Representing Knowledge in the Semantic Web

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Abstract – The Web is an immense repository of data and knowledge. Semantic web technologies support semantic interoperability and machine-to-machine interaction. A significant role is played by ontologies, which can support reasoning. Generally much emphasis is given to retrieval, while users tend to browse by association. If data are semantically annotated, an appropriate intelligent user agent aware of the mental model and interests of the user can support her/him in finding the desired information. The whole process must be supported by a core ontology.

1. Introduction

W3C leads the evolution of the Web. Universal Access and Semantic Web show a significant impact upon interoperability, technological as well as semantic. In this paper we will discuss the role played by XML to support *interoperability within applications*, while RDF helps in *cross applications interoperability*.
Subsequently, the paper considers the metadata issue, with a brief description of RDF and the Semantic Web stack. Finally, we discuss an example in the area of cultural heritage, which is very rich in variety of possible associations, presenting an architecture where intelligent agents make use of core ontology to help users in finding the appropriate information.

2. The World Wide Web Consortium (W3C)

The *Wide Web Consortium* (W3C) was created in October 1994 to lead the World Wide Web to its full potential by developing common protocols that promote its evolution and ensure its interoperability. Main goals pursued by W3C are:

- **Web for Everyone -** The social value of the Web is that it enables human communication, commerce, and opportunities to share knowledge. One of W3C's primary goals is to make these benefits available to all people, whatever their hardware, software, network infrastructure, native language, culture, geographical location, or physical or mental ability.
- **Web on Everything -** The number of different kinds of devices that can access the Web has grown immensely. Nowadays many different devices and even certain domestic appliances can all access the Web. W3C's goal is to make Web access from any kind of device as simple, easy and convenient as Web access from a desktop.
- **Knowledge Base -** The Web is not merely an immense book where people can search, browse, and view information. It is also a vast database that, if designed carefully, can allow computers to do more useful work. By developing a Web that holds information for both human and machine processing, W3C hopes to enable people to solve problems that would otherwise be too tedious or complex to solve.
- **Trust and Confidence -** Ultimately, to be a useful medium for social transactions, people must be able to trust other parties who have earned their trust. Technology should enable secure transactions with trusted parties. W3C promotes technologies that enable a more collaborative environment, a Web where accountability, security, confidence, and confidentiality are all possible.

3. Interoperability

Interoperability is a *key success factor*. However, it is not a merely technological issue. We have to consider differences in cultures and perceptions of concepts, that is, we have to consider not only a *technological interoperability*, but a *semantic interoperability* as well ([Signore2003a], [Signore2003b]).

3.1. Technological interoperability

XML - *Extensible Markup Language* (XML) was born to overcome HTML limitations in implementing new *data-centric Web applications*. Therefore it was a first step to supply semantics to tags, allowing exchange of information among different databases. Great advantages are the possibility of having different views of the same data, and personalize their presentation by means of appropriate agents. Finally, it must be stressed that

XML, independent from platforms and languages, plays a fundamental role towards interoperability. We can have a formal description of the otherwise implicit document structure, named DTD *(Document Type Definition*), that can be included in the document itself, or can be referenced as an external resource.

XML Schema definition - DTDs are expressed using their own syntax; therefore they require appropriate editors, parsers, processors. In addition, their extension is not easy, datatype concept is missing. Finally, DTD must support all elements and attributes described in the included namespaces. Schemas play a role similar to DTDs, but offer significant advantages: are written according to XML syntax, include datatypes, inheritance, schema combination rules, offer better namespace support and allow linking of semantic information.

XML Namespaces - XML is becoming more and more popular, and the possibility of using together different XML applications is increasing. As a consequence, we must be able to distinguish among different namespaces. An *XML namespace* is a *collection of names, identified by a URI reference, which are used in XML documents as element types and attribute names*. To each *nameset* is associated an identifying prefix, and tags are uniquely identified specifying the prefix followed by their "local" name.

3.2. Semantic interoperability

Metadata - Navigating the web, we follow links. The thing which we get when we de-reference a URI[1], is formally called a *resource*. Sometimes it is referred to as a *document* to emphasize that it is human readable, or as *object* to emphasize that it is something which is more machine readable in nature.

Resources, when you retrieve them, do not stand simply by themselves, but there is information about the resource. Information about information is generally known as *Metadata*. We can therefore give the following definition: *Metadata is machine understandable information about web resources or other things*.

The phrase "*machine understandable*" is the key. Metadata is information which *software agents* can use in order to make life easier for us, make appropriate and efficient use of resources, check that we can trust what we are doing, and make everything work more smoothly and rapidly.

To better understand the metadata concept, we must keep clear in our minds that *metadata is data*, and this has some consequences:

- *metadata can be stored regarded as data*, it can be stored in a resource. So, one resource may contain information about itself or about another resource. Metadata about one document can occur within the document, or within a separate document, or it may be transferred accompanying the document.
- *Metadata can describe metadata*. That is, metadata itself may have attributes such as ownership and an expiry date, and so there is meta-metadata but we don't distinguish many levels, we just say that metadata is data and that from that it follows that it can have other data about itself.

Resource Description Framework - Metadata offers a viable solution to the ambitious target of automating the Web, while maintaining consistency with its original architecture, where all information was *machine-readable*, but not *machine-understandable*. However, effective use of metadata requires establish appropriate conventions for s*emantics*, *syntax* and *structure*. Resource Description Framework (RDF) is a foundation for processing metadata; it provides interoperability between applications that exchange machine-understandable information on the Web. RDF emphasizes facilities to enable automated processing of Web resources and can be used in a variety of application areas, such as *resource discovery*, *cataloguing*, *intelligent software agents*. RDF is not describing semantics, but provides a common basis to express it, so allowing defining the XML tags semantics ([RDFMSS], [RDFSS]). The foundation of RDF is a model for representing named properties and property values. RDF properties may be thought of as attributes of resources and in this sense correspond to traditional attribute-value pairs. RDF properties also represent relationships between resources and an RDF model can therefore resemble an entity-relationship diagram. The RDF data model is a syntax-neutral way of representing RDF expressions, and consists of three object types:

Resources All things being described by RDF expressions are called *resources*. A resource may be an entire Web page; or be a part of it, (e.g. a specific HTML or XML element within the document source). A resource may also be a whole collection of pages (e.g. an entire Web site) or be an object that is not directly accessible via the Web (e.g. a book, a painting, etc.) Resources are always named by URIs plus optional anchor ids. Anything can have a URI; the extensibility of URIs allows the introduction of identifiers for any entity imaginable.

Properties A *property* is a specific aspect, characteristic, attribute, or relation used to describe a resource. Each property has a specific meaning, defines its permitted values, the types of resources it can

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1 **URI** (*Uniform Resource Identifier*): the generic set of all names/addresses that are short strings that refer to resources
URL (*Uniform Resource Locator*): an informal term (no longer used in technical specifications) associated with popular URI schemes: http, ftp, mailto, etc

describe, and its relationship with other properties. Each property is identified by a *name*, and takes some *values*.

Statements A specific resource together with a named property plus the value of that property for that resource is an RDF *statement*. These three individual parts of a statement are called, respectively, the *subject*, the *predicate*, and the *object*. The object of a statement can be another resource or it can be a literal or other primitive datatype defined by XML

A set of properties referring the same resource is called *description*.

Namespaces: a key for peer to peer architecture - RDF supports the use of conventions that will facilitate *modular interoperability among separate metadata element sets*. These conventions include standard mechanisms for representing semantics that are grounded in the simple, yet powerful, data model discussed before. RDF additionally provides a means for publishing both human-readable and machine-processable vocabularies. Vocabularies are the set of properties, or metadata elements, defined by resource description communities. The ability to standardize the declaration of vocabularies is anticipated to encourage the reuse and extension of semantics among disparate information communities. RDF uniquely identifies properties using namespaces [XMLns]), that provide a way to unambiguously identify semantics and rules governing properties usage specifying the authority managing the vocabularies. A well known example is the Dublin Core Initiative ([DC]). We can use an XML namespace to unambiguously identify the Dublin Core vocabulary just pointing to the Dublin Core resources defining its semantics. Description of a web site can reference many Namespaces, using some or all Dublin Core properties, as well as properties defined in other namespaces. This simple yet powerful mechanism permits to combine knowledge and terminology from different sources.

4. The "Semantic Web Stack"

The *Semantic Web* which is an extension, not a replacement of the current Web, has the well known layered architecture (Figure 1). To understand the framework, we recall that the Web must be seen as a Universal Information Space, navigable, with a mapping from *URI (Uniform Resource Identifier*) to resources. In this framework, the adjective semantic means *"machine processable"*. The Semantic Web, much like XML, is a declarative environment, where we specify the meaning of data.

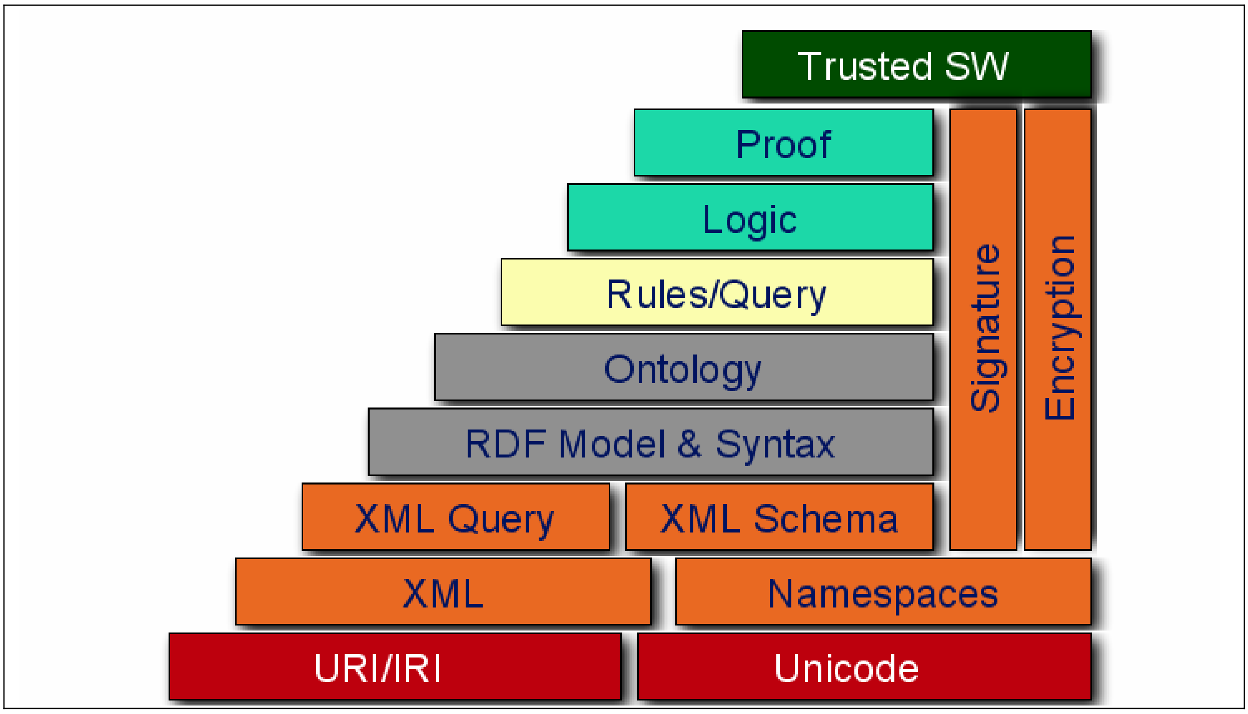

Figure 1 -The Semantic Web stack

As clearly explained in [TBL2001], for the semantic web to function, it is needed that computers have access to *structured collection of information* and set of *inference rules* that they can use to conduct automated reasoning. The challenge of the semantic web, therefore, is to provide a language that expresses both *data* and *rules* for reasoning about data and that allows rules from any existing knowledge-representation system to be *exported* onto the Web.

Going in more detail, Figure 1 clearly shows the importance of XML, which allows users to add arbitrary structure to their documents, and RDF, which can be used to express the meaning, asserting that particular things have properties (like *author-of*). A third component is the *Ontology,* intended as a source that formally defines the relations among terms. Ontologies can have a significant effect in enhancing functioning of the Web (looking for concepts, relating the information on a page to the associated knowledge structures, etc.). Fine grained *digital signature* allows signing different components, like ontologies, inferences, data, the user can trust in.
Additional information can be found starting from [SemWeb].

5. A case study in cultural heritage

Cultural heritage is very rich in variety of possible associations, either between documents themselves either with documents pertaining to other disciplines. Documents concerning history, economy, religion, ethnology, can easily contain information relevant for a scholar interested in archaeology, art history, architecture or any other specific field. A huge amount of information is available on the web, and users need to access the complete universe of information, looking for any fragment of data that may be of interest.
In this section we firstly discuss some issues about accessing information on the web, subsequently, present a model and an example of semantic annotation of documents. Finally, we describe a general, flexible architecture relying on web standards where intelligent agents help users in finding the appropriate information, making use of a core ontology.

5.1. Accessing information on the Web

For effective access to information on the web, we must consider several issues: the importance of link mechanism and challenges in information integration.
Searching vs. Linking - Most of the value in browsing the web comes from following associations coherent with user's interests. Just consider the typical "*search and link*" approach followed by the majority of users. In the typical usage scenario, the user starts with a fairly general query, and the search engine often returns a huge amount of records. The user behaviour is then to look at the most "promising" records. Once an interesting one has been found, the user tends to follow the links, so making use of the knowledge embedded in the document itself, as typically links are inserted by the designer to point to relevant connected information. Adaptive and intelligent systems could take care that navigation is consistent with the real user interests, formalized by a representation of the user's mental model. A possible way to support it without imposing constraints on the data themselves is to implement navigation mechanisms based on a core ontology.
Information Integration - Information integration via a *common schema* appears in principle the simplest way, but experience shows that this approach will almost invariably fail. The main reason is that different schema exists as the heritage of well established cultural traditions and is very unlikely that one of them will accept to conform to the other. As a consequence, it is difficult, if not impossible at all, to agree on a single schema as a way to achieve effective querying.
Integration is often attempted at *metadata* level. In this approach, information is enriched by metadata, which permits to have a common reference schema. A typical example is the Dublin Core initiative. However, as also noticed in [Doerr2003], "the number of metadata vocabularies will continue to grow as individual communities seek to structure their own information for their own purposes".
In addition, in our opinion, metadata by themselves cannot exploit the full richness of possible associations among different information items. The association mechanism remains in the mind of the user.

5.2. Semantics of links and documents

Especially following the wide adoption of XML technologies, documents on the Web are often deeply structured, and this can be the origin of incompatibility between different views of the same matters. As a consequence, it can be useful to have documents where some elements can be seen as "semantic items", useful to identify concepts that characterize the specific part of the document. Links have also their own semantics. This aspect has been often neglected, even if it was present since the inception of the Web, as we can easily see from the original proposal by Tim Berners-Lee. Taking into account both document and link semantics can enhance navigation possibilities, which will really support the association model that is the basis of the hypertext.
The association model. When reading a book or a newspaper, our attention is often captured by some words (*anchor*s) as items leading our mind to other documents. In the Web context, documents, whatever will be their genesis, are seen as resources. We can model the association process as a three stages process: the anchor leads to a concept, the concept is related to other concepts, the new concept is related to some resources.
This basic association mechanism is totally independent from document structuring. In the data space, documents are connected by *extensional* links. In the Semantic Web architecture's ontological level, associations among concepts implement *intensional* links among documents.

Now, two questions arise: how can we implement the link from resources to concepts, and how concepts are linked together. For the first issue, simple and effective way to implement links in their intension is to identify the *semantic items*. We can also characterize each semantic item with a specific semantic category (e.g. person, location, date, taxonomy). The second question directly leads to the *interaction metaphor* issue. Apart the case of taxonomic classifications, where we can make use of the well-known thesaurus techniques, very powerful association mechanisms are space and time. For example, a semantic item can have a spatial valence, then, using an interaction metaphor based upon space, we can both jump on other resources linked to the same place, or select a different place, and then find other resources related to this different place. This simple hyperlink association model can be implemented through a document, link and user model.

Document semantics. In XML documents we must clearly distinguish between *structural* and *semantic* information, which can be associated to elements or part of them. Documents on the web have different structures, which a wide variety of users should be able to share and understand. A way out is to *semantically annotate* both various parts of the documents and links. We can also specify a *weight*, stating the relevance of the concept in the document context.

Link semantics. Semantic qualification of explicit (or extensional) links identifies their meaning in the document and the role of involved resources. However, and probably a more important issue, two documents can be linked through an *intensional* link existing at the ontological level, even in absence of any extensional link specified in the document.

User Model. As a first approximation level, user mental model should be tightly related to the semantic model of documents and links.

5.3. Role of ontologies

Information integration – As it has been yet pointed out, it is unlikely that information integration can be reached just converging on a single set of metadata, while a more useful effort is to attempt to formulate a language as a base for “understanding”. This is what we can define to be a “core ontology” which incorporates basic entities and relationships common across the diverse metadata vocabularies. Such a core ontology might then be useful for integrating information from heterogeneous vocabularies and uniform processing across heterogeneous information sources.

There is an important, even if subtle, difference between a core ontology and core metadata, such as Dublin Core. Even if both are intended for information integration, they differ in the relative importance of human understandability. Metadata is in general created, edited, and viewed by humans. Therefore, human factors, including limits on complexity, should play a primary role in its design. In contrast, a core ontology is a underlying formal model for tools that integrate source data and perform a variety of extended functions. As such, higher levels of complexity are tolerable and the design should be motivated more by completeness and logical correctness than human comprehension.

If must be stressed that ontology based information integration can be performed automatically by software agents.

Deriving knowledge – A core ontology is one of the building blocks to information integration. In accessing information ([Goble2001]) shared vocabularies give a little help in inferring new, previously undisclosed information about resources. Vocabularies based on ontologies that organize the terms in form that has a clear and explicit semantics can be reasoned over. For example, a metadata annotation about a page can be used to search for a resource related to a more general or specific concept, or having some relationship with the current one. This process is fundamental in enriching knowledge.

CIDOC-CRM – CIDOC Conceptual Reference Model represents an ontology for cultural heritage information as it describes, in a formal language, the explicit and implicit concepts and relations underlying the documentation structures used for cultural heritage. The primary role of the CRM is to serve as the semantic 'glue' needed to transform disparate, localized information sources into a coherent and valuable global resource. It is a conceptual model that can be used as a global schema in applications and for query mediation to heterogeneous sources, as well as a set of concepts to create common tagging schemes. The CIDOC CRM is specifically intended to cover contextual information: the historical, geographical and theoretical background in which individual items are placed and which gives them much of their significance and value. As a formal ontology, it can be used to perform reasoning (e.g. spatial, temporal).

5.4. An example

As an example we take the Epitaphios GE34604, referred in [Doerr1998], where the interested reader can find the formal description of this work of art, in terms od CIDOC-CRM.

The graphical representation, in terms of classes and instances, is in Figure 2

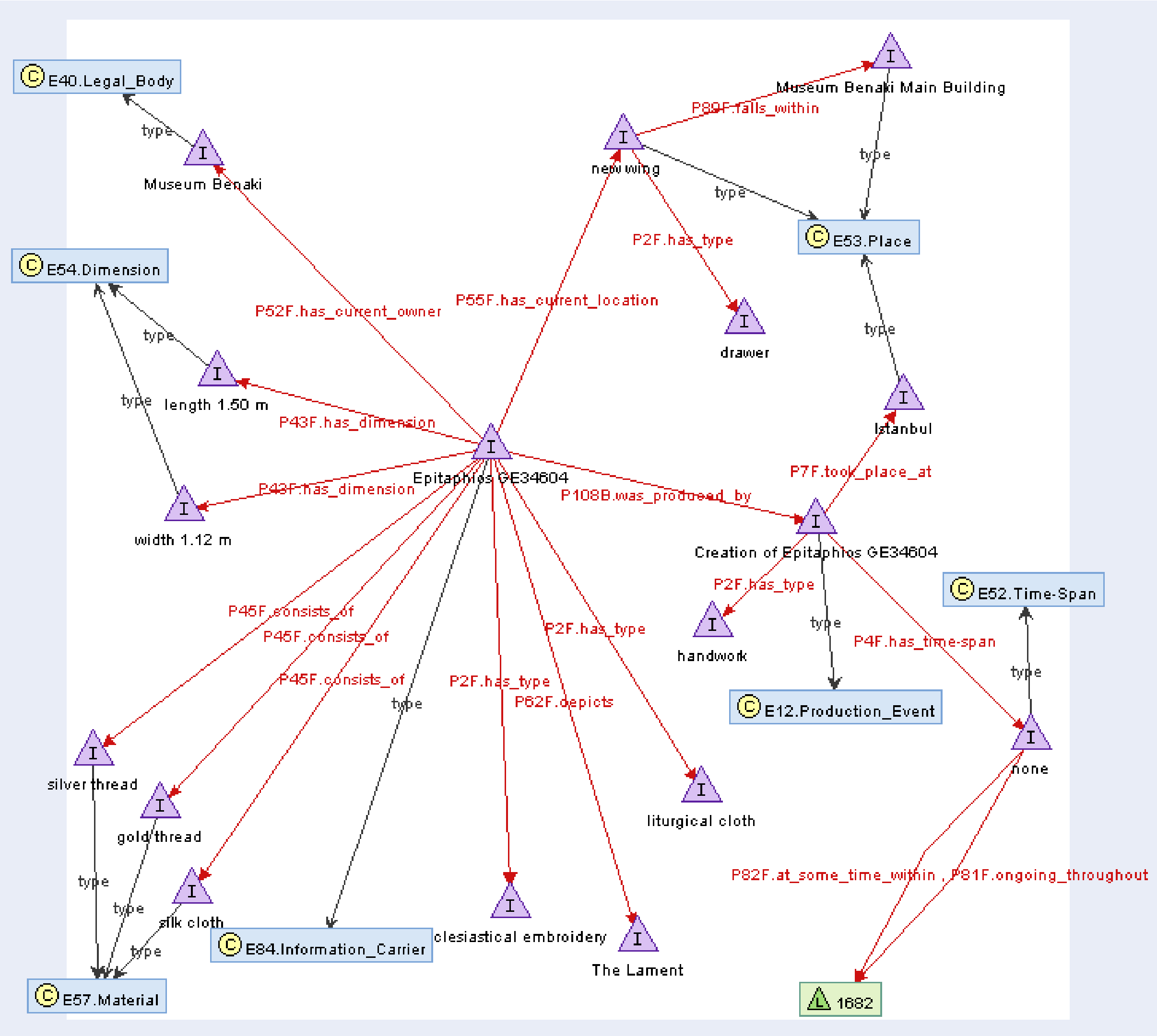

Figure 2 - The class and instances diagram for Epitaphios GE34604

5.5. A possible architecture

The main idea is to have an architecture where intelligent user agents can have access to the mental model expressing the interests of the user. The document can be tagged and semantically annotated using classes and properties defined in CIDOC-CRM. The agent can then perform reasoning, linking the information the user is interested to, following the relevant associations.

Semantic annotation of documents – Documents can be annotated using a formal ontology, like CIDOC-CRM. The main advantage is in having a common frame of reference for all organizations, as a result of several years of effort by many scholars. In the peer-to-peer architecture that is the basis of the web, basic Semantic Web technologies allow semantic markup of content, in a fully decentralized way, without affecting existing data. In fact, a relevant issue is that the annotation can be done in RDF, and can reside on any place in the Web. This implies that semantic annotation must not necessarily be done by the owner of data, but any scholar could, in principle, co-operate in enriching the semantic of documents. Knowledge expressed by the markup can be used by intelligent software agents to make the best use of data, and perform reasoning, making use of an appropriate ontology.

The user mental model. – The user mental model can be expressed in terms of preferred interaction metaphors. Making reference to the ontology used as basis for semantic annotation, this means to specify the set of classes and properties the user can be interested in navigate.

A user interested in the *temporalContext* will be interested in classes like *E2 Temporal Entity* or *E52 Time-span* and their subclasses, at various levels, like *E3 Condition State*, *E4 Period*, *E5 Event*.

The context can be expressed in a more precise way stating the properties the user is interested to navigate (e.g. *P117 occurs during*, *P118 overlaps in time with*, etc.) to build up the temporal interaction metaphor.
Identifying the properties the user is interested in can guide the agent to select the appropriate associations and perform the reasoning.

The architecture - The user agent (the **browser**) is enriched by two components: a **reasoner** and a **finder**, which accomplish the tasks of getting the semantic annotation of the current resource, looking to the user model, finding correspondences between user model and resource metadata, initiating a search following the properties the user is interested in.

The process can be summarized as follows:

- **user** searches for something
- the **browser** displays the list of returned records
- the **user** selects one of them
- the **browser** displays the **currentResource**
- the **reasoner** parses the **userModel** and the **currentResource**, looking for matching of classes and properties the user is interested in
- the **reasoner** looks at the **ontology** to find the kind of information it has to search for
- the request is passed to the **finder**, which will query the Web
- returned resources are passed by the finder to the **reasoner**, for further checking
- the **reasoner** passes returned resources to the **browser**, which will display them as possible linked resources, selecting the appropriate interaction metaphor or suggesting a choice among several of them.

A sample reasoning process – Suppose that the resource is describing a painting done in 1530, describing an event pertaining to the history of Christ, by a painter of Sicilian school, and the user is interested in the temporal context, the **reasoner** can follow the properties relating year 1530 to:

- historical or artistic period
- events occurred in a suitable time interval around 1530.

To do this, it must ask the Finder to access reliable sources describing historical events and artistic schools.
Would the user be interested in the iconographical perspective, the reasoner should look at an iconographic autority (e.g. Iconclass) and afterwards the Finder will search for work of art describing the same subject, or perhaps, with lesser relevance, other works of art related to a similar subject.
The extent of the search will depend on the user preferences, as there can be a limit to the number of returned resources, at least at the first attempt.

6. Conclusion

Relying on a core ontology, web browsing can take advantage of the basic semantic web technologies (RDF, OWL) appropriately linking information according to the user preferred interaction metaphors, associating information on the basis of spatial, temporal, classification affinity, so greatly improving the access to the information and knowledge stored in museums.
The proposed framework intends to use metadata annotations to build and construct complex hypertextual associations. In this sense, this approach differs from the usual one, where metadata are used by an agent (a person or a machine) to perform an effective query, having back a list of returned records. In our approach metadata can be used not only to describe as to link to the resource, but also to indicate *where* and *why* you can go from the resource itself. In the whole architecture, a significant role is played by the search mechanism, as after all, the effective implementation of the interaction metaphor requires finding relevant resources.

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