domain of discourse and a set of information resources (e.g., data, documents, services) and having some common interests
    - Commerce, Education, Health
- The main requirement is to provide a single point of useful, ubiquitous, comprehensive, and integrated access to community information resources
  - Web Portals
- Support an expressive SW Integration Middleware
  - Establish Mapping/Translation Rules
  - Reformulate Conceptual Queries
  - Exploit semantics for Query Optimization and Consistency Checking

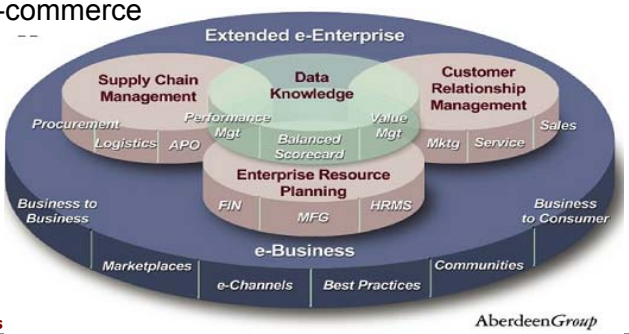


Impact

- The Enterprise Portal Software Market Size (source: Plumtree)

Analyst Firm	Report Date	Market Size	Growth Rate
Gartner	06 - 2002	2001: $709M	24% - 2006
IDC	06 - 2002	2001: $550M	41% - 2006
Delphi	12 - 2002	2002: $787M	20% - 2004

- The case of B2B E-commerce



Old Wine in New Bottles?

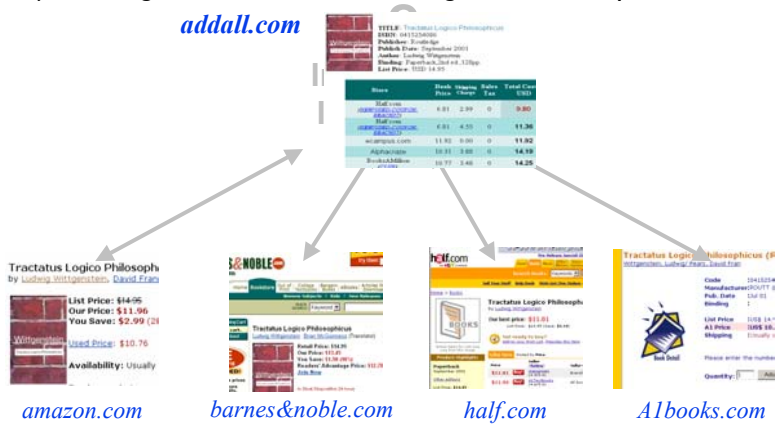
- The Information Integration Challenge:
  - *Given*: data sources S_1, ..., S_k (DBMS, web sites, ...) and user questions Q_1,...,Q_n that can be answered using the S_i
  - *Find*: the answers to Q_1, ..., Q_n
- The Database Perspective: source = "database"
  - S_i has a schema (relational, XML, OO, ...)
  - S_i can be queried
  - define virtual (or materialized) integrated views V over S_1,...,S_k using database query languages
  - questions become queries Q_i against V(S_1,...,S_k)
- Why a Database Perspective?
  - For all the good reasons: scalability, efficiency, reusability (declarative queries), physical and logical data independence
- … complemented by salient KR abstractions / languages / mechanisms

Technical Issues

- Integration Method and Architecture
  - federated DBs, wrapper-mediator approach, GAV/LAV, warehouse/on-demand, ...
- Suitable KRDB Formalisms and Frameworks
  - XML, DTDs/XML Schema, XPath, XQuery, ...
  - RDF(S), Ontologies, Description Logics, DAML+OIL, OWL
  - querying, deduction, subsumption, classification, ...
- Algorithms and Implementation
  - query answering using views, query reformulation, query / view composition, reasoning, source capabilities, ...
- Information Integration Scenario and Scope
  - simple/complex, single/multiple worlds, ...

Scenario #1: a "simple" world

- On-line shopping
  - Scroodge: "*Where can I get the cheapest copy (including shipping cost) of Wittgenstein's Tractatus Logicus-Philosophicus within a week?*"



Scenario #2: multiple "simple" worlds

- Buying a house: *What houses for sale under 300kE have at least 2 bathrooms, 2 bedrooms, a nearby school ranking in the upper third, in a neighborhood with below-average crime rate and diverse population?*

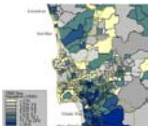
?

Information Integration


Realtor


Crime Stats


School Rankings

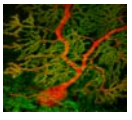

Demographics

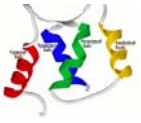
Scenario #3: multiple complex worlds

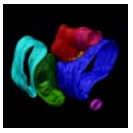
- E-neuroscience: *What is the distribution of rat proteins with more than 70% homology with human NCS-1? Any structure specificity? How about other rodents?*

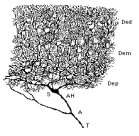
?

Information Integration

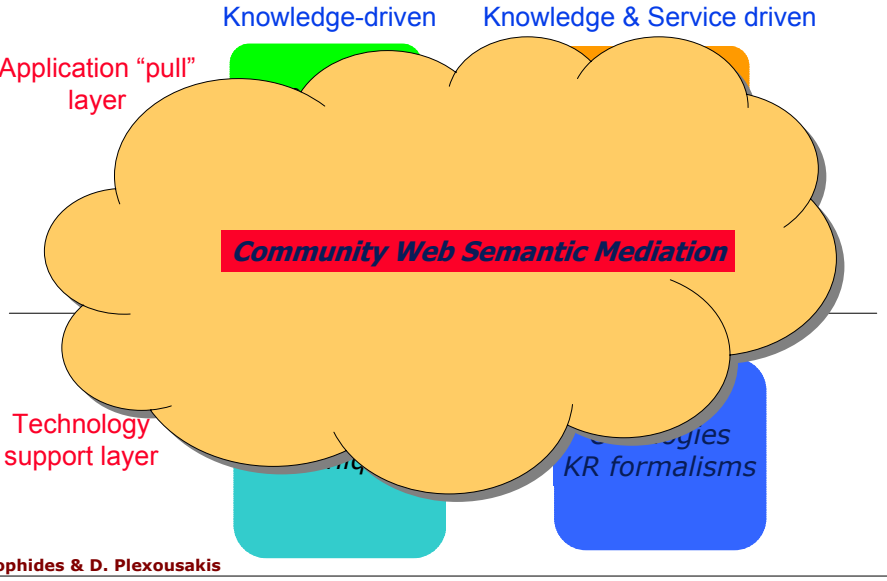

protein localization (NCMIR)


sequence info (CaPROT)


morphometry (SYNAPSE)


neurotransmission (SENSELAB)

The Integration Landscape: Contributing Forces



Semantic Web Middleware

- Design Principles:
  - Philosophical:
    1. K.I.S.S. (keep it simple stupid)
    2. Think globally, work locally
    3. Learn from history (internet and web evolution)
  - Technical:
    1. Formal basis
    2. Makes semantics explicit
    3. Accounts for expressive data models and KR schemes
    4. Serves as a "glue" for information integration and service interoperability
    5. Abstains from low-level commitments

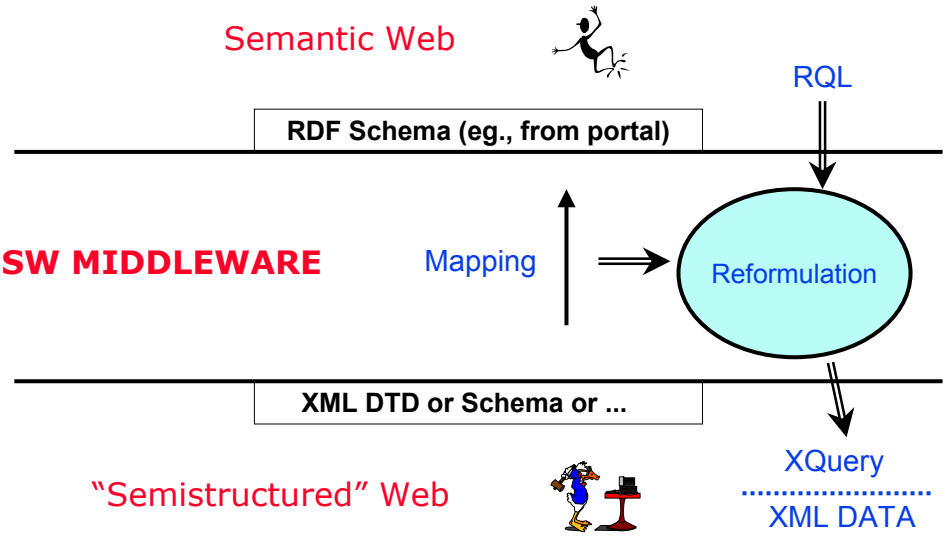
Semantic Web Middleware

- The bulk of existing data is not yet in RDF/S (or any other form suitable for the SW)
  - Data physically stored in relational DBs and/or published as virtual XML
- SW applications require viewing data as virtual RDF
  - valid instances of domain or application-specific RDF/S schemas
- Need the ability to manipulate data with high-level query or view languages (RQL, RVL)
- How to do it?
  - republish XML as RDF
  - publish relational data as RDF
  - do both

Semantic Web Middleware

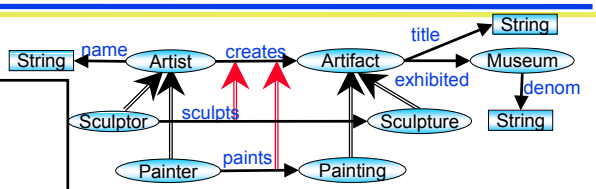
- Practical concerns:
  - XML publishing systems often provide an XML query interface.
    - SW middleware can function as an alternative to the XML publishing systems; SW middleware provides direct access to underlying DBMSs
  - SW middleware may also be required to integrate DBMS data with data in native XML storage
- SW middleware tasks:
  - Specify mappings: XML→ RDF, RDB → RDF
  - Verify conformance to the semantics of employed schemas
  - Reformulate queries (i.e., compose RQL queries with mappings to produce XML or RDB queries)
  - Provide abstractions of RDF data/schemas (views)
  - Compose queries with views

Republish XML as RDF



Motivating Example

```
<ArtDB>
<Sculptor name="Rodin">
   <sculpts>
      <Sculpture title="thinker"/>
   </sculpts>
</Sculptor>
<Painter name="Rodin">
   <paints>
      <Painting title="crucifixion"/>
   </paints>
</Painter>
<Painter name="Picasso">
   <paints>
      <Painting title="guernica">
         <exhibited>
           Reina Sofia
         </exhibited>
      </Painting>
   </paints>
</Painter>
</ArtDB>
```



Artifacts

title(key)	Artist	exhibited	kind
guernica	Picasso	ReinaSofia	Painting
crucifixion	Rodin	NULL	Painting
thinker	Rodin	NULL	Sculpture

Introducing a SW Middleware Server

- By designing (or importing) a (virtual) RDF/S cultural schema, we can answer queries using RQL
  - E.g., Q1: *"List the last names of all artists that have created artifacts exhibited at the Reina Sofia Museum"*

```
SELECT   Z
FROM     {X} creates.exhibited.title {V}, {X} name {Z}
WHERE    V = "Reina Sofia Museum"
```

- Actual data can only be queried using an XML language (e.g., XQuery) or SQL
- The RQL query needs to be reformulated into an XML query
- Reformulation cannot be ad hoc; needs to be driven by a formal description of the relationship between XML and RDF data
- Need a formal basis for expressing such mappings

Mappings: Background

- From relational database theory
  - query containment, query + view composition, query rewriting using views are solvable for a fairly large class of queries in the presence of certain classes of constraints (embedded implicational dependencies)
- A robust formalism to rely on: conjunctive queries and views (non-recursive Datalog)
- A formal data model for RDF/S
  - Validity constraints
- High-level query and view languages for RDF/S adhering to the formal model

XML to RDF Mapping

- Datalog rules with RVL atoms (head) and Xpath atoms (body)

```
...
Painter(X) :--  //Painter (X)                    populates class  Painter
...
Sculpture(X) :--  //Sculpture (X)                "          Sculpture
...
paints(X, Y) :--  //Painter (X),  .//Painting (X, Y)   populates relationship  paints
...
name(X, Y) :--  //Painter (X),  ./@name (X, Y)
                                                  populates   attribute   name
...
```

direct instances

abs-xpath (x) root — xpath — x

rel-xpath (x,y) x — xpath — y

RDB to RDF Mapping

- Datalog rules with RVL atoms (head) and Datalog atoms (body)

```
...
Painter(X) :--  Artifacts(_,X,_,"Painting")          populates class  Painter
...
Sculptor(X) :-- Artifacts(_,X,_,"Sculpture")          "          Sculpture
...
paints(X, Y) :-- Artifacts(Y,X,_,"Painting")   populates relationship   paints
...
name(X, Y) :-- Artifacts(_,X,_,"Painting"), Y=X
name(X, Y) :-- Artifacts(_,X,_,"Sculpture"), Y=X
                                                  populates   attribute   name
...
```

direct instances

N.B.: need to work around schematic and semantic discrepancies

Middleware Internal Model (1)

C_EXT : Class x Resource

P_EXT : Resource x Property x Resource

For reformulation, we translate into the internal model:

Sculpture(X) :-- //Sculpture (X) → C_EXT(Sculpture,X) :-- //Sculpture (X)

paints(X, Y) :-- //Painter (X), .//Painting (X, Y)

→ P_EXT(X, paints, Y) :-- //Painter (X), .//Painting (X, Y)

Middleware Internal Model (2)

CLASS : Class

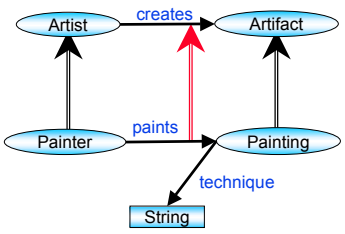
C_SUB : Class x Class

PROP : Class x Property x Class

P_SUB : Property x Property

+ a bunch of constraints

RDF Schema also gets translated into the internal model:



PROP(Painter, paints, Painting) :--

PROP(Painting, technique, String) :--

P_SUB(paints, creates) :--

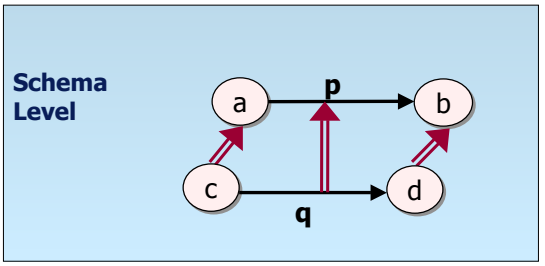
C_SUB(Painting, Artifact) :--

…

RDF/S Compatibility Constraints (1)

For a valid RDF Schema:

The domain (range) of a subproperty must be subsumed by the domain (range) of the super-property

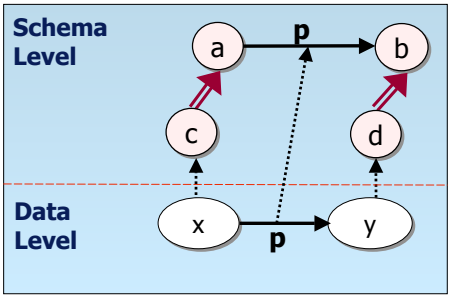


$$\forall a,p,b,c,q,d \;\; PROP(a,p,b) \wedge PROP(c,q.d) \wedge P\_SUB(q,p) \rightarrow C\_SUB(c,a) \wedge C\_SUB(d,b)$$

RDF/S Compatibility Constraints (2)

For a valid RDF description base:

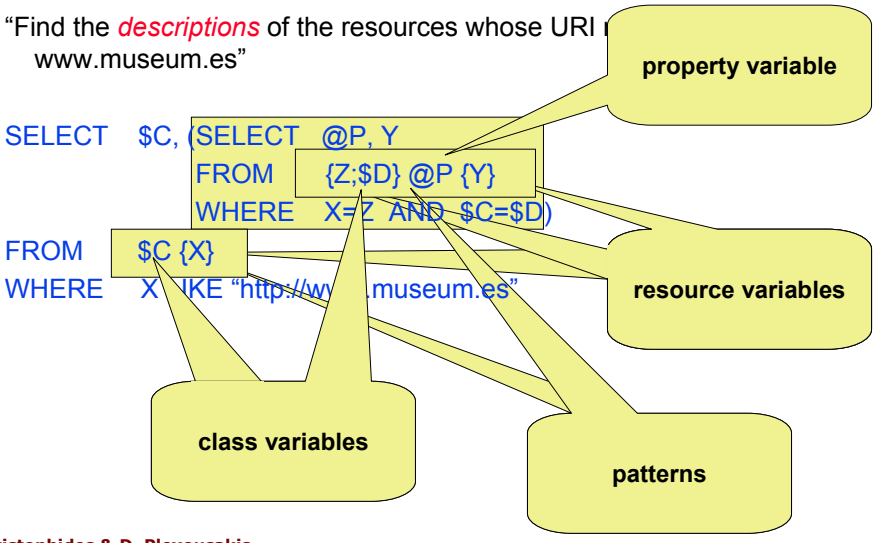
The resources connected by a property at the data level must be instances (i.e., direct instances of some subclasses) of the classes that are the property's domain and range



$$\forall a,p,b,x,y \; PROP(a,p,b) \wedge P\_EXT(x,p,y) \rightarrow \exists c,d \;\; C\_SUB(c,a) \wedge C\_SUB(d,b) \wedge C\_EXT(c,x) \wedge C\_EXT(d,y)$$

More Complex RQL Queries

"Find the *descriptions* of the resources whose URI
www.museum.es"



Internal Translation of RQL Patterns

Conjunctive queries: $ans(X_1, X_2, \ldots, X_k) :- C_1, \ldots, C_n$,

where the C_i's are RQL class or property patterns

ans($C,X) :-- $C {X}

ans(x,c) :-- C_SUB(d,c), C_EXT(d,x)

---

ans(X,$C,@P,Y,$D) :-- {X;$C} @P {Y;$D}

ans(x,c,p,y,d) :-- PROP(a,p,b), P_SUB(q,p), P_EXT(x,q,y),
C_SUB(c,a), C_EXT(c,x), C_SUB(d,b), C_EXT(d,y)

simplifies only under the compatibility constraints

---

ans(X,@P,Y) :-- {X} @P {Y}

ans(x,p,y) :-- P_SUB(q,p), P_EXT(x,q,y),

Translation of Query Q1

```
SELECT   Z
FROM     {X} creates.exhibited.title {V}, {X} name {Z}
WHERE    V = "Reina Sofia Museum"
```

"Paths" provide shorthand notation for sequences of patterns:

```
SELECT   Z
FROM     {X} creates {Y}, {Y} exhibited {U}, {U} title {V}, {X} name {Z}
WHERE    V = "Reina Sofia Museum"
```

In the internal model:

```
ans(Z) :-- P_SUB(P1, name), P_EXT(X, P1, Z),
           P_SUB(P2, creates), P_EXT(X, P2, Y),
           P_SUB(P3, exhibited), P_EXT(Y, P3, U),
           P_SUB(P4, title), P_EXT(U, P4, "Reina Sofia Museum")
```

A conjunctive query!

All Together: An XPath/Datalog Program

```
ans(Z)   :--  P_SUB(P1, name), P_EXT(X, P1, Z),
              P_SUB(P2, creates), P_EXT(X, P2, Y),  …
…
P_SUB(paints, creates)   :--
P_SUB(sculpts, creates)   :--
…
P_EXT(X, paints, Y)  :--   //Painter (X),  .//Painting (X, Y)
…
P_EXT(X, name, X)  :--   //Sculptor (X),  ./@name(X, Y)
P_EXT(X, name, Y)  :--   //Painter (X),  ./@name(X, Y)
…
```

from query

from schema

from mapping

A reformulation, of sorts, but unacceptably inefficient!

Improving the Reformulation (1)

After "partial evaluation" using the schema facts:

ans(Z) :-- P_EXT(X, name, Z), P_EXT(X, paints, Y), …

ans(z) :-- P_EXT(X, name, Z), P_EXT(X, sculpts, Y), …
…
P_EXT(X, paints, Y) :-- //Painter (X), .//Painting (X, Y)
P_EXT(X, sculpts, Y) :-- //Sculptor (X), .//Sculpture (X, Y)
…
P_EXT(X, name, Y) :-- //Sculptor (X), ./@name(X, Y)
P_EXT(X, name, Y) :-- //Painter (X), ./@name(X, Y)
…

Improving the Reformulation (2)

After eliminating the intermediate predicates:

ans(Z) :-- //Painter (X), ./@name(X, Z) ,
//Painter (X), .//Painting (X, Y), …

ans(z) :-- //Sculptor (X), ./@name(X, Z),
//Painter (X), .//Painting (X, Y), …

unsatisfiable!

…

ans(z) :-- //Painter (X), ./@name (X, Z) ,
//Sculptor (X), .//Sculpture (X, Y), …

unsatisfiable!

ans(z) :-- //Sculptor (X), ./@name(X, Z),
//Sculptor (X), .//Sculpture (X, Y), …

…

Requires some reasoning about XPath that can be done with FO tools.

Reformulation, Finally

```
ans(Z)  :-  //Painter (X), .//Painting (X, Y),
            ./exhibited/text() (Y,"Reina Sofia Museum"),
            ./@name (X, Z)

ans(Z)  :-  //Sculptor(X), .//Sculpture (X, Y),
            ./exhibited/text() (y,"Reina Sofia Museum"),
            ./@name (x, z)
```

- More minimization techniques were used to get to this:

  A. Deutsch, V. Tannen,
  "Reformulation of XML Queries…", in ICDT'03,
  "MARS: a System for Publishing XML…", in VLDB'03

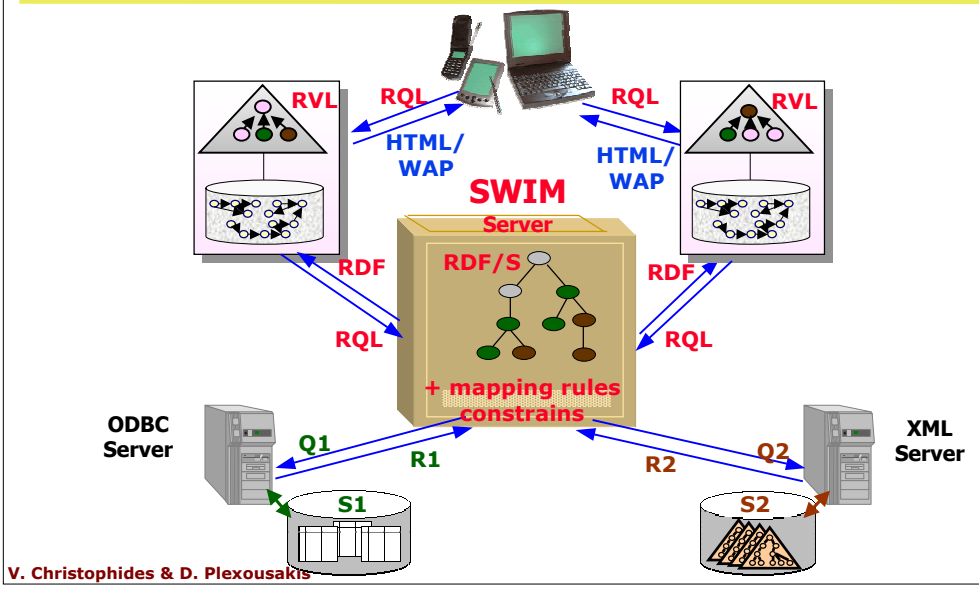
- This can be easily translated into, eg., XQuery

Flexibility

- Same framework can be used for publishing relational data directly as RDF.
- Same framework can be used for composing RQL with RVL views.
- Same framework can be used for heterogeneous integration (mediation).
- Minimization (eliminating redundancies) is essential.
- Many desirable minimizations only hold under constraints.
- For minimization under constraints, use the Chase&Backchase algorithm:

  A. Deutsch, L. Popa, V. Tannen, "… Constraints and Optimization...", in VLDB'03

Let's go SWIM-ming
(Semantic Web Integration Middleware)



Acknowledgements to our Students

- Sophia Alexaki (Master thesis 1998-2000)
- Nikos Athanasis (Master thesis 2001-2003)
- Grigoris Karvounarakis (Master thesis 1998-2000)
- Ioanna Koffina (Master thesis 2002-)
- Giorgos Kokkinidis (Master thesis 2002-)
- Aimilia Maganaraki (Master thesis 2000-2002)
- Stavros Saxtouris (Master thesis 2003-)
- Lefteris Sidirourgos (Master thesis 2003-)
- Giorgos Serfiotis (Master thesis 2002-)
- Karsten Tolle (Diploma Thesis 1999-2000)
- Sotiris Tourtounis (Master thesis 2001-2002)

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Thanks!
Questions?

How to Cope with Heterogeneity in the SW?