NoE InterOp

WP8, subtask 4

State of the Art Report

Ontology-based Services for Enterprise Application Interoperability

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1. INTRODUCTION

Interoperability has been defined in many different ways, e.g. as "the ability of a system or a product to work with other systems or products without special effort on the part of the customer", [IDEAS], as "the ability to share and exchange information using common syntax and semantics to meet an application-specific functional relationship through the use of a common interface", [ISO16100] or as "the unrestricted sharing of data and business processes among *any* connected applications and data sources in the enterprise", [Linthicum03]. One of the major problems in achieving interoperability between systems is to understand and compare the meanings of the components of the systems. One instrument for addressing this problem is the use of ontologies, which provide a shared terminology and understanding for the domain in which the systems are situated.

In order to clarify the notion of interoperability, it can be helpful to structure system aspects by means of a framework like Graal, [WBFE03]. This framework for information processing systems proposes a distinction between process and product; see Fig. 1 (based on Fig. 1 in Graal and extended with aspects for Process). Product aspects are first divided into internal aspects and external aspects, and external aspects are classified into functional and quality aspects. Functional aspects tell what a system does and what it offers to the environment, while quality aspects tell how well the system functions for its stakeholders. Typical quality aspects are usability, efficiency, and security for system users, and maintainability and portability for developers.

For functionality, the basic aspect is the services the system provides to its environment. By providing services, the system delivers value to its environment, which is the raison d'etre of the system. The behaviour aspect has to do with the ordering and control flow of services and activities. The communication aspect concerns interactions with other entities, like people, hardware, and software. Finally, the meaning aspect addresses the interpretation of symbols used in services. It can be noted that the meaning aspect is only relevant for information processing systems, as these provide services through the exchange of symbols. In contrast, other systems can provide their services through physical processes such as the delivery of chemicals or power.

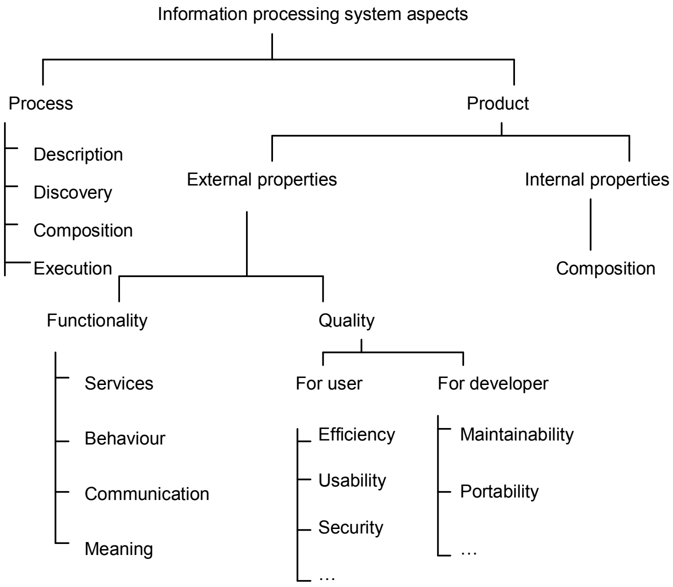

Figure 1: Various Aspects of an Information System

For process aspects, it is possible to identify four aspects for the exploitation of a system in the context of interoperability: description, discovery, composition, and execution, as suggested in [CS03]. Description is the activity of describing the product aspects of the system. Ontology can play a major role in this activity and provide a basis for well-founded and consistent descriptions of different systems. Discovery is the activity of discovering which information and services that can be provided by a system. Ontologies can become useful also in this activity and provide common terminology that supports a user searching for information or services. Composition is the activity of comparing and combining information, services, and processes from different sources. Finally, execution is the activity of actually using the services of a system that may be composed of several subsystems.

The organisation of this report will reflect the structure of system aspects introduced above. Section 2 gives an overview of alternative architectures of relating ontologies to systems together with the introduction of various levels (or types) of ontology. Section 3 discusses the use of ontologies for interoperability of the functional aspect meaning and is structured according to the four exploitation aspects (description, discovery, composition and execution), as are also structured sections 4 and 5. The use of ontologies for the interoperability of the behaviour (process) aspect is discussed in Section 4 and of the service aspect in Section 5. Practical applications of ontologies for interoperability are discussed in Section 6. Finally, Section 7 suggest a number of future research directions in the area.

2. ARCHITECTURE

2.1 Types of Heterogeneity

On the issue of heterogeneity, Ouskel and Sheth, [OS99], have identified the following types of heterogeneity:

- Information Heterogeneity:
    - Semantic Heterogeneity
    - Structural or Representational or Schematic Heterogeneity
    - Syntactic Heterogeneity
- System Heterogeneity

- Information System Heterogeneity (Ex: heterogeneity in digital media repository management systems, Database Management systems)
- Platform Heterogeneity (Ex: Differences in Operating systems, hardware/system, etc.)

Based on the above classification of the various types of heterogeneity, Ouskel and Sheth [OS99], discuss the need for the following levels of interoperability:

- Semantic Interoperability
- Structural Interoperability
- Syntactic Interoperability
- System Interoperability

Research and ongoing standardisation process has achieved notable progress in regard to system (IIOP for interactions between distributed objects, KQML for interaction between agents), structural (RDF, MPEG-4, KIF etc) and syntactic interoperability (XML). However, semantic interoperability is still an immature area. By semantic interoperability, we mean that the intended meaning of the modelled terminology and their relationships should be made clear and machine-readable. Cui and O'Brien [CJO01] have discussed *semantic heterogeneity* and defined the term to refer to both mismatch of conceptualisations as well as mismatch of the modelled realities. Cui and O'Brien classify semantic heterogeneity as seen in the excerpt from [CJO01]:

1. *"Semantically equivalent concepts*
   - Different terms are used to refer the same concept by two models. These terms are often called synonyms. However, synonyms in their common usage do not necessarily denote semantically equivalent concepts.
   - Different properties are modelled by two systems. For example, for the same product, one catalogue has included its colour but the other has not.
   - Property type mismatches. For example, the concept *length* may be in kilometres or miles.
2. *Semantically unrelated concepts*
   - Conflicting term - the same term may be chosen by two systems to denote completely different concepts. For example, *apple* is used to denote fruit or computer.
3. *Semantically related concepts*
   - Generalisation and specialisation One system has only the concept of *fruit*, but the other has the concepts of *apple*, *orange*, etc. Another example is that *student* in one system refers to all students, but the other only to PhD students.
   - Definable terms or abstraction - A term may be missing from one ontology, but it can be defined in other terms in the ontology.
   - Overlapping concepts. For example, *kids* in one ontology means persons aged between 5 to 12 years old, but in the other means persons aged between 3 and 10 years old, and in yet another ontology, *young persons* means persons aged between 10 and 30 years old.
   - Different conceptualisation. For example, one ontology classifies *person* as *male, female*. The other *person* as *employed, unemployed."*

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A more detailed discussion of semantic heterogeneity can be found in ST3, Section 3.1. Semantic heterogeneity can be resolved by mutual agreements or standardisation processes. However, given the distributed and global nature of most domains, this is a non-trivial task that cannot be achieved without automated support. In this context, ontologies are viewed as essential instruments in managing semantic heterogeneity.

2.2 Architectures of Ontologies for Interoperability

Ciocoiu et. al. [CGN00], Ontologies for Integrating Engineering Applications discuss two approaches for the use of ontology in interoperability. First, the *standardisation* approach, wherein all are encouraged to use a common, shared, standardised ontology for their enterprise applications. Such an approach has, however, been deemed impractical. Secondly, the *interlingua* approach, wherein ontology is used as an interlingua and interpreters/translators are written from the ontology to/from the software applications.

The single ontology approach works well if an ontology is to be designed and modelled from scratch. However, the ontology is usually limited to the purpose of its application. That is, it has limited reusability outside the scope of its application. Multiple local ontologies are generally applicable and reusable but difficult to implement practically. Thus, as Ciocoiu et al, propose, the Interlingua approach is a middle road approach. It tries to overcome the applicability problems of a single ontology while keeping translation problems at a manageable level. They propose to have a shared ontology and use it as an Interlingua for translating between communicating systems (much like P2P interoperability). It allows the communicating systems to have their own local ontologies. This approach also has the advantage that the networked system can be easily extended to include other systems as well, without having to create a large number of mapping relations (See figure 2a).

In practice, the implementation of point to point translators between every pair of applications (shown in figure 2a) , requires N(N-1) translators for N applications. Further, if any new application is to be added, N new point-to-point translators are required. With the use of a common shared ontology (which provides all the applications with a common set of terminology and semantics), the number of point to point translators required is reduced to N translators, from each application to the common translator (as depicted in figure 2b). The drawback with this approach is that all the interoperating applications need to understand the formalism /ontology representation language of the shared ontology. Or else they need to be able to interoperate or translate within the different ontology representation formalisms like KIF, DAML, RDFS to name a few. Also, a minimum consensus view for the common ontology needs to be arrived at trough mutual agreements or standardisation process.

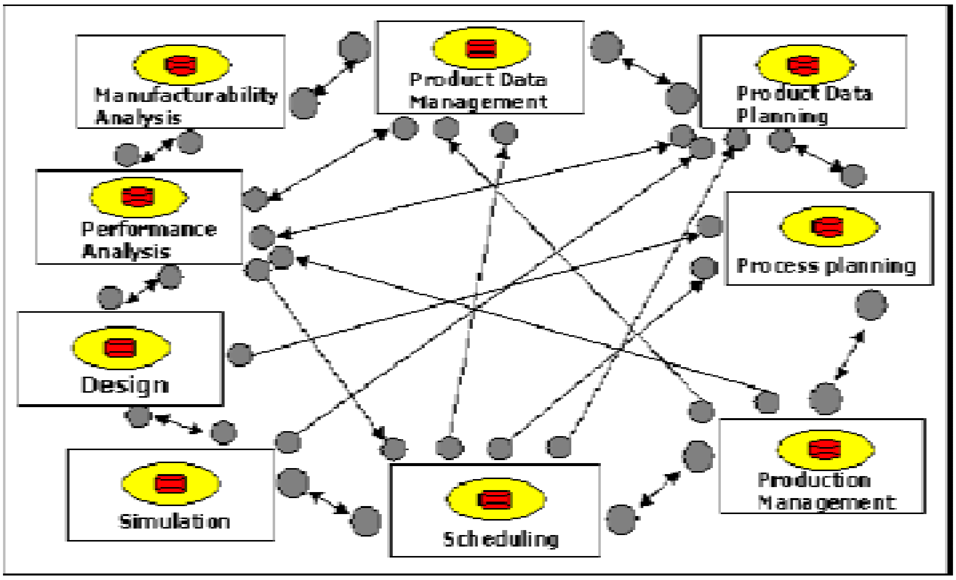

Figure 2 a : Point to Point Interoperability Between N applications (not complete)

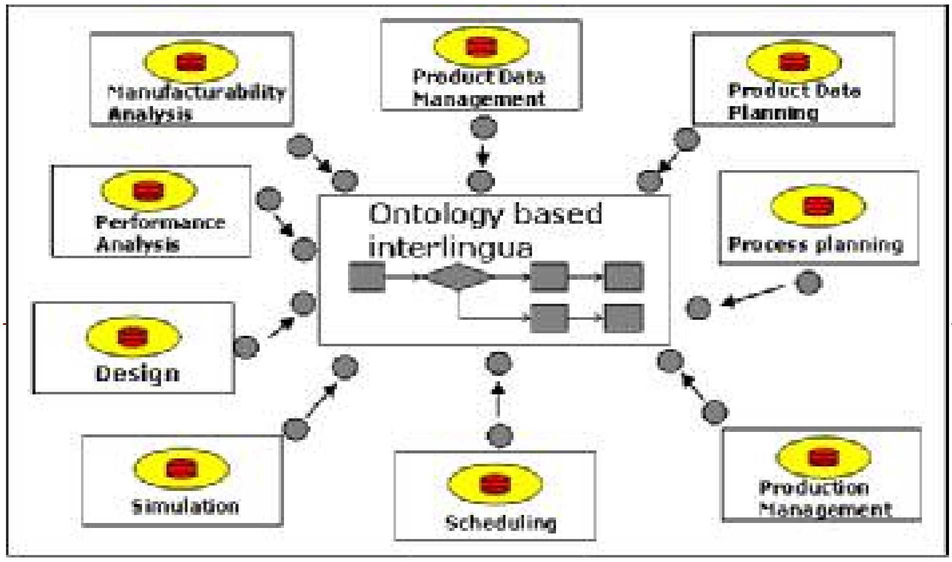

Figure 2b : Use of common ontology to reduce the number of translators between N applications

Wache et al [WVNSSVH01] have presented a survey of about 25 contemporary approaches for ontology based information integration including SIMS, TSIMMIS, OBSERVER [MKSI96], CARNOT [WC93], InfoSlueth, KRAFT, PICSEL, DWQ, Ontobroker, SHOE. In addition to their evaluatory survey, they have also discussed succinctly the major types of ontology design architectures. They identify three main architectures: single ontology, multiple ontology, and hybrid.

Single Ontology Approaches: Single Ontology approaches use one global ontology providing a shared vocabulary for the specification of the semantics (Figure 3 below). Example: the SIMS model [AHK96] of the application domain includes a hierarchical terminological knowledge base. The global ontology can also be a combination of several specialized ontologies, supporting a modular approach in lieu of a large monolithic ontology. The combination has been supported by ontology representation formalisms like ONTOLINGUA [G93]

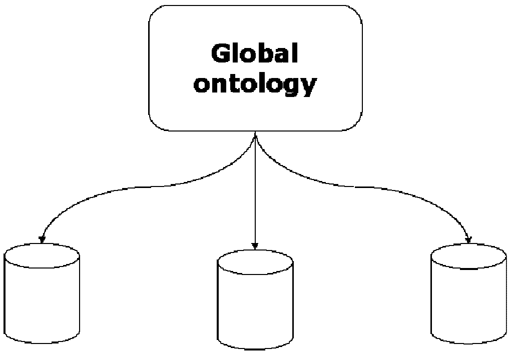

Figure 3: Single Ontology Approach

The single ontology approach works best if all the systems to be integrated share the same view of the domain. But when a single application has a different view, then it becomes difficult to find the *minimal ontological commitment* to define the global ontology. Also, it is difficult to maintain the changes to the single ontology with every change in any of the information sources. This led to the development of the multiple ontologies approaches.

Multiple Ontologies Approaches:

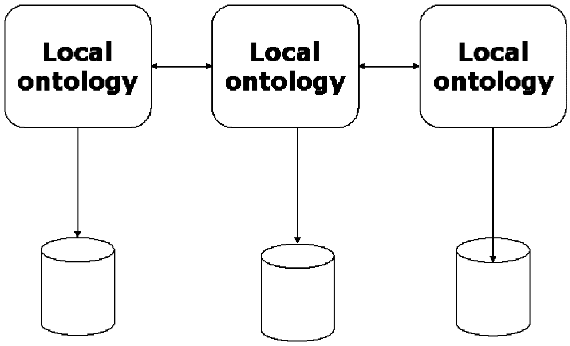

Figure 4: Multiple Ontology Approach

In Multiple Ontologies approaches (figure 4), each information source is described by its own ontology definition like that of OBSERVER. The advantage is that no *minimal ontology commitment* [G95] is required. Each of the source ontologies can be developed with respect to other sources or their ontologies. However, the lack of a common vocabulary makes the task of comparing different source ontologies difficult. An additional inter-ontology mapping is required to identify the semantically corresponding terms of different source ontologies.

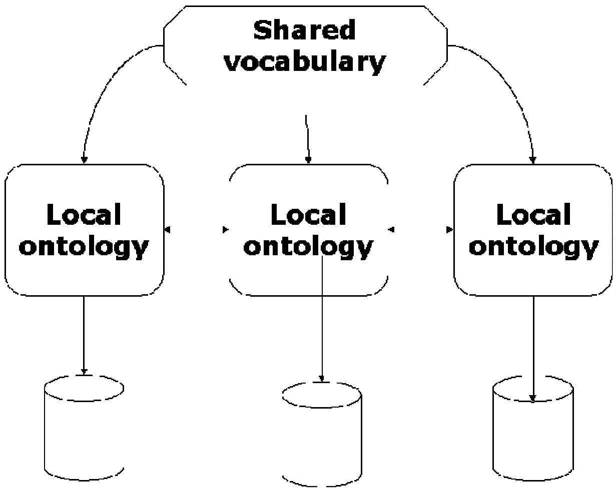

Figure 5 : Hybrid Approach

Hybrid Approaches: To overcome the drawbacks of the multiple and single ontology approaches, a hybrid approach (figure 5) was developed. Each information source was defined by its own ontology, but each ontology is built from a global shared vocabulary. An example is COIN [SM91] in which the local description of information is an attribute value vector. In MECOTA [W99] each source concept is annotated by a label which combines the primitive terms from the shared vocabulary in BUSTER (H Stuckenschmidt et al 2000 [SW00]), which has a shared vocabulary covering attribute value ranges for its defined concepts. Advantages of hybrid approaches are that new information sources can be easily added without the need for modification. The use of a shared common ontology also makes the source ontologies comparable. However, this approach has the disadvantage of having limited reusability outside the scope of the intended use for a source application. Furthermore, the source ontologies and the common ontology all need to be defined using the same ontology representation language, which would not be a problem if all the information source ontologies were to be developed from scratch. But in cases when the information sources have pre-existing ontologies, then rework or mapping issues appear. Further discussions on multiple ontology architectures can be found in ST3, Section 1.5.

A typical architecture of a system supporting interoperability by means of ontologies is the one proposed by OKMS, which is based on the Ontologging project (www.ontologging.com) and illustrated in figure 6. The OKMS is a EU funded project focusing on distributed ontology based knowledge management systems and investigates how ontologies may improve traditional knowledge management systems.

Maedche et al describe the OKMS architecture in [MBS03]: a short excerpt is given below.

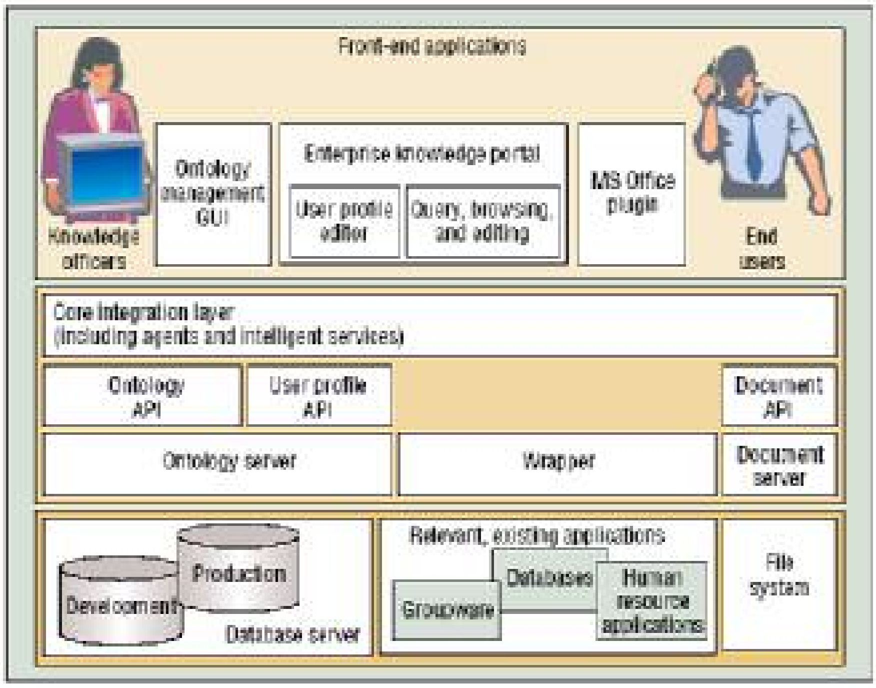

Figure 6: The architecture of the Ontologging ontology based knowledge management system OEKM (reprinted from http://www.computer.org/intelligent/ex2003/x2026.pdf)

"A GUI front-end is provided as an interface to various target user groups, providing facilities to set up, evolve the ontology, or to create mappings between autonomous ontologies. The enterprise knowledge portal provides an integrated platform for different knowledge management tools available. The user profile editor allows the users to express their interests in some part of the domain, so that the system can select relevant information for the users. With the query, browsing and knowledge-editing tool the user can search and navigate through the knowledge base, upload documents and create new instances. Integration to other applications like MS Office through plugins is also available.

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All GUI front-ends are realized on top of a core integration layer that coordinates the interaction of various system components. The OKMS uses Web Service technology to realize this layer. This layer also has a set of intelligent services and agents that improve user interaction with the system by tracking user behaviour.

The Core Integration Layer is realized on top of the Ontology server and the Document Server. The document server stores documents that are annotated using the ontologging domain ontology, and the ontology server stores this information.

The system defines wrappers that lift content from different existing applications to the ontology level. For example, the system has a wrapper for integrating Lotus Notes with the ontologies using a set of rules. The Ontology server component of the OKMS is based on another project: the Karlsruhe Ontology and Semantic Web Framework (www.kaon.semanticweb.org). KAON focuses on integrating traditional technologies for ontology management with those used for business applications like relational databases. The KAON architecture addresses issues like evolution, change reversibility, concurrency conflict detection, optimized loading and query answering."

Another architecture for management of distributed information systems including business processes is HELIOS [CFMZ], which is again an ontology-based framework for knowledge sharing. However, HELIOS focuses on peer-to-peer networking and supports knowledge sharing and evolution between P2P systems. The HELIOS framework consists of a *peer, peer knowledge, peer data, and peer interaction.* The Peer knowledge is organized as ontology. The HELIOS toolkit consists of a query processing manager, a matching manager and an ontology manager. Various types or levels of ontologies may be made available with no regard to the architecture of a system that supports interoperability based on ontologies. This is discussed in the next section.

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2.3 Ontology Architectures

Distributed heterogeneous ontologies, whether they are single global ontology or multiple local ontologies or a hybrid specialized ontology, still need to be able to interoperate with each other. There are generally three approaches for combining distributed heterogeneous ontologies [MBS03]:

- *Ontology Inclusion* in which the source ontology is simply included within the target ontology. All definitions from the source ontology are included within the target ontology and it is not possible to include only parts of the source ontology.
- *Ontology Mapping* in which a part of the source ontology is related to the target ontology's entities. The drawback is the need for flexible mechanisms for transformations.
- *Ontology Merging using Mediators* The most complex approach combines several data sources into a single integrated ontology. A mediator is used to answer queries . The TSIMMIS system (global-as-is-view) and the Manifold system (local-as-is-view) take two different approaches for obtaining the integrated single ontology. Details may be found in [GM97] and [LR096].

Corcho and Gomez-Perez [CGP01] propose multi-layered ontology architecture for promoting interoperability between heterogeneous e-commerce applications. They use a tool *WebPicker* for integrating various e-commerce related standards like UNSPSC, e-cl@ss, RosettaNet, NAICS, SCTG, etc. They build on previously identified and classified ontology types like that of Mizoguchi [M03] who distinguishes between domain ontologies, common-sense ontologies, meta-ontologies and task ontologies. Also Van Heijst [VHSW96] classifies ontologies with respect to amount and type of structure of ontology and subject of conceptualisation. Corcho and Gomez-Perez [CGP01] propose a common framework for understanding both the above two classifications as shown in figure. As the figure illustrates, ontologies are built in top of other ones (application domain ontologies on top of domain ontologies, domain ontologies on top of generic ontologies, etc.). Corcho and Gomez-Perez propose this structure having the following advantages:

1. Maximum monotonic extensibility [G93]: since new terms either general or specialised terms ca be included without requiring a revision of existing ontologies;

2. Clarity: [G93] the structure of terms implies the separation between non similar terms .

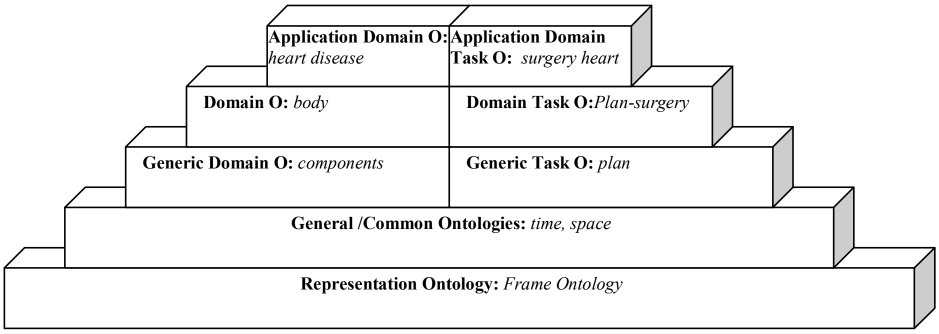

Figure 7 : Multi Layered Ontology architecture proposed by Corcho- Gomez-Perez

Guarino [G92] has defined ontologies as logical theory accounting for the intended meaning of a formal vocabulary, i.e. its ontological commitment to a particular conceptualization of the world. He has further classified ontologies, depending upon their generality as (figure 8):

- ***Top-level ontologies**: Top-level ontologies to describe general concepts like time, space, matter, and event that are independent of domain or a particular problem.*
- ***Domain Ontologies and Task Ontologies**: are described to be ontologies pertaining to a specific domain or task.*
- ***Application Ontologies**: Describe concepts that depend upon both a domain and a particular task, usually being specializations of both ontologies.*

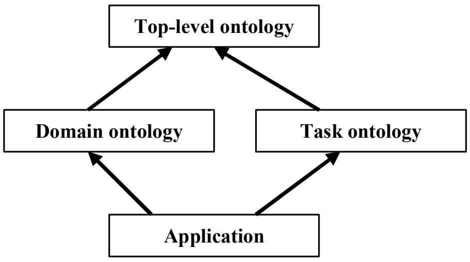

Figure 8: Classification of Ontology by Guarino

We see that Guarino's approach is similar to multiple ontology approach as discussed by Wache et al. The perspective and usage view of ontology differs. Guarino's approach for ontology design needs to be integrated with other methodologies for integration with pre-existing knowledge sources. In this section, we have introduced different architectures for relating ontologies to systems. In the following we will move into the different aspects of information processing systems and study how ontologies can help to achieve interoperability of information, processes, and services.

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3. INFORMATION INTEROPERABILITY

In this section, we discuss how ontologies can be used to achieve interoperability of different information sources.

3.1 Description

The first step in the use of ontologies for information interoperability is to relate each information source to ontologies. Some of the general approaches of relating information sources to ontologies may be summarised as: [WVNSSVH01]

- Structural resemblance: This scheme for connecting an ontology to a database schema creates a one-to-one mapping between the elements in the information source and the concepts in the ontology. As an example, a term "auto" in the information source could be mapped to a term "car" in the ontology. This approach has been implemented in the SIMS mediator [AHK96] and also by TSIMMIS system [GM97].
- Definition of terms: The above approach does not make the semantics of the database schema clear as it only provides a one-to-one mapping. Systems like BUSTER, H stuckencschmidt [S03], use the ontology to further define terms in the database scheme. This is done by relating elements in the information source to definitions in the ontology. As an example, a term "salary" in the information source could be mapped to a definition "base salary + bonus" expressed in the ontology.
- Structural enrichment: This is the most common approach for relating ontologies to information sources. It is a combination of the previous two approaches. A logical model of the structure is built, while at the same time semantically enriching the definitions of the concepts. Detailed discussion on semantic enrichment may be found in Kashyap and Sheth [KS96a]. Systems that use structure enrichment are OBSERVER [MKSI96], KRAFT [K04], PICSEL [GLR00] and DWQ [DWQ].
- Meta-annotation: Meta-Annotation adds semantic information to the information sources and this approach is useful for integrating information source on the internet. OntoBroker [OB] uses annotations that resemble part of the real information. SHOE [SHOE] uses annotations avoiding redundancy.

3.2 Discovery

When discovering relations between elements from distinct information sources, it is typically not sufficient to compare only the syntax and the structure of the elements – the semantics also has to be taken into account. This is typically done by starting from the information elements to be compared, then relating them to structures in an ontology(see Section 3.1) and finally compare these ontological structures in order to measure the similarity between the information elements. There exists a large number of algorithms and approaches for comparing and measuring similarity. One example is HMATCH, an Algorithm for Dynamically Matching Ontologies in Peer-based Systems. Castano et al, [CFMZ03] discusses an algorithm called HMatch for matching heterogeneous information systems (Peer-to Peer) as a part of the HELIOS project. Another example is [BAM03], which presents an ontology design approach based on semi-automated analysis and classification techniques to derive ontological concepts and semantic relationships from document descriptions and service specifications. Further discussion on finding semantic similarities can be found in ST3, Section 1.2.

3.3 Composition

When similarities between elements in different information sources have been found, these can be composed into new complex elements. This is typically done using common data abstractions like specialisation, aggregation, and grouping. Furthermore, the elements in the information sources can also be composed with structures in ontologies. Kashyap and Sheth [KS96b] have carried out work on migrating from database to ontologies and have proposed methods to reconcile the database schematic conflicts with ontology modelling. Stuckenschmidt [S03] also discusses the use of ontology for structuring weakly structured data sources.

3.4 Execution

As discussed in Section 2, ontologies may work as hubs for a number of information sources that are to be interoperable. Ontologies as an interlingua may then channel all execution and querying between the various information sources, which means that users may pose queries using the terminology of the ontology instead of the different terminologies of the individual information sources. This also reduces the compatibility issue of querying in the different languages of each information source, as compared to one ontology representation and querying formalism. The development of the semantic web, and the adoption of OWL as the web ontology language, makes such executions simpler and easier.

4. PROCESS INTEROPERABILITY

In this section, we discuss how ontologies can be used to achieve interoperability of different processes. Process interoperability, which means comparing, matching, and integrating business processes, is much less researched than information interoperability. Most of the work on process interoperability is presented in the context of service interoperability. To enable service composition, one needs to define interoperable process models. The role of ontologies per se in either case is still limited. In the case of services, it is rather the technology, like Web Services, which comes to front as the vehicle for interoperability

4.1 Description

The first step in the use of ontologies for process interoperability is to describe processes according to an ontology. There are several languages for describing and modelling process, BPML, BPEL4WS, YAWL, UMM BPSS, etc. These languages contain specific constructs for process concepts, like activity, event, condition, message, etc. In this way, each language can be seen as defining a high level ontology for process concepts. Specific processes will then be defined using one of these ontologies.

Mark Klein in [KB02] advocates the use of process ontology (modelled on the MIT handbook) as a step to improve the semantic search and retrieval facility for services on the web. A Process Query Language (PQL) has also been defined to retrieve process models from a process ontology. Examples of process models as well as queries can be found in [KB02].

Another project called Process Integration for Electronic Commerce (PIEC) aimed to develop a framework for the analysis of inter-organizational processes and identification and modelling of transaction services for networked enterprises. The PIEC defined a Service Description Language to describe and represent different types of e-services. A Component Definition Language (CDL) has been used to describe the interfaces of the business and legacy systems. Also a Service Request language (SRL) has been used for customers to construct their requests for the service. The comprehensive and integrated framework also includes a service ontology for defining the service. Examples and case study may be referred from the [YHP01].

The Process Interchange Format (PIF) Project was developed to support the automatic process descriptions among business process modelling and support systems such as workflow tools, process simulation tools, process repositories, etc. PIF is a formal ontology (core ontology) with a set of extensions known as partially shared views (PSVs). The PIF core ontology defines basic elements like *activity, object, agent, timepoint* and their relations like *performs, uses, creates, modifies,* etc.

The objective for the NIST Process Specification Language (PSL) project is to create a process specification language to facilitate complete and correct exchange of process information among manufacturing applications (like scheduling, process planning, simulation, project management, workflow, etc.). The PSL ontology has three major components-the axioms of PSL-Core, core theory extensions, and definitional extensions. All concepts in PSL are defined using KIF. A more detailed discussion of PSL can be found in ST1, Section 3.8.3.

In [FG97] a case study for the use of a common ontology as an Interlingua has been discussed. The approach used PSL as an Interlingua medium to translate between two manufacturing process applications, ProCAP (using IDEF3) and ILOG (C++ constraint-based scheduling).

4.2 Discovery

Process definitions may differ from each other in many different ways: syntactically, structurally, and semantically. Some examples of differences are:

- one process may require a set of activities to be carried out in sequence, while another similar process allows them to be carried out in parallel;
- one process may require an acknowledgement message, while a similar process does not;
- one process may send and receive complex messages in one single activity, while a similar process divides the messages between several activities.

How to identify processes that are similar in spite of such differences is still a problem that has not been much investigated. In particular, how to use ontologies to address these problems is not clear. There exist a few initial attempts in the area, like the ECIMF project, [ECIMF], that studies the use of high-level business models for supporting process integration in the area of e-commerce. Shared repositories like the ebXML Core Components [ebXML], CORBA [CORBA], the MIT Process Handbook [MITPH] or even WordNet [Miller90], provide another means for integrating processes. Via the shared repositories business agents may discover each others business offerings as well as establish agreements to invoke cooperation between their respective business processes. Some of these repositories provide hierarchical relationships (such as isa-relationships, aggregation, etc.) between process concepts, which make it possible to infer the degree of similarity between differently described or named concepts [NVG03].

4.3 Composition and Execution

Composition of processes and services is an active research area, but there is not much work on how to use ontologies for supporting process composition.

One major framework intended to support Description, Discovery as well as Composition and Execution of business processes and services across the Internet is ebXML (Electronic Business using eXtensible Markup Language [ebXML]). Composition of services is provided through the ebXML Business Process Specification Schema (ebXML BPSS [ebXML]) and supporting ebXML E-commerce and Negotiation Patterns [ebXML]. The meta-model of BPSS allows to define concepts such as processes, activities etc., and these concepts may in turn be combined into larger chunks via a set of collaboration patterns. The collaboration patterns suggest structures and/or interactions that occur frequently in a certain context or domain. An issue addressed by the Negotiation patterns is how to combine patterns of processes and services (as opposed to combine processes and services themselves) , and how to avoid combining them in an incorrect way [BJJW04].

The aforementioned shared repositories like the MIT Process Handbook [MITPH] or the ebXML Core Components [ebXML] define hierarchical relationships between processes (and subprocesses). These relationships are typically used as instruments in both composition and decomposition of processes.

5. SERVICE INTEROPERABILITY

In this section, we discuss how ontologies can be used to achieve interoperability of services. There are many different kinds of services. One of the most basic is the information service, where the service provides static information upon request. More generally, there are services that not only provide information but also produce some effect or change of the environment, e.g. establishing a contract or manipulating a mechanical device.

5.1 Description

The description of a service can be divided into the following three parts [CS03]:

- Capability representation: what the service does;

- Quality of Service representation: how well the service works;
- Process representation: how the service is carried out.

There are two main forms of capability representation: explicit capability representation and implicit capability representation, [SKW99]. For explicit capability representation, it is assumed that an ontology provides an explicit representation of the capability of a service. More precisely, the ontology describes each task by one concept, and the capability of a service is equal to a set of tasks, i.e. the tasks that the service is able to perform. An advantage of the explicit representation is that the ontology directly represents the tasks that the service can perform, which gives a clear and simple description of the service and reduces the effort of modelling the service. However, explicit capability representation may require huge ontologies, as every task that some service can perform requires its own concept in the ontology. Such large ontologies may be difficult to manage and they may be hard to use for search, as the user needs to understand a large number of concepts. An alternative and complement to external capability representation is implicit capability representation, which focuses on the state transformation and information transfer produced by a service. In this type of representation, the tasks performed by a service are not directly represented; instead they can be inferred from state transformation and information transfer. Implicit capability representation has the advantage that it does not necessarily require large ontologies, as tasks are not modelled but only the domain of the services. On the other hand, search may become more difficult as tasks are not made explicit but only inferred.

An example of an ontology used for explicit capability representation is the MIT Process Handbook, [KB02]. Figure 9 shows a small part of the ontology, which shows a specialisation hierarchy, where the root is the process "Sell financial services". In addition to the specialisation concept, the ontology also provides a structuring mechanism through the decomposition of processes. Using this ontology, a service that sells management services would be associated with the concept "Sell management services" in the ontology.

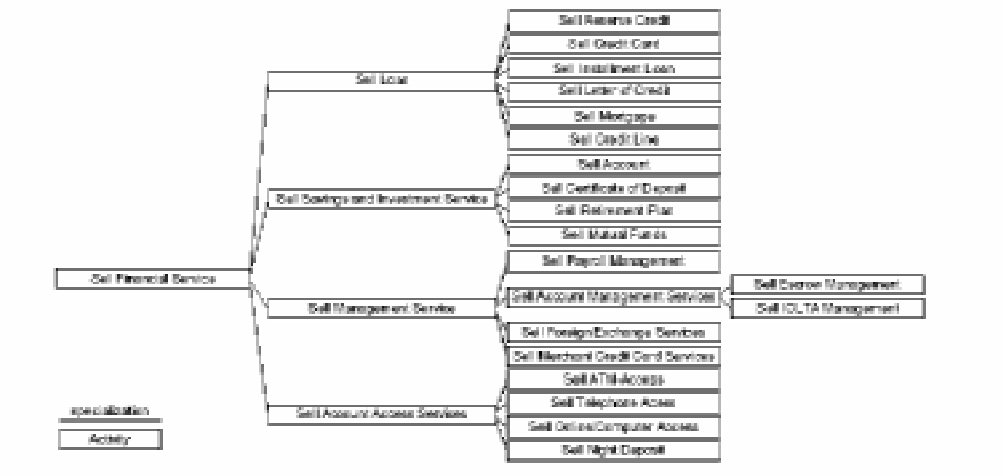

Fig. 9 Explicit Capability Representation From [SKW99]

In implicit capability representation, a service is described by its state transformation and information transfer, i.e. the input, output, preconditions, and effects of the service have to be described:

- Input: the information the service needs to execute, similar to arguments of functions in programming languages;
- Output: the information produced by executing the service;
- Preconditions: conditions that must be satisfied for the process to execute;
- Effects: the changes in the environment produced by executing the service;

All these four components are described using an ontology that models the domain in which the service is situated. An example of a language that uses implicit capability representation is OWL-S. An example, taken from [SKW99], of a service description is given in Fig.10. The service provides stock reports; its input is a ticker symbol, the output is a quote for that ticker, the precondition is a valid credit card, and the effect is that the account is charged.

```
<profile: precondition>
 <profile: ParameterDescription rdf: ID = ”valid_membership”>
   <profile: restrictedTo rdf:resource = ”Financial_valid(account)”\>
<\profile: ParameterDescription>
<\profile:precondition>
<profile: effect>
 <profile: ParameterDescription rdf: ID = ”charged_account”>
   <profile: restrictedTo rdf:resource = ”Financial_charged(account)”\>
<\profile: ParameterDescription>
<\profile:effect>
```

Fig. 10 OWL-S example

In the paragraphs above, we have discussed different approaches to the capability representation of a service and the role of ontology. Additionally, a service can be described by its QoS attributes, and for this purpose a QoS ontology can be used. A service can also be described by a process representation, which could utilise ontologies as discussed in Section 4.

5.2 Discovery

The process of discovering services can be viewed as consisting of the following steps:

1. Define a Service Target, i.e., describe what service you are looking for; this can be done using explicit or implicit capability representations as discussed in the previous section.
2. Relate the components of the Service Target to ontology, i.e. relate task descriptions, input, output, preconditions and effects to one or several ontologies.
3. Identify (a large number of) potential Service Objects, i.e. offered services that may satisfy the Target Service; this can be done by simple name matching techniques resulting in high recall but low precision.
4. Relate the components of the Service Objects to ontology, i.e. relate task descriptions, inputs, outputs, preconditions, and effects to one or several ontologies.
5. For each Service Object, compare its distance to the Service Target.

Amit Sheth and Jorge Cardoso [CS02] have discussed issues in semantic interoperability of services. They propose the need for enhancing workflow systems and process models in order to enable service discovery and composition. The paper provides detailed analysis of semantic matching functions to improve QoS.

Some approaches presented in literature try to improve discovery by means of better semantic characterization of services by adding semantic annotations to the service descriptions. One of these approaches is described in [KDHPS03], where an extension of WSDL service description language, called WSSP (Web Service Semantic Profile), is proposed to encode semantic information by annotating I/O entities with concepts defined in RDF, DAML+OIL or OWL domain ontologies and by expressing constraints on service inputs and outputs. Semantic annotations can be used both when a new service is registered into the UDDI Registry and when a service request is formulated. A semantic matchmaker then performs matchmaking among a service request and the registered service descriptions. The matchmaker applies different filtering techniques to allow service retrieval at different levels of precision both according to user request and available information on services. Firstly, the matchmaker uses the well-known information retrieval technique of TD/IDF (Term Frequency/Inverse Document Frequency) as a first filter to select candidate services in the UDDI Registry even if no semantic information has been provided. Then two other filtering techniques are possibly applied, based on semantic description of services: (i) a type-based filter, that is able to establish if subtype relationships hold among inputs and outputs (defined as classes in the domain ontologies) in the request and in the service descriptions; (ii) a constraint-based filter, that is able to establish if a logical implication holds among constraints in the request and in the service descriptions by means of automated logical reasoning. Other works such as Sriharee and Senivongse [SS03] and Shet et al. [SVSM03] stress the extension of industrial standards for e-services to allow rich representation of service semantics for discovery purposes. In particular, in the [SS03] approach, an *upper ontology* is used to model capability of services according to a behavior-oriented representation that is based on description of operations, inputs, outputs, preconditions and effects. On the basis of this upper ontology, a DAML+OIL *shared ontology* for a particular service domain can be defined and, if it does not cover all needed concepts for describing a particular service, it can be supplemented by a specific *local ontology* for that service. Concepts within shared and local ontologies are used to annotate WSDL descriptions of services, while other semantics extensions (like preconditions and effects) are added as extra elements. Specifications of operations, inputs, outputs, preconditions and effects are used in queries as constraints to enhance service discovery. Authors propose a framework that allows for storing elements used for service description with ontological annotations expressed as triples `<subject, predicate, object>` and they use a reasoning engine for these triples to find exact matching between the query and available services.

The following approaches are instead based on service ontologies to organize services according to semantic relationships in order to enhance the discovery and to allow its scalability when a large number of services is considered. In [KB02], already cited in Section 5.1, the proposed process ontology is the basis of an approach for indexing and retrieval of services. In this approach, indexing a service means to exploit its structure to classify both the service and its constituents (sub-activities, inputs, outputs and so on) in the ontology. A service target is expressed as (possibly partially specified) service model by means of the Process Query Language (PQL) and the matchmaking process exploits the semantic relationships in the process ontology to retrieve those services that satisfy the service target. Puyal et al. [PMI03] studied selection and execution of remote services on mobile devices and proposed a system, REMOTE, where a service ontology stores information about the available services in a frame-based way by simply using service categories and keywords to classify services in a taxonomy (where only generalization relationships are taken into account). When a service request is posed, a corresponding concept (that is the target service) is created from it and automatically classified into the taxonomy with the support of a Description Logic reasoner. The child nodes in the ontology of the classified concept as resulting from the classification process are the answer given to the user. This happens since the child nodes specialize the target service and therefore they represent services having the same or more specific features than the required ones. [BAM03] discusses ontology-based techniques and tools for the classification of services by considering offered functionalities and reference quality parameters. In particular, firstly the services to be classified are compared among them to evaluate their similarity by analyzing the affinity of both service operations names and input and output parameter names on the basis of a thesaurus, where terms are related by weighted semantic relationships to allow quantification of their similarity. Then, services are clustered on the basis of their similarity and are organized by means of semantic relationships (equivalence, specialization/ generalization, disjunction.), that are exploited during the discovery phase to enhance service retrieval. Moreover, construction of cluster representatives and service categories are provided to organize the service ontology on different levels of abstraction and support more retrieval methods.

5.3 Composition and Execution

Composition of processes and services is an active research area, but there is as yet not much work on how to use ontologies for supporting service composition. One contribution to the area is

Blake et al [BWP03], that provides a technique to define a global consensus ontology for the automated composition of Web services adopting B2B agents, and Papazoglou and Yang, 2002 [YP02] that addresses the issue of packaging together elementary or complex services in a consistent and uniform manner. For futher discussion see section 4.3 on composition of processes and services through collaboration patterns and common repositories.

6. STATE OF PRACTICAL USE OF ONTOLOGIES FOR INTEROPERABLITY

This section introduces a number of practical applications of ontologies for interoperability. As can be seen from these, applications of ontologies in this area are still very few and preliminary.

6.1 Interoperability in TC industry (technologies and experiences)

Extremely high needs. The T/C (Textile/Clothing) industry is characterised by an extreme urgence of interoperability but, in the same time, is in difficulty to adopt interoperability technologies.

The sector is characterised by a supply chain of many rings (the processes are complex, and there are many different and independent actors that are specialised in specific ones), but also by the presence of large and very small firms that have to co-operate to obtain products that have a very long lead time (from design to the availability on the shelves might be 50 weeks) and a very short commercial life (few weeks). All these enterprises are forced to co-operate strictly but the request for higher integration between existing systems is hampered by the traditional difficulties in the duiffusion of ICT in the sector.

The diffusion of EDI based approaches (typical of other sectors) is very poor and limited to the final phase of relationships between retail organisations and garment producers, and poorly diffused yet.

There is a difficulty in this area and large organisations involved in standardisation for retailing organisation and B2B, such as EAN, are facing a great difficulty to have a diffusion in this portion of the Supply Chain differently from, for example, the food and beverage sector.

In the upstream side of the supply chain (production of yrans, fabrics and garments) the situation is, if possible, more disappointing.

Activity towards inter-company co-operation. There is a large number of actors, mainly SMEs; only very recently (2003) the CEN/ISSS workshop TexSpin has lead to the definition of a common prenormative platform of XML based messages for B2B in the T/C sector (accordingly with the CEN/ISSS policy to build sectorial standardisation initiatives in specific sectors: Health, Building, Footwear, Textile/Clothing [1]). More information of TexSpin in note[2].

Presently this approach, based on an XML and Internet based evolution of the EDI peer-to-peer architecture is poorly diffused, and is trying to gain a critical mass of users to become a de facto standard.

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[1] see "CEN/ISSS report and recommendations on key eBusiness standards issues 2003-2005", which is available at http://www.cenorm.be/sh/eBiz

[2] CEN/ISSS TEXSPIN Workshop (http://www.uninfo.polito.it/WS_TEXSPIN/default.htm or http://www.cenorm.be/isss), co-ordinated by Euratex (european association of the industrial associations of the sector) and comprehending the contribution of MODA-ML and eTeXML experiences. The goal of TEXSPIN Workshop is to supply a pre-normative platform of data exchange models, XML messages and dictionaries of terms that cover different aspects of the supply chain, from sales organization to production in its different aspects.

This means that TEXSPIN supplies some suggested models and an exchange language that technological solutions providers and enterprises will be able to conveniently use for implementing their own solutions.

TexSpin was a standardisation activity; in parallel or previously the main initiatives of system integration were based on three main architectures:

- peer-to-peer exchanges of XML documents (more or less XML evolution of EDI) like Moda-ML (an IST Take Up Action, see www.moda-ml.org) and eTeXML (a french national initiative centered on Web EDI)

- asp integration services through a center of services (e-Chain, TextileBusiness, Italfabrics and others)

- private company portals dedicated to sales agent, supplier or subcontractors based on many different WEB technologies.

The main point is that around TexSpin is arising a sector-specific dictionary of terms and experiences have been proposed to approach its organisation and maintenance with an ontology based approach.

The most relevant is the Leapfrog IP Proposal (submitted in June 2004) that aims, in one of its tasks, to the creation of a sectorial collaborative framewok using ontologies to facilitate the creation and maintenance of a common dictionary.

Between other more specific research projects can be mentioned the Sewasie project (www.sewasie.org)[3] that is experiencing the creation of a sectorial ontology in the T/C sector to build an agent based system and other less recent experiences of ontology creation for the Supply chain management.

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[3] SEWASIE (SEmantic Webs and AgentS in Integrated Economies**)** will design and implement an advanced search engine that provides access via a machine-processable semantics of data, which can form the basis of structured web-based communication. Tools and methods will be developed to create and maintain multilingual ontologies, with an inference layer grounded in W3C standards (XML, XML Schema, RDF(S)), that are the basis for the advanced search mechanisms; these will provide the terminology for the structured communication exchanges.

SEWASIE has the following specific objectives:

- To develop an agent-based, secure, scalable and distributed system architecture for semantic search (ontology based) and for structured web-based communication (for electronic negotiation).
- To develop a general framework responsible for the implementation of the semantic enrichment processes leading to semantically-enriched virtual data stores that constitute the information nodes accessible by the users.
- To develop a general framework for query management and information reconciliation taking into account the semantically enriched data stores.
- To develop an information-brokering component that includes methods for collecting, contextualising and visualising semantically-rich data.
- To develop structured communication processes that enable the use of ontologies. The communication tool enables structured negotiation support for human negotiators engaging in business-to-business electronic commerce and employing intelligent software agents for some routine communication task.
- To develop end-user interfaces for both the semantic design and the query management.

6.2 Aspects related with standardisation procedures and potential role of ontologies

The world of standards for B2B interoperability is strongly focused on the EDI approach (not the EDIFACT technology) based on electronic document interchange (different document templates are corresponding different actions that are asked or answered.

The basic reason to work with a new EDI approach, let say an XML/EDI approach, is that companies has huge systems that are a legacy that is quite difficult to ignore and that cannot be simultaneously redesigned in order to activate collaborative networks of enterprises with significant numbers.

ebXML is presently considered as the most complete meta-standard, a standard to create standards or, more precisely, collaborative frameworks addressed to specific domains. It is promising but still in Europe the implementation are not very spreaded (despite the CEN/ISSS committment) while in Asia and USA it appears more adopted.

Some statements are emerging from the world of standardisation (for example eBiz group and eBif Forum) at CEN/ISSS: there is acknowldegement about the fact that the duration of the standard building/updating processes is too long and their implementation is often too difficult for software house developers.

Key action lines are emerging:

a. sectorial action lines facilitates diffusion in sectors dominated by SMEs
b. facilitation of the integration front-end/back-end

But a further aspect has to be taken in account and deals with the essence of a standard for interoperability:

We have a problem of convergence of standardisation initiatives (and of management of potential overlapping or conflicts) and of improvement of the flexibility of their paradigms.

Presently is running the OIDDI initiative for the construction of a methodology to make comparable and 'orthogonal' dictionaries, created by different bodies and related to different domains.

The starting point of this approach is that many different domains require different vocabularies and that the two main actions to pursue are the creation of a common way to address the dictionaries (unique global coding) and to assure their orthogonality or identify the area of overlapping.

The project is starting in summer 2004 and foresees to adopt ontologies, built on top of the dictionaries, in order to make them comparable.

Presently the activities of creation of standards, being devoted to the only inter company collaboration aspects, could be a starting point for the creation of reference ontologies that could simplify the work of construction of tools for management and integration based on ontologies for interoperability.

Commento [n5]: The whole section requires better formulation: it looks like a sequence of unrelated sentences.

Commento [n6]: This sentence is ununderstandadble to me.

Commento [n7]: Provide a reference to this initiative.

6.3 Applications in the Tourism Sector

In Missikoff 2003 [MI03], the main issues of an Ontology-based platform for semantic interoperability, with particular attention to the underlying methodology, are illustrated. The solutions presented have been developed in the context of Harmonise, an IST project aimed at developing an interoperability platform for SMEs in the tourism sector. The illustrated platform is an advanced software solution, based on the use of computational ontologies, aiming at the reconciliation of conceptual, structural, and formatting differences that hamper information exchange. The proposed approach relies on the availability of a domain ontology, used as a semantic reference for cooperating systems. The approach addresses semantic clashes, arising when a conceptual local schema is contrasted with the ontology. Semantic clashes are taken into account when the elements of a conceptual local schema are semantically annotated. Semantic annotation is requested to reconcile existing differences of cooperating information systems.

7. FUTURE RESEARCH DIRECTIONS

Based on this state-of-the-art report, the following future research directions can be identified:

1. The use of ontologies for process interoperability. There has been much work done on the use of ontologies for information interoperability and service interoperability, but much less on process interoperability. This could be a fruitful area, where there is still much work to be done. Furthermore, ontology support for process interoperability would also be relevant for service interoperability, which adds to the significance of the topic.
2. Empirical studies. Most work on ontologies for interoperability has a very theoretical flavour. There is clearly a need for empirical studies that apply and evaluate the usefulness of ontologies as a support for interoperability. Such studies should preferably have a large scale and can, therefore, constitute good projects for cooperation among INTEROP partners.
3. There has been much work on how to use ontologies for describing and discovering information, processes and services. In contrast, there are not many results on how to use ontologies for composition and execution of processes and services. Investigating this topic would be worthwhile, as it could provide a basis for methods and tool support for concrete tasks in interoperability.
4. ...

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