IMPROVE BUSINESS INTEROPERABILITY THROUGH CONTEXT-BASED ONTOLOGY RECONCILIATION

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ABSTRACT

In collaborative environment, providing flexible interoperation between heterogeneous knowledge-based software applications is critical for efficiency reasons, particularly in the context of unanticipated business collaborations. It is an objective pursued by ongoing research efforts on semantic interoperability: one expects that describing information within ontologies and reconciling these ontologies is sufficient to reach seamless information exchange. However, limits of ontology model and development result in lack of reliability of agreement between ontologies, thus reconciliation of ontologies is often pragmatically inconsistent. This paper proposes a methodology to determine what is contextual information, how to model and use it. Then, this methodology is applied to the reconciliation of ontologies, in the situation of unanticipated collaborations across organizations and between collaborators. The outcome is a context-based system that provides an evaluation of the pertinence of data associated with a concept, based on three distinct kinds of contextual information: (1) user's domains and tasks, to personalize the search interface according to user's needs; (2) perspectives used to annotate ontology concepts, as means for disambiguation of the pragmatic meaning of concepts; (3) the task for which the data is intended to, as a way to evaluate data relevance to fill the interoperability need.

Keywords: Ontology Alignment, Context, Semantic Interoperability, Matching

1. INTRODUCTION

With globalization and competition increase, companies need to collaborate more than ever with other organizations, in order to achieve better products with reduced cost. These collaborations require from organizations that they reach an agreement to achieve interoperability between all layers of the organizational system [22]. The realization of interoperability for the business-specific layer is contingent on the reality of interoperability for the information and communication technology layer, which is seamless information exchange through software applications.

Interoperability is traditionally achieved by developing standard formats that serve as neutral representation, or by the ad-hoc development of translators and matching of database schemas to integrate existing software applications together. However, integration is costly, time-consuming and error-prone, and the process of standardisation takes too long to deal efficiently with the increasing needs, as the pace of technology fastens. Because of these limitations, the scientific community is much concerned with providing systems supporting flexible information exchange. Thus, current research direction intends to achieve interoperability at the semantic level: semantic annotations are used to describe concepts, and then one may match those annotations that have similar meaning. These mappings can serve to bind software applications that

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use those concepts and related information, so that they can work together. Interoperability achieved this way is named semantic interoperability, *"the ability of information systems to exchange information on the basis of shared, pre-established and negotiated meanings of terms and expressions"* [26]. We consider that meaning can be established in an *ontology; of which our definition, adapted from* [13] follows: an engineering artefact describing a machine-processable model, that is constituted by a formal vocabulary plus a set of explicit assumptions defining precisely and with clarity the intended meaning of the vocabulary; the model describe classes (representing concepts), instances (representing individuals of concepts), attributes, and constrained relations.

Organizations will refer to distinct ontologies to establish the meaning of their applications data; these ontologies have to be reconciled – that is, brought into agreement – to enable organizations to collaborate, hence facilitating semantic interoperability. This may be done by aligning their ontologies, or by aligning them with an intermediary ontology that defines the most important concepts on which the organizations agree. While direct ontology alignment is the most suitable approach to allow exchange among resources developed for independent purposes and which evolve independently, Chen and Doumeingts [7] advice the mediated approach for interoperability, as it limits the number of correspondences to find between resources (see [24] for a methodology to define such a mediator ontology).

Both methods rely on ontology matching, which mainly consists of relating concepts one-to-one. In the same way word-by-word automatic sentence translation is generally unreliable, the reconciliation of ontologies by ontology mappings suffers from the loss of contextual information. Ontologies often represent complex realities, and choices had to be made as to how designing them. A few concerns have guided the knowledge engineers when selecting concepts to be included in the ontology and choosing which granularity to adopt. These concerns are not documented inside the ontology in any computer-processing manner. Yet they influence the meaning of relations and concepts, and are responsible for the most irrelevant results when comparing ontologies built independently.

According to Giunchiglia and colleagues [12], *"semantic interoperability is highly context- and task-dependent"*; assuredly, all data is not useful for all task, and all data is not appropriate in all context. When using equivalence mappings, one expects to be able to replace one entity by the other, for a given task. This makes no sense if the tasks for which the ontologies were developed are totally incompatible. To achieve semantic interoperability, it is therefore

necessary to take context and task into account either when establishing, evaluating or using ontology mappings.

The purpose of this study is to evaluate whether the consideration of context can lead to the improvement of reliability of ontology mappings for interoperability. We propose a methodology to determine what contextual information is, and how to collect, model, and employ it. Applying this methodology, we select three usages of context that may be used together to improve ontology reconciliation and business interoperability. Taking into account that, by the term "perspective" we understand various considerations that may explain design choices, and that are notably influenced by the intended use of the ontology for a given application and with particular data, we propose, as follows:

1. To disambiguate among the possible pragmatic meanings of concepts by comparing perspectives with or for which concepts have been developed;
2. To personalize this comparison by considering the agent's context, made of a relevant selection of agent's company domains and tasks;
3. To evaluate the pertinence of the data associated with the concept for the task that triggered the interoperability need.

2. LITERATURE REVIEW

According to The Free Dictionary [25], context is "the part of a text or statement that surrounds a particular word or passage and determines its meaning" and also "the circumstances in which an event occurs". We consider context as the *information that participates in characterizing an entity of interest involved in the event that triggers the need for context, including its interactions with other entities, where the distinctive features that compose the characterization are judged according to the purpose of explaining the emergence or some remarkable characteristic(s) of the entity of interest*.

We split context-based approaches in three main categories, whether it is to collect, model or employ contextual information. These approaches are explained hereafter.

2.1 Collect Contextual Information

When the collection of information is done before the emergence of any need, more data is actually collected than that which will be judged to be contextual. Examples of such data are history of operations and the record of artefact metadata. The history of operations can serve to characterize the emergence of any particular event. Brézillon [5] uses it to select which action is appropriate in response to a given event. The SearchPad tool [3] keeps track of the circumstances of a discovery: it records queries made during one or more sessions of Web search to

associate them with respective results that have been found relevant.

Paslaru-Bontas [21] proposes a metadata model in OWL-DL [20] which includes characteristics of ontology development relevant for the guidance of the ontology reuse process. This model serves to evaluate whether two ontologies were developed in similar enough contexts so that it makes sense to reconcile them. Suggested characteristics refer to the development of ontologies as a whole, and cannot therefore directly serve to reconcile ontologies: there is indeed no evident method of using the metadata to adapt the way ontologies entities are to be related with one another.

2.2 Model Contextual Information

Some authors aim at representing knowledge formally in a way that should permit logical reasoning with inconsistent sets of rules about the same objects, and generate context-dependent conclusions. For instance, McCarthy [19] and Guha [14] focus on modelling background information that vary according to the location or circumstances, while Attardi and Simi [1], Bouquet et al. [4] attempt to represent various viewpoints on a same reality.

Baldauf et al. [2] survey context-aware systems, which act as middleware between sensors– that collect data to detect the location, environment change, etc. – and applications – that select data which is actually relevant in the context of a given interaction with the user.

Firat, Madnick and Grosof [11] consider context as information that varies from one data source to another. They model typical business information with a fixed list of "modifiers", which vary in a fixed "dimension". Modifiers include units (such as currency), formats (for example date format), and background assumptions, such as services, taxes included or not in the price. Context models are instantiated to describe the characteristics of data sources as well as users' preferences. Conversion functions transform the data at need from one dimension to another (for example conversion from one currency to another) to enable their comparison.

2.3 Employ Contextual Information

Context is often used as a means to *disambiguate* keyword-based search by generating an augmented query from the paragraph which contains the term submitted [10]. Budzik and Hammond [6] consider a wider context to disambiguate keyword-based search; they assume that information needs probably occurred as the user was working on some artefact. Hence, they use the textual content of artefacts such as Word documents opened at the request time.

Context is also used with the purpose of *personalization*. Most context-based approaches for "Web search" employ context for this usage [17]. Some model context as users' preferences, assuming that the search involves personal information needs; some model it as the statistical analysis of queries from various users, to pair keywords associations in queries with probable search goals; some still model it as technical information such as the search engine used or the IP address, that presumably relates to current location.

"Context awareness" brings portable electronic devices to be "aware" of the environment in which they are used and to *adapt* their behaviour consequently. Context-aware systems rely on various sensors, such as GPS, RFID and clock, to provide a human-computer interaction adapted to the circumstances. Thus, here context is understood as "environmental" and essentially "situational" information [2].

Context serves also as a means for *evaluation*. Paslaru-Bontas [21] provides a context-sensitive methodology to discriminate ontologies that should be reused for a particular ontology development. She proposes to evaluate ontology candidates for reuse by criteria such as estimated relevance for the application domain, quality of the modelling, technical context, and tasks for which the ontology was built. The evaluation involves comparing answers to these criteria with information from the context in which the need of an ontology has occurred. Hence, the context of ontology reuse is constituted by task and role for which the new ontology will be used, and the reuse level (vocabulary, vocabulary and semantics, or instance data). Thus, evaluation fosters the refinement and optimization of the integration strategy.

Additionally, context is employed for *recovering* entities based on the context of an event where they were involved. This is the case when searching documents by their date of modification, or searching for artefacts that the user has seen previously [9]. Beagle++ [8] extends the Beagle desktop search infrastructure with context-based search where context is mainly constituted of user activity and represented with the help of RDF (Resource Description Framework) [23] annotations. Table 1 summarises approaches that employ context.

Characteristics that compose context are not likely to be relevant from an approach to another. Contextual information describes the connection of an entity into focus to other entities that are related to it. Thus, it has to be confronted against other information in order to be *employed* for a given usage [16]. The evaluation of this confrontation leads to a decision. Therefore, from all information about the entity into focus, only the type of information that leads to an informed decision is contextual, so as to take the appropriate action corresponding to a desired usage.

Table1: Main approaches that employ context

Domain	Purpose	Focus	Composition of the context	Ref.
Information Retrieval	Disambiguate among possible meanings of the term	Word queried	Surrounding text	[6]
		User's task	Text in documents opened by the user	[4]
	Uncover the way the document was obtained	Discovery of the document	Queries done concurrently	[2]
Ubiquitous Computing	Adaptation of service to the situation (external)	Interaction of the user with a device	Location, noise, light, time, and role	[1], [5]
Problem Solving	Discover the circumstances that were the origin of the problem	Problem that occurs	Different stages that lead to the problem, and the stages to solve it	[3]
Ontology Integration	Evaluate the interest of the ontology for reuse	Ontology artifact development	Methods used, topics, tasks the ontology is designed for, information sources	[7]

3. METHODOLOGY TO ADD CONTEXT-SENSITIVITY INTO A SYSTEM

The methodology we propose (Figure 1) intends to integrate a context-based approach into a system. It has three stages and each one details in further specific steps. All methodology phases are explained in Table 2. The first stage sets objectives for the addition of context-sensitivity into a system, selects usages of context that address these objectives, and adapts usages to the application in view.
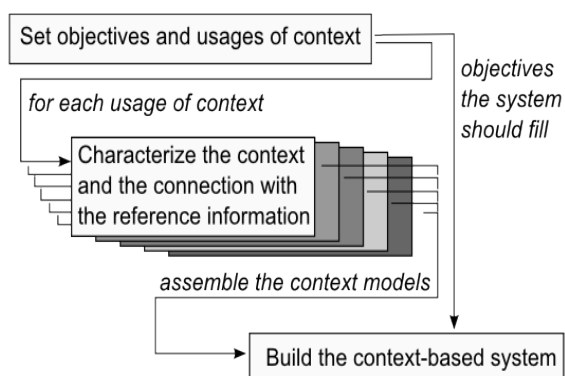

Figure 1: The three-stage methodology to build a context-based system

Table 2: Details of the three-stage methodology

Stage 1	Determine the application to contextualize
	Set a list of objectives for the context-based system, including the deficiencies to solve, the improvements expected, the assets to preserve
	Determine the usages of context to implement so as to reach the objectives
	Determine, for each usage: the target, the reference, and the decision of comparing the target's context with the reference information
Stage 2: for each usage	Determine the features that are the most relevant to compare the target context with the reference
	Find the most relevant sources of available contextual data; respect the conditions that ensure the validity of the data retrieved; establish a measure with pertinent precision and scale
	Model features so that they represent the contextual properties in an appropriate and effective way
	Model the connection between target context and reference with joints and joint-specific methods, which compare contextual data with corresponding reference information and return a normalized measure of their agreement
	Balance joint-specific measures with weights so as to form normalized measures that represent the match of the target with the various alternatives
	Put into action the result of the alternative selected, so as to achieve the general purpose for the usage
Stage 3	Combine all models developed for each usages of context into a unique context-based system
	Evaluate the context-based solution according to the objectives set in the first stage
	Adjust, adding methods, models and measures to help the context-based solution to reach the objectives set

Table 3: Examples of usages of context and corresponding target, reference and action

	Purpose	**Trigger event**	**Target**	**Reference**	**Action**
Disambiguate	Use the entity according to its correct meaning	Situation where the meaning of an entity needs to be clarified	The entity to disambiguate	The possible variants	Select the correct variant
Personalize	Personalize the interaction	The interaction of the user with an application	The user	The possible options	Select the more appropriate for the user
Adapt	Change the behavior of the device when the situation occurs	The use of the device (at a given time and place)	The current environment, such as time and place (with sensors)	A list of situations described by a set of conditions	Select the situation(s) that correspond to the information sensed
Adapt	Use the device with the best possible configuration	Interaction with the device for a particular service	The device	Set of configurations considered	Select the appropriate configuration
Evaluate	Act accordingly to the result, or transfer the information to the user	Situation of choice between different options	An option to evaluate	The criteria and requirements	Note the options according to their suitability with criteria and requirements

The second stage aims at characterizing the target context and connecting it with reference information. Six phases make up this stage: first, find out features that characterize the target context the best (Table 3); second, choose available sources of valid contextual data; third, provide access to feature-related data; fourth, connect target context and reference information using joints; fifth, balance measures to evaluate alternatives; and lastly, put into action these alternative measures. Finally, the third stage has three phases: develop, evaluate and adjust the system being built.

4. APPLICATION OF THE METHODOLOGY FOR ONTOLOGY RECONCILIATION

We show hereafter how we apply the methodology so as to determine an appropriate contextualization for the reconciliation of ontologies. We considered the case of unanticipated collaborations between organizations, where ontologies are developed autonomously and evolve independently, and have to be reconciled by the means of ontology alignment methods.

4.1 Stage 1 - Set Objectives and Usages of Context
4.1.1 Set Objectives for the Addition of Context Sensitivity into the System

Hindrances to ontology reconciliation can be lowered in a context-based system that would realize the following objectives:

1. *Expand the usability of ontology reconciliation* by proposing an evaluation measure between custom concepts (not sole concepts for which there exists a correspondence in an ontology alignment);
2. *Evaluate concepts based on their pertinence for the interoperability need*: as collaboration is based on data exchange, it is important to know whether data associated with an ontology concept defined by the partner organization are pertinent for a given need;
3. *Consider practical implications when evaluating the connection between concepts*: would an ontology concept defined by a partner organization actually be suited to "replace" another concept in an ontology of the company?
4. *Do not alter the ontologies*: ontologies developed by collaborating companies are expected to evolve independently. The flexibility of federative approaches, which record linking data outside the ontologies, should be preserved.

In addition, the system architecture has to meet needs for collaborating companies, and models developed should therefore meet the following requirements:

1. To be simple and based on standards, to limit the overall energy and time spent on it;
2. To be flexible, so as to allow for partial reuse as

new collaborations arise: this involves separating the organization-specific from the collaboration-specific;

3. To be secure, to limit access to the company's confidential data.

4.1.2 Select Usages of Context that Answer to the Set Objectives

We have analyzed three usages of context that are *disambiguation*, *personalization* and *evaluation*, which should be adjusted to fit our application of ontology reconciliation. As collaboration is based on data exchange, it is important to know whether data associated with an ontology concept defined by a partner organization are pertinent for the task-driven interoperability need. We, thus, need a context-based *evaluation* of concepts.

A generic notion of similarity expressed by ontology mappings does not take into account the various viewpoints and the actual use of the concept in the application. As mappings simply relate concepts without making a distinction between possible points of view, *disambiguation* among perspectives will help determine which mappings are appropriate and which are not, in a given context.

The perspectives that have been judged appropriate may still be restricted by the role that the agent holds in the organization: assembly engineers and businessmen will look at distinct features of the concepts they manipulate. *Personalization* allows the ranking of concepts by their pertinence for the agent essential domain and tasks.

Table 4: Term definitions for our approach

Term	Definition
Applicant	The agent that makes the interoperability request
Agent	User or autonomous software component
Company	The organization of whom the applicant is member
Partner	Any organization that collaborates with the company
Root concept	The concept selected in an ontology of the company that illustrates the kind of concept that the applicant seeks.
Concept enquired	The concept selected in any of the partner ontologies and that is the subject of the evaluation of pertinence
Pragmatic meaning of a concept	Practical significance of a concept in terms of the actual data associated with it. See example in Table 5, where the type of data associated with almost identical concepts differ slightly, as between the concepts **Textbook** Nathan editions and **Book** from Amazon.com, or completely, as between the two **Book** concepts

The usage of *adaptation* would focus on automatically adapting the behavior of the device used for performing the interoperability task. As we

are concerned with software-related business interoperability issues, this usage is not critical. The usage of context-based *searching* is not essential either.

We present here in detail the *disambiguation* case. This study deals with *disambiguation* between pragmatic meanings of concepts, through evaluating whether two concepts may be associated with data that is comparable, in terms of practical use.

We define, in Table 4, a list of terms that will simplify the description of our approach, and that we use from now on. Table 5 presents examples of the concept of book with different pragmatic meanings.

4.1.3 Instantiate Context Usage in Accordance with the Application

We present the instantiation of *disambiguation* usage of context, by adapting it to the application of ontology reconciliation. We intend to disambiguate the pragmatic meaning of the concept enquired by comparing its possible pragmatic meanings with ones of the root concept. We thus need to compare the context of these two concepts. As collaborations are seldom unidirectional, concepts may play the role of concept enquired and of root concept at different times. It seems therefore appropriate not to make any distinction between the two roles but to make the model of concept's context symmetric. Table 6 summarizes triple (target, reference, action) of *disambiguation* usage of context.

Following sections relate to the second stage of the methodology, thus characterizing the target context, connecting it with reference information, and adapting actions to the various alternatives.

Table 5: Example of concepts with different pragmatic meanings

Concept	**Book**	**Textbook**	**Book**
Organization	Books on Demand www.bod.fr	Nathan Editions http://www.nathan.fr/	Amazon.com www.amazon.com
MetaData	Digital mock-up, ISBN, Barcode, Bookstores (where sold)…	Title, grade, Mandatory/optional Year of publication, Editors, Authors, Collection…	Title, Authors, Review, List price, Price, In stock…
Point of view	Book edition	Specialized Book seller	Book seller

Table 6: Summary of instantiation of *disambiguation* usage of context

Usage	Target	Reference	Action
Disambiguation	Concept enquired	Context of the root concept	Determine whether the concept enquired can "replace" the root concept

4.2 Stage 2 - Connect the Contexts of the Root Concept and of the Concept enquired

4.2.1 Find Out Features that Characterize the Target Context the Best

Knowing the perspectives which guided the ontology development process might help discriminate among the various implications that the ontology engineers have attached to the ontology entities. In the same way, perspectives that manifest the factual use of the ontology should represent the current meaning associated with concepts. We will therefore select all these perspectives as features characterizing the ontology context.

4.2.2 Choose Available Sources of Valid Contextual Data

The applications for which ontologies were built and the data sources that they served to integrate are probably the most pertinent resources to identify ontology perspectives, when they are available. Perspectives can be identified through the observation of applications, by finding out the main operations and concerns.

Another possible resource is the ontology itself, with the disadvantage that perspectives do not determine the ontology design in a unique way. Ontology development is indeed subjective, and the effect of perspectives may be local or distributed in the whole ontology. The recognition of different perspectives in an ontology therefore requires an analysis of their effect, of which Table 7 enumerates a few signs.

The success of our approach depends on the discovery of most of perspectives that have guided the ontology development process, and that express connection with the data. Ideally, this process of discovery should be done by a domain expert who participated in the ontology development, as he/she is in the right spot to know the rationale for the choice of each concept, its placement in the *is-a* classification, its name, attributes, and semantic relations.

Table 7: Signs enabling to recognize the effect of various kinds of perspectives in an ontology

Type of perspective	The perspective may be recognized by
Application domain	Higher granularity in a portion of the *is-a* hierarchy than in the rest of the ontology
Application or technical purpose	The presence of entities (in particular, attributes) whose meaning is not akin to the application domain, or that is described with a thinner granularity than the rest of the ontology
Viewpoint or role	The presence of different criteria of categorization in the *is-a* hierarchy

4.2.3 Provide Models to Ease Access to Feature-related Data

Perspectives may be represented with a list of textual identifiers, using RDF annotations, or classes in an OWL-DL ontology. We decided to represent perspectives with textual identifiers as it is the simplest to use and implement, which was our first criterion. It is possible to evolve toward an ontological approach such as the one presented in [15] once the approach has proved to effectively answer the company needs.

The representation of perspectives by a list of identifiers can be efficiently implemented using a relational database. Technical solutions are available that should simplify the annotation of ontologies with perspectives for non-ontology-experts, by providing user-friendly web forms to edit the content of relational databases. The management of confidential data may be realized by annotating ontology entities and associated data with perspectives of a specific class, so as to restrict their access.

4.2.4 Connect Target and Reference Information Using Joints

The comparison of the context of concepts defined by ontologies from different organizations requires establishing relations between their perspectives. It is not likely that two perspectives may be equivalent, but they may be "compatible", that is, similar enough so that concepts annotated by these perspectives might be used conjointly with no critical distortion of meaning. All such relations are not symmetric, as for example a perspective that correspond to a restricted point of view of another is compatible with this latter, while the opposite is not necessarily true. The same example shows that a perspective might be compatible with many perspectives, as there may be various perspectives that correspond to a restricted point of view of a given perspective.

Perspectives are supposed to convey a homogeneous pragmatic meaning. They should not be cases when perspectives are compatible and cases they are not. As for the degree of their compatibility, it is difficult to give an evaluation of how well they are fitted for one another. Therefore we decided for a binary evaluation: either they are compatible or not. Once again, it is possible to change this later if one would prefer a thinner grain, probably with a few fixed values to simplify the evaluation and limit the subjectivity, especially if more than one expert participates in describing the connection.

The automatic comparison of perspectives is hindered by the diversity of applications and point of view, the freedom of naming of perspectives, and the fact that they represent abstract realities, hard to match together. This limitation should not be an obstacle to the adoption of the approach, though, as

the number of perspectives should not be high. Experts could take advantage of existing alignments: if, for example, many concepts annotated with two given perspectives are mapped together, it may be a clue that the two perspectives are closely related.

4.2.5 Combine Joint-specific Measures to Evaluate Possible Alternatives

The root concept and the concept enquired are both associated with perspectives that have been recognized to influence the development of ontologies or that characterize their use. Relations of compatibility between perspectives from the company and its partner organization constitute measures that relate the context of the root concept with the context of the concept enquired.

To evaluate possible alternatives of pragmatic meaning that the concept enquired may have, one therefore has to retrieve all couples of perspectives (A, B) so that:
1. The root concept is annotated by A,
2. The concept enquired is annotated by B, and
3. A is compatible with B.

4.2.6 Put the Result of Measures into Action

The disambiguation is effected by simply selecting perspectives that annotate the two concepts and are compatible with one another, since perspectives are homogeneous and restrict possible pragmatic meanings of concepts.

The pragmatic meanings that the root concept may take are not all significant for an agent. Let us consider two perspectives A and B that annotate, respectively, the root concept and the concept enquired, and are compatible. If the pragmatic meaning that the root concept has under the perspective A is not significant for the applicant, then the perspective B will not be relevant either, and any further operation based on the evaluation result will be beside the point. We will therefore study the applicant's context and compare it to the company perspectives, to find out which perspectives that annotate the root concept are relevant for the applicant, and thus get a more faithful evaluation of pertinence.

Let us now demonstrate the potential benefits of our methodology in addressing a realistic example of business interoperability problem.

The company Imano specializes in the preparation, assembly, and packaging of sports equipment. An assembly engineer is currently involved in the preparation of a new front wheel assembly for racing bikes to answer a demand from the retailer TenThlons; she has already selected the rim, the front hub and the spokes, and has now to select a tire that should provide the wheel with road qualities best suited for racing beginners and still be reasonably priced.

She will carry out extensive negotiations with two potential suppliers, FireStorm and Richelin, so as to find the best tire at the best price. These negotiations will involve several information exchanges between software applications at these companies, and raise interoperability problems due to the difference of tire categorization that these applications are built upon.

In the design context-based system the engineer browses the ontology, selects the concept "Tire", and right-click to "find appropriate part" (Figure 2a). The design application, prepares a suite of requests to the context-based system, composed of the following information:
1. Agent on the account of whom the request is made: *Mary*
2. Concept from Imano ontology that describes the kind of part that is being searched for: *BikeTire*
3. Interoperability task that describes how the result of the search is to be used: *Quality Assembly for Medium distribution.*

The business application then searches for corresponding concepts in the suppliers' ontologies, and interrogates the context-based system to evaluate them. Finally, the engineer is being displayed a screen form with these concepts ordered by relevance (Figure 2b). She can now make the best choice and automatically retrieve the data associated with the concept, to complete her project.

We therefore follow now operations of an expert working for the Imano company. This expert has access to the management of the context-based system, including the data and contextual data stored for the company.

The company has developed various ontologies, including (1) the "Kits classification" ontology which describes the kits prepared by the company to be sold, and the (2) "Bike and motorbike parts" ontology which describes the parts of bicycles and motorcycles sold or obtained by the company from suppliers, for assembly or for the preparation of kits;

The company Imano follows marketing strategies, and design products assembled by the company for enthusiasts and beginners; other products are middle-range products that propose performance/value quality considered tough to beat. Perspectives proceed from these marketing strategies and are named: "enthusiasts", "beginners", "challengers".

Imano company distributes its products through two retail companies TenThlon and MySport, which are interested in distinct products. Thus, Imano has decided to use two perspectives named "tenthlon" and "mysport" to take into account this information. Ontology engineering and product Imano experts annotated ontology concepts with these various perspectives (Figure 3).

Tires have various characteristics: dimensions differ; some are tubeless while others require an inner tube; some are excellent in dry conditions but lose their grip when the weather gets wet; others have a light weight, are comfortable to ride, are particularly durable, and so forth.
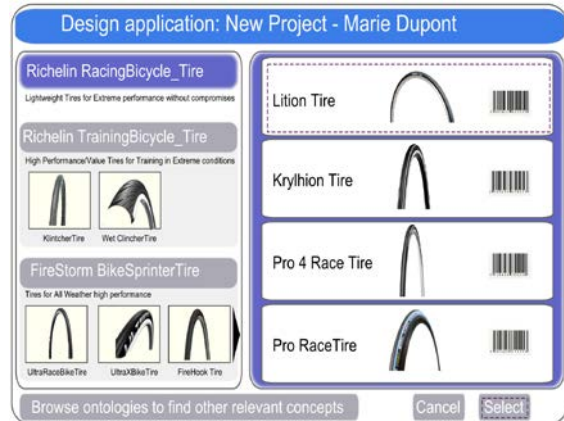

Figure 2a: Query of a concept "Tire"

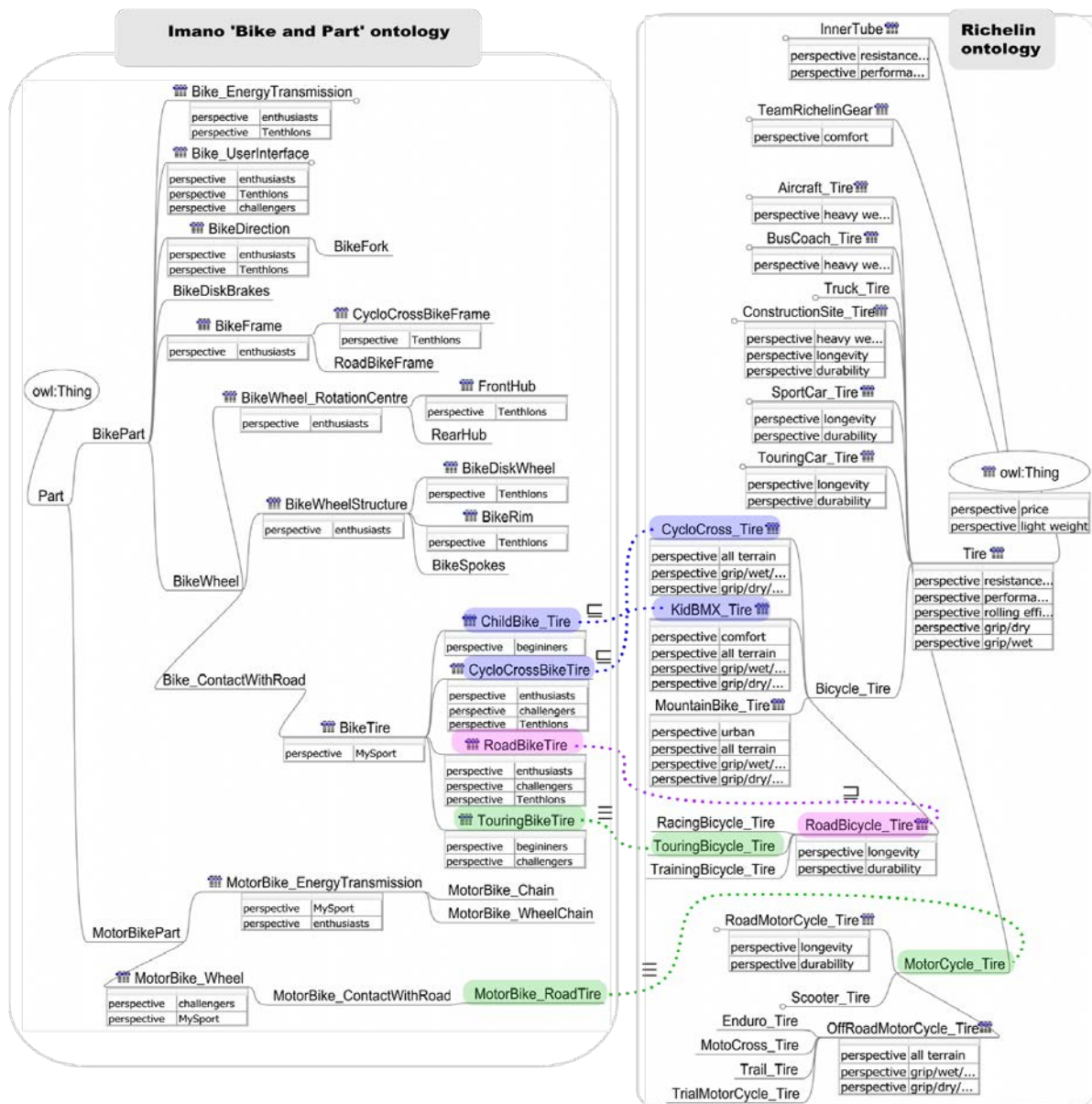Figure 2b: Ranking of "Tire"-equivalent concepts

Figure 3: Mappings between concepts of Imano "Bike and motorbike parts" ontology (left) and Richelin's ontology (right), both annotated with their respective perspectives

Data associated with different types of tires vary primarily because needs diverge: requirements for aircraft tires include high resistance to both compression and extreme changes of temperature, which would be excessive for car tires; but those have to endure much longer distance. Cross country bicycles and motorcycle tires have to grip rocky and muddy terrains, while road bikes grip bitumen.

The organization Richelin has perspectives that depend on various categories of vehicle that share similar characteristics: (1) cars, vans, pickups and SUVs, (2) bicycles and motorcycles, (3) trucks and bus. For each of these, they indeed have distinct strategies: for trucks and cars, where competition is strong, perspectives are durability and reduction of rolling resistance, grip under extreme weather circumstances. For heavy earthmovers, it is the ability to support heavy weight over a long distance. Figure 3 shows annotation of the product ontology with perspectives that experts of the Richelin organization have applied. These annotations show that if some notions are relevant for all products, such as price, others are specific to a selection of concepts. Not all tires are adapted for all terrain and the style "urban" applies only to a few tires.

Richelin manufactures tires in different factories. Some tires are produced in all factories, but some of them are produced only in one factory.

Richelin has therefore decided to add perspectives to the name of its factories: Charlesruhe, Clerront-Fermand, Mehico City.

At the start of the new collaboration between Imano and Richelin, experts use ontology matching tools to find mappings between ontologies of the Imano company and the product ontology of Richelin (Figure 3). After validation, these mappings are imported in the context-based system and bidirectional mappings of equivalence are converted into two directional mappings.

Imano ontology engineering experts connect perspectives from Imano with perspectives from Richelin. Table 8 presents relations found between perspectives. For each of perspectives of the Imano company, appropriate perspectives defined by Richelin are marked with a cross. The only exceptions are the last four lines of the table, which show Richelin perspectives that are not related at all to any perspective defined by the company Imano.

4.2.7 Resulting Action for the Usage of Personalization

The applicant's context is made of domains and tasks that the applicant performs in the company. Domains and tasks are related with perspectives with assigned values of relevance. For a given perspective, there may be distinct couples (domain, task) in the applicant's context whose relevance value is not null. The applicant-specific value of relevance for the

perspective is the maximal value among these. The personalization process can be implemented by withdrawing concepts enquired of null applicant-specific relevance value from the selection result of the disambiguation process. Concepts enquired may then be ranked according to the applicant-specific relevance value of corresponding root concept's perspective, to judge of their relative pertinence for the applicant.

4.2.8 Resulting Action for the Usage of Evaluation

The interoperability task -- data-dependent task for which the data retrieved from the request is intended -- varies with the request, and must therefore be informed dynamically, along with the request. The pertinence of a perspective for an interoperability task may be determined once for the collaboration and be represented by a single value of pertinence. Concepts enquired may then be evaluated according to the pertinence values defined for couples formed by any of their perspectives and the interoperability task selected.

4.3 Stage 3 – A Context-based Architecture

We present the application of the last stage of our methodology to design an architecture that assembles the proposed models, with the purpose of improving the reconciliation of ontologies by the means of a full context-based approach. We have to ensure that the architecture fulfils all objectives that we have stated in the first stage.

Table 8: Connection between perspectives of the two organizations

Imano perspectives / Richelin perspectives	Enthusiasts	Challengers	Beginners	Tenthlon	MySport
Price	X	X	X	X	X
Comfort	X	X	X	X	X
Performance	X	X		X	
Rolling efficiency	X	X		X	
Light weight	X	X		X	
Resistance to puncture	X				
Good longevity	X				
Durability for distance	X				
Road	X	X		X	X
All terrain	X	X	X		
Grip under dry conditions	X	X	X		
Grip under wet conditions	X				
Grip in a dry country terrain	X	X		X	X
Grip in a wet country terrain	X	X		X	X
Heavy weight handling					
Charlesruhe					
Clerront-Fermand					
Mehico city					

4.3.1 Elaborate the Context-based System

The applicant, root concept, concept enquired and interoperability task are given at the moment of the request. The request made by the applicant is composed of:

1. The root concept which is usually part of the company ontology and describes the kind of data that the applicant searches;
2. The concept enquired to be evaluated and which can be chosen in a partner ontology;
3. The interoperability task, which the applicant may select in a list, and that signals what task the applicant intends to perform with the data retrieved.

The three usages put together permit the context-based evaluation of the concept enquired. By order of computations:

1. The usage of evaluation associates a value of pertinence to all perspectives associated with the concept enquired, according to the relevance of the data from the collaborating organization for the identified interoperability task;
2. The usage of disambiguation limits the perspectives associated with the concept enquired to those that are compatible with the perspectives associated with the root concept;
3. The usage of personalization restricts the perspectives associated with the root concept to

only those that are relevant for the applicant. With each of these perspectives, a value of relevance is associated that indicates the highest relevance possible of the perspective for the applicant's domains and tasks.

4.3.2 Working of the Context-based System

Figure 4 illustrates a possible working of the context-based system. While interacting with a user, the business application submits a request to the context-based system. This request is made of (1) the root concept – from an ontology defined by the user's company; (2) the concept enquired – from an ontology of the partner organization, (3) the user ID, and (4) an interoperability task from the user's company.

In response to this request, the following items are generated:

1. A value of global pertinence,
2. A generic value of similarity between concepts, and
3. As many couples of relevance and pertinence as there are couples of perspectives corresponding to couples of concepts that are compatible with one another. The first perspective is relevant according to the agent's domains and tasks, and the second perspective is pertinent according to the interoperability tasks indicated.
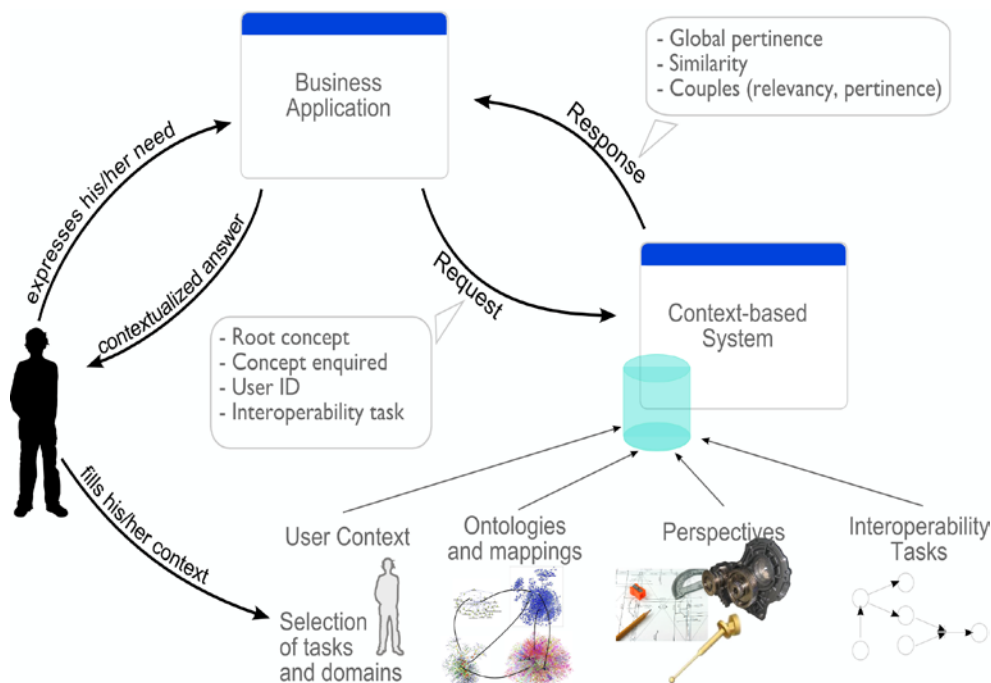

Figure 4: Illustration of the context-based approach

To achieve this, three preliminary stages are necessary: the first stage consists of the preparation of ontologies, domains and tasks, interoperability tasks and perspectives, and of the association of

perspectives with domains and tasks, along with a value of relevance.

The second stage relies on the agents' selection of their context among domains and tasks of the

company. The system uses this information along with the relevance associated with each triple (domain, task, perspective) to compute an applicant-specific value of relevance for each perspective of the company.

Collaborations with a new partner organization require that a third stage should be accomplished, which starts by the publication of ontologies and perspectives of organizations in a shared space. Then, external ontology matching tools can be used to generate mappings between ontologies of organizations. Finally, perspectives of the two organizations must be related, and interoperability tasks of the company should be associated with perspectives defined by the partner organization, along with a value of pertinence.

4.3.3 Evaluate the System Against Objectives

The solution that we proposed answers almost completely objectives posed at the beginning of the application of our methodology (section 4.1.1):

1. It improves the current usability of ontology reconciliation by providing an evaluation measure between custom concepts;
2. It is based on contextual information specific to the applicant (i.e. the user), the ontologies and the interoperability need. This contextual information puts ontology reconciliation in the larger context of the collaboration between two organizations, and of the practical use of the data retrieved through the collaboration;
3. It considers the pertinence of the data associated with the concept enquired. It does not consider directly the data associated with the root concept, but the perspective associated with it should show the connection with the data. The evaluation of the connection between concepts is based on the comparison of perspectives of concepts, thus taking into consideration the data associated with them;
4. It does not require the modification of ontologies, nor of data sources, thus preserving the flexibility of federative approaches. More, the system proposed behaves well in the case ontologies evolve and some entity names are altered: the system will stay workable (though not returning any result in relation with the entities altered).

However, our evaluation of the connection between concepts does not consider any of the information that is usually considered to define the meaning of concepts relatively to one another: mappings and semantic relations including *is-a* relations. This may result in retrieving concepts related to the task and meaningful to the applicant, yet not akin to the root concept at all. We will address this issue by a further analysis in next section.

4.3.4 Complete and Adjust the System

We need to complete the system with a similarity measure that should relate the root concept and concept enquired, that were previously connected only indirectly by their perspectives. We need to adapt a similarity measure between concepts in an ontology to a similarity measure between concepts defined in distinct ontologies.

The edge-counting similarity measure from Leacock and Chodorow [18] is simple (Equation 1), yet it always finishes first or second among 12 measures of different types [23] while getting homogeneously good results in another review [7]. Therefore, we consider this measure as our basic similarity measure that we will adapt so that it can be used to compare concepts from distinct ontologies, using mappings between concepts. Let a root concept c_1 defined in an ontology O_1 be compared with a concept enquired c_2 defined in an ontology O_2. If we can find a mapping of equivalence that relates the concept c_{m1} defined in O_1 with the concept c_{m2} defined in O_2, then c_1 and c_2 can be related to one another by a succession of is-a relations, and the mapping $c_{m1} - c_{m2}$. Equation 2 shows the measure adapted based on definitions from Table 9.

Table 9: Definitions for the measure of similarity

$c_1 \in O_1, c_2 \in O_2$	Concepts defined respectively in an ontology of the company, or in an ontology of the partner
$len(c_1,c_2)$	minimum number of *is-a* edges needed to relate concepts
D_1, D_2	Depth of the ontology O_1 (resp. O_2)
$\lambda_{subs}(c_{m1},c_{m2})$	1 if the mapping determined by (c_{m1}, c_{m2}) is a subsumption mapping, 0 otherwise
$p_1 \lhd c_1, p_2 \lhd c_2$	Perspectives p_1 and p_2 associated respectively with the concepts c_1 and c_2
$rel_{applicant}(p_1)$	Applicant specific relevancy
$pert_{ITask}(p_2)$	Interoperability-task specific pertinence

$$sim_{LC}(c_1,c_2) = -\log \frac{len(c_1,c_2)}{2D} \qquad (1)$$

$$sim(c_1,c_2) =$$
$$\max_{\{c_{m1}-c_{m2}\}} \left\| \frac{len(c_1,c_{m1})}{2 \cdot D_1} + \frac{len(c_{m2},c_2)}{2 \cdot D_2} + \frac{\lambda_{subs}(c_{m1},c_{m2})}{D_1 + D_2} \right\| \quad (2)$$

At the time of the request, mappings that relate ontologies in which the root concept and the concept enquired are defined are selected. For each mapping $c_{m1}-c_{m2}$, the distances $len(c_1,c_{m1})$ and $len(c_2,c_{m2})$, where c_1 is the root concept and c_2 the concept enquired, are computed. The required comparison of

thousands of say 200-character strings (twice the possible number of mappings) can be done in less than 100 ms on a recent computer.

We then compute a global value of pertinence based on the product of the relevance with the parameterized average of the values of similarity and pertinence (Equation 3).

$$sim_{applicant,ITask}(c_1, c_2) = \max_{p_1 \triangleleft c_1, p_2 \triangleleft c_2}$$

$$\sqrt{rel_{applicant}(p_1) \cdot (\lambda \cdot sim(c_1, c_2) + (1 - \lambda) \cdot pert_{ITask}(p_2))}$$

$$\text{with} \quad 0 \leq \lambda \leq 1 \tag{3}$$

5. DISCUSSION

The work includes two major innovations that are (1) the proposal of an unprecedented generic methodology to make any software system context-sensitive and (2) its application along with proof-of-concept to the realization of pragmatic semantic interoperability between business application systems. To our knowledge, this work is indeed the first to methodologically explore how context may be used to improve the pertinence of ontology reconciliation. Unless perspectives are considered, the use of ontology mappings for relating business information will necessarily prove insufficient due to the approximate coupling of concepts that they represent, and the likely irrelevance of associated information for the work at hand.

A context-based solution based on the architecture we propose can return relevance and pertinence values for each possible triple (root concept, concept enquired, interoperability task). The architecture that we came to as we applied the methodology answers all objectives set for a context-based ontology reconciliation system. It was yet limited in that the root concept and concept enquired were not compared with any of the semantic relations defined in ontologies, nor by mappings. They might therefore have been very dissimilar, while the root concept is supposed to guide the evaluation of the concept enquired. Hence, we included a generic measure of semantic similarity into the architecture that we adapted from [18] to the comparison of concepts across ontologies.

Our approach requires a certain amount of preliminary work being done by some members of the organization having good knowledge of the company domains and tasks, and able to identify perspectives with or for which ontologies have been developed. Is the preparatory work worth it? It certainly is, if as a result mappings can actually be used, and the comparison between ontology business concepts should gain in trust.

6. CONCLUSION

Our study demonstrates the advantages that the addition of context sensitivity brings to the mapping-based reconciliation of independent ontologies, as far as reaching down-to-earth business collaboration is concerned. The hypothesis is that organizations have ontologies that represent concepts corresponding to data they manipulate, and that they need to collaborate for concurrent projects. For these projects, organizations have to reconcile their ontologies to facilitate data exchange.

As ontologies were developed independently and are evolving autonomously, ontology mapping is the appropriate approach to reconcile these ontologies. The problem is that ontologies have been developed in totally different settings, entities mapped have different scope, for specific applications. Ontologies are mapped without considering any contextual information on how concepts will actually be used. We argue that by taking context into account, one can provide a better evaluation of pertinence of a concept for a given interoperability request.

We proposed a general definition of context, and have developed a methodology to determine what is contextual information, how to model and use it. We have applied this methodology to the reconciliation of ontologies, in the situation of concurrent collaborations across organizations where flexibility is needed. The result is a context-based evaluation of pertinence across ontologies, based on three kinds of contextual information:

1. The context of the ontology concepts made of perspectives, recognized to have guided the ontology development process, or revealing different kinds of data associated with the ontology. Perspectives of the root concept are compared with perspectives of the concept enquired, to *disambiguate* the pragmatic meanings of concepts by keeping only couples of perspectives that are compatible with one another;

2. The context of the agent (i.e. the user) that makes the request, which consists in a selection of domains and tasks of his company; this context is introduced to *personalize* the measure, by recognizing the understanding that the user has of the root concept, and retaining sole, the perspectives that are relevant for him;

3. The context of the interoperability need, made of the interoperability task for which the entity searched for is intended to be used. This context is introduced so as to *evaluate* the practical value of the concept enquired. Perspectives of the concept enquired are evaluated against the interoperability task, to judge of their pertinence.

This measure of pertinence is completed with a generic semantic similarity measure across ontologies

to relate all concepts defined in ontologies from the agent's company with concepts defined in ontologies from other organizations.

We are currently working on an extended proof-of-concept that should validate the pertinence of our work in the context of unanticipated business collaborations. The next step will be to offer assistance for two business companies in actually applying this approach to a collaboration need.

The methodology is generic and could be applied to other domains, such as healthcare: a context-based system could, for instance, automatically *evaluate* the criticality of the state of patients arriving at hospital based on sensor data, or assist medical doctors by automatically adapting medical software interfaces to match with the situation at hand based on correlated previous patients records.

The system proposed would be advantageously extended by the incorporation of schema matching tools, so as to facilitate data retrieval and exchange, once the suitable concepts have been identified. Further development of standard (preferably light) ontologies defining task-oriented concepts and relations for most business domains, could improve the reliability of ontology reconciliation and would benefit our approach.

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