Towards Trustworthy Resource Selection in Grid: A Fuzzy Partial Ordering based Approach

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Summary

The problem of resource selection in Grid is challenging because of the wide range of selection and the high degree of strangeness. Efficient resource sharing and utilization cannot be achieved without the guarantee of a higher degree of trust relationship. In this paper, reputation mechanism is introduced to resource selection in Grid, which aims at leverage the guarantee of trustworthiness and reliability. According to the fact that reputation is multi-faceted and uncertain, guided by the evaluation and decision making ideas from fuzzy partial ordering, the proposed approach makes fuzzy partial order modeling on each resource provider's multi-faceted reputation, integrates overall information, and choose proper resource providers according to the final integrative order. Compared with other methods, this approach has better overall consideration.

Key words:

resource selection; reputation; fuzzy partial order; Grid

Introduction

The wide application of the Internet and the increasing performance improvement of computer systems and network devices, have continuously promote the evolution of computing patterns. Currently, a new network computing patterns-Grid computing has emerged as one of the key computing paradigms that enable the creation and management of Internet-based utility computing infrastructure for realization of e-Science and e-Business at the global level. The Grid, as envisaged by Foster & Kessselman [1] and more recently by Berman, Fox and Hey, is a ubiquitous computing infrastructure that allows flexible, secure, coordinated resource sharing among dynamic collections of individuals, institutions, and resources. The concept of Grid as an infrastructure is important because it is concerned, above all, with large scale pooling of resources, regardless of computer cycles, data, sensors, or people, undertaken in a transparent and pervasive manner [2].

The emergence of Grid computing has promoted the development and application of the Internet to a new era. Yet, many challenging problems should be conquered before cooperative resource sharing and problem solving can really come true in such wide distributed and pervasively heterogeneous computing environment as in Grid. Among all the problems, one is how to make a reliable and trustworthy selection from all the wide distributed and large-scale resources available. In Grid, resource sharing and accessing has broken the boundary of administrative domain, spanning from the closed, acquaintance-oriented and relatively static intro-domain computing environment to the open, decentralized and highly dynamic inter-domain computing environment. The scale of resources and the strangeness of entities complicate the process of resource selection. Without certain trust relationship underlying, efficient resource sharing cannot be achieved in Grid, as a high-efficient society cannot go with a high-trustworthy social relationship.

Recently, with wide application in e-commerce and on-line communities, reputation mechanisms as is distinguished for its better scalability and flexibility has become one of the key techniques underpinning the internet-based e-commerce, distributed application and system security. Reputation mechanisms provide a way for building trust through social control by utilizing community based feedback about past experiences of entities to help making recommendation and judgment on quality and reliability of the transactions [3]. For the inherent sharing and cooperative nature of Grid, reputation mechanism is promising to perform well in Grid. It can be expected to improve the reliability and trustworthiness of resource selection, and further promote efficient resource sharing and benign evolution of the Grid, if we introduce reputation mechanisms to Grid, and choose resources according to the provider's reputation. As reputation is a multi-faceted concept [16], which means that reputation has multiple aspects, such as capability, honesty, and reliability and so on, any resource provider will combine many aspects of reputation in one. Among those aspects, some might be higher, some might be lower. Confronted with so many aspects, how to scientifically evaluate them, reasonably integrate information, and make the final selection? This is what we focus on solving in this paper-evaluation and decision making on reputation with multi-facet. The main idea is based on fuzzy partial ordering and selection is made from within. For space limitation, we will not elaborate on reputation evaluation methods on single aspect. Anyone interested in this may refer to [4] [5] for details.

The rest of the paper is organized as follows: in Section 2 fuzzy partial order models of evaluation and decision

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making are introduced; in Section 3, the proposed trustworthy resource selection method is given by means of a case study; in section 4, related work is briefed and compared; and finally in Section 5, the whole paper is concluded.

2. Fuzzy Partial Order Models of Evaluation and Decision Making

2.1 The Basic Idea of Evaluation and Decision Making

Generally speaking, evaluation means the behavior of specifying the goal, measuring entity's attributes, and turning them into subjective effect (which will satisfy what the evaluator demands to a certain degree). The object under evaluating might be a person, an organization, a product, a project, or a solution etc. By means of relative attribute or mutual relationship measuring, an object's value is judged. [8] According to the evaluatee's different features and forms provided in evaluation, the evaluation patterns are different. There are 2 typical evaluation models:

Definition 1 (U, A, F) is called a **value evaluation model**, if $U=\{x_1, x_2, \ldots, x_n\}$ is a set of objects or solutions under evaluation, where x_i is the i^th object under evaluation; $A=\{a_1, a_2, \ldots, a_m\}$ is a set of evaluated attributes, where a_l is the l^th evaluated attribute; $F=\{f_l: U\rightarrow V_l(l\leq m)\}$ is a set of relationships between objects and attributes, where $f_l(x_i)$ is the measured value of object x_i on attribute a_l, and V_l is all the possible values for attribute a_l, which is called a_l's range. If $f_l(l\leq m)$ is in form of numerical value, the model is called **cardinal value evaluation model**; and if $f_l(l\leq m)$ is in form of preferable position, the model is called **ordinal value evaluation model**.

Definition 2 $(U, \boldsymbol{R})$ is called a **relation evaluation model**, if $U=\{x_1, x_2, \ldots, x_n\}$ is the set of objects to be evaluated, R is the set of mutual relations between to-be-evaluated objects, i.e.

$$R=\begin{pmatrix} R(x_1,x_1) & R(x_1,x_2) & \cdots & R(x_1,x_n) \\ R(x_2,x_1) & R(x_2,x_2) & \cdots & R(x_2,x_n) \\ \vdots & \vdots & & \vdots \\ R(x_n,x_1) & R(x_n,x_2) & \cdots & R(x_n,x_n) \end{pmatrix}$$

Where $R(x_i, x_j)$ stands for some superior or inferior relation between object x_i and x_j. If $R(x_i, x_j)$ is in form of preferable relation, the model is called ordinal relation evaluation model; if $R(x_i, x_j)$ is in form of numerical value, the model is called **cardinal relation evaluation model.**

There is substantial difference between value evaluation model and relation evaluation model. Value evaluation model consists of the set of objects under evaluation, the set of attributes, and the set of attribute values, which is in form of datasheet; Whereas, relation evaluation model consists of the set of objects under evaluation and bi-relation between objects, which is in form of relation matrix. For value evaluation model, information is integrated by means of building up objects' attribute values; for relation evaluation model, information is integrated by means of building up objects' bi-relation. Since multiple attributes or entities are involved, any evaluation model is a kind of partial order. Information integration is to turn partial order into total order, and get the superior and inferior order of the objects under evaluation.

Value evaluation model and relation evaluation model can be transformed mutually. Deem that (U, A, F) is value evaluation model,

$$F=\{f_l: U\rightarrow V_l\,(l\leq m)\},$$
$$V=\{v=(v_1, v_2, \ldots, v_m)\mid v_l\in V_l\,(l\leq m)\},$$

Then, $(V, \leq)$ is partial order. Denote that:

$$F(x_i)=(f_1(x_i), f_2(x_i), \ldots, f_m(x_i)),$$

$$R(x_i,x_j)=\begin{cases} \succ, & F(x_i)>F(x_j) \\ \prec, & F(x_i)<F(x_j) \\ \approx, & F(x_i)=F(x_j) \\ ?, & others \end{cases}$$

Then ordinal relation evaluation model is obtained.

Relation evaluation model can be transformed to value evaluation model. As in relation evaluation model, mutual relation is given between objects, such relation should be quantified in information integration, and then get the complete comparing relation. For a group of individual evaluating relation given by multiple attributes, after integration the model will be transformed to value evaluation model.

For value evaluation model (U, A, F), if there are multiple evaluating attributes, object xi's evaluating value can be denoted by $F(x_i)=(f_1(x_i), f_2(x_i), \ldots, f_m(x_i))(i\leq n)$. Each object's attribute value is an m dimensional vector. And there are n vectors under comparison. If $F(x_i)\leq F(x_j)$ stands for $x_i\leq x_j$, then $(U, \leqq)$ is a quasi-order set. For quasi-order set $(U,\leqq)$, we use $R=\{(x_i,x_j)\mid x_i\leq x_j\}$ to stand for the relation set that x_i is inferior to x_j, and use $R^{-1}=\{(x_i,x_j)\mid x_j\leq x_i\}$ to stand for the relation set that x_i is superior to x_j. Then, $R\cap R^{-1}=\{(x_i,x_j)\mid x_i\approx x_j\}$ stands for the relation set that x_i and x_j is the same or equivalent. And stands for the relation set that x_i and x_j is incomparable.

Definition 3 Deem that $(U, \leqq)$ is a quasi-order set, and the evaluating result $(U, \leq)$ is a set in total order. If for any $(x_i, x_j)\in R$, $x_i\leq x_j$ holds, and for any $(x_i, x_j)\in R^{-1}$, $x_j\leq x_i$ holds, then $(U, \leq)$ is called a **reasonable evaluation**. If for any $(x_i, x_j)\in R$ and $(x_i, x_j)\notin R\cap R^{-1}$, $x_i<x_j$ holds, and for any $(x_i, x_j)\in R^{-1}$ and $(x_i, x_j)\notin R\cap R^{-1}$, $x_i>x_j$ holds, then $(U, \leq)$ is called a **strict reasonable evaluation**.

Lemma 1 Deem that $(U, \leq)$ is a set in partial order, then:

(1) $R\cap R^{-1}$ is an equivalent relation;
(2) $\sim(R\cup R^{-1})$ is symmetrical, but not reflexive and transitive;
(3) R and R^{-1} are both reflexive and transitive, but not symmetrical.

Proof. Direct validation can prove it.

Lemma 2 Deem that (U, $\leq$) is a partial-order set, then there exists a total order on U for (U, $\leq$) to be a strict reasonable evaluation.

Proof. Denote that

$$R(x_i,x_j)=\begin{cases}1, & (x_i,x_j)\in R^{-1},(x_i,x_j)\notin R\cap R^{-1},\\ \delta\in(0.5,1), & (x_i,x_j)\notin R\cup R^{-1},\\ 0.5, & (x_i,x_j)\in R\cap R^{-1},\\ 0, & (x_i,x_j)\in R,(x_i,x_j)\notin R\cap R^{-1}\end{cases}$$

If $x_i > x_k$, then:

(1) when $x_k > x_j$, $x_i > x_j$ holds;

(2) when $x_k ? x_j$, $x_i ? x_j$ or $x_i > x_j$ holds;

(3) when $x_k < x_j$, $x_i < x_j$ or $x_i > x_j$ or $x_i ? x_j$ holds.

Therefore, for $R(x_i)=\sum_{j\neq i} R(x_i,x_j)$, when $x_i > x_k$, $R(x_i) > R(x_k)$ holds. If we ordering U by $R(x_i)$'s value, we will get a strict reasonable evaluation on U.

In evaluation and decision making, relation evaluation model gives a kind of partial-order relation. For the uncertainty in the evaluated objects and the features representing the objects, classical partial-order relation cannot reflect such uncertainty, i.e. it cannot reflect the uncertainty in objects' relation. Whereas, fuzzy partial order is a more suitable choice to reflect such uncertainty.

Definition 4 Deem that (U,≤) is a partial-order set, relation model (U,≤,R) is called a fuzzy partial order model, if R is fuzzy partial-order relation, it satisfies:

（1） $0\leq R(x_i, x_j)\leq 1$ ($x_i, x_j\in U$);

（2） when $x_i\geq x_j$, $R(x_i, x_j)\geq R(x_j, x_i)$ holds, ($x_i, x_j\in U$);

（3） when $x_i\geq x_j$, $R(x_i, x_k)\geq R(x_j, x_k)$ holds, ($x_i, x_j, x_k\in U$);

（4） when $x_i\geq x_j\geq x_k$, $R(x_k, x_j)\geq R(x_k, x_i)$ holds, ($x_i, x_j, x_k\in U$).

If we change (2) to: when $x_i > x_j$, $R(x_i, x_j)=1$ holds, and when $x_i\approx x_j$, $R(x_i, x_j)=0.5$ holds, R is called **fuzzy strict partial order relation**.

2.2 Several Fuzzy Partial Order Relations

(1) Deem that (U, ≤) is a partial-order set, denote

$$R(x_i,x_j)=\begin{cases}1, & x_i > x_j,\\ 0, & x_i < x_j,\\ 0.5, & x_i \approx x_j,\\ 0.8, & x_i\, ?\, x_j.\end{cases} \quad (1)$$

Then, R=($R(x_i, x_j)$, $x_i, x_j\in U$) is a fuzzy strict partial order relation.

Proof. What needs to prove is that when $x_i\geq x_j$, $R(x_i, x_k)\geq R(x_j, x_k)$ holds. There are 3 scenarios to consider. As $x_i\geq x_j$, when $x_j > x_k$, $x_i > x_k$ holds; when $x_j\approx x_k$, $x_i\approx x_k$ or $x_i > x_k$ holds; when $x_j ? x_k$, $x_i ? x_k$ or $x_i > x_k$ holds. In all the above scenarios, $R(x_i, x_k)\geq R(x_j, x_k)$ holds. Similarly, we can prove when $x_i\geq x_j\geq x_k$, $R(x_k, x_j)\geq R(x_k, x_i)$ holds.

(2) Deem that (U, ≤) is a partial-order set, denote

$$R(x_i,x_j)=\frac{\left|\{x_k\mid x_k\leq x_i\}\right|}{\left|\{x_k\mid x_k\leq x_i\}\right|+\left|\{x_k\mid x_k\leq x_j\}\right|}(x_i,x_j,x_k\in U) \quad (2)$$

where |·| stands for the number of elements in a set. Then, R=($R(x_i, x_j)$, $x_i, x_j\in U$) is a fuzzy strict partial order relation.

We can prove that: $0\leq R(x_i, x_j)\leq 1$. When $x_i\geq x_j$, $R(x_i, x_j)\geq 0.5$; when $x_i < x_j$, $R(x_i, x_j) < 0.5$ and $R(x_i, x_j)+R(x_j, x_i)=1$; when $x_i\geq x_j$, $R(x_i, x_j)\geq R(x_j, x_i)$. In the following, we prove that when $x_i\geq x_j$, $R(x_i, x_l)\geq R(x_j, x_l)$ holds. As

$$R(x_i,x_l)=\frac{\left|\{x_k\mid x_k\leq x_i\}\right|}{\left|\{x_k\mid x_k\leq x_i\}\right|+\left|\{x_k\mid x_k\leq x_l\}\right|},$$

$$R(x_j,x_l)=\frac{\left|\{x_k\mid x_k\leq x_j\}\right|}{\left|\{x_k\mid x_k\leq x_j\}\right|+\left|\{x_k\mid x_k\leq x_l\}\right|},$$

With the fact that when $a\geq$b, $\frac{a}{a+c}\geq\frac{b}{b+c}$ holds, it can be concluded that when $x_i\geq x_j$, $\left|\{x_k\mid x_k\leq x_i\}\right| \geq \{x_k\mid x_k\leq x_j\}$ holds, so $R(x_i, x_l)\geq R(x_j, x_l)$.

Similarly, we can prove that when $x_i\geq x_j\geq x_l$, $R(x_l, x_j)\geq R(x_l, x_i)$holds.

(3) Deem that (U, A, F) is an evaluation model, $F=\{f_l: U\rightarrow[0,1](l\leq m)\}$,

$$R(x_i,x_j)=\frac{\left|\{a_l\mid f_l(x_i)\geq f_l(x_j)\}\right|}{m} \quad (3)$$

Where m is the number of elements in set A, then $R(x_i, x_j)$ is a fuzzy partial order relation.

(4) Deem that (U, $\leq$) is a partial-order set, and $[x_i]^{<}=\{x_j \mid x_i\leq x_j\}$ stands for the category that is superior to x_i. Then

$$R^{<}(x_i,x_j)=\frac{\left|\sim[x_i]^{<}\cup[x_j]^{<}\right|}{|U|} \quad (4)$$

is a fuzzy partial order relation on (U, $\leq$). Similarly, denote the category inferior to x_i as $[x_i]^{>}=\{x_j \mid x_i\geq x_j\}$, then after transforming to superior relation, we get:

$$R^{>}(x_i,x_j)=1-\frac{\left|\sim[x_i]^{>}\cup[x_j]^{>}\right|}{|U|} \quad (5)$$

Relation (5) is also a fuzzy partial order relation on (U, $\leq$).

(5) For continuous system (U, A, F), relations given by formula (6) (7) and (8) are fuzzy partial order relations on (U, ≤).

$$R_l(x_i, x_j) = 1 \wedge (1 - f_l(x_i) + f_l(x_j)) \quad (6)$$

$$R(x_i, x_j) = \min_{l \le m} R_l(x_i, x_j) \quad (7)$$

$$R(x_i, x_j) = \frac{1}{m} \sum_{l=1}^{m} R_l(x_i, x_j) \quad (l \le m) \quad (8)$$

(6) For continuous system (U, A, F), relation given by formula (9) is a fuzzy partial order relations on (U, ≤).

$$R(x_i, x_j) = \frac{\sum_{l=1}^{m} (f_l(x_i) \wedge f_l(x_j))}{\sum_{l=1}^{m} f_l(x_j)} \quad (9)$$

2.3 Information Integration on Fuzzy Partial Order Relations

Deem that (U, A, F) is a continuous system, that is $F=\{f_l: U \to V_l (l \le m)\}$, $V_l = [0, 1]$, and $F(x_i) = (f_1(x_i), f_2(x_i), \ldots, f_m(x_i))$ ($x_i \in U$), and we have the following denotation:

$$x_i \ge x_j \Leftrightarrow F(x_i) \ge F(x_j) \Leftrightarrow f_l(x_i) \ge f_l(x_j) \quad (l \le m)$$

$$x_i \approx x_j \Leftrightarrow F(x_i) = F(x_j) \Leftrightarrow f_l(x_i) = f_l(x_j) \quad (l \le m)$$

Then, (U, ≤)is a partial-order set.

For continuous system, we can build a fuzzy partial order relation with methods given in section 2.2, and then using formula (10), we can get the total orer on U:

$$R(x_i) = \sum_{j=1}^{n} R(x_i, x_j) \quad (10)$$

3. Trustworthy Resource Selection based on Fuzzy Partial Ordering

To guarantee the trustworthiness and reliability of resource selection, a provider's reputation is a main factor that decides our selection. To convenient the feedback, analysis, evaluation and aggregation of reputation ratings, we introduce two reputation related service to Grid, their basic functionalities and interactions will be given in section 3.1. According to the different types of resources, reputation may have many different aspects to rate. The main steps for resource selection are: first retrieve ratings for the candidate providers, then according to methods proposed in [4, 5] analyze and aggregate each aspect of ratings, finally according to the aggregated ratings from all aspects build fuzzy partial order relation with methods given in Section 2, and make the final selection. As to the last step, we will give a case study in Section 3.2.

3.1 Basic Trust Model

This model is built on top of SOA (Service Oriented Architecture) and is an improvement on the model proposed by us in [6], which has two fundamental components: Grid Reputation Service and Grid Contract Service. Grid Reputation Service is responsible for the acquisition, storing, dissemination, retrieving and aggregation of first-hand reputation ratings, while Grid Contract Service provides a supervising mechanism and help with the negotiation of service providers and consumers. Besides, we adopt the Service Negotiation and Acquisition Protocol (SNAP) proposed in [7], which gives 3 kinds of service level agreement: RSLA (Resource Service Level Agreement), TSLA (Task Service Level Agreement) and BSLA (Binding Service Level Agreement). The 3 agreements supplement each other, clarify an interaction's context, which are ideal container for first-hand reputation ratings. The main interactions among these components are as follows: before transaction service providers will publish their RSLA and service consumers will post their TSLA; by means of Grid Contract Service, BSLA will be formed between providers and consumers. After transaction, both participants will submit ratings (Ratings are given in form of value within [0,1], the bigger the value, the more trustworthy the entity is.) of counterpart's behavior to Grid Reputation Service. Grid Reputation Service will insert this reputation information into RSLA and TSLA. After this modification, RSLA, TSLA and BSLA will be stored to reputation repository as first-hand reputation evidence (with RSLA and TSLA contain ratings and BSLA specifies context) for later retrieval. In this way, we can get related evidence for reputation evaluation as needed anytime and anywhere. Our work is carried out on this model. The combination of reputation ratings and SLA can not only clarify cooperation context, but also prevent faked ratings with no transactions happening flooding the system.

3.2 A Case Study

Deem that $U=\{p_1, p_2, p_3, p_4, p_5, p_6\}$stands for 6 computing resource providers, their reputation has 3 aspects: computing capability (r_1), reliability(r_2) and honesty(r_3). The 6 providers' aggregated reputation ratings in 3 aspects are given in Table 1, which is the to-be-evaluated information system:

Table 1: Resource providers' aggregated reputation ratings in 3 aspects.

U	***r1***	***r2***	***r3***
p_1	0.3	0.6	0.3
p_2	0.9	0.6	0.6
p_3	0.3	0.3	0.6
p_4	0.6	0.3	0.9
p_5	0.9	0.9	0.6
p_6	0.9	0.6	0.9

(1) Using formula (1), we get the following partial order relation on U:

$$R = \begin{pmatrix} 0.5 & 0 & 0.8 & 0.8 & 0 & 0 \\ 1 & 0.5 & 1 & 0.8 & 0 & 0 \\ 0.8 & 0 & 0.5 & 0 & 0 & 0 \\ 0.8 & 0 & 0.5 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0.8 & 0.5 & 0.8 \\ 1 & 1 & 1 & 1 & 0.8 & 0.5 \end{pmatrix}$$

With formula (10), we get:

R(p_1)=2.1, R(p_2)=3.3, R(p_3)=1.3, R(p_4)=3.9, R(p_5)=5.1, R(p_6)=5.3

Then the total order is: $p_6 > p_5 > p_4 > p_2 > p_1 > p_3$.

(2) With formula (2) and (10), we get:

R(p_1)=1.95, R(p_2)=3.4, R(p_3)=1.95, R(p_4)=2.85, R(p_5)=3.78, R(p_6)=4.06

Then the total order is: $p_6 > p_5 > p_2 > p_4 > p_1 \approx p_3$

(3) With formula (3) and (10), we get:

R(p_1)=2.67, R(p_2)=5, R(p_3)=2.67, R(p_4)=3.67, R(p_5)=5.33, R(p_6)=5.67

Then the total order is: $p_6 > p_5 > p_2 > p_4 > p_1 \approx p_3$

(4) With formula (4) and (10), we get:

$R^<$(p_1)=4.17, $R^<$ (p_2)=5, $R^<$ (p_3)=3.5, $R^<$ (p_4)=5.17, $R^<$ (p_5)=5.67, $R^<$ (p_6)=5.83

Then the total order is: $p_6 > p_5 > p_4 > p_2 > p_1 > p_3$

With formula (5) and (10), we get:

$R^>$(p_1)=4, $R^>$ (p_2)=5.17, $R^>$ (p_3)=4.17, $R^>$ (p_4)=4.5, $R^>$ (p_5)=5.5, $R^>$ (p_6)=5.83

Then the total order is: $p_6 > p_5 > p_2 > p_4 > p_3 > p_1$

(5) With formula (6), (7)and(10), we get:

R(p_1)=3.3, R(p_2)=5.1, R(p_3)=3.6, R(p_4)=4.5, R(p_5)=5.4, R(p_6)=5.7

Then the total order is: $p_6 > p_5 > p_2 > p_4 > p_3 > p_1$

With formula (6), (8) and (10), we get:

R(p_1)=3.83, R(p_2)=5.67, R(p_3)=4.17, R(p_4)=4.17, R(p_5)=5.67, R(p_6)=6

Then the total order is: $p_6 > p_5 \approx p_2 > p_4 \approx p_3 > p_1$

(6)With formula (9) and (10), we will get:

R(p_1)=3.82, R(p_2)=5.58, R(p_3)=4.08, R(p_4)=4.84, R(p_5)=5.71, R(p_6)=5.88

Then the total order is: $p_6 > p_5 > p_2 > p_4 > p_3 > p_1$

According to the total order obtained, we can decide which resource to choose.

In this case, reputation ratings are given in form of some value within [0,1], in some case they might be given in form of an interval. For such case, we can process as foloows:

For interval model (U, A, F), we have the following denotations:

$$f_l(x_i)=[a_l(x_i), b_l(x_i)],$$

$$R_l(x_i,x_j)=\begin{cases} \frac{1}{2}\left(\frac{(a_l(x_i)-a_l(x_j))+(b_l(x_i)-b_l(x_j))}{|a_l(x_i)-a_l(x_j)|+|b_l(x_i)-b_l(x_j)|}+1\right) & f_l(x_i)\neq f_l(x_j) \\ 1 & f_l(x_i)=f_l(x_j) \end{cases}$$

Then, relations given by formula (11) and (12) are fuzzy partial order relations on (U, ≤). Similar to information integration in continuous systems, we can get information integration methods for interval type of fuzzy partial order relation.

$$R(x_i,x_j)=\min_{l\le m} R_l(x_i,x_j) \quad \textbf{(11)}$$

$$R(x_i,x_j)=\frac{1}{m}\sum_{l=1}^{m} R_l(x_i,x_j) \quad \textbf{(12)}$$

4. Related Work

Trust is the cornerstone of human society. Trust is involved all the time in many fields such as social science, technological science, commerce and so on, even in daily life.

Research related to trust has been a focus of social science ever since, but these researches emphasize particularly on qualitative studies in humanities. As a whole, trust has been regarded as subjective, imprecise, unreliable and untrustworthy for long, especially lacking of formalized quantitative research. But with the emergence and development of the open networks represented by the Internet, things have changed, and it becomes more and more urgent to perform formalized studies on trust. In 1994, Marsh initiated the research on trust formalization. He started with the concept of trust, made classification on the content and degree of trust, proposed a mathematical model for trust evaluation [9]. In 1996, to solve the security problems related to network services in the Internet, M. Blaze et al first brought forward the concept of Trust Management [10]. The basic idea is that: they acknowledge the incompleteness of security information in open systems, and suggest that systematic security decision demands extra security information. Afterwards, different people have carried out thorough studies on trust model and trust management technologies from different aspects and in different environment [11] [12].

Currently, many trust related researches have been carried out in Grid, which mainly focus on resource management and security enhancement. In [13], trust is integrated to resource management, such that the allocation process is aware of the security implications. Its starting point accords with our consideration, but [13] focused on reputation-guided resource matching, which adopts a heuristic method with minimum cost with no consideration of reputation's multi-faceted characteristics. In [14], a fuzzy-logic trust model is proposed for securing Grid resources. Grid security is enforced through trust update, propagation, and integration across sites. The adoption of fuzzy logic accords with our solution. In [15], Grid Eigen trust, a framework for reputation computing in Grid is introduced. It adopts a hierarchical model, reputation computing is performed from 3 levels: VO, Institution and Entity, that is, an entity's reputation is computed as weighted average of new and old reputation values, an institution's reputation is computed as the eigenvalue of composing entities' reputation matrix, and a VO's reputation is computed as weighted average of all composing institution's reputation value. None of the above solutions consider reputation's multi-facet characteristics, but regard it as a concept with a single aspect. Therefore, they might attend to one thing and lose another, overall consideration cannot be guaranteed. Whereas our solution just focuses on the multi-facet nature of reputation, resource selection is based on an integrative order with all aspects considered.

5. Conclusions

Large-scale resource sharing is one of the paradigms that Grid computing aims to realize. Efficient resource sharing and accessing cannot go without the guarantee of high trustworthiness. In this paper, we combine resource selection with reputation mechanisms, in this way both QoS (Quality of Service) and QoP (Quality of Protection) have been taken into unified consideration. As reputation is uncertain, we base our method on fuzzy logic. As reputation is multi-faceted, we build fuzzy partial order relation to model resource providers' inferior and superior relationship, and by means of information integration we will get the final total order, which is used to guide the final resource selection. Compared with the other resource selection methods, this method has considered reputation's multi-facet nature, belongs to evaluation and decision making based on multiple attributes, and has better overall consideration.

In this paper, we only consider how to choose a trustworthy provider in resource sharing and accessing. In fact, selection is mutual: on one hand, users will select providers; on the other hand, providers will select users. The proposed method can also be applied to user selection.

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