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ABSTRACT

Web contents can be represented in a structural form by a finite list of vocabularies and their relationships using ontologies. The concept of ontology and its related mediation methods is capable of enhancing the collaboration among Knowledge Management (KM) approaches that only focus on managing organizational knowledge. Those KM approaches are developed in accordance with organizational KM strategies and business requirements without the concern of system interoperation. In this research, an ontology-based collaborative inter-organizational KM network is proposed to provide a platform for organizations to access and retrieve inter-organizational knowledge in a similar domain.

Keywords: ontology mediation, ontology mapping, ontology merging, ontology integration, knowledge management

INTRODUCTION

Over the past two decades, a lot of efforts have been placed in order to integrate heterogeneous information systems. This integration is essential because systems of different characteristics are able to communicate, cooperate, exchange information as well as reuse knowledge and services with one another. Especially in the era of the Internet, a transaction can hardly be completed without making use of others' data, information, knowledge and services, for instance, when customer is shopping in an online store, s/he may need to seek comments on the quality of a particular product from an external forum. Once s/he decides to purchase the product, the online store will have to contact related financial institutes for payment verification and confirmation. The online store is also required to arrange delivery service with shipping company. Such a simple online shopping transaction involves interoperation of at least three heterogeneous information systems, the complexness could be imagined if it is a multi-million dollar trade that involves the participation of more enterprises.

Artificial intelligence researchers first applied the concept of ontology in intelligence system development so that knowledge could be shared and reused among artificial intelligence systems. Ontology as a branch of philosophy is the science of what is, of the kinds and structures of objects, properties, events, processes and relations in every area of reality [26]. Ontology can be further elaborated as a particular system of categories accounting for a certain vision of the world [11]. The term, ontology, was then borrowed by artificial intelligence community and Tom Gruber's definition was widely accepted within the community: an ontology is an explicit specification of a conceptualization while a conceptualization is an abstract, simplified view of the world that we wish to represent for some purpose [10]. Later on, Borst [5] refines Gruber's definition by labeling an ontology as a formal specification of a shared conceptualization. Based on Gruber's and Borst's definitions, Studer, Benjamins and Fensel [27] make the following conclusion: 1) an ontology is a machine-readable specification of a conceptualization in which the type of concepts used and the constraints on their use are explicitly defined, and 2) an ontology should only capture consensual knowledge accepted by large group of people rather than some individual. By representing knowledge with representational vocabulary in terms of objects and their interrelated describable relationships, inference engine and other application program from one intelligence system will be able to understand the semantic of knowledge in another knowledge base.

The popularity of the Semantic Web further magnifies the importance of ontology. The Semantic Web is the extension of the current one, in which web content is represented in a structural form within ontologies by a finite list of vocabularies and their relationships [4]. In this way, ontologies enable computer program, software agent and search engine to understand the semantics, thus making it possible for them to process the web content. Ontologies also provide a shared understanding of a domain which is necessary to overcome differences in terminology from various sources [2].

Unfortunately, it is unrealistic to expect all individuals and organizations will agree on using one or even a small set of ontologies [6]. The adoption of such an approach is problematic. On one hand, it is lengthy and non-trivial to define and maintain a large globally shared ontology, on the other hand, the globally shared ontology approach may hinder a system from reflecting its actual business requirements due to the fact that the design of the system is restricted by terminologies defined in the ontology [14]. Researchers such as Berners-Lee, Hendler and Lassila [4] state that there would be a large number of small domain specific ontologies developed by communities, organizations, departments or even individuals. While multiple ontologies allow systems to be designed according to their actual requirements without committing to a particular set of terminologies, data heterogeneity caused by multiple ontologies has become an obstacle for the interoperation of systems. Since vocabularies and their relationships defined in the ontologies are

inconsistent, therefore it is impossible for one system to understand and reuse other ontologies unless the ontologies are reconciled in some form. The above inconsistent problem caused by multiple ontologies is commonly termed as ontology mismatches.

This research describes the three main meditation methods used to reconcile mismatches between heterogeneous ontologies. The research also investigates the application of ontologies and its mediation methods in the aspect of Knowledge Management (KM). The rest of the Chapter is organized as follows. Section 2 describes various approaches of ontology mediation. Section 3 discusses the application of ontology and its mediation methods in KM. This includes the development of a proposed mediation selection framework and ontology-based collaborative KM network. Finally, conclusion is given in Section 4.

ONTOLOGY MEDIATION APPROACHES

Based on the actual requirements, organizations and individuals are expected to develop their own ontologies of different languages, scopes, coverage and granularities, modelling styles, terminologies, concepts and encodings. To reuse other ontologies of different types, ontology mediation is required to reconcile mismatches between heterogeneous ontologies so that knowledge sharing and reuse among multiple data sources can be achieved [22]. There are three major kinds of ontology mediations which include mapping, merging and integration. Ontology mapping is a process of relating similar concepts and relations from different ontologies to each other in which the correspondences between different entities of the two ontologies are formulated as axioms in specific mapping language [6]. Since the involved ontologies do not require any adaptation, ontology mapping often specifies just a part of the overlap between ontologies which is relevant for the mapping application [23]. Two common approaches used to establish mapping between ontologies are listed as follows.

- The first approach is to relate all ontologies to a common top-level ontology so that different ontologies are mapped together indirectly by the top-level ontology [6]. Consequently, conflicts and ambiguities can be resolved since concepts used in different ontologies are inherited from the common ontology. However, this approach has three major drawbacks. First, constructing a large-scale common top-level ontology from scratch is never a simple task. Even if we take a simpler path by merging various local ontologies together, the experiences of building the Suggested Upper Merged Ontology (SUMO) told us that the actual merging process was trickier than expected, not only because there was inconsistency between chunks of theoretical content but also because there were structural differences between the local ontologies [18]. Second, this approach can only be adopted in a relatively stable environment where maintenance is minimal because a substantial amount of resources and overheads are required to maintain a common top-level ontology. Third, established mappings between local ontologies and top-level ontology can easily be affected by the elimination and addition of local ontologies as well as changes in either local or common ontologies because local ontologies are related indirectly with each other through the common ontology.

- Rather than mapping all ontologies to a common top-level ontology, one-to-one mapping approach requires mappings to be created between each pair of ontologies [22]. The lack of a common top-level ontology in this approach makes it possible to be adopted in a highly dynamic environment. This advantage may be offset by the lack of common terminologies, thus increasing the complexity of defining mapping between local ontologies. Another major drawback of this approach occurs when a large number of heterogeneous ontologies are involved in the interoperation. Such an interoperation will greatly increase the amount of mappings and extra effort is required to control and maintain the mappings.

The second type of ontology mediation is merging. Unlike mapping that links two separate ontologies together in a consistent and coherent form, ontology merging creates a new ontology (in one subject) by unifying two or more different ontologies on that subject and it is usually hard to identify regions of the source ontologies from the merged ontologies [21]. As compared with mapping that keeps the original ontologies unchanged, merging requires at least one of the original ontologies to be adapted so that the conceptualization and the vocabulary match in overlapping parts of the ontologies [7]. While a majority of semantic web researchers foresee the main stream would switch to the approach of developing enormous amount of small domain specific ontologies, McGuinness et al. [16] argue that some of the industries or organizations still require to develop very large and standardized ontologies, for instance, SNOMED CT is a comprehensive clinical ontology developed by the College of American Pathologists that contains about 344,549 distinct concepts and 913,697 descriptions [15]. Theoretically, it is more efficient and effective to merge existing ontologies than to build a large ontology from scratch. In practice, the process of ontology merging is more than just simple revisions, improvements or variations of the source ontologies since the involved ontologies are developed by different people for different purposes with different assumptions and using different vocabularies [21].

One of the most important phrases in the process of ontology mapping and merging is ontology matching. In general, ontology matching can be defined as the process of discovering similarities between two ontologies with the purpose of establishing semantic relationships in between [27]. It determines the relationships holding between two sets of entities that belong to two discrete ontologies. In other words, it is the process of finding a corresponding entity in the second ontology for each entity (for example, concept, relation, attribute and so on) in the first ontology that has the same or the closest intended meaning. This can be achieved by analysing the similarity of the entities in the compared ontologies in accordance with a particular metric [8]. Ontology matching (or similarity computation) can be processed exploiting a number of different techniques. To

provide a common conceptual basis, researchers have started to identify different types of ontology matching techniques and propose classifications to distinguish them, for example, Shvaiko and Euzenat [25] propose a classification that consists of ten ontology matching techniques. Another example is the classification framework developed by Leung, Lau and Fan [14]. Their framework provides an effective method to identify seven types of matching techniques and its related executive approach simply by examining the input of mediation system. The seven types of techniques are string-based, linguistic resources, constraint-based, alignment reuse, graph-based, taxonomy-based and model-based.

Finally, the third type of ontology mediation is integration. Pinto and Martins [21] define ontology integration as a process of building an ontology in one subject reusing one or more ontologies in different subjects and it is always possible to identify regions of the source ontologies from the integrated ontologies. Source ontologies may need some sort of refinements before they can be aggregated, combined and assembled together to form the resulting ontology. It is also important to include ontology integration in the early stage of the ontology building process, preferable during conceptualization and formalization, so as to simplify the overall ontology building procedure.

Application of Ontology in Knowledge Management

The concept of ontology and its related mediation methods can also be applied to solve the interoperation problem in the distributed KM environment. At the very beginning, KM is emerged with the purpose of preserving and capitalizing on organizational knowledge for the future benefit of organizations. KM encourages organizations to create and use knowledge continuously for the innovation and enhancement of service, product and operation. Simultaneously, it also aims to improve the quality, content, value and transferability of individual and group knowledge within an organization [17]. This is achieved by organizing formal, direct and systematic process to create, store, disseminate, use and evaluate organizational knowledge using the appropriate means and technologies.

Nonaka, Toyama and Konno [19] suggest that there are four methods to create organizational knowledge by means of interaction between explicit and tacit knowledge. While tacit knowledge is personal, complex and hard to communicate and formalize because it is gained through individual insights overtime and is resided in human, mind and body, explicit knowledge is structured, relatively simple and can be captured, recorded, documented, codified and shared using formal and systematic language [9]. The first method to create knowledge is socialization. It is the process of developing new tacit knowledge from tacit knowledge embedded in human or organization through experience sharing, observation and traditional apprenticeship. The second method is called externalization. This is the process of turning tacit knowledge into new explicit knowledge simply by transforming tacit knowledge in the form of document such as manual and report. The third method is combination. This is the process of merging and editing "explicit knowledge from multiple sources" into a new set of more comprehensive and systematic explicit knowledge. The last one is called internalization. This is the process of embodying explicit knowledge as tacit knowledge by learning, absorbing and integrating explicit knowledge into individual's tacit knowledge base.

The second and third stage of KM, store and disseminate, are often linked with technologies. Explicit knowledge created is collected and stored in some sort of database or knowledge base in which the users can access using "search and retrieve" tools, intranets, web access and applications, groupware and so on [1]. The retrieved knowledge can then be used by knowledge workers to add value to current business process, implement and coordinate organizational strategy, predict trends in the uncertain future, deliver new market values, create new knowledge, solve existing problems and so on [3]. The fifth stage of KM is knowledge evaluation. This phrase eliminates incorrect or out-dated knowledge [1]. In other words, organization must keep creating new knowledge to replace any knowledge that has become invalid.

Unfortunately, it is shown that some of the KM approaches, ranging from industrial specific, theoretical, to procedure-wise, are incompetent to cooperate with the current distributed knowledge environment, especially those that are designed to manage merely organizational knowledge, for example, the re-distributed KM framework is developed to manage organizational help desk knowledge [12]. Those approaches are tailor-made according to different organizational KM strategies and business requirements without the concern of system interoperation. The lack of interoperability means that heterogeneous Knowledge Management Systems (KMSs) from different organizations are not able to communicate, cooperate, exchange as well as reuse knowledge with one another. Wagner and Buko [28] argues that knowledge-sharing in an inter-organizational network allows a richer and more diverse body of knowledge to be created as compared with sharing in one organization.

The non-collaborative KMSs have several disadvantages for both knowledge workers and knowledge engineers. In terms of knowledge workers, they have to spend a lot of time and effort to look for relevant knowledge from different KMSs because they are often required to access knowledge from other knowledge sources in order to complete their works in the knowledge explosion era, for instance, an investment manager has to retrieve companies' financial reports, share performance reports and regional economy reports from external sources if s/he wants to adjust the proportion of a particular share in a investment portfolio. In terms of knowledge engineers, they have to waste a lot of resources in creating and updating organizational knowledge even though the same knowledge is available in other KMSs. As external source of knowledge is essential for organizational performance, a new inter-organizational KM practice is required to enhance the interoperability among independent KMSs and to encourage the sharing of knowledge across organizational boundaries in their business networks [20].

Nevertheless, the absence of a common language or

standardization has put up a barrier to prevent the collaboration of KMSs [24]. Although the emergence of middleware technology has provided a way to enhance the interoperability of KMSs, the concept of middleware can hardly be accommodated in the era of the Internet as each pair of KMSs are required to implement a tailor-made middleware for interoperation [13]. Since a single KMS is interconnected with a huge amount of systems via the Internet, it is impractical to customize and install a middleware for each connection. Another deficiency of middleware is that even if the involved systems only undergo minor modification, the middleware may require a complete re-construction.

Ontology-based Collaborative Inter-organizational Knowledge Management Network

Let us consider the following scenario. At University A, if a lecturer does not know how to send customised email to his/her students using Mail Merge, the first thing s/he can do is to access the KMS managed by the IT help desk of the university. S/he can then search the relevant knowledge by making selections from several drop-down lists on the user interface of the KMS that can best describe Mail Merge. If the knowledge is available, then it will be shown on the user interface of the KMS. If not, s/he will have to search again in knowledge bases offered by University A or other organizations. Unfortunately, the process needs to be repeated for every single knowledge base until s/he can find the desired knowledge. Finally, if s/he still cannot find any related knowledge, s/he may choose to search again using other search mechanisms such as Yahoo and Google.

In this research, we propose to use ontology and its related mediation methods to solve the collaboration problem of heterogeneous KMSs in the Internet environment. Ontology is incorporated to allow explicit knowledge to be annotated in the form of machine process-able metadata. Although different organizations possess their own set of ontologies, the mediation methods are capable of reconciling the underlying heterogeneities of ontologies. In this way, the concept of ontology and mediation enables organizational KMS to understand incoming request and the returned knowledge, thus making it possible for them to collaborate and communicate with each other. We argue that the knowledge reusability and mismatches reconcilability of ontology and its related mediation methods can further contribute towards reformation of existing KM frameworks that focus only on managing organizational knowledge. Therefore, we propose to develop an ontology-based collaborative inter-organizational KM network that provides a platform for organizations to access and reuse inter-organizational knowledge with a similar domain. Here, inter-organizational knowledge is defined as a set of explicit knowledge formalized and created by other organizations. In the network, the formalized inter-organizational knowledge is reusable in a way that it can be retrieved by any organizations to support their own KM processes in terms of knowledge creating, storing, dissemination, using and evaluation.

Each network should only contain knowledge of a specific domain to ensure knowledge workers can retrieve relevant knowledge in an efficient manner, for example, an IT network should only provide knowledge in the discipline area of IT. Once an organization recognizes the need for a certain type of knowledge, the organization can invite other organizations and knowledge providers to establish a domain specific knowledge network, for example, an IT help desk of a university can decide to invite IT help desk of other universities and organizations as well as IT service providers to establish a knowledge network that contains only IT knowledge. When a network for a particular knowledge becomes mature, organizations in need may choose to join instead of establishing new one. Within the network, each organization or knowledge provider must commit to a mutual agreement to allow other participants to access an agreeable portion of ontology and the associated knowledge in its knowledge base. Besides, a single organization can commit to more than one knowledge network regardless of domain, for instance, a university may choose to commit to networks of IT, economics, mechanical engineering, education and chemistry whereas IT help desk of Company A may choose to commit to network of hardware and software..

Selection Framework for Ontology Mediation

Before continuing the description of the proposed network, the participating organizations must first make four important decisions related to ontology mediation. Figure 1 illustrates a selection framework for ontology mediation in the form of a matrix. The first decision is whether to adopt top-level ontology or one-to-one as the network level mapping approach. As this decision is on the network level rather than an organizational aspect, the organizations as a whole must compromise in order to select the most appropriate mapping approach for the benefit of the entire network. The decision process should include a thorough assessment and discussion from the aspects of resources, expertise and frequency of modification among all organizations in the network. The top-level ontology approach can only be applied to an environment where maintenance effort is minimal even though such an approach can provide a better mechanism to resolve conflicts and ambiguities. Whenever a minor modification is performed in one of the ontologies in the network, the shared ontology used in the top-level ontology approach may need a complete reconstruction. The organizations must also make sure that they have sufficient resources and expertise to build the shared ontology. If frequent maintenance is required or resources and expertise are insufficient, it may be more appropriate to use the one-to-one approach.

The second decision is whether to perform mediation automatically or semi-automatically. Mediation can be performed semi-automatically which requires the support of automatic tools as well as human intervention. The forms of support provided by automatic tools include similarity computation, post-mediation verification, validation, critiquation as well as conflict recognition and resolution. Although semi-automatic mediation could have a better performance than the manual one in terms of accuracy, it still substantially relies on human efforts and can be time consuming. Without human intervention, the process of

semi-automatic mediation cannot be completed, thus compromising accuracy of the mediation result. As semi-automatic tool is not capable of supporting mediation on-the-fly, it would be ideal to perform mediation automatically. Unfortunately automatic tools are unable to detect and interpret concepts that do not have close correlation. Moreover, it may also fail to handle any unforeseeable situations as the tool is designed to perform mediation under certain pre-defined conditions. However, if automatic mediation is adopted and inference mechanism is built on top of it, then inaccurate results can reduce the value of the mediation process.

The third decision is whether to adopt merging, mapping and/or integration as the desired mediation method for each organization. Each organization can choose one or more methods based on its own need. The concept of mapping enables ontology to be developed in response to its actual business requirement and is more suitable in a fluctuant business environment. Here, fluctuant business environment refers to an environment where organizations need to modify their ontologies in a frequent manner. Unless ontology has undergone major modification, simple modification, such as adding or deleting a concept from ontology, may merely require updating the mappings accordingly. Alternatively, merging is an appropriate method for creating an ontology that combines common views of multiple source ontologies. In other words, the merged ontology should include all possible correspondences and differences among the entire set of source ontologies. As a result, the merged ontology could act as 1) a single ontology used to substitute individual source ontology, 2) a shared ontology (reference point) used in top-level ontology mapping approach, or 3) an organizational ontology that includes all possible views of other organizations' ontologies. Unlike merging, integration selects only opposite modules from individual source ontologies to form an integrated ontology. Thus, integration is appropriate for organizations to customize ontologies based on their own needs. For example, the library at University A can customize a KM-based ontology by integrating portions of ontologies derived from other libraries and other academic publishers.

The final thing needs to be considered is whether to adopt single or multiple matching techniques. In the decision process, organizations must also take execution duration, acceptable level of matching accuracy and resources level for implementation into consideration. In general, multiple strategies are expected to generate more accurate result than single matching technique; however it is not always the case. The choice of aggregation algorithm and cut off point also plays an important role in determining the level of matching accuracy. When choosing multiple strategies as its matching technique, organization must conduct a series of experiments with the purpose of finding the right combination of multiple strategies, aggregation algorithm and cut off point to produce the most accurate result. Compare with single matching technique, multiple strategies are relatively difficult to design and implement and it requires longer execution time.

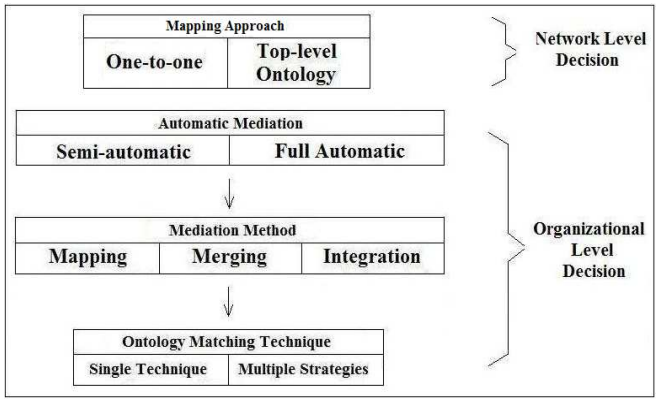

FIGURE 1: SELECTION MATRIX FOR ONTOLOGY MEDIATION

Operation of the Ontology-based Collaborative Inter-organizational Knowledge Management Network

The reconcilability of ontology mediation allows the participating organizations to reuse inter-organizational knowledge within the network even if there are fundamental differences among organizations in terms of KMS structures and formats. Under mutual agreement, organizations are permitted to retrieve inter-organization knowledge and the retrieved knowledge can be reused to support the five stages of KM process. Conventionally, technology has very limited contribution in knowledge creating stage especially in socialization, externalization and internalization where tacit knowledge is involved, for example, word processing tools can be used to record and visualise explicit knowledge in externalization and internalization, whereas communication tools such as email and telephone provide platforms for exchanging explicit knowledge in socialization.

However, ontology merging tool can provide a practical way to create knowledge by combining two or more ontologies together semi- or automatically in the network. This can be achieved on both network and organizational level. On the former level, merging tool is capable of creating a shared ontology for top-level mapping approach that contains common views of all organizational ontologies in the network. On the latter level, organization can create its own domain specific ontology by merging relevant ontologies from other organizations within the network. In addition, ontology integration tool provides an alternative way to create knowledge. Using integration method, organization can create its own knowledge by integrating relevant parts of ontologies from other organizations in the network into its own ontology building process. Both merging and integration enable organizations to reuse not only the contents of other ontologies but also their associated inter-organizational knowledge stored in the knowledge bases of other organizations. While ontology merging and integration are never a trivial task even with the assistance of automatic tools, they are still less demanding than building it from scratch.

Knowledge dissemination tool allows user to retrieve and use

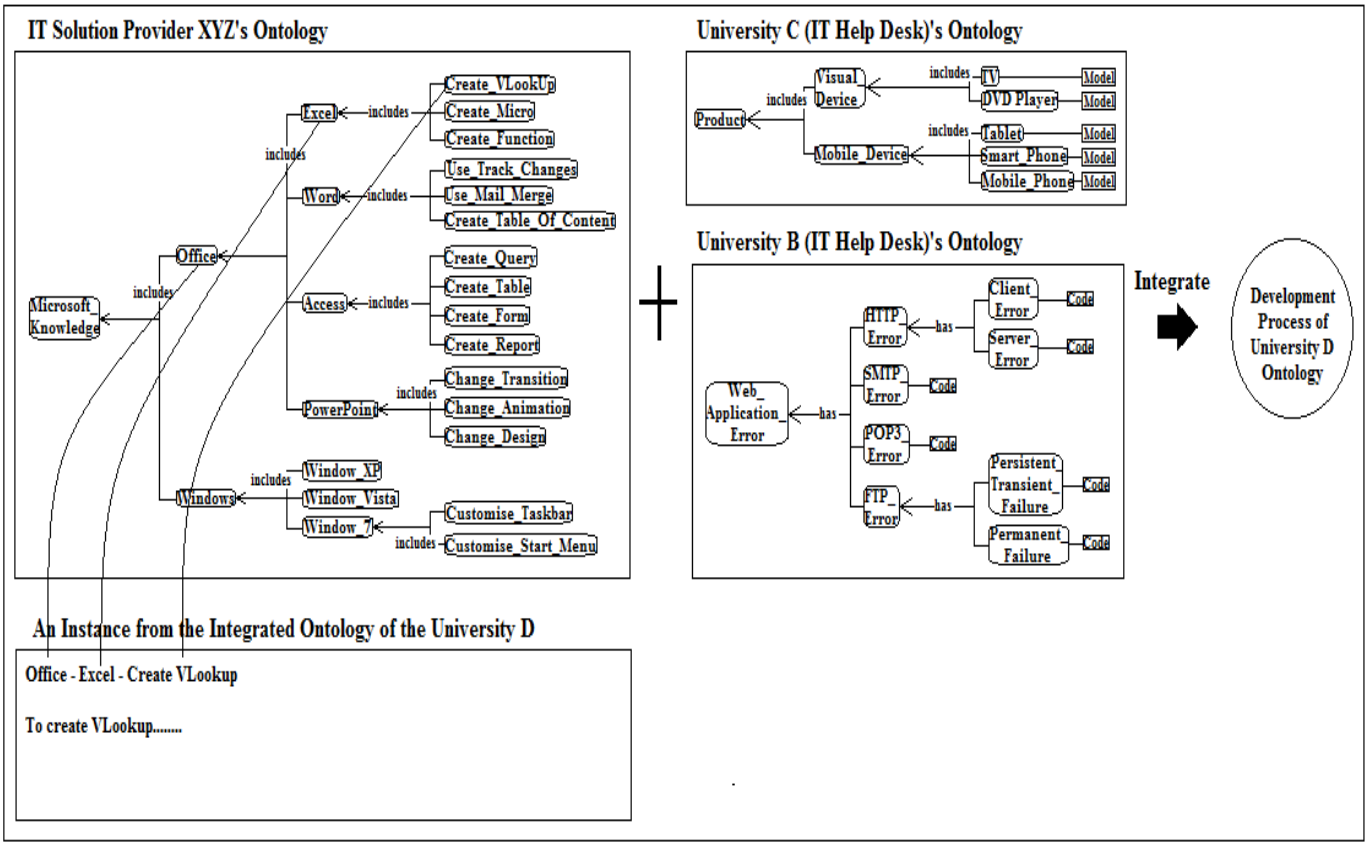

FIGURE 2: PROCESS TO DEVELOP UNIVERSITY D'S ONTOLOGY USING INTEGRATION METHOD

knowledge from organizational knowledge repository. If user cannot find suitable organization knowledge, s/he has to seek from other external sources. This can be achieved by creating mappings among ontologies of different organizations either semi- or automatically with the support of ontology mapping tools. The established mappings allow one KMS to access another KMS in the same network. Besides, it is also practical for mapping to be performed on-the-fly. In this case, automatic mapping tool is responsible to look for, select and establish mapping with the most relevant concepts and properties from other ontology in the network. Whenever the required knowledge is not available in the organizational repository, the KMS is able to retrieve and deliver inter-organizational knowledge in a "black box" through the establishment of mappings. In addition, inter-organizational knowledge can be reused to support knowledge evaluation process. This is accomplished by setting up dedicated mapping between two or more ontologies. Once a piece of inter-organizational knowledge is updated, this it will be translated into a suitable format and delivered from source knowledge base to the target automatically via the pre-established mappings. To demonstrate the reconcilability of ontology mediation and reusability of inter-organizational knowledge in the network, let us consider the following scenario.

Assuming IT help desk of University A realizes that there is an increasing demand in IT related knowledge and this demand cannot be satisfied with the current knowledge reposited in its knowledge base. Consequently, University A decides to invite IT service providers and IT help desks of other organizations to establish a network that contains IT related knowledge which include help desk of University B, University C and University D, Application Service Provider ABC and IT Solution Provider XYZ. Except for University D, all other participating organizations possess ontologies. Figure 3 shows a partial view of the classification ontology adopted in the IT help desk of University A. In this ontology, the concept software problem has two concepts, performance problem and functional problem, as its subclasses. Each subclass can be further categorized according to its own needs, for instance, University A supports four type of standard application software in its IT help desk. Thus, the ontology reflects this by including concept Internet Explorer problem, McAfee Virus Scan problem, Ms Office problem and Adobe PDF problem as an extension of concept standard software problem. Figure 3 also shows a partial view of the classification ontology in IT Solution Provider XYZ. There are two major subclasses under concept Microsoft knowledge, namely concept Office and Windows. Similar to University A, each subclass can be categorised into a set of more specific subclasses, for example, concept Excel, Word, Access and PowerPoint are specified as subclasses for concept Office. As the network supports IT related knowledge, both University A and IT Solution Provider XYZ are willing to share their IT knowledge that belongs to concept software problem and Microsoft knowledge respectively for mutual benefits.

After careful consideration, the six organizations have reached a mutual agreement not to adopt top-level ontology as the network-wide mapping approach. This decision is based on the fact that there will be many more organizations wishing

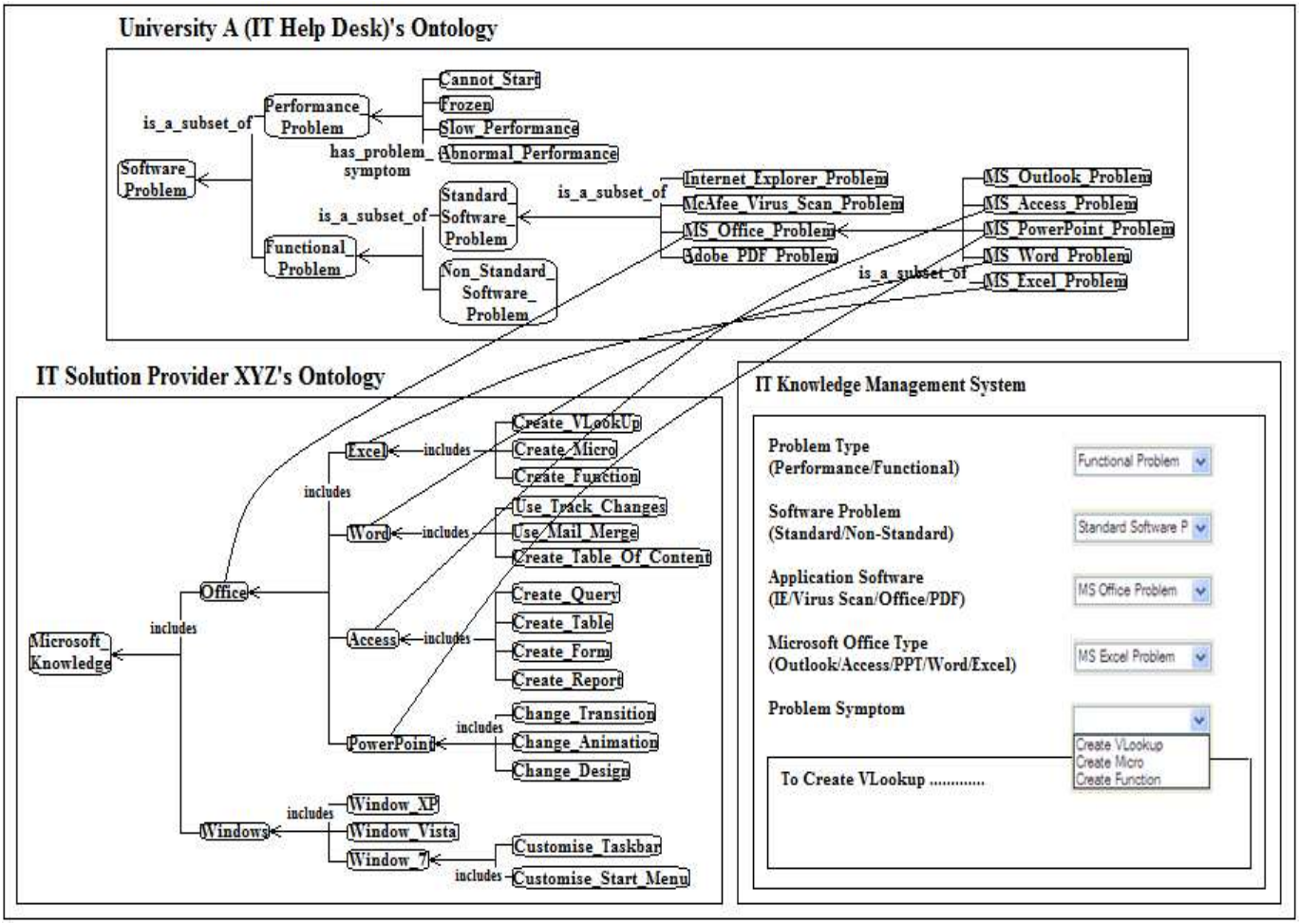

FIGURE 3: INTER-ORGANIZATIONAL KNOWLEDGE RETRIEVAL AND REUSING PROCESS

to join the newly established network, so the shared ontology built for the top-level ontology mapping approach may require to undergo a series of reconstructions. Although they have sufficient expertise and resources to build and reconstruct the shared ontology, it is not cost effective to do so. In addition, the reconstruction works will definitely affect the stability and performance of network-wide mediation because the shared ontology will be mapped by all other ontologies as a reference point. At this moment, the organizations prefer to use one-to-one mapping approach. However they have agreed to review the mapping approach after the organizations wishing to join the network stabilized.

As the IT help desk of University D does not possess ontology, the help desk has to create one in order to fulfil the requirement of joining the network. Instead of building from scratch, the help desk decides to reuse ontologies from other organizations and integrate them into its own development process using ontology integration method. However, the chosen ontologies must contain IT knowledge in the areas of hardware, software or web applications. Based on this criterion, the IT help desk reuses only a portion of the three ontologies that include the concept web application error and its subclasses derived from the IT help desk of University B, the concept product and it subclasses derived from the IT help desk of University C and the concept Microsoft knowledge and its subclasses derived from IT Solution Provider XYZ (see Figure 2). In the ontology development process, the IT help desk of University D can reuse not only the ontologies of other organizations, but also their inter-organizational knowledge associated as instances of those ontologies. As illustrated in Figure 2, the IT knowledge (instance) described using concept Office, Excel and create Vlookup can be captured from the knowledge base of IT Solution Provider XYZ and stored in the knowledge base of University D. This integrated ontology created by the help desk of University D has an additional function. By establishing dedicated mappings between integrated ontology and its ontology providers (that is, University B and C as well as IT Solution Provider XYZ), the associated knowledge captured in the knowledge base of University D can be automatically updated as long as there is a revised version generated from the ontology providers, In this case, whenever the knowledge (create VLookup) undergoes a revision in the knowledge evaluation process, the revised knowledge will not only be stored in the knowledge base of IT Solution Provider XYZ, it will also be broadcasted to other KMS through the dedicated mappings that include the knowledge base of University D. To allow general users to retrieve and use inter-organizational knowledge, organizations are required to establish mappings between its own ontology and ontologies of other organizations in this network. As shown in Figure 3, each solid line represents a mapping between a pair of concepts that belong to two different ontologies. Making use of string-based and linguistic resources matching techniques, two similar concepts from the ontologies of University A and IT Solution

Provider XYZ are mapped with each other, for instance, two semantically identical concepts, Office and Ms Office Problem, from the ontologies of University A and IT Solution Provider XYZ are mapped together.

In Figure 3, a user is searching for IT knowledge by choosing right options from problem type, software problem, application software and Microsoft Office type drop-down list on the user interface of the KMS of University A. Since there is no relevant knowledge stored in the KMS that can satisfy user's criteria, the system begins to search other KMSs including IT Solution Provider XYZ. The mappings allow the KMS of IT Solution Provider XYZ to understand incoming requests, for example, the options chosen in application software and Microsoft Office type drop-down list are semantically identical to Office and Excel concept in IT Solution Provider XYZ. The chosen options also trigger the ontology of IT Solution Provider XYZ to populate problem symptom drop-down list with concept create VLookUp, create macro and create function. As long as the requested knowledge is available in the knowledge base of IT Solution Provider XYZ (in this case, it is the knowledge on how to create VLookUp), it will be delivered to the user interface of University A. Subsequently, the knowledge will be displayed as if it is retrieved from its own knowledge base. In other words, the entire inter-organizational knowledge retrieval and displaying mechanism are performed in a "black box" manner.

Conclusion

Organizations are not capable of reusing inter-organizational knowledge even though the required knowledge is available in knowledge bases of other organizations because the organizational based KM approaches are designed for managing organizational knowledge only. An ontology-based collaborative inter-organizational KM network is proposed to solve the problems. A selection framework is also proposed to assist organizations in choosing suitable ontology mediation approaches during the establishment of the KM network, ranging from mapping approaches, levels of automation, mediation methods to matching techniques. The knowledge reusability and mismatches reconcilability of ontology and its related mediation methods enable organizational KMSs to understand the incoming request and the return knowledge, thus making it possible for them to collaborate and communicate with each other. By annotating knowledge explicitly in the form of machine process-able representation, organizations within the network can access, retrieve and reuse domain specific inter-organizational knowledge to support the five stages of organizational KM process. While knowledge engineers could reuse inter-organizational knowledge to create and evaluate organizational knowledge, general users are benefit from the effectiveness and efficiency in searching for relevant inter-organizational knowledge within the network.

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