Available online at www.sciencedirect.com
SCIENCE DIRECT®
The Journal of Systems and Software 73 (2004) 389–396
The Journal of Systems and Software
www.elsevier.com/locate/jss

Fuzzy resource space model and platform ☆

Hai Zhuge *

Knowledge Grid Research Group, Key Lab of Intelligent Information Processing, Institute of Computing Technology, Chinese Academy of Sciences, P.O. Box 2704, Beijing 100080, PR China

Received 8 January 2003; received in revised form 26 May 2003; accepted 26 May 2003
Available online 5 December 2003

Abstract

The resource space model (RSM) is a model for organizing versatile resources in normal forms and providing uniform resource management operations. In applications, we find three important factors that influence the effectiveness of organizing and operating resources: *natural semantics of resources, resource providers' beliefs*, and *resource users' beliefs*. The relationship between the three factors influences the effectiveness of resource management operations. This paper proposes a fuzzy resource space model (FRSM), which consists of a fuzzy resource space and a fuzzy operation language expressing the resource providers' beliefs and the resource users' beliefs. By properly dealing with the two kinds of beliefs, the FRSM improves the RSM in effectively managing resources. The proposed model has been implemented in the Knowledge Grid platform VEGA-KG.

Keywords: Data model; Fuzzy sets; Semantic Grid; Resource organization; Query language; Web

1. Introduction

The current Web resources have three major characteristics: *rapid expansion, global disorganization, local autonomous*, and *separation of machine-understandability and human-understandability*. Their combinatorial effect determines that the previous resource sharing and management approaches could hardly stride over the barriers of the accuracy, effectiveness, and efficiency when using the globally distributed Web resources, although many Web-based approaches have made some limited success (Henzinger, 2001). People are targeting the next-generation Web. The Grid (http://www.gridforum.org), the Web Service (http://www.webservice.org), and the Semantic Web (http://www.semanticweb.org) are three examples of this effort.

The Web Service aims at providing an open platform for the development, deployment, intelligent interaction, and management of globally distributed e-services. Web standards like Web Service Description Language, Simple Object Access Protocol and Universal Definition Discovery and Integration play the key role in Web Service.

The Grid is a technology that enables a large-scale distributed computing system to share, manage, coordinate, and control distributed computing resources (Foster, 2000). The resources could be computers, networks, data, and any types of computing devices. The key ideal is that any compatible device could be plugged in anywhere onto the Grid and be guaranteed a certain level of services regardless of where those resources might come from, just as the power grid. The Grid aims at a new interconnect mechanism that is independent of the current Web. The Global Grid Forum was established in 2001 to promote and develop Grid technologies and applications (http://www.gridforum.org). The current Open Grid Service Architecture has absorbed the idea of Web Service.

The Semantic Web is an effort to improve the current Web by making the Web resources machine-understandable, because the current Web resources could not reflect machine understandable semantics (Hendler, 2001; McHraith et al., 2001). Currently, research on the Semantic Web mainly focuses on ontology, logic, and markup languages such as Resource Description Framework (RDF) (Klein, 2001), Ontology Inference

☆ The research work was supported by the National Science Foundation and the National Basic Research Plan of China.
* Tel.: +86-1062565533; fax: +86-1062567724.
E-mail address: zhuge@ict.ac.cn (H. Zhuge).

0164-1212/$ - see front matter © 2003 Elsevier Inc. All rights reserved.
doi:10.1016/S0164-1212(03)00235-8

Layer, and DARPA Agent Markup Language (Hendler and McGuinness, 2000). Intelligent indexing and semantic retrieval of multi-model documents have been investigated (Srihari et al., 2000). The Semantic Grid is the combination of the Grid and the Semantic Web (http://www.semanticgrid.org).

A special Semantic Grid model VEGA-KG has been proposed (Zhuge, 2002a). It inherits the standards suggested by the Semantic Web community and uses new resource organization model (Zhuge, in press). It aims at a new interconnection platform that can normally organize, semantically interconnect and intelligently cluster versatile resources. A soft-device model has been proposed as the uniform resource model of the Semantic Grid environment (Zhuge, 2002b). The kernel of the VEGA-KG model includes a resource space model (RSM) and a uniform resource-using mechanism. The RSM is a uniform coordinate system with independent coordinates and orthogonal axes for correctly and efficiently organizing and managing resources. It is different from the traditional relational data model, the nest relational model, and the object-oriented model in notion, theory and method (Codd, 1970; Mok, 2002; Rumbaugh et al., 1991). The uniform resource-using mechanism includes an operable resource browser, a resource-using engine, an SQL-like resource operation language (ROL), an operation enactment mechanism, and an application development environment. The operable resource browser provides an easy-to-use interface for end-users to select the proper resources and operation, determine operation parameters, and then submit the operation. The resource-using engine accepts the submitted operation and then performs the operations according to the types of the resources to be operated. The ROL supports the end-users carrying out one-stop operations or the application developers composing resource operation programs to realize applications. The ROL also supports the application systems using the resources and the resource browser operating the resources. The end-users can use either the application system to process domain business or a resource browser to directly operate the resources.

In applications, we find three important factors that influence the effectiveness of organizing and operating resources: *the natural semantics of resources, the resource providers' beliefs*, and *the resource users' beliefs*. The main intention of this paper is to propose a fuzzy resource space model (FRSM) to improve the RSM in effectively managing resources by properly dealing with the relationship between the three factors.

Human factors have been studied in human-computer interaction area concerning users' cognitive models, distributed cognition, and knowledge reuse (Hollan et al., 2000; Ritter and Young, 2000; Sutcliffe, 2000), as well as in cognitive cooperation aspects (Zhuge, 2000). These previous work neglected an important phenomenon that users can be dynamically classified into two categories: the *resource providers* and the *resource users*. Any user plays the role of either the resource provider or the resource user at a certain time. The match degree between the beliefs of the two roles affects the effectiveness of resource retrieval and management. The effective organization of versatile resources is also an important factor of raising the efficiency and effectiveness of resource retrieval and management.

2. Resource space model

A *resource space* is an n-dimensional space where every point determines a set of resources, denoted as $\mathrm{RS}(X_1, X_2, \ldots, X_n)$, where RS is the name of the resource space and X_i is the name of an axis. $|\mathrm{RS}|$ denotes the number of dimensions, $|\mathrm{RS}| = n$. $X_i = \langle C_{i1}, C_{i2}, \ldots, C_{in}\rangle$ represents an axis with its coordinates and their order. Two axes are called the same if their names are the same and all the corresponding coordinates are the same. $R(C_i)$ denotes all the resources determined by coordinate C_i.

Assumption 1. An ontology-service mechanism is available: $Output = Ontology{-}Service(Input)$. The input parameter is a word or a word phrase. The ontology-service outputs a word set with the following elements: the synonym(s), the abstract-concept(s), the specific-concept(s), and the instance(s) of the input word.

Definition 1. A coordinate C is independent of another coordinate C' if $C \notin Output = Ontology - Service\ (C')$.

Definition 2. Let $X = (C_1, C_2, \ldots, C_n)$ be an axis and C_i' be a coordinate at another axis X', we say X fine classifies C_i' (denoted as C_i'/X) if and only if:

(1) $R(C_1) \cap R(C_i') \neq \phi$, $R(C_2) \cap R(C_i') \neq \phi, \ldots,$ and $R(C_n) \cap R(C_i') \neq \phi$;
(2) $(R(C_1) \cap R(C_i')) \cap (R(C_2) \cap R(C_i')) \cap \ldots \cap (R(C_n) \cap R(C_i')) = \phi$; and,
(3) $(R(C_1) \cap R(C_i')) \cup (R(C_2) \cap R(C_i')) \cup \ldots \cup (R(C_n) \cap R(C_i')) = R(C_i')$ hold.

As the result of the fine classification, $R(C_i')$ is classified into n categories: $R(C_i'/X) = \{R(C_1) \cap R(C_i'), R(C_2) \cap R(C_i'), \ldots, R(C_n) \cap R(C_i')\}$.

Definition 3 (*Fine classification*). For two axes $X = (C_1, C_2, \ldots, C_n)$ and $X' = (C_1', C_2', \ldots, C_m')$, we say X fine classifies X' (denoted as X'/X) if and only if X fine classifies $C_1', C_2', \ldots,$ and C_m'.

Definition 4 (*Orthogonality*). Two axes X and X' are called orthogonal each other (denoted as $X \perp X'$) if X fine classifies X' and vice versa, i.e., both X'/X and X/X' hold.

For example, $KnowledgeLevel = \langle Concept, Axiom, Rule, Method \rangle \perp Discipline = \langle Computer, Communication, Ecology, Math \rangle$ because of $\langle Concept, Axiom, Rule, Method \rangle$ constitutes a fine classification of every coordinate of the "Discipline" axis and $\langle Computer, Communication, Ecology, Math \rangle$ also constitutes a fine classification of every coordinate of the "*KnowledgeLevel*" axis. To answer the question of what is a good design of the resource space, we need to define the normal forms of the resource space.

Definition 5. The *first-normal-form* of a resource space is a resource space, and there does not exist name duplication between coordinates at any axis.

Definition 6. The *second-normal-form* of a resource space is a first-normal-form, and for any axis, any two coordinates are independent of each other.

Definition 7. The *third-normal-form* of a resource space is a second-normal-form where any two axes are orthogonal each other.

The three normal forms provide the designers the guidelines to design a proper resource space. The setting of the coordinates of a resource space is relevant to the type of resources. The role of the three normal forms is very similar to the normal forms of relational data model. The main differences are that the former is based on orthogonal classification and the latter is based on functional dependence relationship, and that the former is used for organizing versatile resources and the latter is used for organizing atomic data.

We have applied the RSM to organize and manage information, knowledge and service resources (http://kg.ict.ac.cn). Fig. 1 shows the retrieval interface of the Knowledge Grid, where the middle portion is a two-dimensional knowledge space and the lower portion is the operation interface corresponding to an operation button at the up-portion. An operation process includes the following steps: (1) choose an operation by clicking the relevant operation button; (2) choose a node of the category tree shown on the left portion; (3) choose a rectangle in the two-dimensional space by moving the mouse and then clicking the right point; (4) complete the query statement; and, (5) submit the query by clicking the "go" button.

3. Fuzzy resource space

3.1. Fuzzy semantics of resources

The management and retrieval of resources can be regarded as a kind of resource-mediated human-to-human interaction processes. The efficacy and efficiency are closely related to the consensus between people's understandings of resources when providing and using resources. Resources have the following fuzzy characteristics:

(1) *Overlap between some resources' natural classification semantics*. This naturally hinders resource providers from correctly putting resources into the exact categories and retrieving the right resources from the exact categories.
(2) *Resource providers' fuzzy beliefs on the classification of the resources they provide*. This causes a resource to be put into an incorrect category.
(3) *Resource users' fuzzy beliefs on the category of the resources they expect to use*, i.e., users do not know the exact category that the required resources belong to.

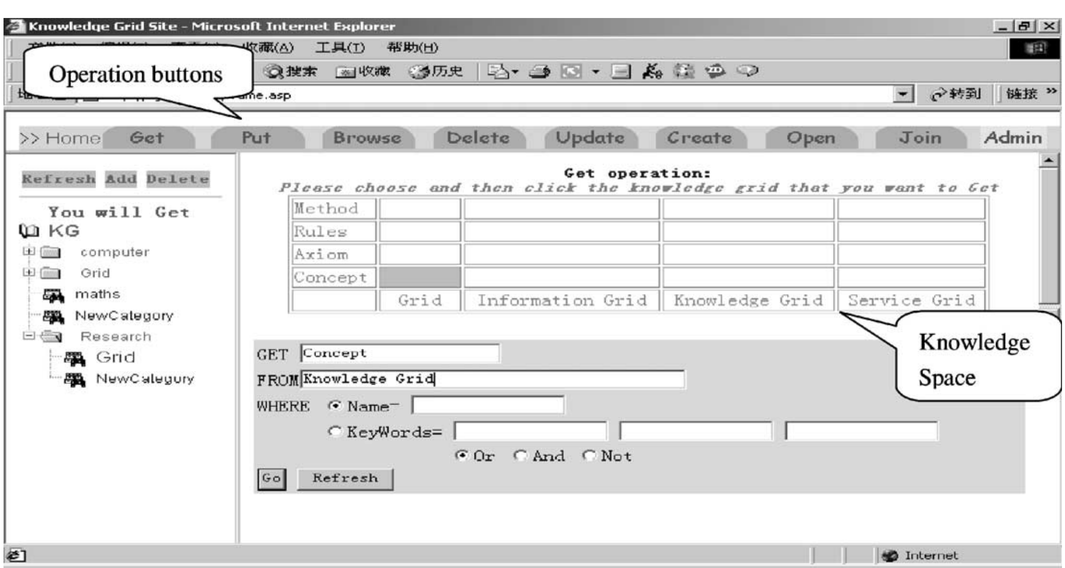

Fig. 1. Knowledge retrieval interface of the Knowledge Grid.

The current resource retrieval and management approaches do not deal with the above fuzzy characteristics. Users have to specify the exact resource retrieval condition even though they are not sure.

3.2. Fuzzy resource space

Recall and precision are criteria for assessing the effectiveness of information retrieval. They are defined as: *recall = the number of relevant resources retrieved/ the number of relevant resources existing*, and *precision = the number of relevant resources retrieved/ total number of resources retrieved*. Users of different application domains have different requirements on the lowest recall and precision.

Assumption 2. There exist the lowest *recall* and *precision* that satisfy the application requirement of the given domain, denoted as η_{recall} and $\eta_{\text{precision}}$.

Based on the fuzzy set theory (Zadeh, 1965), we define the fuzzy resource space as follows.

Definition 8. Let $\text{RS}(X_1, X_2, \ldots, X_n)$ be an *n*-dimensional resource space, C_{ij} be the coordinate of X_j, $\mu_{ij} \in [0,1]$ be the resource provider's belief on whether the resource belongs to category C_{ij} $(\mu_{1j} + \mu_{2j} + \cdots + \mu_{kj} = 1)$. A *Fuzzy Resource Space* of $\text{RS}(X_1, X_2, \ldots, X_n)$ is an *n*-dimensional fuzzy space represented as FRS $(F_1/X_1, F_2/X_2, \ldots, F_n/X_n)$, where $F_i = (\mu_{i1}/C_{i1}, \mu_{i2}/C_{i2}, \ldots, \mu_{in}/C_{in})$ is a fuzzy set on X_i.

The fuzzy resource space (FRS) is defined together with the corresponding resource space. In application, we can first use the RSM to define and normalize the resource space, then define the corresponding fuzzy resource spaces. η_{recall} and $\eta_{\text{precision}}$ determine the α-level fuzzy sets on the fuzzy resource space that meets the needs of domain applications. For example, Fig. 2 shows a two-dimensional fuzzy resource space: FRS $(F_x/X, F_y/Y)$. The expected η_{recall} and $\eta_{\text{precision}}$ determine two α-level fuzzy sets on F_x and F_y, which determine two rectangle regions in the space.

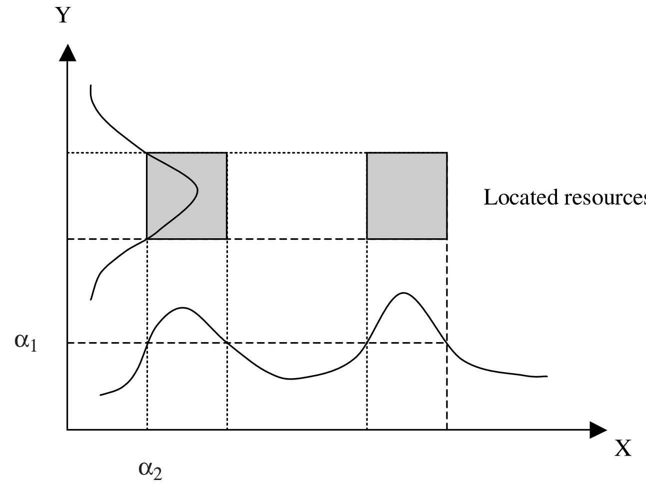

Fig. 2. Resource location in a two-dimensional fuzzy resource space.

3.3. Fuzzy resource operations

A fuzzy resource operation language (FROL) supports users to operate resources in the fuzzy resource space. We have developed the FROL based on the syntax and semantics of our previously developed resource operation language ROL (Zhuge, 2002a). The major difference is their condition portions. The syntax of the condition portion of the FROL is: $(F_1/X_1)\&(F_2/X_2)\&\ldots\&(F_n/X_n)$, which specifies the fuzzy resource spaces that contain the resources to be retrieved. The following are two examples of the FROL for putting a resource into and getting a resource from a FRS respectively.

PUT R INTO FRS WHERE $(FX = 0.5/X1 + 0.2/X2 + 0.3/X3)\&(FY = 0.4/Y1 + 0.3/Y2 + 0.3/Y3)$
GET* FROM FRS WHERE $(FX = 0.4/X1 + 0.3/X2 + 0.3/X3)\&(FY = 0.4/Y_1 + 0.4/Y2 + 0.2/Y3)$

The put operation assigns resource *R* the provider's belief μ_{provider}. The get operation provides the resource user's belief μ_{user}. Usually the retrieval result is a set of resources that satisfies: (1) μ_{user} matches μ_{provider} in a certain degree; (2) the *recall* of the returned result $\geqslant \eta_{\text{recall}}$; and, (3) the *precision* of the returned result $\geqslant \eta_{\text{precision}}$.

The FROL enables developers to compose resource operation programs to realize domain applications. We have implemented the operation interface as shown in Fig. 3 to support end-users directly operating resources.

4. Implementation, analysis and strategy

4.1. Implementation

The FRSM and the operation language have been implemented in the initial version of the Knowledge Grid platform VEGA-KG (http://kg.ict.ac.cn) and published online since 2001. The structure and semantics of resources in the FRS are represented by the XML and RDF (Klein, 2001; http://www.w3c.org/RDF/). Semantic relationships between resources are represented by semantic links rather than traditional hyperlinks. Fig. 3 shows the fuzzy knowledge retrieval interface, where the middle portion shows the two-dimensional resource space, and the lower portion displays the interface for specifying the constraint of the fuzzy retrieval. The operation process of the interface is the same as Fig. 3

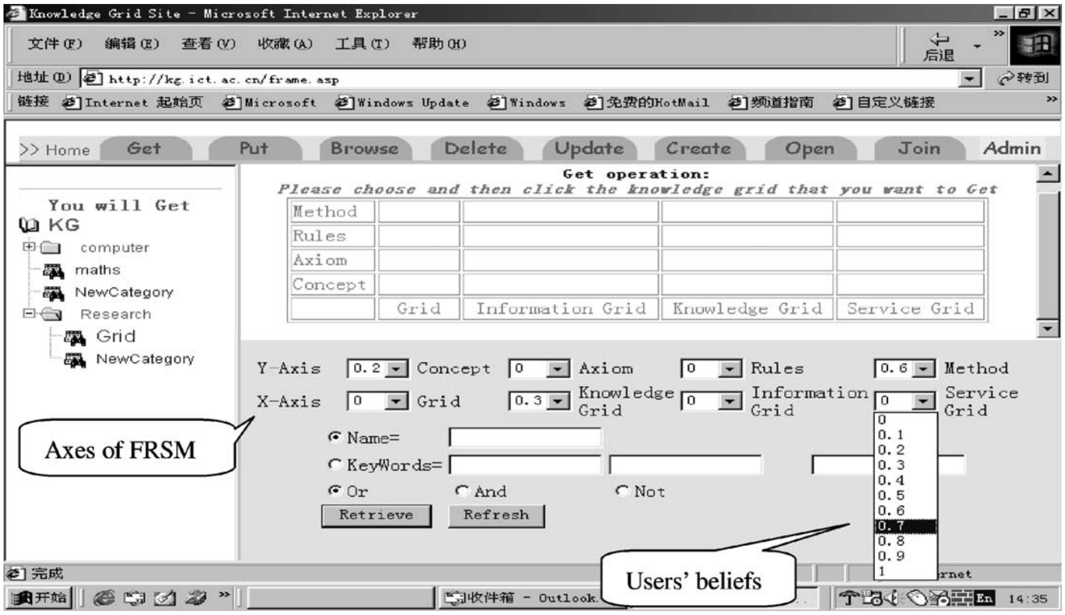

Fig. 3. Interface of fuzzy retrieval in fuzzy knowledge space.

except for the lower portion that determines the user's beliefs on the coordinates of two axes. The retrieval result is displayed in the lower portion of the interface shown in Fig. 4. The interface for putting knowledge into the knowledge space is similar to that shown in Fig. 3. Currently, we are implementing the fuzzy Service Grid by using the FRSM.

4.2. Impact analysis

The resource retrieval operation is the basis of resource management operations, so we herein focus on analyzing its precision and recall. Previous work on information retrieval mainly focuses on technical aspects like the improvement of the efficiency and effectiveness (Flake et al., 2002; Srihari et al., 2000). In the following, we analyze the human factors in retrieval process.

Table 1 shows the relationship between the resources' natural characteristic, the resource providers' belief, the resource users' belief, and their impact on the retrieval result in case of without using the fuzzy beliefs. "$R \in A \cup B$" means that resource R belongs to or is put into both A and B. "$R \in A$ or $R \in B$" means that the

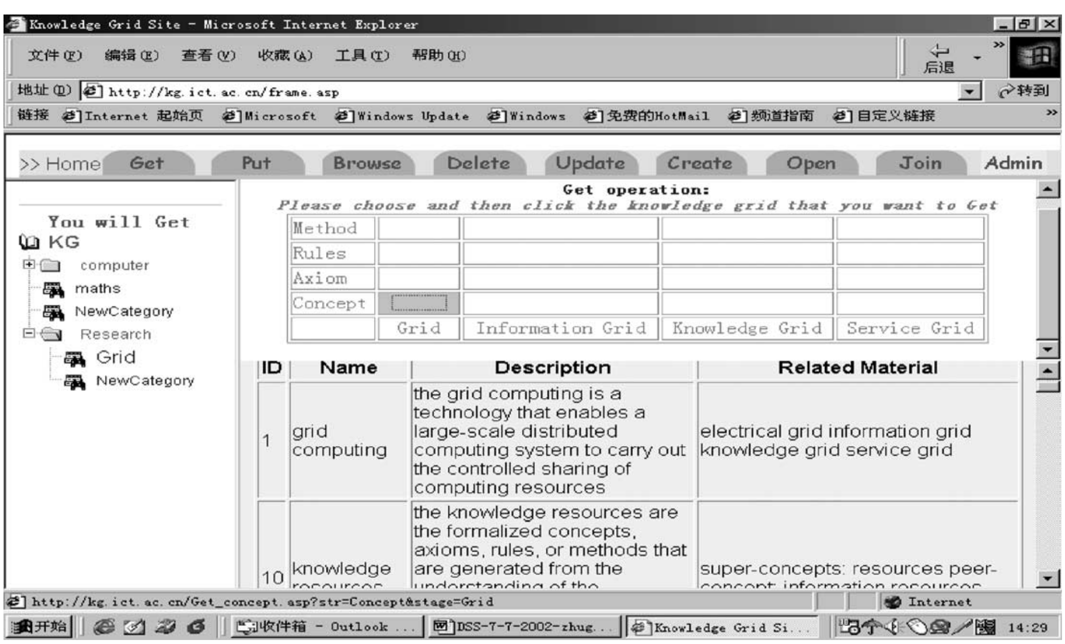

Fig. 4. Interface for displaying results of fuzzy retrieval.

Table 1
Impact analysis of exact resource retrieval

Resources' natural characteristic	Resource providers' beliefs	Resource users' beliefs	Impact on retrieval result	Reference value
$R \in A$	$R \in A$	$R \in A$	+	+1
$R \in A \cup B$	$R \in A \cup B$	$R \in A \cup B$	+	+1
$R \notin$ any subspace	$R \notin$ any subspace	$R \notin$ any subspace	+	+1
$R \in A \cup B$	$R \in A$	$R \in A$	+	+0.9
$R \in A \cup B$	$R \in A$	$R \in A \cup B$	+	+0.7
$R \in A \cup B$	$R \in A \cup B$	$R \in A$	+	+0.7
$R \in A$	$R \in A$ or $R \in B$	$R \in A$ or $R \in B$	+	+0.4
$R \in A$	$R \in A$ or $R \in B$	$R \in A$	+	+0.4
$R \in A$	$R \notin A$	$R \notin A$	0	0
$R \notin$ any subspace	$R \in A$	$R \in A$	0	0
$R \notin$ any subspace	$R \in A$	$R \notin A$	−	−1
$R \in A$	$R \in A$	$R \notin A$	−	−1
$R \in A$	$R \notin A$	$R \in A$	−	−1
$R \notin$ any subspace	$R \notin$ any subspace	$R \in A$	−	−1

Note: A and B are the subspaces that contain resource R, "+" means positive, "−" means negative, "+1" means the most positive, "−1" means the most negative, and "0" means neutral impact.

provider does not know exactly which category (A or B) resource R belongs to, but he/she must decide to put the resource into a category. The consistence among the three factors forms the positive impact on the retrieval result.

Table 2 considers the fuzzy characteristics of the resource providers' beliefs and the resource users' beliefs and their impact on the retrieval result in case of using the fuzzy beliefs. "$R \in A \cup B$ with μ_1" means that the provider should put R into both A and B with the same belief μ_1. For the provider, "$R \in A$ with μ_1 or $R \in B$ with μ_2" implies that the provider does not know exactly which category (A or B) resource R belongs to, he/she can put the resource into both A and B but with different beliefs. The degree of impact on retrieval result is a value in [0, 1], the larger one means more positive impact on the retrieval result.

To compare the effectiveness of the fuzzy and exact retrieval approaches under different conditions, we have carried out experiment by selecting the exact "get" operation and the inexact "get" operation of the Knowledge Grid prototype (see http://kg.ict.ac.cn). We assume that the resource's natural characteristic is "$R \in A$ ", the resource provider's belief is "$R \in A$ with μ_1", and the resource user's belief is "$R \in A$ with μ_1'" in the fuzzy approach. Table 3 shows the average retrieval results of three times independent experiments. The number of retrieval results of the exact approach is exact and reduces sharply with the increase of the number of keywords under "and" conjoint condition. The number

Table 3
Comparison between the number of retrieval results of the exact and fuzzy approaches

No.	Condition	Exact approach	Fuzzy approach
1	Without keyword	13	0–51
2	1 keyword	8	0–36
3	2 AND keywords	3	0–13
4	3 AND keywords	3	0–8
5	2 OR keywords	12	0–43
6	3 OR keywords	12	0–49

Table 2
Impact analysis of fuzzy resource retrieval

Resource's natural characteristic	Resource providers' beliefs	Resource users' beliefs	Degree of impact on retrieval result
$R \in A$	$R \in A$ with μ_1	$R \in A$ with μ'_1	$\mathrm{Min}(\mu_1, \mu'_1)/\mathrm{Max}(\mu_1, \mu'_1)$
$R \in A$	$R \in A$ with μ_1	$R \notin A$ with μ'_1	$\mathrm{Min}(\mu_1, 1-\mu'_1)/\mathrm{Max}(\mu_1, 1-\mu'_1)$
$R \in A$	$R \notin A$ with μ_1	$R \notin A$ with μ'_1	$\mathrm{Min}(1-\mu_1, 1-\mu'_1)/\mathrm{Max}(1-\mu_1, 1-\mu'_1)$
$R \in A$	$R \notin A$ with μ_1	$R \in A$ with μ'_1	$\mathrm{Min}(1-\mu_1, \mu'_1)/\mathrm{Max}(1-\mu_1, \mu'_1)$
$R \in A$	$R \in A$ with μ_1 or $R \in B$ with μ_2	$R \in A$ with μ'_1 or $R \in B$ with μ'_2	$0.5 * (\mathrm{Min}(\mu_1, \mu'_1)/\mathrm{Max}(\mu_1, \mu'_1) + \mathrm{Min}(\mu_2, \mu'_2)/\mathrm{Max}(\mu_2, \mu'_2))$
$R \in A \cup B$	$R \in A$ with μ_1 or $R \in B$ with μ_2	$R \in A$ with μ'_1 or $R \in B$ with μ'_2	$0.5 * (\mathrm{Min}(\mu_1, \mu'_1)/\mathrm{Max}(\mu_1, \mu'_1) + \mathrm{Min}(\mu_2, \mu'_2)/\mathrm{Max}(\mu_2, \mu'_2))$
$R \in A \cup B$	$R \in A \cup B$ with μ_1	$R \in A \cup B$ with μ'_1	$\mathrm{Min}(\mu_1, \mu'_1)/\mathrm{Max}(\mu_1, \mu'_1)$
$R \notin$ any subspace	$R \in A$ with μ_1	$R \in A$ with μ'_1	$0.8 * \mathrm{Min}(\mu_1, \mu'_1)/\mathrm{Max}(\mu_1, \mu'_1)$
$R \notin$ any subspace	$R \in A$ with μ_1	$R \notin A$ with μ'_1	$0.4 * \mathrm{Min}(\mu_1, 1-\mu'_1)/\mathrm{Max}(\mu_1, 1-\mu'_1)$
$R \notin$ any subspace	$R \notin$ any subspace	$R \in A$ with μ'_1	$-\mu'_1$

Note: A and B are the subspaces that contain resource R.

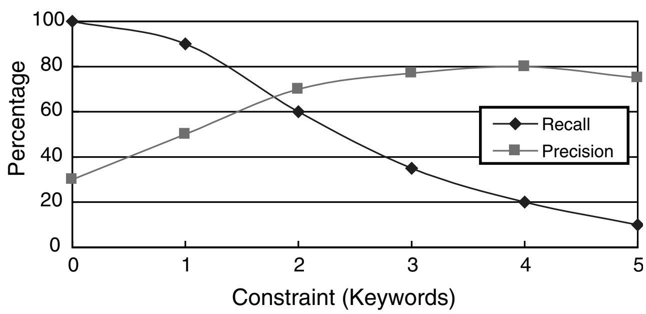

Fig. 5. Recall and precision of resource space search.

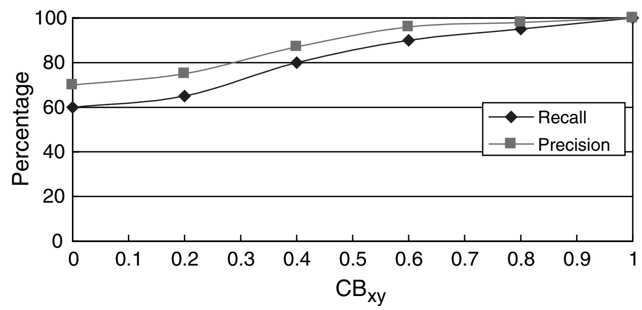

Fig. 7. Recall and precision with the change of CB_{xy} under the same constraint.

of retrieval result of the fuzzy approach is a range determined by the matching degree of the resource provider's belief and the resource user's belief. The range is narrowed quickly with the increase of the number of keywords under "and" conjoint condition.

Fig. 5 compares the recall and precision with the change of constraints (the number of keywords) in case of exact approach based on the average experimental results of a set of retrieval operations. The precision goes up and the recall goes down with tightening the constraint. The reason of the high starting points of the two curves is that the orthogonal multi-dimensional resource space limits the search space in polynomial scale (this enables resource retrieval to be accurately carried out).

Fig. 6 compares the user's beliefs with the provider's beliefs in a two-dimensional fuzzy resource space. The dark areas CB_x and CB_y respectively reflect the common beliefs between the provider and the user on axes X and Y. $CB_x = \text{Min}_{X1}(\mu_{\text{provider}}, \mu_{\text{user}})/X_1 + \cdots + \text{Min}_{Xn}(\mu_{\text{provider}}, \mu_{\text{user}})/X_n$, and $CB_y = \text{Min}_{Y1}(\mu_{\text{provider}}, \mu_{\text{user}})/Y_1 + \cdots + \text{Min}_{Yn}(\mu_{\text{provider}}, \mu_{\text{user}})/Y_n$, where X_i and Y_i are the coordinates of X and Y respectively. We can use $CB_{xy} = (\text{Min}_{X1}(\mu_{\text{provider}}, \mu_{\text{user}}) + \cdots + \text{Min}_{Xn}(\mu_{\text{provider}}, \mu_{\text{user}})) \times (\text{Min}_{Y1}(\mu_{\text{provider}}, \mu_{\text{user}}) + \cdots + \text{Min}_{Yn}(\mu_{\text{provider}}, \mu_{\text{user}}))$ to reflect the general common beliefs between the provider and the user.

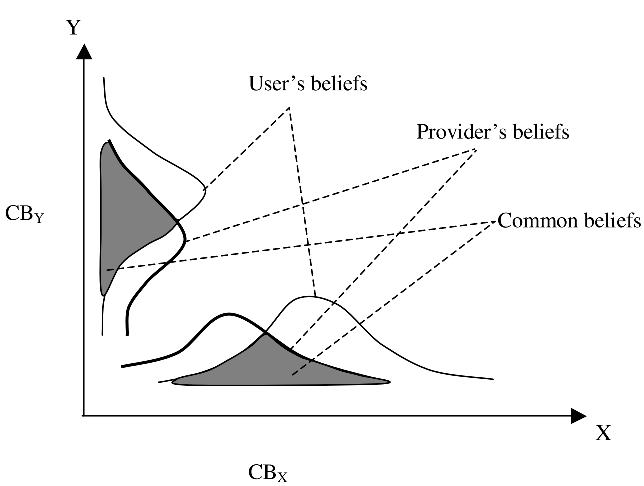

Fig. 6. Common beliefs between providers and users in a two-dimensional fuzzy resource space.

To examine the recall and precision of the fuzzy retrieval approach in the fuzzy resource space, we asked one group of students to provide resources and the other group to use resources under the same topic. One student records the belief of each student when providing and using resources and records all the retrieval results under different beliefs and constraints. The two groups of students were asked to jointly compute the recall and precision by comparing the provided resources and the retrieval results. Fig. 7 reflects the change of recall and precision with the change of CB_{xy} under the same constraint (two "and" conjoint keywords). *It shows that more common beliefs between the provider and the user lead to higher precision and higher recall.*

4.3. Strategies

According to the above analysis, the following strategies can be adopted to increase the effectiveness of resource management:

(1) The resource providers and users should put resources into and use resources in the resource space with high beliefs when they are sure of the categories of the resources, and do with average beliefs on all coordinates when they are not sure.
(2) The resource users should tighten or loosen the retrieval constraint (e.g., by providing more or less "and" conjoint keywords) to raise the starting points of the precision and recall.
(3) Communication between resource providers and resource users is a way to raise the effectiveness of resource management and retrieval. The communication provides the chance to update their beliefs and make their beliefs better match each other. The current information management and retrieval mechanisms do not provide such a communication function.
(4) Establish feedback mechanism and belief maintenance mechanism. The feedback mechanism enables

resource users and providers to adjust their beliefs during using resources and collects their opinions on beliefs (in form of voting). The belief maintenance mechanism can dynamically synthesize a kind of *reference beliefs* according to the providers' beliefs and the users' beliefs. The reference belief will approach the natural classification semantics of the resources after a long-term execution of the maintenance mechanism.

5. Summary

Based on the RSM, this paper proposes the FRSM, which includes a FRS and a fuzzy ROL. The major contribution concerns the following factors: first, we have proposed a new approach to improve the effectiveness of resource operation by taking into account the fuzzy semantics of resources, the resource providers' beliefs, the resource users' beliefs and the relationship between them. These characteristics are often neglected in previous works. Second, we proposed a solution to balance between the ideal: normal organization of versatile resources that guarantees the correctness and efficiency of resource operations, and the reality: the fuzzy characteristics of resource organization and management as well as the application requirement of flexible resource operation. Third, we have implemented the software platform based on the proposed model. The proposed model and platform provide a promising way to organize and manage versatile resources in the next-generation Web environment.

Acknowledgements

The author thanks all members of China Knowledge Grid Research Group for their diligent work especially Yanyan Li, Jie Liu, Peng Shi, Weiyu Guo, Liping Zheng, Lianhong Ding, Jia Bi and Ruixiang Jia.

References

Codd, E.F., 1970. A relational model of data for large shared data banks. Communications of the ACM 13, 377–387.

Flake, G.W., Glover, E.J., Lawrence, S., 2002. Extracting Query Modifications from Nonlinear SVMs. In: Proceedings of the 11th International World Wide Web Conference, Hawaii, May, 317–324.

Foster, I., 2000. Internet Computing and the Emerging Grid, Nature, December 7. Available at <http://www.nature.com/nature/webmatters/>.

Hendler, J., 2001. Agents and the semantic web. IEEE Intelligent Systems 16 (2), 30–37.

Hendler, J., McGuinness, D., 2000. The DARPA agent markup language. IEEE Intelligent Systems 6 (15), 72–73.

Henzinger, M.R., 2001. Hyperlink analysis for the web. IEEE Internet Computing (Jan/Feb), 45–50.

Hollan, J., Hutchins, E., Kirsh, D., 2000. Distributed cognition: toward a new foundation for human-computer interaction research. ACM Transactions on Computer-Human Interaction 7 (2), 174–196.

Klein, M., 2001. XML, RDF, and relatives. IEEE Internet Computing (March/April), 26–28.

McHraith, S.A., Son, T.C., Zeng, H., 2001. Semantic web services. IEEE Intelligent Systems (March/April), 46–53.

Mok, W.Y., 2002. A comparative study of various nested normal forms. IEEE Transactions on Knowledge and Data Engineering (14), 369–385.

Ritter, F.E., Young, R.M., 2000. Supporting cognitive models as users. ACM Transactions on Computer-Human Interaction 7 (2), 141–173.

Rumbaugh, J., Blaha, M., Premerlani, W., Eddy, F., Lorensen, W., 1991. Object-Oriented Modeling and Design. Prentice-Hall.

Srihari, R.K., Zhang, Z., Rao, A., 2000. Intelligent indexing and semantic retrieval of multimodel documents. Information Retrieval (2), 245–275.

Sutcliffe, A., 2000. On the effective use and reuse of HCI knowledge. ACM Transactions on Computer-Human Interaction 7 (2), 197–221.

Zadeh, L.A., 1965. Fuzzy sets. Information and Control (8), 338–353.

Zhuge, H., 2000. Conflict decision training through multi-space co-operation. Decision Support Systems (29), 111–123.

Zhuge, H., 2002a. A knowledge grid model and platform for global knowledge sharing. Expert Systems with Applications 22 (4), 313–320.

Zhuge, H., 2002b. Clustering soft-devices in semantic grid. IEEE Computing in Science and Engineering 6 (4), 60–62.

Zhuge, H., in press. Design Method for Resource Space Model RSM. Journal of Systems and Software.

Hai Zhuge is a professor at the Institute of Computing Technology, Chinese Academy of Sciences. He leads the Key Lab of Intelligent Information Processing and the China Knowledge Grid research group (http://kg.ict.ac.cn). He is serving on the editorial boards of a number of international journals such as *Information and Management*, *Journal of Systems and Software*, and *Future Generation Computer Systems*. His current research interest is the theory and model on the next-generation Web including the knowledge and semantic grid. He is the author of two books and over sixty papers appeared mainly in leading international conferences and journals such as *Communications of the ACM*, *IEEE Intelligent Systems*, *IEEE Computing in Science and Engineering*, *IEEE Transactions on Systems, Man, and Cybernetics*; *Information and Management*; *Decision Support Systems*, and *Journal of Systems and Software*.