Developing ontology revision framework: A case study on the use of the coherence theory for semantic shopping mall

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Abstract

Why is ontology revision important? Very often, ontology exists in a particular period of timeline is often designed based on the purpose of a domain of interest at that instance of time. However over time, ontology needs to be revised due to changes in content, environment, requirements, or even structural representation. As a result, revision and updating of necessary components in the pre-defined ontology is unavoidable. When this happens, it is important to ensure that revision is conducted in a consistent manner so that it does not result in unforseen redundancies and inconsistencies. Any revision performed must be accompanied by a rational change to be dealt with from the consistency perspective. This paper presents an ontology revision approach to achieve this aim based on the coherence theory model of belief revision theory. An application scenario of semantic shopping mall is used to demonstrate the approach.

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Developing Ontology Revision Framework:
A case study on the use of the coherence theory for semantic shopping mall

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Abstract - **Why is ontology revision important? Very often, ontology exists in a particular period of timeline is often designed based on the purpose of a domain of interest at that instance of time. However over time, ontology needs to be revised due to changes in content, environment, requirements, or even structural representation. As a result, revision and updating of necessary components in the pre-defined ontology is unavoidable. When this happens, it is important to ensure that revision is conducted in a consistent manner so that it does not result in unforseen redundancies and inconsistencies. Any revision performed must be accompanied by a rational change to be dealt with from the consistency perspective. This paper presents an ontology revision approach to achieve this aim based on the coherence theory model of belief revision theory. An application scenario of semantic shopping mall is used to demonstrate the approach.**

Keywords – **Semantic web, ontology, ontology revision**

I. INTRODUCTION

The World Wide Web (WWW) has changed the way information is accessed and disseminated. It has also changed the way business is conducted through e-business systems. In its simplest form, web documents are marked up using hyperlinks and information are accessed and cross-referenced in a non-linear fashion. Web documents can be retrieved based on individual's information needs. However this type of web-based information seeking fashion has been designed mainly for human interpretation. The increasingly widespread WWW applications have extended the opportunity for software agents to access and interpret web documents and resources. This is the vision of the Semantic Web, which aims to enable content of web resources to be interpreted and processed by software agents. According to Berners-Lee [1], the Semantic Web is an extension of the current Web because it provides a framework to share and reuse data associated with web resources in a manner that can be autonomously performed by software agents [18]. In fact, the term "semantic" in the Semantic Web refers to the way data in the Web conveys meaning in such a form that makes it machine- readable and processable [1], thus providing a mechanism for software agents to interpret data in web resources and to perform any task autonomously in the WWW environment. Examples of such tasks include scheduling, searching for information, controlling and managing work processes and even authentication and security. The agents need to understand the meaning associated with web resources before it can read data and process any task. The agents also need to know how to integrate data and information from different resources such as integrating product information from different web sites to complete a purchase transaction.

The motivation of this research is to investigate ways to ensure consistency can be achieved when ontology revision is performed. This is important because the Semantic Web usually comprises of small, simple ontology constructed separately by different users [9]. Thus, there will be a time when existing ontology needs to be updated or revised due to discovery of new information or changes made in the application domain. In this case, any changes made to the structural representation in ontology needs to be checked to ensure the newly revised representation is consistent with existing representation. We applied belief revision theory as a means to revise ontology and to ensure consistency is achieved after the ontology is revised. We will describe the approach through an application scenario of Semantic Shopping Mall.

The rest of this paper is organised as follows. Section 2 presents background to ontology. Belief revision theory will also be discussed in this section. Section 3 presents a scenario of semantic shopping mall together with illustration of the ontology revision operators. Section 4 discusses issues and problems encountered in the implementation and section 5 concludes the paper.

II. BACKGROUND

The application of ontology in the Semantic Web facilitates conceptualisation of abstract world. Ontology is a form of knowledge representation that enables integration of data amongst web resources and to link well-defined, agreed and commonly used vocabularies to allow software agents to perform tasks autonomously. In the context of knowledge representation, ontology is a specification of conceptualisation [7]. Conceptualisation is an abstract, simplified view of the world that we wish to represent [6]. In this case, we can say that ontology represents the abstract world of web resources in the Semantic Web. This abstract world is represented by ontology and its meanings are conveyed through definition of relevant terminologies and vocabularies associated with that conceptual information. As ontology deals with representation of web resources to enable it to

be machine- readable and processable, it holds the representation of what is believed to be valid for a web resource. This representation of web resource is similar to the belief that an agent has. In this aspect, revising structural representation of ontology, in a similar way, is dealing with revising the belief sets of web resources in the Semantic Web.

Just as web pages are constructed individually and links are set up by individual to inter-relate web documents, ontology associated with different web resources is similarly constructed individually based on individual definitions of associated with each web resource. According to Hendler [9], the Semantic Web comprises of small, simple ontology constructed separately by different users. In this case, there will be a time when existing ontology needs to be updated and revised due to discovery of new information, discarding of old information or even revising information due to changes associated with the application domain [8]. Generally speaking, ontology is used to structurally represent a conceptualisation, therefore any changes made to the structural representation in ontology needs to be checked to ensure the newly revised representation is consistent with the existing representation. Current research on ontology revision has been investigated mainly from ontology evolution and ontology maintenance perspectives [1, 2, 3, 11, 12, 15, 17]. However it has rarely been investigated from the revision perspective, in particular in ensuring that structural consistency is achieved after the revision process.

The study of belief revision theory has been extensively discussed in the area of Artificial Intelligence (AI). From the AI perspective, belief revision is a process by which an intelligent agent revises her set of belief at a particular instant of time [13]. It deals with the way intelligent agent revises or changes its own belief through interaction with the external world. A belief is a kind of mental state that represents one's attitude towards some state of event or thing. It can be something that we know to be true or false. Common representation of belief can be formed in a set of propositions, which are logic sentences that affirm or deny a fact. The coherence theory draws attention to the logical structure of things in a world [5]. It emphasizes on beliefs being able to remain consistent with each other in the belief set. The coherence theory does not require beliefs to be justified on the basis of support evidence and prior conclusions rather than on the basis of what one already knows. Generally when a belief cannot be justified, it needs to be removed after the beliefs are revised. In the case of coherence theory, new belief can be accepted in the belief set if it is coherent with existing beliefs in the belief set. Here, coherent refers to there exists inter-relation amongst beliefs that are connected with other beliefs in a belief set.

In this paper, we focus on the coherence theory of belief revision. In the coherence theory model, minimal loss of

information is preserved using the concept of epistemic entrenchment, which is a concept that describes the degrees of importance of a belief. It is a useful concept to decide which belief to remove during the belief revision process. The application of epistemic entrenchment ensures only beliefs that are least entrenched being removed, in which the coherence of a belief with other beliefs is emphasised through minimal belief change. This is based on the principle of information economy to keep as much old beliefs as possible and to make minimal changes to the belief set [14].

There are three belief revision operators associated with the belief revision theory: expansion, contraction and revision. Firstly, an expansion of a belief set can be thought of as a set operation that changes the belief state from the state of *unknown* to *true* or from *unknown* to *false*. This is a common change resulting from learning new belief. Secondly, a revision of a belief set can be thought of as a set operation that changes the belief state from *true* to *false* or from *false* to *true*. Finally, a contraction occurs when a belief in the belief set is retracted. There are several postulates to enable the above three operators to perform successfully. For an expansion operator, postulates from (K+1) to (K+6) in TABLE 1 should be satisfied [4]. The *closure* postulate states that when a new sentence α is added to K together with its logical consequences, the belief set that results from expanding K by α is also a belief set. It is denoted as K^+_α. The *success* postulate shows α is accepted into the expanded belief set K. This is the requirement to be accepted for K. In the *expansion* postulate, it shows that after expanding α to belief set K, we can show that the original belief set K is a subset of the expanded belief set K^+_α. If α is already in the belief set K, the *inclusion 1* postulate shows that expanded K is the same as K. Thus K^+_α is the same as K. The *inclusion 2* postulate shows that if belief set K is a subset of H, then expanding K by α will also result in the expanded set of K^+_α remain the subset of H^+_α. The *representation* postulate indicates that K^+_α should be the smallest possible set, and its expansion should not include beliefs that do not meet requirements of $(K+1) – (K+5)$.

TABLE 1
EXPANSION RATIONAL POSTULATES

(K+1) For any sentence α and any belief set K, K^+_α is a belief set.	(Closure)
(K+2) $\alpha \in K^+_\alpha$.	(Success)
(K+3) $K \subseteq K^+_\alpha$.	(Expansion)
(K+4) If $\alpha \in K$, then $K^+_\alpha = K$.	(Inclusion 1)
(K+5) If $K \subseteq H$, then $K^+_\alpha \subseteq H^+_\alpha$.	(Inclusion 2)
(K+6) For all belief sets K and all sentences α, K^+_α is the smallest belief set that satisfies (K+1) – (K+5).	(Representation)

The contraction operation retracts a belief from the belief set without adding any new belief. The result of contracting K with respect to α is denoted as K^-_α. TABLE 2 shows the postulates in relation to contraction operation. The *closure* postulate shows the outcome of contraction

applied to K is also a belief set. In the *inclusion* postulate, the resulting belief set K^-_α is a subset of K. This is obvious because a belief has been removed from K. The next *vacuity* postulate states that if α is not in K, then K^-_α is identical to the original belief set K. The *success* postulate states if α does not logically entail, then α *is not in* K^-_α. The *recovery* postulate shows that α can be recovered by expanding the same input α in K^-_α. The *extensionality* postulate states that if α and β are logically equivalent, then it leads to identical contractions, that is, $K^-_\alpha = K^-_\beta$. The *conjunction 1* postulate states that two contracted belief sets are a subset of belief set that contracted both beliefs. Finally the *conjunction 2* postulate expresses that if α is not in $K^-_{\alpha \wedge \beta}$, then $K^-_{\alpha \wedge \beta}$ is a subset of K^-_β. Similarly, if α is not in $K^-_{\alpha \wedge \beta}$, K^-_β can be recovered by $K^-_{\alpha \wedge \beta}$

TABLE 2
CONTRACTION RATIONAL POSTULATES

(K-1) For any sentence α and any belief set K, K^-_α is a belief set.	(Closure)
(K-2) $K^-_\alpha \subseteq K$.	(Inclusion)
(K-3) if $A \notin K$, then $K^-_\alpha = K$.	(Vacuity)
(K-4) if not $\vdash \alpha$, then $\alpha \notin K^-_\alpha$.	(Success)
(K-5) if $\alpha \in K$, then $K \subseteq (K^-_\alpha)^+_\alpha$.	(Recovery)
(K-6) if $\vdash \alpha \leftrightarrow \beta$, then $K^-_\alpha = K^-_\beta$.	(Extensionality)
(K-7) $K^-_\alpha \cap K^-_\beta \subseteq K^-_{\alpha \wedge \beta}$	(Conjunction 1)
(K-8) if $\alpha \notin K^-_{\alpha \wedge \beta}$, then $K^-_{\alpha \wedge \beta} \subseteq K^-_\beta$.	(Conjunction 2)

Finally, the revision operation refers to changing the state of a belief from truth to false or from false to truth. It aims to ensure consistency is maintained when a new sentence that has been added causes contraction with existing beliefs in K. Thus, we can say that revision operation can be seen as a combination of expansion and contraction. In fact, revision postulates have some of the expansion postulates such as (K*3), and (K*4) and contraction postulates (K*6). The result of revising K by a sentence α is denoted as K^*_α. There are six basic AGM revision postulates: (K*1) − (K*6) (See TABLE 3). The *closure* postulate shows that when we revise a belief set K by α, the outcome of that operation also result in a belief set. The *success* postulate guarantees that α is accepted in K^*_α. The next two postulates (K*3) and (K*4) show that the revision can be seen as expansion. In the *expansion 1* postulate, it shows that the revised belief set K^*_α is a subset of K^+_α. According to *expansion 2* postulate, if $\neg \alpha$ is not in K then K^+_α is a subset K^*_α. In other words, we say that if α is consistent with expanded K, then all elements of K are consistent in the revised K by α. In the *consistency preservation* postulate, logically equivalent sentences should lead to identical changes. The *extensionality* postulate shows that if α logically entails β, then K^*_α is the same as K^*_β. This means logically equivalent sentences α and β should lead to identical changes in K. The *conjunction 2 and rational monotony* postulates show that if β is not contracted in K^*_α, composite revision in K by α and β should be done by first revising K with α and then expanding by β.

TABLE 3
REVISION RATIONAL POSTULATES

(K*1) For any sentence α and any belief set K, K^*_α is a belief set.	(Closure)
(K*2) $\alpha \in K^*_\alpha$.	(Success)
(K*3) $K^*_\alpha \subseteq K^+_\alpha$.	(Expansion 1)
(K*4) If $\neg \alpha \notin K$, then $K^+_\alpha \subseteq K^*_\alpha$.	(Expansion 2)
(K*5) $K^*_\alpha = K\perp$ if and only if $\vdash \neg \alpha$.	(Consistency Preservation)
(K*6) If $\vdash \alpha \leftrightarrow \beta$, then $K^*_\alpha = K^*_\beta$.	(Extensionality)
(K*7) $K^*_{\alpha \wedge \beta} \subseteq (K^*_\alpha)^+_\beta$.	(Conjunction 1)
(K*8) If $\neg \beta \notin K^*_\alpha$, then $(K^*_\alpha)^+_\beta \subseteq K^*_{\alpha \wedge \beta}$.	(Conjunction 2, Rational Monotony)

One of the main concerns relating to the underlying idea of revision and contraction operations is the removal of potentially useful information. Unfortunately, there is no formal way to decide what sentence is to be removed or to be modified in the belief set [16]. To address the problem of which belief to revise and contract during the belief revision process, an idea based on accepting different degrees of epistemic entrenchment is considered. The basic idea of epistemic entrenchment is that some beliefs have different degrees of importance in the belief set. It implies that certain beliefs are more important than others. In the case of a contraction or a revision, epistemologically least entrenched sentence is retracted first to ensure minimal loss of information. There are five postulates in relation to entrenchment (see TABLE 4). The first *transitivity* postulate states that if π is more entrenched than θ and χ is more entrenched than π, then χ is more entrenched than θ. The second *dominance* postulate states if θ logically entails π, then π is more entrenched than θ. The underlying idea of this postulate is related to the *minimal change principle*, that θ is at most as entrenched as π so that θ may be given up without retracting π. In the *conjunctiveness* postulate, for any θ and π, the conjunct of sentence $(\theta \wedge \pi)$ is more entrenched than either θ or π separately. Retracting the conjunction $(\theta \wedge \pi)$ can be achieved either by retracting θ or retracting π. The next *minimality* postulate states that when K is not equal to $K\perp$, then θ is not in K if and only if π is more entrenched than θ. This means sentences already not in K have minimal epistemic entrenchment in relation to K. Finally, if θ is more entrenched than π, then θ logically entails, which represents only logically valid sentences are maximal in the relations.

TABLE 4
EPISTEMIC ENTRENCHMENT POSTULATES

(EE1) if $\theta \leq \pi$ and $\pi \leq \chi$, then $\theta \leq \chi$.	(Transitivity)
(EE2) if $\theta \vdash \pi$, then $\theta \leq \pi$.	(Dominance)
(EE3) For any θ and π, $\theta \leq (\theta \wedge \pi)$ or $\pi \leq (\theta \wedge \pi)$.	(Conjunctiveness)
(EE4) When $K \neq K\perp$, $\theta \notin K$ iff $\theta \leq \pi$, for all π.	(Minimality)
(EE5) if $\pi \leq \theta$ for all π, then $\vdash \theta$.	(Maximality)

III. THE SEMANTIC SHOPPING MALL

We describe an online shopping mall that is built in the Semantic Web as the *semantic shopping mall*. The semantic shopping mall consists of ontology constructed based on information or knowledge currently held by agent. In terms of business transaction process, the agent will attempt to complete the transaction autonomously based on ontology associated with the semantic shopping mall. The agent may or may not be able to complete the transaction based on the beliefs it currently has. If it has the corresponding information in such a way that its beliefs are consistent with the request, then the transaction will be performed. Alternatively if transaction information is found to be inconsistent with that of its beliefs, the ontology revision operations will be triggered to update its existing ontology in order to complete the transaction. This is achieved through discovery of new information and relationships from another ontology, which we call the *foreign* ontology. The following activities can take place in the semantic shopping mall: (i) an agent enters the shopping mall to search for products, (ii) the agent browses the products offered in the shopping mall, (iii) the agents encounters or be presented with missing information that prevents it from completing the transaction, and (iv) the agent completes transaction and leaves the shopping mall. We will use scenario (iii) above to describe the ontology revision process when the agent encounters or be presented with missing information. An example of agent being presented with missing information can include missing product description or inconsistent product description with that offered by the seller. When this occurs the agent either needs to discover new information associated with the product and to update its current product ontology based on information obtained from the foreign ontology. For instance, an expansion operation can be triggered to obtain new information from other shopping mall, such as finding new product information. A contraction operation can occur when the shopping mall needs to remove some product description because it is no longer consistent with the current product information offered by the foreign ontology stored in the manufacturer web site. Finally a revision operation can be triggered if inconsistent information is found between its own product description and that being offered by the manufacturer. Fig. 1 shows the missing information gained from foreign website, such as the manufacturer website.
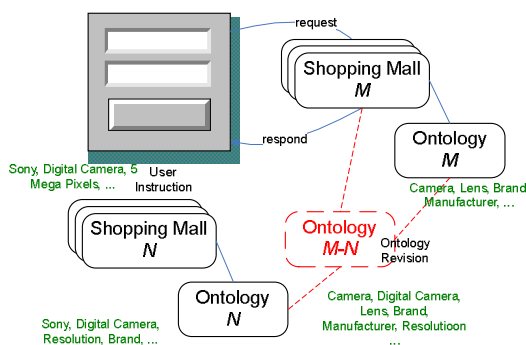
Fig. 1. Missing Information gained from the foreign website *N*.

The ontology is developed using the Protégé ontology editor utilised with existing Jena Application Programming Interface (API). The Jena API provides a collection of toolkits to build a hierarchy of concepts as well as to manipulate ontologies in the OWL (Web Ontology Language). To model the implemented ontology, a particular OWL model is created with in-memory storage model using the Jena API. To construct usable ontologies, small and manageable pieces ontologies are built with OWL. The advantage of this small modularisation has less complicated ontologies so that is more reusable and manageable. To illustrate the principle of using the Jena ontology API, we use an example of ontology that describes an electronic product. The electronic ontology contains a set of classes describing some aspects of domain of electronics.

Let us consider a transaction to purchase "a Sony digital camera with 5 megapixels resolution". The ontology associated with the semantic shopping mall describes camera as "an electronic product that takes photos" and is identified by manufacturer. To complete this transaction, the agent will visit various online shopping malls to access their ontology and to determine whether it can learn new concept associated with the concept of digital camera. For example, in visiting shopping mall *M*, the agent discovers the ontology of shopping mall *M* conceptually represents digital camera "as a kind of computer that takes photos and its resolution is measured in megapixel". The agent learns that the digital camera as represented in ontology of shopping mall *M* has the same function as the conceptual representation of camera as described in its own ontology. The agent will attempt to update its own ontology to include this new conceptual representation of digital camera so that it can complete the transaction.

Based on the coherence theory model, the least important information will be given up first to ensure minimum loss of information [14]. In this research, each concept in ontology is ranked to show its degree of importance in the ontology. We use this ranking information to determine the ontology revision operations. The ranking is assigned based on hierarchical relationship of parent-child relationship. In this aspect the more information the parent-child relationship depicts, the more valuable that information is.

In the example shown in Fig. 2, *Sony_Style* is assigned a rank of 1 and *Samsung* a rank of 2 in ontology *m*. Similarly, let us assume that *Dell* is assigned a rank of 1, *Sony* a rank of 2 and *LG* a rank of 3 in ontology *n*. To expand *LG* into ontology *m*, we first ensure that it is consistent with the existing concept, i.e., *LG* is also a subclass of *Manufacturer*. When it is found to be the case, then *LG* is expanded in ontology *m*. The bottom part of

the screen shot in Fig. 3 shows the result of the new conceptual model for ontology *m* after *LG* is expanded in *m*.
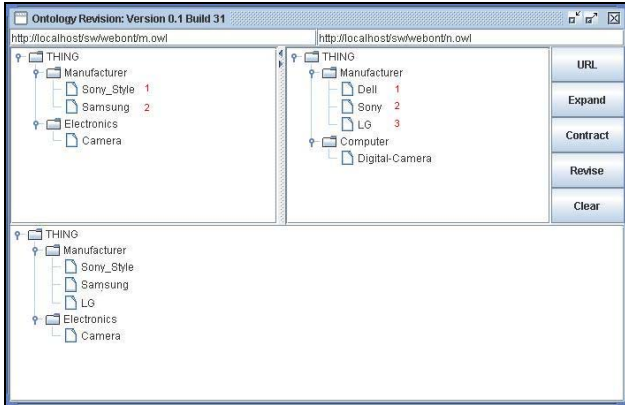

Fig. 2. An example of expansion for ontology *m*.

Secondly, we consider an illustration to remove inconsistencies using the contraction operation. In this example, we contract the concept of *Electronics* and its associated sub-concept of camera in order to ensure consistency in the ontology. In this instance if the concept of *Electronics* is retracted, then the concept of *camera* will also be removed too because it is the logical consequences of *Camera* which is in ontology *m*. The reason is due to the minimum change principle, whenever it is possible all remaining concepts in a contracted concept hierarchy must have exactly the same concept hierarchy as it did before the contraction was carried out. Thus *Camera* must be removed with the minimum change principle. Fig. 3 shows a sample screen shot of the result of the ontology *m* after the contraction after the contraction operation.
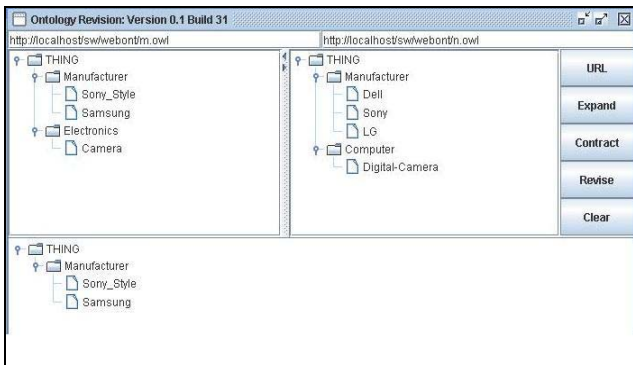

Fig. 3. An example of contraction for ontology *m*.

Finally, we consider the revision operation. Let us consider adding the concept of *Sony* from ontology *n* to ontology *m*. In our example *Sony* in ontology *n* is assigned a ranking of 2. Compared to the same concept (*Sony_Style*) in ontology *m* (which has been assigned a ranking of 1) it therefore has a higher value of epistemic entrenchment ranking. In this case, the revision operator will first contract the concept of *Sony_Style* in model *m*

and then expand the concept of *Sony* from model *n*. Again, the bottom part of the screen shot in Fig. 4 shows the result of the revised ontology *m* after the revision operation.
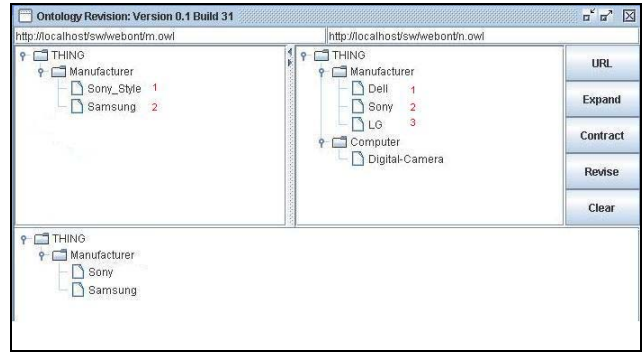

Fig. 4. An example of revision for ontology *m*.

IV. DISCUSSIONS

The WWW has changed the way business is conducted through e-business systems and e-commerce environment. The increasingly widespread WWW applications have extended the opportunity for software agents to function as intelligent agents that can act autonomously. The agents are able to interpret data and revise data, thus able to learn through the process of ontology revision. The proposed ontology revision framework has enabled agents to learn and revise their belief sets associated with the web applications in a way that was not possible previously. The proposed ontology revision framework has allowed the agents to revise its belief sets in a consistent manner will have an important implication when ontology is designed. It is no longer necessary to ensure the agents possess all required definitions of concepts and relationships when a web-based application is designed, the agents can learn and revise its belief sets as the ontology is revised or when the agents roam in the WWW to acquire new information. This aspect will allow the agents to start with simple, basic, core concepts and relationships. As time progresses, the agents can revise its own belief sets through the proposed ontology revision framework and be expanded to handle more complex applications. The dynamic nature of ontology revision process using the proposed ontology revision framework will result in greater flexibility in the design of e-business applications.

For developing more practical Semantic Web application, a way of working with *persistent* ontologies is recommended. As ontologies are stored as a form of file-based system, it often takes longer process time for ontologies than counterparts such as a database management system. A term persistent ontology means that ontologies are parsed and sourced each time it runs queries in a database. Once the ontology is stored in a relational database, the application can use faster insertion

and retrieval for queries that give some control over the process time.

One of the limitations encountered in this research is the computational overhead issue when multiple large ontologies are implemented in the application scenario. For instance, we have tried to use eCl@ss, an industry-strength ontologies for products and service over 25,000 categories [10]. However we were not able to load it using currently available ontology editors such as the Protégé editor due to limitation in the size of built-in memory. In another instance we have tried to use the WORDNET-like ontologies, again it has become computationally too complex to integrate it pass the design phase. This is an important research issue that warrants future research to make the proposed ontology revision framework practical in e-commerce environment. In separate situations, we need to consider computational overhead issue when union and intersection of multiple ontologies are performed. Very often exponential increase in computational overhead can render the approach to be inefficient in practice. The influence on design of ontologies for instance the use of synonyms to relax computational overhead is worth investigating. Similarly it is envisaged that computational inadequacy may be overcome through controlled user query as a mean to restrict computational overhead. This issue is to be investigated in future research to determine its suitability in the proposed ontology revision framework, particularly from the aspect of ontology consistency.

V. CONCLUSION

This paper has presented an approach of ontology revision based on the coherence theory of belief revision. The approach is developed to perform three operations of ontology revision to reflect changes in conceptualisation in domain of interests. The concept of epistemic entrenchment and minimal loss of information principle have been applied to ensure minimum information loss. The rationale is that the least important information is given up first to ensure minimum loss of information. We have demonstrated the application of approach in the domain of semantic shopping mall. The proposed approach has a practical implication in the design of ontology as ontology can evolve over time.

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