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循環合作式本體論建置系統

An Iterative, Collaborative Ontology Construction Scheme

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循環合作式本體論建置系統

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摘　要

在數位學習領域中，智慧型數位學習系統應用本體論來提供學習者適性化教學的引導及有效地管理數位學習教材。但是新的概念及相關的子概念會伴隨著新教材出現，使得建置教材管理系統的本體論變得非常困難。然而，如何透過社群提供知識來建置社群共識的本體論變成一個有趣且具挑戰性的議題;我們定義此問題為本體論結晶。由於新的概念會伴隨著教材不斷的產生，需要漸進地建置社群共識的本體論來描述新概念的教材，因此提出循環式收斂機制來減低建置本體論的時間與人力。在每個循環中，社群提供知識來合作建置本體論，並透過收斂機制來評斷社群共識的層級。我們提出循環本體論建置系統來解決知識結晶問題，在系統中，我們提出 Wiki-like 本體論編輯器作為合作貢獻知識的平台，Questionnaire-based crystallizer 利用 Delphi-like 的方法循環地收斂社群知識。由我們實驗得知，使用 ICOC 系統能建構出更高層級的社群共識的本體論。

關鍵字: 本體論結晶、本體論建置、社群共識本體論

An Iterative, Collaborative Ontology Construction Scheme

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ABSTRACT

In e-Learning domain, ontology of subject knowledge is applied for intelligent e-learning systems to provide learners with adaptive learning guidance and efficient learning content management. However, the ontology construction for the learning content management system is difficult because new concepts or related sub-concepts are always required along with the new contents. Therefore, "*how do we construct the ontology via community to achieve social agreement*" becomes a challenging and interesting issue and we define it as the Ontology Crystallization problem. Since making a social agreement its corresponding new version ontology is needed to represent new content for learning content management system, the idea of iterative-based convergence process is proposed to reduce the effort of construction. In each iteration, community members can contribute their knowledge collaboratively to incrementally construct the ontology. Finally, the degree of social agreement can be estimated for the ontology. With the ideas above, we propose an Iterative, Collaborative Ontology Construction (ICOC) scheme, where the Wiki-like ontology editor is proposed as collaborative knowledge contribution platform. Next, a Questionnaire-based crystallizer is proposed as the iterative convergence process with Delphi-like method. The experimental result shows that the ontology constructed by ICOC scheme can achieve higher degree of social agreement.

Keywords: Ontology Crystallization, Ontology construction, Social agreement ontology.

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Chapter 1. Introduction

As Internet usage becomes more popular over the world, e-Learning system, such as online learning, employee training, and e-book, has been accepted globally in the past ten years. Currently, in order to offer learners customized courses in accordance with their aptitudes and learning results to help learners gain higher learning performance, many adaptive learning systems have been proposed [21][22][23]. Therefore, a predefined ontology of a given domain is often used to generate adaptive learning guidance, where an ontology is used to denote the representative concepts and associated relations for each learning material. Besides, for managing a large number of learning materials, many Learning Content Management Systems have also been proposed by means of the ontology-based approach [1][5][13], Therefore, the learning contents can be retrieved appropriately and managed efficiently according to the ontology structure.

Since an acceptable ontology should be constructed by integrating a number of knowledge of experts, collaborative ontology construction for knowledge integration has become a feasible approach [2][2]. Moreover, because the integration of multiple experts' knowledge is still difficult and time consuming to create the ontology of subject knowledge based on [2][2][6][14], how to facilitate the ontology construction becomes an important issue.

Since the new concepts of the research papers are incrementally generated along with the progress of science and technology, it is difficult for a predefined ontology to scope new concepts. With rapid growth of Web 2.0, one of the emerging vision is the “harnessing the collective intelligence” of communities to offer their knowledge. Virtual communities are emerging as emerging a new organization form supporting knowledge sharing and diffusion. Therefore, it is a feasible way to construct an incremental ontology by communities for incrementally generated new concepts content management. In this thesis, we attempt to collaboratively construct the ontology for the learning content management system of research papers and technical documents.

Since ontology is represented as a common knowledge among communities, in order to avoid misunderstanding of knowledge among communities, ontology should be agreed with most of communities. Therefore, the social agreement is represented as the small enough deviation and sufficient support among communities’ opinions. Ontology crystallization problem is to construct a social agreement ontology by communities through social interaction consensus evaluation.

The degree of social agreement is defined to estimate ontology constructed by community. Since making a social agreement and the new version ontology is needed to represent new content for learning content management system, the idea of iterative-based convergence process is proposed to reduce the effort of construction. In each iteration, community members can contribute their knowledge collaboratively to increase the ontology. Finally, the degree of social agreement can be estimated for the ontology. We propose an Iterative, Collaborative Ontology Construction (ICOC) scheme to solve ontology crystallization problem. As we know, Wikipedia is a well-known online encyclopaedia which is entirely edited by its users. In each iteration, we proposed wiki-like ontology editor based on the concept of Wikipedia for community members collaboratively contribute their knowledge. Next, based on the heuristic assertion of Support-Against-New opinions, the template-based questionnaire generator can automatically generate an appropriate questionnaire to integrate new knowledge and converge conflict opinions among communities to a new version of ontology using a Delphi-like method. The convergence process stops when all the relations are converged or eliminated by the questionnaire analysis. According to this ICOC scheme, the created ontology can achieve higher degree of social agreement.

The rest of this thesis is organized as follows. Chapter 2 briefly introduces the related researches about ontology construction methods. In Chapter 3, the issue of ontology construction and the definitions of ontology crystallization problem are given. The ideas and the architecture of ICOC scheme and Wiki-like ontology editor are described in Chapter 4. Chapter 5 describes Questionnaire-based crystallizer to integrate and converge communities' diverse opinions and solve conflicts. Moreover, system implementation and experiment of ICOC scheme are shown in Chapter 6. Finally, conclusions and future works are given in Chapter 7.

Chapter 2. Related Works

To manage a large number of learning materials, many Learning Content Management Systems (LCMS) have been proposed by means of the ontology-based approach [1][5][13], where the ontology is used to denote the representative concepts and associated relations among learning materials. Therefore, the Ontology for an agent or a community of agents should be the consensus and social agreement of the concepts and relationships in a specific domain. In order to assist the experts constructing ontology, traditional ontology authoring tools such as Protégé [14], OilEd [26], JOE [27], and SWOOP [30] with Graphical User Interface have been developed to visualize the concepts and their associated relations. These tools are designed for individual user ontology construction. However, in some dynamic or complex domain, it is costly and time-consuming for individuals to construct an acceptable ontology. Therefore, the collaborative ontology construction approaches are proposed with different incremental ontology learning strategies. Well-known researches are introduced as follows.

- ***Ontology integration***

The ontology integration method maintains the original ontology structure and enriches it by integrating other ontologies. Traditionally, they combine the ontology editor and the online portal to allow experts cooperatively maintain the ontology with different management roles. Researches such as MarcOnt [33], Co-Protégé [31], and CODE [34] are well-known ontology integration approaches. However, there exist some drawbacks. Since the integration tasks have been done manually, it is costly and time-consuming for administrator even with clear management process. Moreover, it is impractical to manage the structure of the ontology manually if the scale of the ontology is large.

- ***Ontology Fusion***

The ontology fusion method attempts to reconstruct a new ontology by fusing others rather than enriching the initial ontology. Traditionally, the automatic or semi-automatic ontology learning approaches are proposed. Researches such as FCA-Merge [11], PROMPT [10] and Chimaera [38] are ontology fusion approaches. For example, PROMPT constructs the ontology by means of the metadata editing and concepts similarity computation. However, these automatic approaches tempt to be noise sensitive for new domain. If there exists some noises in the ontology, it is difficult to revise the ontology since they should follow the predefined constraints.

- ***Folksonomy***

With rapid growth of Web 2.0, one of the emerging vision is the "harnessing the collective intelligence" of a users community to contribute their knowledge. The folksonomy means the user-generated classification, emerging through bottom-up consensus [39]. In this thesis, we regard folksonomy as an ontology constructed by community. According to Wikipedia experience, we know that communities can provide knowledge more quickly and widely than small group of experts. Therefore recent researches turned to propose the collaborative community-oriented ontology construction approaches. Researches such as Ontolingua [28], Collaborative Ontology Building (COB) [32], and OntoWiki [2] construct a web space where members of the ontology developers community can access, browse, edit, and modify ontologies. Each member of community can contribute to ontology with their background knowledge. Although the various knowledge can be rapidly collected from the community members, the system administrator still has to manage the ontology manually. Furthermore, the growth of the amount of data brings more conflicts and noises. The lack of a convergence methodology may result in ontology distortion. Table 1 shows the comparisons of surveyed ontology construction approaches.

Table 1.Comparisons of ontology construction tools

User Demand	Tool Name	Conflict Resolution	Noise Sensitivity	Convergence Evaluation
Ontology Editor	Protégé	Not available		Not available
	OilEd	Not available		Not available
	JOE	Not available		Not available
	SWOOP	Interact with user		Not available
Taxonomy (Ontology Integration)	CO-Protégé	Session & Communication	Low	Session & Communication
	MarcOnt	Rules	High	Rules Mapping
	CODE	Weighted statistical algorithm	Medium	Administrator maintains
Taxonomy (Ontology Fusion)	FCA-Merge	Not available	High	Administrator maintains
	PROMPT	Interact with user	Medium	Administrator interacts with suggestion service
	Chimaera	Interact with user	Medium	Administrator interacts with suggestion service
Folksonomy	Ontolingua	Session & Communication	Low	Session & Communication
	COB	Package owner maintains	High	Administrator maintains
	OntoWiki	Not available	High	Not available

In this thesis, we attempt to construct the ontology for the learning content management system of research papers and technical documents. Since the new concepts of the research papers are incrementally generated along with the progress of science and technology, it is difficult for a predefined ontology to scope new concepts. Therefore, it is a feasible way to construct an ontology incrementally by communities for research papers and digital documents management since they can provide new knowledge of new concepts of these contents. However, the content providers are not ontology engineers; there is still a gap among the folksonomies and precise concepts associated with relations of the ontology. To solve this issue, we need a process to transform and extract the acceptable ontology from different folksonomies which may contain conflicts and ambiguities opinions among communities.

In knowledge management domain, Knowledge Crystallization [35] approach utilizes various possible context information in knowledge creation process and reconstructs a new knowledge base. It is used to merge and extract different contexts into new knowledge based on the predefined criteria. Next, we use this idea in ontology construction and define this process as the ontology crystallization problem.

Chapter3. The Ontology Crystallization Problem

In this section, we define the Learning Content Management Ontology and the ontology crystallization problem when constructing the LCMO.

3.1 Community-based Ontology Construction

As mentioned above, the ontology construction system using the folksonomy is an emerging approach. We firstly introduce the process of community-based ontology construction cooperated with Learning Content Management System (LCMS) as shown in Figure 1.

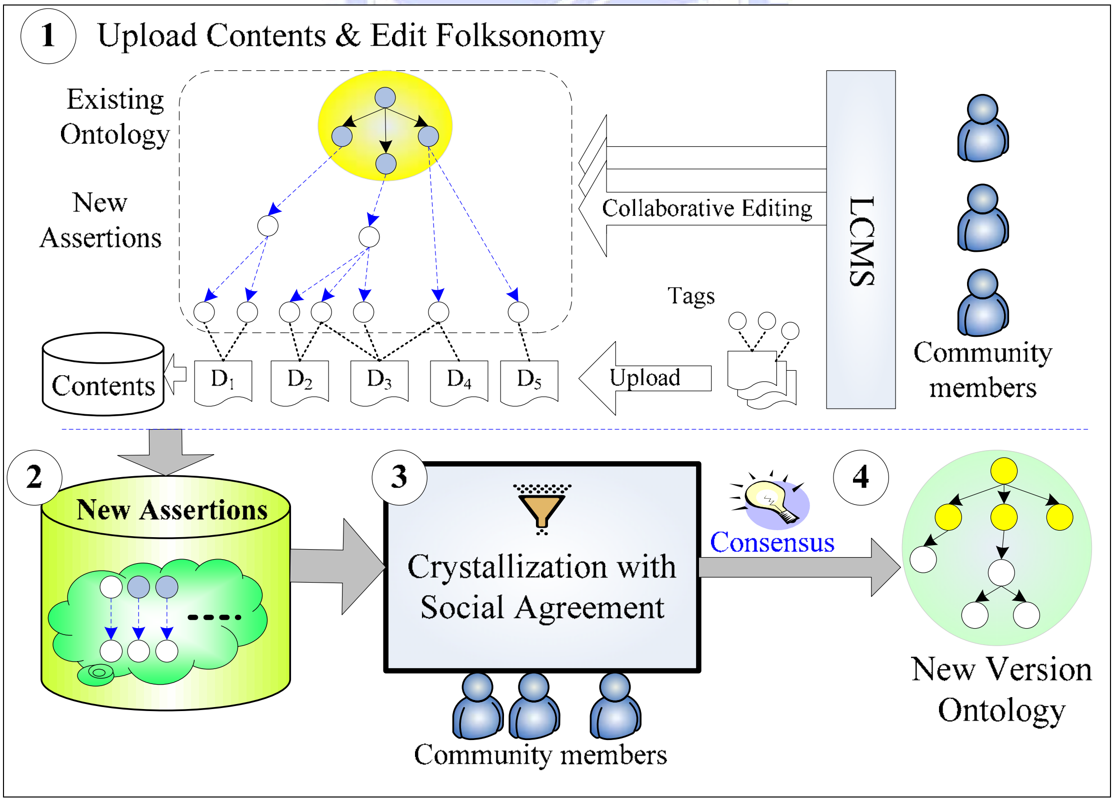

Figure 1 The Community-based Ontology Construction

Firstly, when community members upload their contents to LCMS, the system also asks them to collaboratively construct folksonomies for their contents. Next, the folksonomies are replaced by the concept keywords and users are asked to contribute the assertions by associating the concepts to the existing ontology. Next, new assertions are collected and the ontology inconsistency is detected. In the crystallization process, the inconsistency should be resolved by community members to achieve the social agreement. Finally, the new version ontology is constructed for the LCMS.

In the learning content management domain, the relations that we discussed include hierarchical relation, prerequisite relation, and reference relation. The ontology of the specific domain and its constraints are listed in Table 2. Formal definitions of terms are described as follows.

- Ontology Concept $C = \{C_1, C_2, C_3, ..., C_n\}, where\ C_i : concept$
- Direct Hierarchical Relation (DHR): $DHR = \{AKO, APO\}$
- Hierarchical Relation (HR):

  $DHR(C_i, C_j) \Rightarrow HR(C_i, C_j)$

  $DHR(C_i, C_j) \wedge HR(C_j, C_k) \Rightarrow HR(C_i, C_k)$

  $A(C_i\ R_k\ C_j) \leftrightarrow A(C_i \xrightarrow{r_1} B_1 \xrightarrow{r_2} B_2 \xrightarrow{r_3} B_3 \rightarrow ... \xrightarrow{r_i} C_j), where\ r_i \in IHR, i \geq 1, B_i \in C$

  $HR = \{R_k \mid A(C_i, R_k, C_j), where C_i, C_j \in C\}$
- Direct Prerequisite Relation (DPR): DPR = {Prereq.}
- Prerequisite Relation (PR):

$A(C_i\ R_k\ C_j) \leftrightarrow A(C_i \xrightarrow{r_1} B_1 \xrightarrow{r_2} B_2 \xrightarrow{r_3} B_3 \rightarrow ... \xrightarrow{r_i} C_j), where\ r_i \in IPR, i \geq 1, B_i \in C$

$PR = \{R_k \mid A(C_i, R_k, C_j), where\ C_i, C_j \in C\}$

- Reference Relation (RR): RR = {Ref.}

Table 2. Relations and constraints of LCM ontology

Relation Type	Description	Assertion Constraints
A kind of (AKO)	A AKO B, B is A's parent.	Mutual Exclusive, Acyclic
A part of (APO)	A APO B, A is component of B	
PrerequisiteOf(Prereq.)	A Prereq. B, A is prerequisite of B.	Acyclic
ReferenceOf(Ref.)	A Ref. B, A has reference B.	

*Assertion Constraints: restrictions between two assertions

With the relations defined above, the LCM Ontology can be applied for content management, adaptive learning, and related content reference. In the application of content management, AKO and APO relations are used to categorize content. In the application of adaptive learning, prerequisite relation is used to represent the suggesting reading sequence of learning contents. Finally, the reference relation can cooperate with AKO and APO relations to provide content searching application.

- Hierarchical Relation (HR): Transitive
  - $AKO, APO \in DHR$(Direct HR)
  - $DHR(C_i, C_j) \Rightarrow HR(C_i, C_j)$
  - $DHR(C_i, C_j) \wedge HR(C_j, C_k) \Rightarrow HR(C_i, C_k)$
- Prerequisite Relation (PR):Transitive
  - Prereq. $\in$ DPR(Direct PR)
  - $DPR(C_i, C_j) \Rightarrow PR(C_i, C_j)$
  - $DHR(C_i, C_j) \wedge PR(C_j, C_k) \Rightarrow PR(C_i, C_k)$
- Reference Relation (RR)
  - Ref. $\in$ RR

Without loss of generality, we assume the ontology is composed of assertions.

Definition 1. Learning Content Management (LCM) Ontology

Learning Content Management Ontology O_L is composed of assertions. Given Ontology Concept $C = \{C_1, C_2, C_3, ..., C_n\}, where\ C_i : concept$

- LCM ontology Relation R : DHR, HR, DPR, PR, RR $\in$ R
- Assertion : $Assertion : R(C_i, C_j)$
- LCM Ontology O_L={ $R(C_i,C_j)$ }

3.2 Ontology Crystallization Problem definition

In order to clearly identify the issues of ontology construction by the community, we define the Ontology Crystallization Problem as "***how do we construct the ontology via community to achieve social agreement***". The formal definition of the social agreement and inconsistency detection of ontology crystallization problem is as follows.

When the assertions contributed by the community members violate the constraints of relations in LMS ontology, the inconsistency should be detected and resolved.

Definition 2. Inconsistency of LMS Ontology

For a **LCM Ontology** O_L={ $R(C_i,C_j)$ }, the assertion inconsistency is defined as follow.

Ontology Concept $C = \{C_1, C_2, C_3, ..., C_n\}, where\ C_i : concept$

Relations Of LCM ontology : R = {HR, PR, RR}

- **Hierarchical cycle:** It denotes that there is a cycle in the hierarchical relations. The hierarchical cycle of ontology O_L is defined as:

  $$\exists C_i \in C, s.t.\ HR(C_i, C_i) \in O_L \Leftrightarrow Hierarchical\ cycle\ is\ true$$

- **Hierarchical redundant:** Since the AKO and APO relation are transitive, it is redundant assertion when there are two assertions from ancestor to decedent.

  $$\exists C_i, C_j \in C, r_i, r_j \in HR, r_i \neq r_j,\ s.t.\ A(C_i, r_i, C_j), A(C_i, r_j, C_j) \in O_L,$$
  $$\Leftrightarrow Hierarchical\ radundant\ is\ ture$$

- **Mutual exclusive:** It denotes that there are both AKO and APO relations in the same pair of concepts. The mutual exclusive of ontology O_L is defined as:

  $$\exists C_i, C_j \in C, s.t.\ APO(C_i, C_j), AKO(C_i, C_j) \in O_L,$$
  $$\Leftrightarrow Mutual\ Exclusive\ is\ ture$$

- **Prerequisite cycle:**

  $$\exists C_i \in C, , s.t.\ PR(C_i, C_i) \in O_L \Leftrightarrow \text{Prerequisite}\ cycle\ is\ true$$

Therefore, collaboratively constructing learning content management ontology have to solve of Hierarchical cycle, Mutual exclusive relation, Hierarchical redundant relation, Concept granularity, Isolated partial ontology, and Prerequisite cycle. However, most ontology integration approaches use the predefined rules to solve above-mentioned issues. But the resulted ontology does not reach social agreement.

Definition 3. Incompleteness of LMS Ontology

- **Isolated partial ontology:**

  $$\forall A_i(C_x, r_m, C_y) \in O_1,\ for\ O_1 \in O_L, \exists\ (C_x, r, C_{root}) = \Phi$$

- **Concept granularity:** It happens when the branch number of a concept is larger than the threshold.

  Concept granularity Criteria 1:

  $$BranchNo(C_i) = |\ A(C_i, r, C_j) \in O_L\ |, where\ C_i, C_j \in C, r \in IHR$$

$$\exists C_i \quad ,BranchNo(C_i)/(\frac{1}{n}\sum_{k=1}^{n} BranchNo(C_k)) \geq \theta, \theta \text{ is constant}$$

Concept granularity Criteria 2:

ContentCount(C_i):total count of contents have concept C_i

*if ContentCount(Ci) >= MaxContentNo,where MaxContentNo is*constant

then Ci is too general concept granularity problem happens

Definition 4. Social Agreement of Ontology Crystallization

Assume that for an **LCM Ontology** $O_L=\{A_1,A_2,\ldots,A_n\}$, each community member U_i has an agreement degree value w_k^i for assertion A_k:

$$Deg_i(O_L)=\{ w_1^i, w_2^i, \ldots, w_n^i \} \text{ where } 0(disagree) \leq w_k^i \leq 1(agree),\ 1 \leq k \leq n, 1 \leq i \leq m$$

$$\Delta(Deg_i(O_L), Deg_j(O_L)) = \sum_{k=1}^{n} \left| w_k^i - w_k^j \right|$$

LCM ontology achieved the social agreement:

$$\forall i, j \quad U_i, U_j \in Community, \quad \sum_{i,j} (\Delta(Deg_i(O_L), Deg_j(O_L))) \leq \theta$$

where θ is the deviation threshold.

Example 1. LCM ontology Inconsistency example

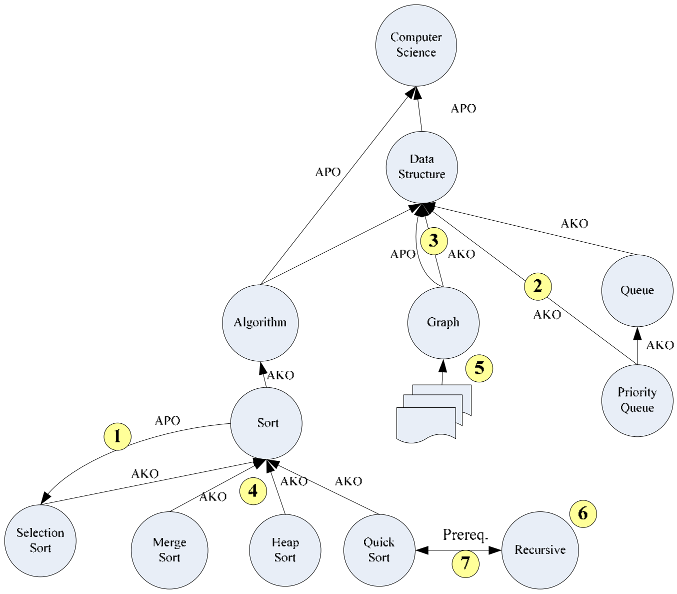

Figure 2. Data Structure ontology Inconsistency example

Table 3. Reasons of Data Structure ontology Inconsistency example

Inconsistency	No	Condition
Hierarchical Cycle	①	(Sort, APO,Selection Sort) , (Selection Sort, AKO,Sort)
Hierarchical Redundant	②	(Priority Queue, AKO, Queue), (Queue,AKO,Data Structure), (Priority Queue,AKO,Data Structure)
Mutual Exclusive	③	(Graph,AKO,Data Structure), (Graph, APO,Data Structure)
Concept Granularity Criteria 1	④	Assume Average BranchNo=2, $\theta = 2$ BranchNo(Sort)=4/2=2>=2
Concept Granularity Criteria 2	⑤	$Content\ No\,(Graph) \geq \alpha$
Isolated Partial Ontology	⑥	Recursive has no parent node
Prerequisite Cycle	⑦	(Recursive, Prereq., Quick Sort),(Quick Sort, Prereq.,Recursive)

The ontology crystallization allows the members of community collaboratively construct folksonomy for ontology construction and reduce time complexity of ontology construction. Since folksonomies are constructed from users instead of experts, the consensus evaluation should collect sufficient amount of supports to achieve the social agreement. Therefore we propose an iterative-based approach for solving ontology crystallization problem. Each iteration of ontology crystallization, a stable ontology is provided for members of community to use and further contribute knowledge by ontology modification. After iteratively crystallizing ontology, the resulting ontology would finally achieve higher degree of social agreement.

Chapter 4. Iterative, Collaborative Ontology Construction Scheme

In order to solve ontology crystallization problem, we propose an Iterative, Collaborative Ontology Construction scheme, called ICOC scheme which constructs a social agreement ontology based upon folksonomies via community social interaction for ontology-based LCMS.

4.1 System Architecture of ICOC Scheme

There are two major modules in the ICOC scheme shown in Figure 3. The first one is Online Collaborative Ontology Construction module where the communities collaboratively construct and modify global ontology according to their uploaded contents. The second one is Questionnaire-based Crystallizer which is based on community construction content knowledge to iteratively and automatically generate questionnaire for integrating new knowledge and resolving conflict among communities. The new version of ontology is generated by using the Delphi-like method with questionnaire analysis. This scheme is processed iteratively until all relations are converged or exceeding predefined number of times.

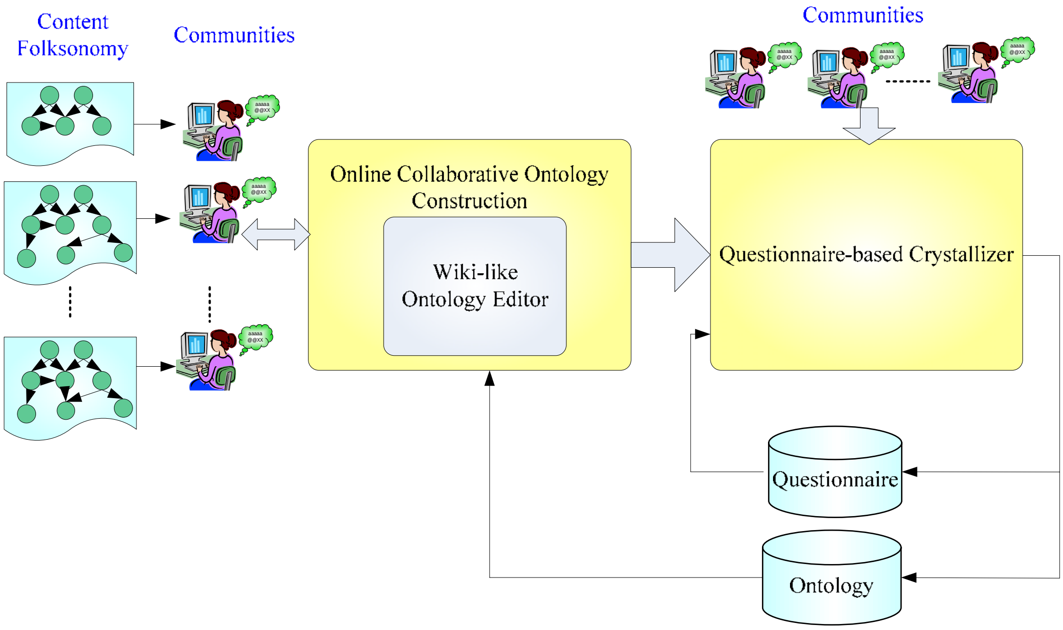

Figure 3. ICOC scheme System Architecture

In each construction iteration, the concept of wiki application approach is applied for communities to contribute their content folksonomies by creating and revising the global ontology. At the end of each iteration, since the folksonomies are provided by different community members, the Delphi convergence method is applied to converge diverse concepts and assertions to a social agreement one. To support the Delphi convergence method, the Template-based Questionnaire item generator is proposed to generate questionnaire dynamically according to communities' content folksonomies. The ICOC scheme tempts to converge the assertions into ontology with higher degree of social agreement.

4.2 Wiki-like ontology editor

In the scenario of LCMS, content providers upload their contents to LCMS for content knowledge contribution. However, it is difficult for content providers to construct their own ontology to describe their contents by themselves. In order to collect a great deal of and valorizing of knowledge contribution and alleviate content providers' ontology construction effort and further acquire more precise knowledge of content, we proposed Wiki-like ontology editor based on the concept of Wikipedia for communities collaborative contribute their content knowledge by global ontology modification.

Figure 4 shows the scenario of Wiki-like ontology editor among communities. Community members upload their contents to LCMS and based on global ontology to contribute their content knowledge for collaboratively global ontology construction and maintenance.

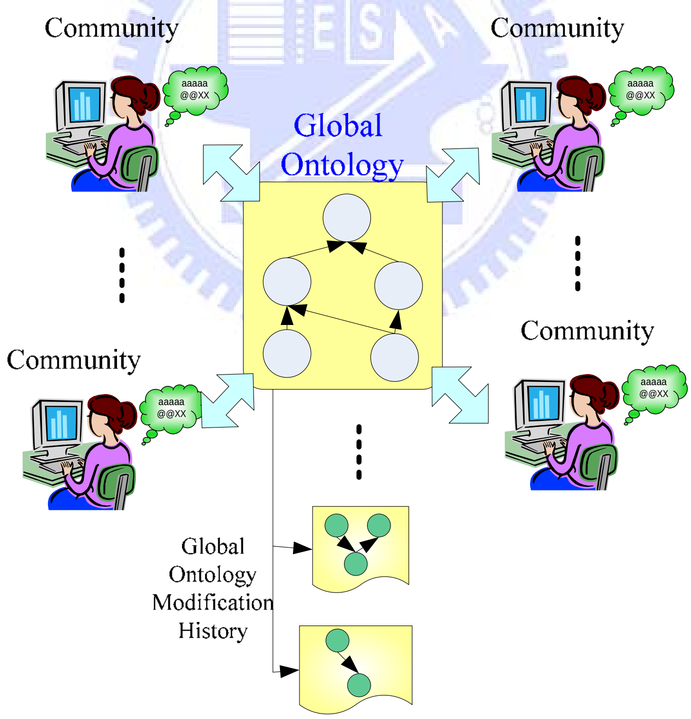

Figure 4. **The scenario of Wiki-like Ontology Editor**

The **Collaborative Ontology Construction Algorithm** describes procedures of Wiki-like ontology editor.

Algorithm 1: **Collaborative Ontology Construction**

Input: The latest version of ontology

Output: A set of new assertions created by members of community

Step 1: For each member, upload his/her learning content and input the keywords to describe the learning content.

Step 2: Align keywords to global ontology concepts by computing similarities.

Step 3: Refine the existing assertions of latest version ontology that related to the input concepts

Step 4: Repeat Step 1 until the number of assertions exceeds the predefined threshold.

Step 5: Output the new assertions.

As we know, the keywords of content are represented as the concepts of content. However, the members of community may use different keywords to represent the same concept. We should align keywords of content to concepts of ontology before they construct content folksonomies. Firstly, we align the keywords of content to concepts of ontology and ask community members to select one accurate concepts by the defined Keyword-Concept similarity before they constructing their content folksonomies.

The Keyword-Concept similarity function is based on the normalization of Tversky's model [40] and the longest common subsequence (A∩B) and difference (A-B) is given in (1)

- Keyword-Concept Similarity Function:

$$S(A,B)=\frac{(A\cap B)}{(A\cap B)+\alpha(A-B)+(1-\alpha)(B-A)},(1)$$
$$for\ 0\le\alpha\le 1$$

Example 2. In this example, we show how to compute similarity between "Wikipedia" and "OntoWiki" with Keyword-Concept similarity function. A=Wikipedia, B=OntoWiki, assume α=0.5

$$S(Wikipeida, OntoWiki)$$
$$=\frac{(Wikipedia\cap OntoWiki)}{(Wikipedia\cap OntoWiki)+0.5(Wikipedia-Wiki)+0.5(OntoWiki-Wiki)}$$
$$=\frac{4}{4+0.5*4+0.5*4}=\frac{4}{8.0}=0.5$$

In order to collaboratively construct global ontology without concurrency problem, the Wiki-like ontology editor store each community member global ontology modification records. Therefore, after keyword-concept alignment, community members can select the most appropriate global ontology version from global ontology modification history of current iteration to contribute assertions about his contents for global ontology modification.

However, there are ontology incompleteness problems when community members construct content folksonomies such as isolated partial ontology or unbalance concept granularity. Based on our criteria of ontology incompleteness defined in section 3.2, the ontology incompleteness information is provided in Wiki-like editor and ask community members to refine it.

After each community member finishing content folksonomy construction, we compare the difference of the previous version and new version for community member assertions opinions acquisition.

- **Heuristics of assertion Support-Against-New Opinion**

From the experience of Wikipedia, there are three different opinions of contributor when he editing the Wikipedia content page. The first opinion heuristic is "Support" when contributor agrees and doesn't change the content. The second opinion heuristic is "Against" when contributor disagrees and delete or modify the content. The final opinion heuristic is "New" when contributor contributes new knowledge to content. Based on the viewpoints of Wikipedia, we define the heuristics of assertion Support-Against-New opinion.

Given Community member' assertion contribution: A_x=(C_i, r_m, C_j) , Ontology O_L={A_1,…, A_n}

- **Support**: $\exists A_i \in O$, $s.t.$ $A_i = A_x$,
- **Against**: $\exists A_i \in O$,$s.t.$ A_x *is inconsistent with* A_i
- **New**: $A_x \notin O$ & $A_x \notin$ *Against*

Example 3: An example of Assertion opinions between global ontology and community member's assertion contribution

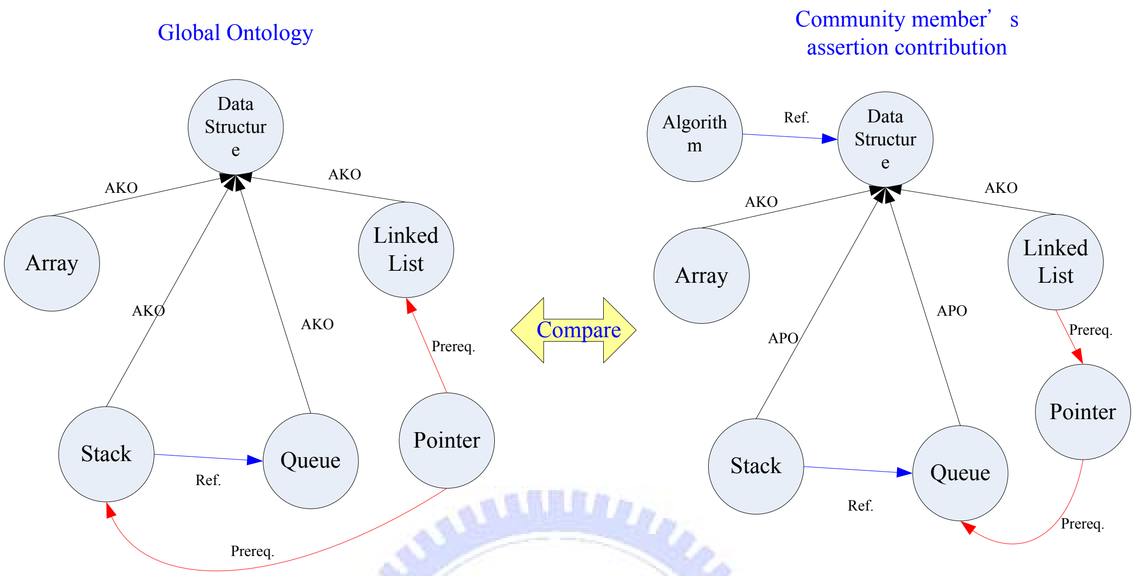

Figure 5. An example of comparison between global ontology and community member's assertion contribution

Table 4. The comparisons between ontology and community member's assertion contribution

Assertion	Opinion
(Array, AKO, Data Structure)	Support
(Linked List, AKO, Data Structure)	Support
(Stack, AKO, Data Structure)	Against
(Queue, AKO, Data Structure)	Against
(Stack, APO, Data Structure)	New
(Queue, APO, Data Structure)	New
(Stack, Ref, Queue)	Support
(Pointer, Prereq., Stack)	Against
(Pointer, Prereq. , Queue)	New
(Pointer, Prereq., Linked List)	Against
(Linked List, Prereq., Pointer)	New
(Algorithm, Ref., Data Structure)	New

In each iteration, many content folksonomies are contributed collaboratively to construct global ontology. Based on our heuristics assertion of Support-Against-New opinions to acquire community members' knowledge, we construct an **iteration temporal ontology** to record and summarize all communities' assertion Support-Against-New opinions during content folksonomy construction. However, there exist some new assertions and conflicts among community members to integrate and converge. Therefore, we apply Questionnaire-based crystallizer to resolve our collected community members' knowledge.

Chapter5. Questionnaire-based Crystallizer

The questionnaire researches have been studied in past several ten years. A questionnaire is used to efficiently gather information from respondents. The questionnaire is effective to acquire users' opinions of specific issue. The analysis of questionnaire result is a good way to represent social agreement. As we know, **Delphi technique** is used to converge multiple experts' opinions by several rounds questionnaire analysis. However, there are conflicts and ambiguities among communities in collaborative ontology construction phase. In order to resolve these different diverse knowledge among communities, we utilize our heuristic assertion of Support-Against-New opinions of each community member folksonomy contribution to analyze and summarize all communities' knowledge. We propose Questionnaire-based crystallizer is to extract and refine communities' assertion contribution to achieve social agreement, and integrate and resolve conflict knowledge among communities, then generate new social agreement ontology.

- ***Delphi technique***

The Delphi technique is a method for obtaining forecasts from a panel of independent experts over two or more rounds. Experts are asked to predict quantities. After each round, an administrator provides an anonymous summary of the experts' forecasts and their reasons for them. When experts' forecasts have changed little between rounds, the process stops and the final round forecasts are combined by averaging. Delphi is based on well-researched principles and provides forecasts that are more accurate than those from unstructured groups (Rowe and Wright 1999, Rowe and Wright 2001). [41]

Figure 6 shows our proposed Questionnaire-based Crystallizer which is used to integrate and converge communities' content folksonomies to achieve social agreement ontology.

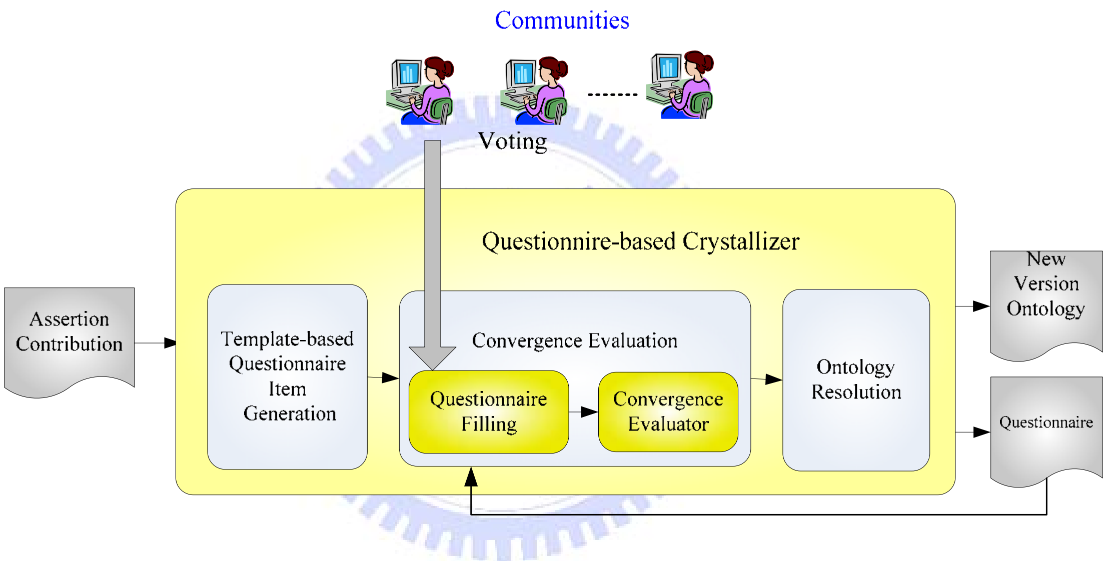

Figure 6. Questionnaire-based Crystallizer

Based on communities' content folksonomies through Online Collaborative Ontology Construction, the **Template-based Questionnaire Item Generation** process can automatically detect these conflict relations of concepts which are emerged due to the difference of communities' assertion opinions. Accordingly, in this process, an appropriate questionnaire will be generated by selecting the suitable questionnaire item templates. The **Convergence Evaluation** process, the concept of Delphi-like method is applied to integrate and converge the conflict relations.

Therefore, in the Questionnaire Filling sub-process, new communities are asked to fill in the generated questionnaire in terms of conflict relations. Whenever the amount of receiving questionnaires exceeds the predefined threshold, the **convergence evaluation sub-process** is triggered to analyze these results of questionnaires for finding the consensus among communities' opinions and evaluating level of social agreement. Finally, the **Ontology Resolution** process detects the conflicts by adding the consensus and generates the new version global ontology. This scheme will be processed iteratively until all relations are converged or exceeding number of times.

5.1 Template-based Questionnaire Item Generation

The question types can be divided into open-ended question and close-ended question. The open-ended questions provide more free to response, but it is designed to encourage a full, meaningful answer using the subject's own knowledge and/or feelings. The closed-ended questions are easy for users to response and measure respondents' viewpoints. However, our goal is to converge all communities' assertion opinions from ontology construction phase at this iteration; therefore closed-ended questions are more suitable than open-ended questions.

5.1.1 Questionnaire Item Template

We converge communities' assertion opinions based on the concept of Delphi technique. We interview domain experts and survey the closed-ended questions of Delphi [4][8][12][42][43][44][45][46] to design four questionnaire item templates which meet our domain requirements.

- **T1 : Likert five-point scales :** To measure level degree of agreement with some new assertion.
- **T2 : True/False** : To make sure the correctness of the assertion and tolerate noise when degree of agreement of the assertion has known.
- **T3 : Multiple, multiple concept selection** : To solve **granularity problem**, choose some of synonym candidates merging to one concept.
- **T4 : Multiple relation selection** : To solve some conflict relations such as **Mutual exclusive relation**. Because there exist inconsistent relations between concepts, therefore choose correct one.

Table 5 shows these four context formats of question item template.

Table 5. Questionnaire Item Template

Item Type	Question Item Template
T1: Likert five-point scales	Do you agree or disagree with this relationship? *Concept* (Ci) *Relation* (*rm*) *Concept* (Cj) (1)Strongly Agree (2)Agree (3)Not Agree and Not Disagree (4)Disagree (5)Strongly Disagree
T2: True/False	Do you agree or disagree with this relationship? *Concept* (Ci) *Relation* (*rm*) *Concept* (Cj) (1)Agree (2)Disagree
T3: Multiple, multiple concept selection	Please write down the order of the following *Concept* (CX) is the most suitable for *Concept* (CX/Ci) *Relation* (*rm*) *Concept* (Cj/Cx) ? ( )Concept1 ( )Concept2 ( ) …( )Conceptn (n+1) Not Above All (, where n≦5)
T4: Multiple relation selection	What is your opinion about which *Relation* (*rm*) that is the most suitable to describe the relationship between *Concept* (Ci) and *Concept* (Cj) ? (1)Relation1 (2) Relation 2 (3) …(n) Relation n (n+1) Not Above All (, where n≦5)

5.1.2 The Decision table for Questionnaire Item Selection

According to our result of domain experts' interview and our observation, we design three conditional criteria below to decide which questionnaire item will be chosen based on defined decision table as shown in Table 6. We utilize our heuristics assertion of Support-Against-New opinions to construct the **iteration temporal ontology** to record and summarize all communities' assertion Support-Against-New opinions during content folksonomy construction. Assume one assertion of the current version of ontology: $A_c=(C_a, r_i, C_b)$ and the other assertion of iteration temporal ontology: $A_t=(C_a, r_j, C_c,)$,

- **Three conditional criteria for questionnaire item selection:**
  - **Support-Against-New Opinion**
  - **Convergence State (CS) :** degree of social agreement of A_c, where
    CS={ High, Normal, Low}
  - **Opinion Divergence (OD) :**the diverge of concept or relation
    if $C_b \neq C_c$ and $ri = rj$, *then OD=Concept*
    if $r_i \neq r_j$ *and* $C_b = C_c$ *,then OD=Relation.*

Table 6. Decision table for Questionnaire Item Selection

Decision #	**Support-Against-new Opinion**	**DSA (Degree of Social Agreement)**	**OD (Opinion Divergence)**	**Questionnaire Item Type**
1	Support	*High*		
2		*Middle*		T2
3		*Low*		T1
4	Against	*High/Middle*		T2
5		*Low*	*Relation*	T4
6		*Low*	*Concept*	T3
7		*Low*		T1
8	New		*Relation*	T4
9			*Concept*	T3
10				T1

Example 4: In this example, we show how to select questionnaire item type using Decision table.

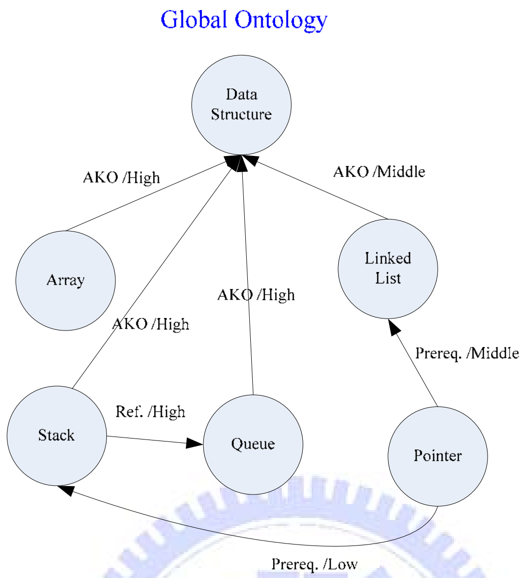

Table 7. The result of Questionnaire item selection using Decision table

Assertions of Iteration Temporal ontology	Opinion	Decision #	Type
(Array, AKO, Data Structure)	Against	3	T2
(Linked List, AKO, Data Structure)	Support	2	T2
(Stack, AKO, Data Structure)	Against	3	T2
(Queue, AKO, Data Structure)	Against	3	T2
(Stack, APO, Data Structure)	New	8	T3
(Queue, APO, Data Structure)	New		
(Stack, Ref., Queue)	Support	1	
(Pointer, Prereq., Stack)	Against	6	T1
(Pointer, Prereq., Queue)	New	9	T1
(Pointer, Prereq., Linked List)	Against	3	T2
(Linked List, AKO. ,Pointer)	New	7	T4
(Algorithm, APO., Data Structure)	New		

5.2 Social agreement Evaluation

5.2.1 Social agreement Evaluation Function

In order to measure which assertions achieve sufficient amount of support have been different level of social agreements. We design a social agreement evaluation function to evaluate which level of social agreement of assertion. However the voting results are collected by community members with different domain expertise. Therefore, we consider members' domain expertise to design weighted social agreement evaluation to estimate degree of social agreement of assertion among community members.

In our Questionnaire-based crystallizer, questionnaire item type of T3 and T4 are used to determine which assertion is more appropriate to describe by mode estimation. Thus, questionnaire item type of T1 and T2 are used to measure which degree level of social agreement.

We modify Delphi technique social agreement measure criteria to design ICOC weighted evaluation function to determine which level of social agreement and a trustworthiness value to measure degree of trustworthiness of assertion.

- **Weighted Evaluation Function (WEF):**

$E_i : Domain\ Expertise\ of\ User_i, \sum_i E_i = 1$

$Vote\ V = \{V_1, V_2, V_3, ..., V_n\},\ where\ V\mathrm{i} = (E\mathrm{i}, Value\mathrm{i})$

$WeightedMean(A_i) = WM(A_i) = \sum_i E_i * Value_i$

$$WeightedSD(A_i) = \left(\frac{\sum_i E_i * (Value_i - WM(A_i))^2}{N - 1/N}\right)^{1/2}$$

$$WM_{T2}(A_i) = \left| \sum_{j,Valuej=Agree} E_j - \sum_{i,\,Valuei\,=\,Disagree} E_i \right|$$

$$WEF(A_i) = \left(\sum_{i=1\sim n} \left| \frac{Value_i - WeighterMean(A_i)}{WeightedSD(A_i)} \right|\right) / n$$

$$trustworthoness(Ai) = \left[\frac{(5 - WEF(Ai))}{5}\right] * (1-\alpha) + WMT2(Ai) * \alpha, where \begin{cases} \alpha = \text{constant if T2 is true} \\ 0 \text{ if T2 is false} \end{cases}$$

- **Heuristic of degree of social agreement of A_i:**

Questionnaire item type: T1 (five-point likert scales)

- $WEF(A_i) < 0.4, Convergence\ State\ of\ A_i = High$
- $0.9 < WEF(A_i) <= 0.4, Convergence\ of\ A_i = Middle$
- $WEF(A_i) \geq 0.9, Convergence\ of\ A_i = Low$

Questionnaire item type: T2 (True/False)

- $WM_{T2}(A_i) \geq 0.75, Convergenece\ State\ of\ A_i = High$
- $0.6 \leq WM_{T2}(A_i) < 0.75, Convergenece\ State\ of\ A_i = Middle$
- $WM_{T2}(Ai) < 0.6, Convergence\ Satet\ of\ A_i = Low$

Example 4: In this example, we show T1 questionnaire item type and five members with different domain expertise how to decide which level of social agreement among them by Weighted Evaluation Function.

$$V = \{(0.2,5),(0.1,3),(0.2,5),(0.1,4),(0.2,4),(0.2,5)\}$$

$$WM = 0.2*5 + 0.1*3 + 0.2*5 + 0.1*4 + 0.2*4 + 0.2*5 = 4.5$$

$$WSD = \left(\frac{(0.2)*(5-4.5)^2 + (0.1)*(3-4.5)^2 + (0.2)*(5-4.5)^2 + (0.1)*(5-4)^2 + (0.2)*(5-4)^2 + (0.2)*(5-4)^2}{5/6}\right)^{1/2}$$

$$= 0.995$$

$$WEF(V) = ((0.5 + 1.5 + 0.5 + 0 + 0.5)/0.995)/5 = 0.7.....Middle$$

5.2.2 Ontology Resolution

Adding new consensus assertions to original ontology may cause new conflicts such as hierarchical cycle, prerequisite cycle. Therefore we do cycle detection to find these conflicts and then remove minimum trustworthiness of assertion in the cycle.

Ontology Resolution Algorithm
Input: a consensus assertion list and origin version of ontology
Output: the refined version of ontology
Step 1: For new consensus assertions add to origin ontology.
Step 2: Detect the refined ontology to find inconsistent assertions. (Cycle Detection)
Step 3: For each inconsistent assertion, detect it from the refine ontology and delete minimum trustworthiness of assertion to break cycle.
Step 4: Output the refined version of ontology.

Chapter 6. System Implementation & Experiment

6.1 System Implementation

We apply ICOC scheme to NCTU Knowledge and Data Engineering Lab's paper system to construct the ontology of research papers. The operating system of ICOC scheme is Windows Server 2003. Besides, we use ASP.net as the programming language and Sever Server 200 as the database to build up the whole system.

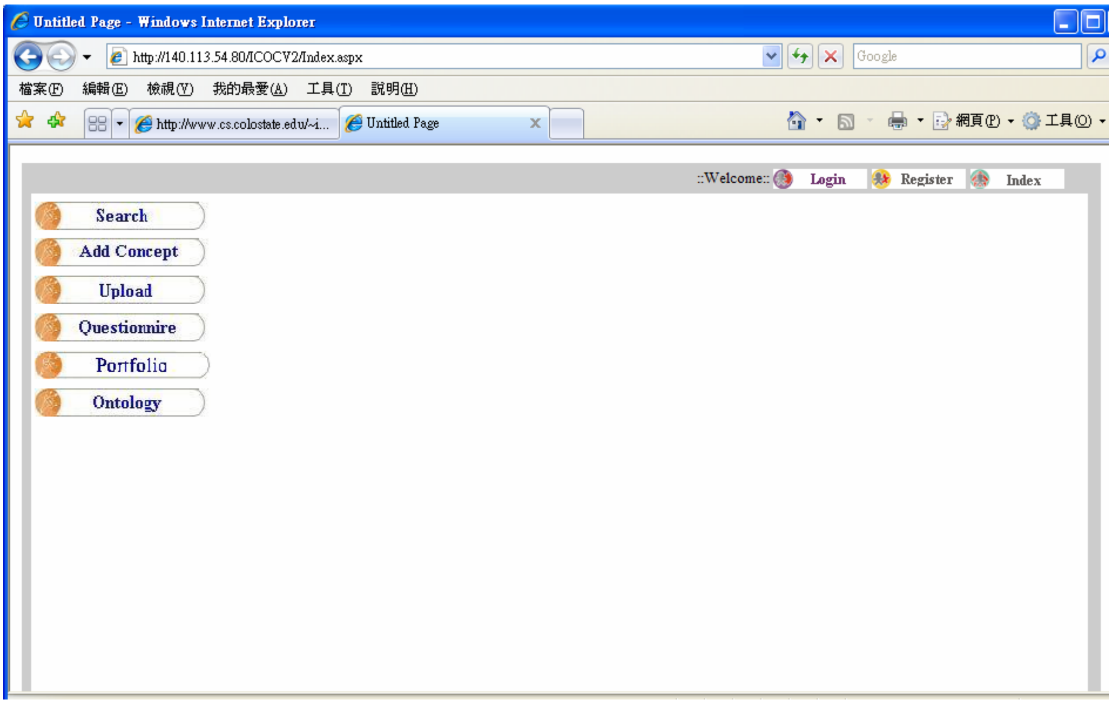

Figure 7. User menu of ICOC scheme

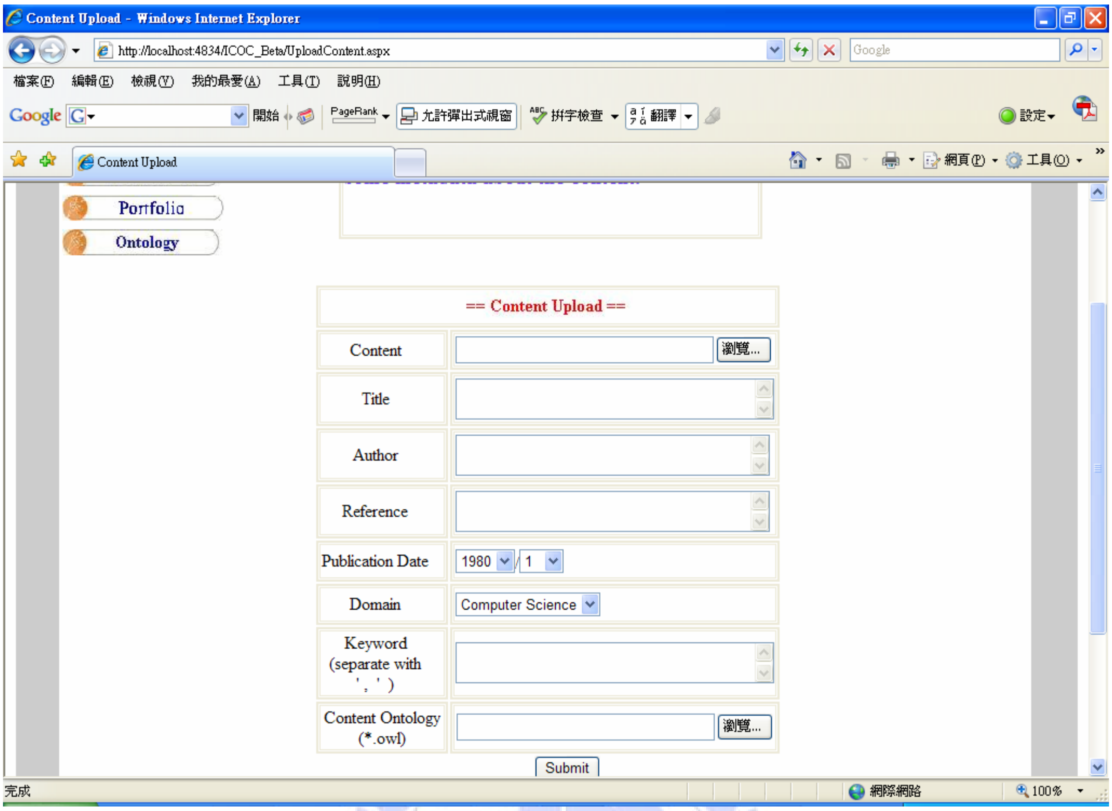

Figure 8. Content Metadata contribution

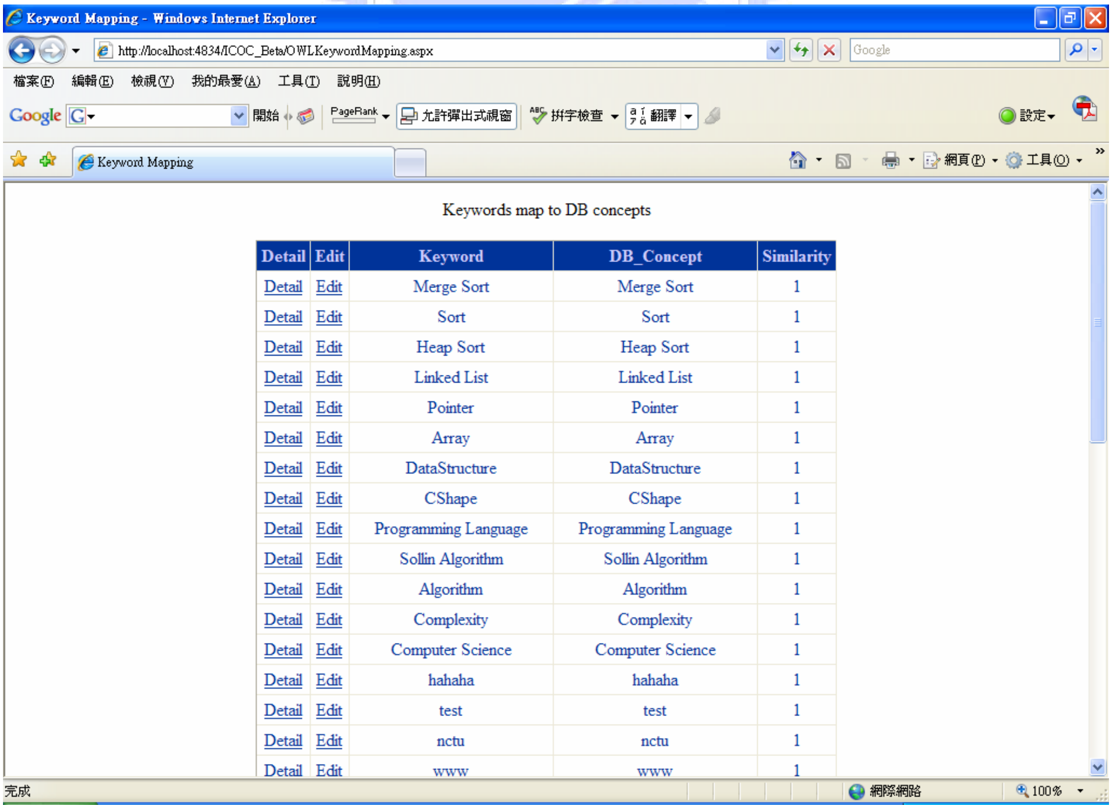

Figure 9. Keyword-Concept Mapping and editing

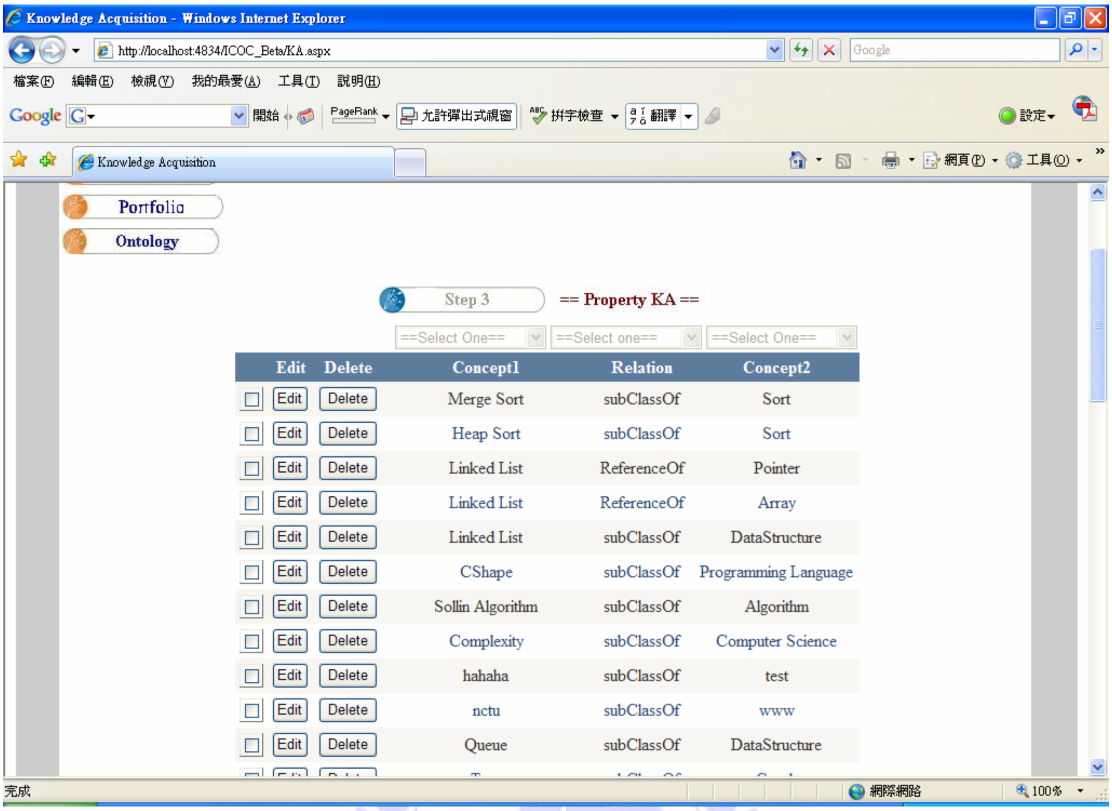

Figure 10. Collaborative ontology construction

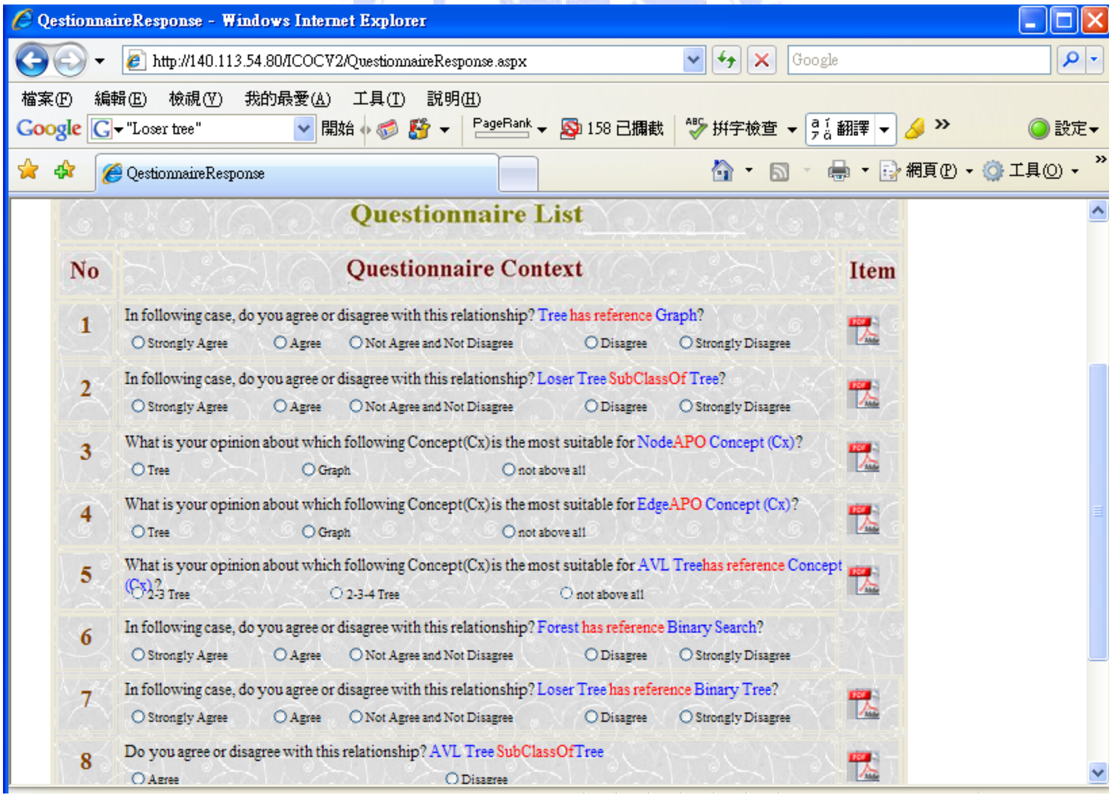

Figure 11. Print screen of Questionnaire List in ICOC scheme

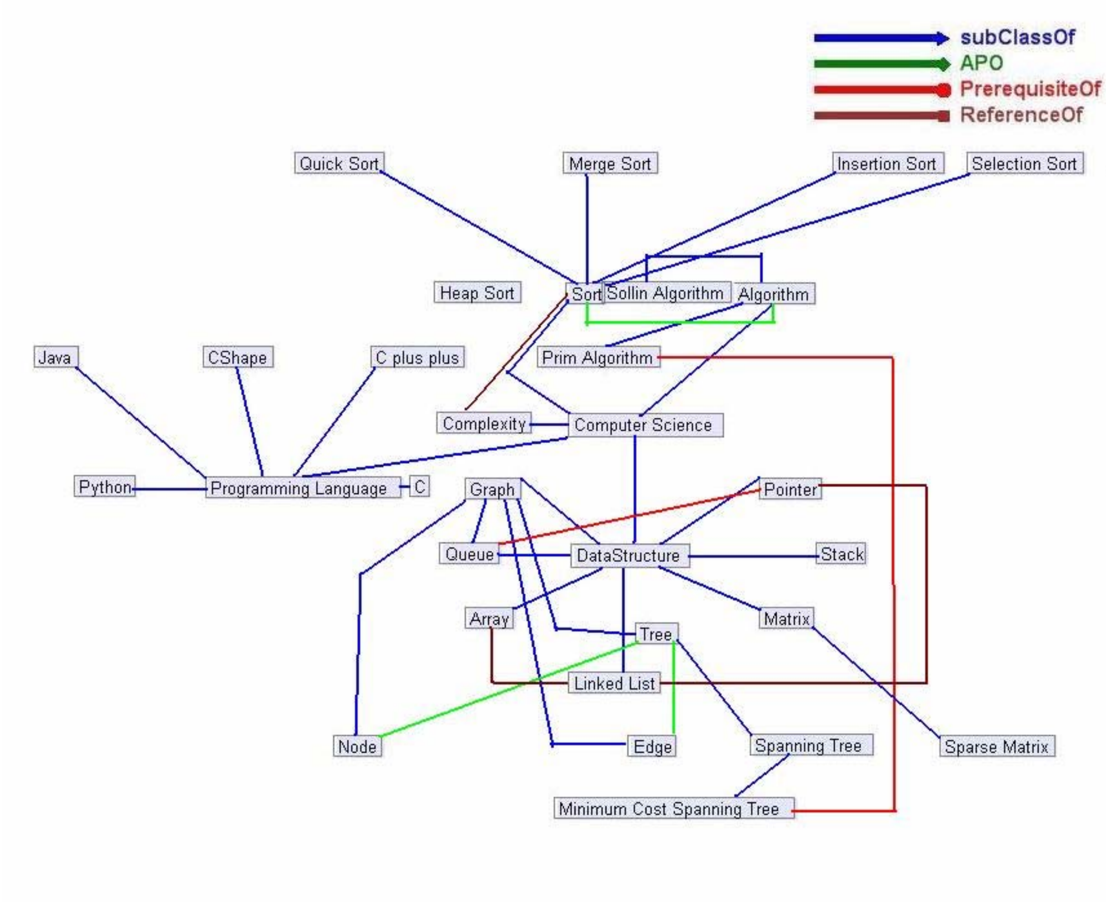

Figure 12. Ontology Visualization

6.2 Experiment Design

In order to evaluate degree of social agreement of ontology constructed by ICOC scheme. We choose Prompt an ontology integration tool to integrate several ontologies. Compare the integrated ontology by Prompt with the constructed ontology by ICOC scheme.

We choose 20 participants of interest to the subject of “Data structure”, respectively according to their background knowledge capability divides into two groups. One is ICOC scheme test group, and the other is Prompt matched group. The two groups have the similar knowledge capability members. Participants have similar background knowledge given the same contents for their content contribution. An stable ontology is given to both of groups for participants to modify according to their content.

The members of ICOC test group based on the stable ontology collaboratively contribute their content knowledge by Wiki-like ontology editor, and questionnaire-based crystallizer by means of automatically generated questionnaires crystallizes to “ICOC ontology”.

The members of Prompt matched group modify the stable ontology to construct their own content ontologies by protégé tool. Then importing these 10 individual content ontologies to Prompt tool integrates a “Prompt ontology”.

6.3 Experiment Result

Initial stable ontology:

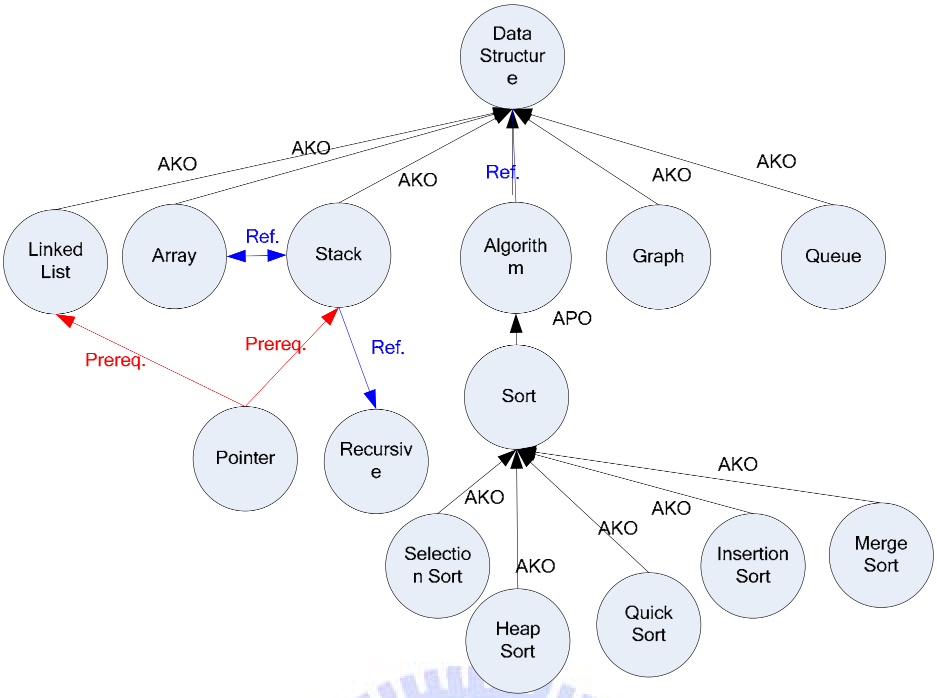

Figure 13. Initial Data Structure Ontology

ICOC Ontology:

Figure 11. Total number of assertions in social agreement ontology.

Figure 11 shows our constructed ontology grows stably in four iterations. Therefore, based on our heuristics assertion of Support-Against-New opinions generated questionnaires is useful to lead communities for achieving social agreement.

■ Partial ontology result constructed by ICOC scheme

Concept1	Relation	Concept2	Domain	ConvergenceState	Weight
Linked List	SubClassOf	Data Structure	Computer Science	2	0.975
Array	SubClassOf	Data Structure	Computer Science	2	0.96
Stack	SubClassOf	Data Structure	Computer Science	2	0.9
Graph	SubClassOf	Data Structure	Computer Science	1	0.75
Queue	SubClassOf	Data Structure	Computer Science	2	0.95
Data Structure	has reference	Algorithm	Computer Science	1	0.8
Tree	SubClassOf	Data Structure	Computer Science	2	0.98
Data Type	APO	Data Structure	Computer Science	2	0.9333334
Matrix	SubClassOf	Data Structure	Computer Science	1	0.7333334
Heap	SubClassOf	Data Structure	Computer Science	2	0.96
Sort	APO	Algorithm	Computer Science	1	0.7
Sollin Algorithn	SubClassOf	Algorithm	Computer Science	1	0.48
Selection Sort	SubClassOf	Sort	Computer Science	1	0.7
Heap Sort	SubClassOf	Sort	Computer Science	2	0.95
Quick Sort	SubClassOf	Sort	Computer Science	2	0.95
Insertion Sort	SubClassOf	Sort	Computer Science	1	0.745
Merge Sort	SubClassOf	Sort	Computer Science	2	0.94

Chapter 7. Conclusion

In this thesis, we attempt to construct the ontology for the learning content management system of research papers and technical documents. Since the new concepts of the research papers grow up with contents, it is difficult for a predefined ontology to scope new concepts. We define Ontology crystallization problem is "*how do we construct the ontology via community to achieve social agreement*". The degree of social agreement is defined to estimate ontology. In order to achieve higher social agreement and continuously update the ontology for learning content management system. We propose an Iterative, Collaborative Ontology Construction (ICOC) scheme to solve ontology crystallization problem. With our experiments, it shows that the ontology constructed by ICOC scheme can achieve higher degree of social agreement

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