Virtual Knowledge Service Market

—For Effective Knowledge Flow within Knowledge Grid*

Hai Zhuge[1,2] and **Weiyu Guo**[1,2,3]

[1]*China Knowledge Grid Research Group, Key Lab of Intelligent Information Processing, Institute of Computing Technology, Chinese Academy of Sciences, Beijing, China*

[2]*Graduate School of Chinese Academy of Sciences, Beijing, China*

[3]*Shangdong Institute of Light Industry, Jinan, Shangdong, China*

SUMMARY

A knowledge service consists of systematic knowledge and the mechanism of using the knowledge to perform a task. The supply of knowledge services forms a knowledge service layer over the knowledge flow network formed by free knowledge sharing. To stimulate the supply of knowledge services, this paper proposes a virtual knowledge service market by establishing reward and reputation mechanisms. Simulations demonstrate that a team with the market mechanism performs better than those without it. The virtual knowledge service market provides an experimental platform for exploring the rules of knowledge service such as the impact of individual behavior on states of individual and team as well as the change of the states.

KEY WORDS: Knowledge Grid, knowledge service, knowledge flow network, reputation, market, auction, bargain.

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1. INTRODUCTION

Effective knowledge management could raise the productivity of teamwork [3, 4]. Knowledge flow network is formed by knowledge sharing within team, especially geographically distributed teams. It can be used to realize effective team knowledge sharing by managing knowledge sharing process [15, 17, 18]. Two approaches to effective knowledge sharing are optimizing knowledge flow process to avoid unnecessary knowledge flow and stimulating individuals (knowledge nodes in knowledge flow network, or nodes in simple) to actively contribute knowledge.

Previous studies on knowledge flow networks assume that knowledge nodes are all willing to contribute knowledge. Actually, team members would probably hesitate to do that especially when they consider the cost of generating knowledge and worry about losing position in organization. Absence of incentive mechanism could hamper the performance of a knowledge flow network.

Except altruistic behaviors, individual motivation of sharing knowledge includes the following aspects:

- Expectation of gaining material rewards;
- Expectation of gaining appreciation, recognition, reputation, etc;
- Expectation of gaining knowledge reciprocity with others when needed.

The expectation of gains stimulates people to contribute knowledge.

Studies have shown that organizations actually behave as potential knowledge markets, with buyers (people seeking knowledge), sellers (people with systematic knowledge), and brokers [1]. Online knowledge exchange markets, classification of users, reputation mechanisms, and dynamic pricing algorithms have been studied [2, 7, 11].

A knowledge service is the integration of systematic knowledge and the mechanism of using the knowledge to perform a task. Knowledge is relatively static. Knowledge service is static in definition but it is dynamic during supplying. Different from ordinary services, the service receiver could obtain some knowledge from the provider by the underlying knowledge flow network during knowledge service process.

Different from exchanging knowledge that faces the trouble of speculation and unfair price because of high cost of knowledge creation and low cost of knowledge duplication, knowledge services are more suitable for trade.

Actually, knowledge service exists in our society to purse profit. Service and market are inseparable. This inspires us to establish a knowledge service market over knowledge flow network to stimulate knowledge flow and knowledge services.

Figure 1 shows the relationship between knowledge flow, knowledge service and knowledge service market. Nodes provide services for others according to market mechanism, and at the same time they involve in the knowledge flow network to share knowledge according to rules of knowledge flow. Rewards from the market stimulate the production of new services and arouse more knowledge flows. The virtual money owned by each node changes with the trades of knowledge services.

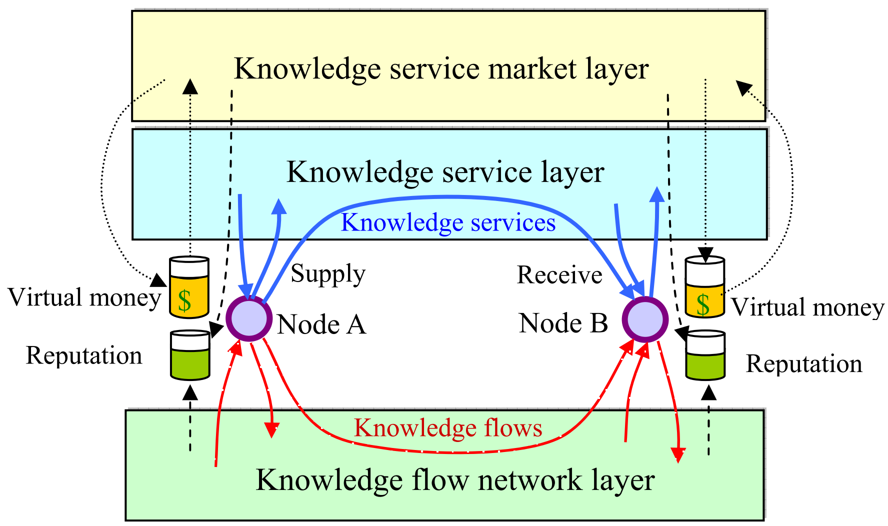

Figure 1. Knowledge flow, knowledge service and knowledge service market.

A knowledge service market is suitable for a geographically distributed loosely-coupled large knowledge flow network. Its feasibility lies in the following aspects:

1) Knowledge is valuable but owners usually could not get direct profits, so they are willing to share knowledge service with fellows to improve teamwork or obtain some rewards in a virtual market.
2) Trades in the market change the status (e.g., reputation) of nodes and their relationships

(e.g., friendship). Such a change in turn influences the market. A knowledge service market can quantify knowledge services and provide a means for us to explore the evolution process of team knowledge sharing.

3) The value of a knowledge service varies with people. The discrimination of various knowledge services can encourage nodes to provide with more valuable knowledge services.
4) Rewards like virtual money, reputation and friendship inspire members to provide knowledge or knowledge services for others.

The following constraint ensures the effectiveness of teamwork:

Team members could acquire what they need, and *contributors could gain profit*.

2. KNOWLEDGE SERVICE MARKET

2.1. Assumption and market process

The following two assumptions establish a reasonable research scope:

Assumption 1. Team members are personal rationality, and they can recognize others' personal rationality. They tend to try for their individual maximal interest and prefer long-term profit rather than short-term profit.

Assumption 2. Nodes autonomously make decisions to provide with knowledge services at certain price, without obligations or supervisory orders in a flat organization.

The knowledge service market runs as follows:

(1) Sellers describe their knowledge services on condition, type and context of the problem and solution. Knowledge services are priced and put into the market for sell.

(2) Buyers describe their demands and enter the market with their budget. The demands and prices are put into the market.

(3) Potentially matched sellers and buyers get together to form a temporal market.

(4) The price game carries out in the market. If an agreement is reached, a knowledge service trade happens.

The knowledge services are priced and paid in virtual money, which can be earned by selling knowledge services and be spent by buying required knowledge services. The formation of the price is based on the quality of the knowledge services themselves, and the balance between supply and demand.

2.2 Selection of market mechanisms

The uniform price mechanism is not suitable for knowledge service market as it denies the difference of knowledge services and influences nodes' enthusiasm of innovation and contribution.

Auction model can differentiate knowledge services so it is suitable for large-scale knowledge service trades. The market makes knowledge service producers know what is the most need in the organization.

Using the bargaining model, sellers and buyers negotiate until they reach an agreement. A knowledge service may be given different prices due to different requirements, urgency, and friendship established in a long-term cooperation experience. Promoting friendship is another reward besides gaining money and reputation.

2.3 Auction mechanism considering reputation

Auction has many forms like ascending or descending auction, sealed or open-cry auction, first-price or second-price auction, single or double auction, etc [10, 12]. Considering the imperfect and asymmetry information in knowledge service market, and for the players' convenience of pricing and the simplicity of the auction process, double second-price sealed auction is adopted here. It has the following characteristics [8]:

1) There is only one chance for a player to bid and no one knows others' bids;
2) The dominant strategies of players are pricing according to their own real assessments;
3) The buyers are sorted in a descending order $b_1 \geq b_2 \geq \cdots \geq b_m$. The sellers are sorted in an ascending order $s_1 \leq s_2 \leq \cdots \leq s_n$;
4) The final trade price $prc = (b_{k+1} + s_{k+1})/2$, where k satisfies $b_k \geq s_k$ and $b_{k+1} < s_{k+1}$.

The prices are the only basis of sorting in the double auction model [8]. To stress the incentive effect, we improve MacAfee's double auction model by introducing discrimination based on the reputation into the sorting process. The reason is that discrimination (e.g., a discount to large volume long-term contracts and a favorable price to familiar clients) is popular in real trades. Reputation could affect the Internet auctions because people have to guess based on experiences in a virtual environment [13, 14]. Here gives the proposition when nodes make a market decision.

Proposition 1. Nodes expect the future based on experiences. That is, nodes are likely to act as usual.

Reputation reflects the public view on nodes' past behaviors. Good reputation may mean higher reliability of the traders. On the other hand, in the basic model of indirect reciprocity, reputation is a basis for people to help others [9].

People would trade with reputable partners rather than earn a little more with a possible risk. This phenomenon lets us adjust the prices according to the reputation of nodes in advance.

The price of buyer $br(n)$ and seller $sr(m)$ are adjusted as follows:

$$sr(m) = (1 + \frac{1}{rep(m)}) \times s(m) \quad (1)$$

$$br(n) = (1 - \frac{1}{rep(n)}) \times b(n) \quad (2)$$

Where $s(m)$ is the original price asked by a seller m and $sr(m)$ is the adjusted price, $b(n)$ is the original price bided by a buyer n and $br(n)$ is the adjusted price, and $rep(i)$ is the reputation degree of node i. After adjustment, we sort the nodes according to new prices, the sellers in an ascending order and the buyers in a descending order.

We improve the double sealed auction of MacAfee [8] as follows:

Algorithm Rr-DKAA{

1. Compute the reputation-ranked prices for all bids;
2. Sort all reputation-ranked buyers in descendent order $br(1) \geq br(2) \geq \cdots \geq br(m)$;
3. Sort all reputation-ranked seller in ascendant order $sr(1) \leq sr(2) \leq \cdots \leq sr(n)$;
4. Find k satisfying $k \leq \min\{m, n\}$ & $br(k) \geq sr(k)$ & $br(k+1) \leq sr(k+1)$

   // k is the efficient trade number
5. $prc = 1/2 * (br(k+1) + sr(k+1))$;
6. If $prc \in \{sr(k), \text{br}(k)\}$, for each $i \leq k$, the ith highest buyer trades with the ith lowest seller in prc;
7. If $prc \notin \{sr(k), br(k)\}$, for each $i \leq k-1$, the ith highest buyer trades with the ith lowest seller,

with buyers paying br(k), sellers earning $sr(k)$, and the market earning $(k–1)(br(k)– sr(k))$.

}

Difference exists between the paying and the earning of two sides when $prc \notin \{sr(k), br(k)\}$, which might cause the losses of nodes' profits. But MacAfee has given that the expected efficiency loss per potential trader is $O(1/(m \wedge n)^2)$, where $m \wedge n = \min\{m,n\}$ [8]. For large organization, the knowledge service market can reach economical efficiency.

Our improvement is that higher reputation nodes would have more opportunity to win in auction. Although it could decrease the amount of trades, it can motivate nodes to regard the reputation and then actively supply knowledge services to gain good reputation.

Knowledge service provision and knowledge sharing can both improve the reputation of nodes. So the reputation of node v should be the synthesis of the reputation obtained from the knowledge flow network $R_f(v)$ and the reputation obtained from the service trades in the market $R_s(v)$ as follows:

$$REP(v) = \varphi(R_f(v), R_s(v)) \tag{3}$$

The function φ enables $REP(v)$ to be in direct proportion to $R_f(v)$ and $R_s(v)$. Knowledge flow sharing is free, but nodes' reputations are changed according to certain social evaluation in the network. $R_f(v)$ can be defined to be in direct proportion to the number of nodes benefit from it.

Trust built in the knowledge service trades can be synthesized in the reputation of node $R_s(v)$. The trust degree can be defined by collecting feedbacks in trade experiences [6].

Let $Fb_{uv}(i)$ be the feedback from u to v for the *ith* trade, $Dc(i)$ be the time-decay function, $TD_{uv}(i)$ be the degree of u trust to v after the *ith* trade, then $TD_{uv}(i+1)$ can be computed as follows after the $i+1$*th* trade:

$$TD_{uv}(i+1) = \mu(TD_{uv}(i) * Dc(i) + Fb_{uv}(i+1)) \tag{4}$$

Where the feedback value of a trade $Fb_{uv}(i)$ can be given by the satisfactory degree of node $Sat_{uv}(i)$, which is weighted by the value of the knowledge service $V_{uv}(i)$ according to formula (5). In practice, the satisfactory degree is given by nodes directly after trading, and the value of the knowledge service is replaced by its price.

$$Fb_{uv}(i) = V_{uv}(i) * Sat_{uv}(i) \tag{5}$$

Introducing the decay function is to decrease the importance of the feedbacks with time. Let $T(i)$ be the length of the trade history among nodes, λ be the decay factor and satisfy $0<\lambda<1$, then $Dc(i)$ is denoted as follows:

$$Dc(i) = \lambda * (\frac{T(i)}{T(i+1)}) \tag{6}$$

Having assessed the trust degrees of relative nodes to node *v*, we can compute *v*'s reputation obtained from knowledge service trades. Let $C_{in}(k)$ be the in-centrality (importance) of node *k* and $R_s(v, t)$ be the reputation of node *v* from knowledge service market at time *t*, then the reputation at time *t*+1, $R_s(v, t+1)$ can be computed as follows:

$$R_s(v,t+1) = \sum_k C_{in}(k) * R_s(v,t) * TD_{kv}(t) \tag{7}$$

Where the in-centrality and reputation of each relative node *k* are weights of their trust relationships. The in-centrality is the centrality and relevancy of a node in a local region based on the in-degree of the node ($d_{in}(u)$) [5]:

$$C_{in}(u) = \frac{d_{in}(u)}{n-1} \tag{8}$$

Reputations of nodes keep changing. Here computes the reputation by a definite time unit like an hour or a day for simplification.

2.4 Bargaining mechanism considering friendship

When a seller and a buyer intend to trade some knowledge services (here we consider only the one-to-one bargaining), they will give prices respectively according to the utility and quality of knowledge services, the urgency of the demand, and the friendship with the partner. Bargaining agents are used to help nodes to bargain according to the strategies and prices (the starting prices, the reserved prices, and the increments) given by nodes. Let the starting prices given by buyer and seller be $Ps(b)$ and $Ps(s)$ respectively, the reserved prices be $Pr(b)$ and $Pr(s)$, the increments of each bargaining step be $Ic(b)$ and $Ic(s)$, and the final price after bargaining be *prc*.

The knowledge service bargaining algorithm is described as follows:

KSBargain(*Ps*(*b*), *Pr*(*b*), *Ic*(*b*), *Ps*(*s*), *Pr*(*s*), *Ic*(*s*)) {

if $Pr(b)<Pr(s)$, then return fail;

else

if $Ps(b)=Ps(s)$ then buyer and seller trade at the price $prc=Ps(b)=Ps(s)$, return success;

if $Ps(b)>Ps(s)$ then buyer and seller trade at the price $prc=Ps(s)$, return success;

if $Ps(b)<Ps(s)$ then // begin to bargain

while $(Ps(b)+ Ic(b)<Pr(b))$ && $(Ps(s) - Ic(s)<Pr(s))$

KSBargain($Ps(b)+Ic(b)$, $Pr(b)$, $Ic(b)$, $Ps(s)- Ic(s)$, $Pr(s)$, $Ic(s)$))

}

The buyer and seller need to bargain when they cannot reach an agreement ($Ps(b)<Ps(s)$). Not exceeding their reserved prices $Pr(b)$ and $Pr(s)$, the buyer will make increment $Ic(b)$ in each bargaining step and the seller will make some concession $Ic(s)$.

When $Ps(b)>Ps(s)$, the buyer and seller will trade at the price $prc=Ps(s)$, and there exist a difference between the expected lowest payoff of the buyer and the final price in the trade, that is, $Ps(b) - prc$. It can be regarded as a discount from the seller, which can be used to assess the friendship between nodes. *Friendship* FR_{bs} can be computed by accumulating the discount of prices from the seller *s* as follows:

$$FR_{bs} = \frac{\sum_i (PB(i) - prc(i))}{\sum_i prc(i)} \tag{9}$$

where $PB(i)$ is the starting price of buyer *b* and $prc(i)$ is the final price of *i*th trade.

Friendship degree between nodes can help users price. If a node does not give its price, the market system can price in default as follows: The start price asked by the seller is $Ps = P_{ave}(1 - FR_{uv})$ and the start price bided by the buyer is $Pb = P_{ave}$, where P_{ave} is the average price of the knowledge service and FR_{uv} is the friendship degree.

3. Behaviors and Effect

This section studies the capability and efficiency of knowledge service market, and explores the underlying principles.

3.1. Market mechanism and its efficiency

The first experiment is to test the success rates of knowledge service trades and the efficiency of the knowledge service markets in contrast to the uniform price model and the manner without any incentive measures.

Simulation 1 uses three groups of nodes, each has 30 nodes. Each node can supply knowledge services, which is related to its potential knowledge energy [17]. For simplicity, we suppose Θ be the universal knowledge service set, and set |Θ|=100. Knowledge services are distributed over all nodes, and satisfies: $|\Psi_i| = \alpha * KE_i * |\Theta|$, where Ψ_i is the individual knowledge service set of node *i*, and its cardinal number $|\Psi_i|$ is in proportion to the potential knowledge energy of *i*. Suppose all the knowledge services in Θ are not equal, and their value is assigned randomly. The cost of the knowledge service is in proportion to its value, that is, the higher value knowledge service might cost more and the lower value knowledge service might cost less.

In the simulation process, every node must send out 10 times of knowledge service demands. The target of every demand is the one randomly selected from Θ that the node has not possessed. At the same time, the node will put its own knowledge services into market to wait for trades.

The probability of a node's joining market λ is assumed in direct proportion to its anticipative profit. When this profit is negative, we set λ=0.05 to include the altruistic activities.

Three groups of nodes adopt different strategies as follows:

1) Group 1 adopts the auction-based market strategy.
2) Group 2 adopts the uniform price market strategy.
3) Group 3 adopts the strategy without any incentive measures. Nodes in group 3 gain no rewards for providing knowledge services.

We identify several metric to evaluate the simulation results.

1) Number of successful knowledge service trades in organization;
2) Value distribution of the knowledge service trades;
3) Average contribution of nodes; and,
4) Average profit of nodes.

Figure 2 compares the amount of successful knowledge service trades of three groups with different strategies. We can see that the amount of group 3 without incentive measures is the lowest. The reason is that the low probability of nonprofit knowledge service provision in group

3 relies only on the altruistic chance. The status of group 2 is better than group 3, because nodes in group 2 can make profit in some cases due to selling knowledge services in uniform price. But when the price of a knowledge service is below its cost, the node cannot make any profit from the trade. The probability of success will be influenced by price and cost. Nodes in group 1 with the auction strategy provide knowledge services at the auction price. They can obtain possible maximum profit because the high-value knowledge service often makes high price. So their successful trades are more than the other two groups.

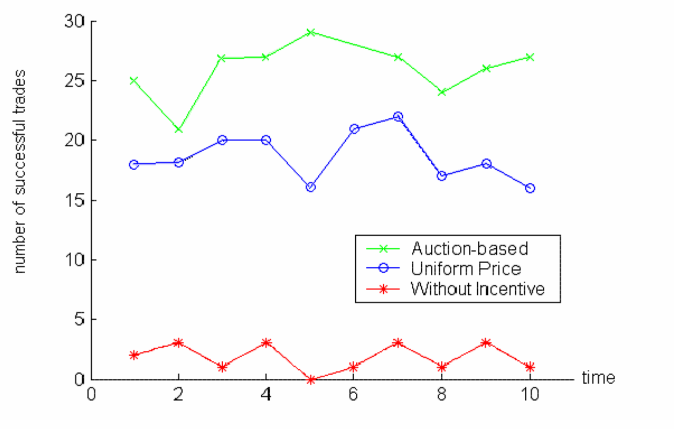

Figure 2. Comparison of successful knowledge service trades

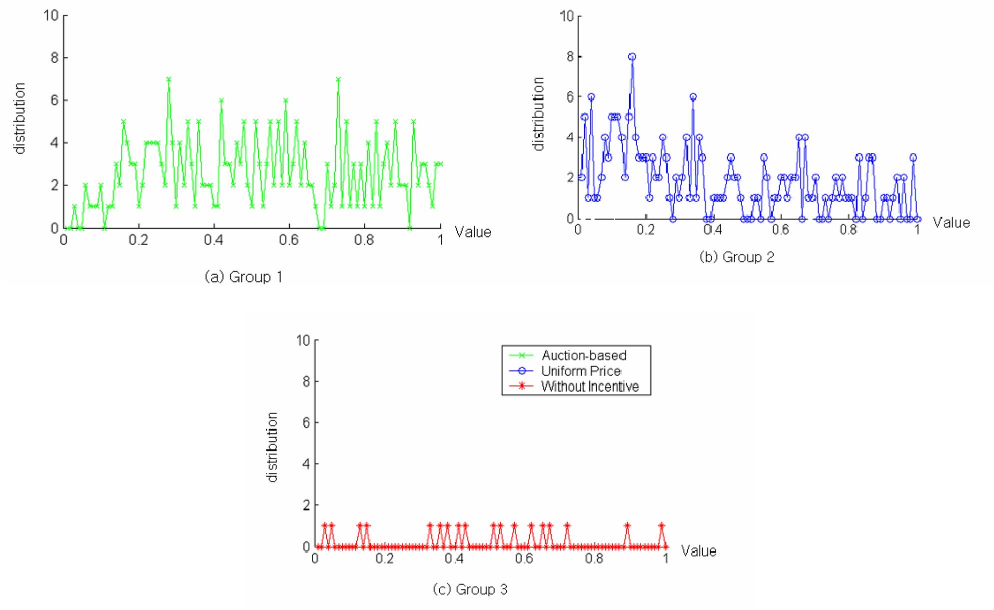

Figure 3. Comparison of value distribution of knowledge service trades.

Figure 3 compares the value distributions of the knowledge service trades of three groups. We can see that the distribution of group 3 is irregular, because the trades only happen randomly based on the occasional altruistic. The curve of group 2 represents a descending distribution. The reason is that the higher the knowledge services' values are, the less the sellers can earn. To earn more money, nodes prefer to sell low value knowledge services. On the contrary, the curve of group 1 represents an ascending distribution. It is because higher value knowledge services would make more profit, which stimulate nodes to supply more.

Figure 4 compares the average knowledge service contributions of three groups. Group 3 performs the worst: each node averages less than a knowledge service, knowledge service demands are almost unsatisfied, so the supply is seriously insufficient. The average contribution of group 2 is much better although lots of their contributions are of low value. Group 1 trades the largest number of knowledge services (more than 8) based on auction. The comparison shows that nodes can be motivated by the market strategies.

Figure 5 illustrates the average profits of three groups in different strategies. Nodes in group 1 (using auction market strategy) get the largest profit, nodes in group 2 (using uniform price market strategy) the second, and nodes in group 3 (without incentive strategy) almost get no profit.

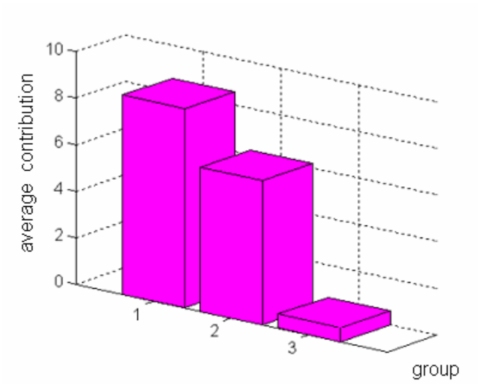

Figure 4. Comparison of average contributions.

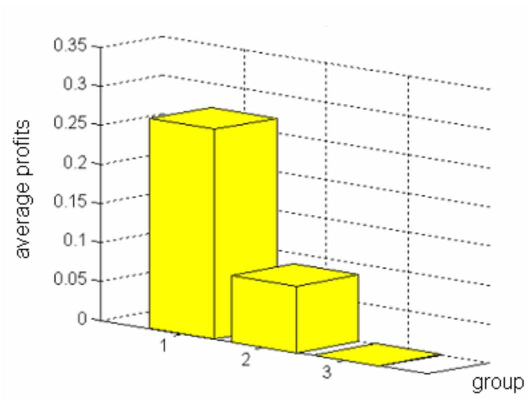

Figure 5. Comparison of average profits.

Experiment 1 demonstrates that the market strategy can stimulate knowledge services in the organization. The auction mechanism enables nodes to earn more by supplying high-value knowledge services. This can stimulate nodes to contribute more knowledge services, and can avoid free-riding and insufficient knowledge services supplies.

3.2. Motivations and behavior modes and their impact

Different motivations make the diversity of nodes' behaviors. Some aim at earning more and will put their knowledge service in the auction market, some want to develop some solid and close partnership and then will actively participate knowledge service bargaining, and some want to make a compromise.

Experiment 2 is to test the impact of motivations and behavior of nodes on trade effect based on the following settings: Θ is the universal knowledge service sets of a certain field, |Θ|=500; the initial knowledge services owned by node *i* are randomly selected from Θ. Nodes have some initial money for three times of trades.

Nodes are supposed to behave according to the following three modes:

1) Trades are all in the auction market (denoted as Auc);
2) Trades are all in the bargaining market (denoted as Bar); and,
3) Trades are in both auction and bargaining market. The ratios of auction and bargaining are 50% respectively (denoted as Auc+Bar).

The marketing strategies of nodes are as follows:

1) Mammonist: Selling knowledge services at the prices higher than the real values in auction, and never at preferential prices in bargaining (denoted as Mam).
2) Generosity: Selling knowledge services at the prices below the real values in auction, and always at *k*% preferential prices in bargaining (denoted as Gen).
3) Compromise: Selling knowledge services at the prices of the real values in auction, and always at preferential prices according to their friendship degree in bargaining (denoted as Com).

Nodes are classified into 9 categories according to their behavior modes and market strategies. Each category includes 20 nodes. The distribution of nodes is shown in the following table.

Table 1. Node classification.

Category	1	2	3	4	5	6	7	8	9
Behavior Modes	Auc	Auc	Auc	Auc+Bar	Auc+Bar	Auc+Bar	Bar	Bar	Bar
Market Strategies	Mam	Gen	Com	Mam	Gen	Com	Mam	Gen	Com
Node Number	1-20	21- 40	41- 60	61-80	81-100	101-120	121-140	141-160	161-180

The auction market includes nodes of six categories (1-6), and the bargaining market includes six categories (4-9). The nodes of category 4-6 belong to both auction and bargaining market at the same time.

The simulation runs through 50 time slots. In each time slot, every node sends a demand and their services to the auction market or the bargaining market according to its behavior mode. When trades are successful, virtual money is paid and the related nodes' reputation and friendship degree are changed. The changes reflect the effect of the behavior modes and strategies.

The following indicators are selected for evaluating the behavior modes and strategies:

1) Changes of virtual money;
2) Changes of the friendship;
3) Changes of the reputation;
4) The net profits;
5) The number of purchased knowledge services; and,
6) The number of sold knowledge services.

Points in Figure 6 represent the corresponding values of nodes and the lines represent the average value of each category. The figures show the performance of each category varies as follows:

(1) In category 1-3, nodes all trade in the auction market. Nodes of category 2 (Gen) obtain significantly better results than the other two categories in trade amounts, monetary

incomes, and the reputation degrees. But their net profits are negative, because each time they sell knowledge services at so low prices that they will loss virtual money, although it can increase the probability of win. Nodes of category 1 (Mam) cannot get good results because they are difficult to win the auction at too high prices, so do the nodes of category 3 (Com) adopting compromise strategy due to the price disadvantage.

(2) In category 7-9, all nodes trade in the bargaining market. Nodes in category 8 (Gen) perform a little better than the other two (Mam and Com), because the probability for them to sell is higher than the other two owing to generous low price. The differences among three strategies are smaller than that in the auction market. The reason is that the influence of strategy is weakened owing to one-to-one bargaining. Net profits for the generous strategy are also negative, but their friendship degrees have increased. This can be seen as the compensation for the loss of money to some extent.

(3) In category 4-6, nodes trade in both auction and bargaining market. They are in the median state between the former two types of nodes. Nodes in category 5 (Gen) also gain the most. Nodes in category 4 (Mam) and 6 (Com) perform better than corresponding nodes in the auction market (category 1 and 3) and they are poorer than those purely in the bargaining market (category 7 and 9).

Experiments show that the market strategies and behavior modes adopted by nodes greatly influence the results of trades and the gains of nodes. Nodes adopting generosity strategy would gain more opportunities for trade but they often could not make monetary profit, while in bargaining market they can enhance the friendship as a feedback for low prices. The intention of mammonist is to gain more money but most of them cannot reach their goal. The reason is that once any competitor offers lower bids, they would lose the opportunity to trade. Nodes taken compromise strategy get the median results.

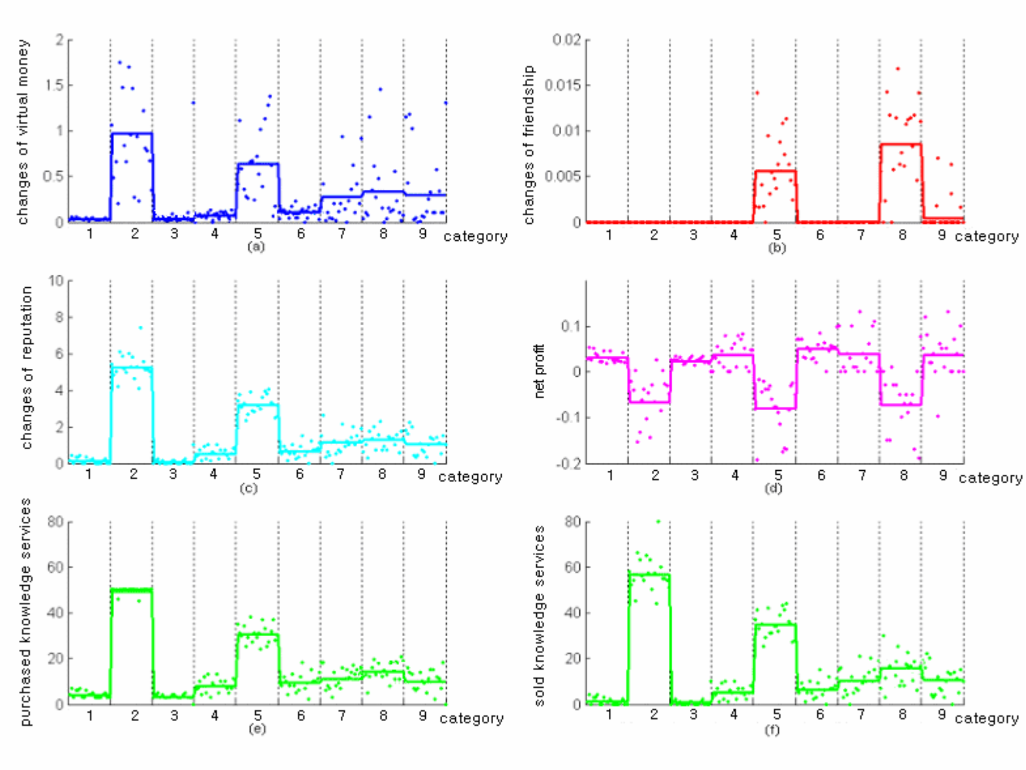

Figure 6. Comparison of the impact of motivations and behavior modes of nodes.

3.3. Active degree and its impact

Active degree represents how much a node is willing to participating knowledge service trades and how often it trades. Experiment 3 is to examine the impact of active nodes on the knowledge service market.

Simulation runs in three virtual teams composed of 200 nodes respectively. Nodes trade knowledge services in the auction market. The initial reputations of nodes are randomly distributed, and the virtual money owned by a node can meet the need of several initial trades. The proportions of active nodes of 3 teams are 25%, 50% and 80% respectively. A node's active degree is based on a certain probability for participating the auction.

We set several indicators to compare the simulation results:

1) The amount of sold knowledge services by a node;
2) The amount of purchased knowledge services by a node;
3) The increase of reputation of a node;
4) The change of average reputation of the team.

Figure 7 compares the amount of sold knowledge services of each node during 20 time slots. In every team, the amounts increase with the active degrees of nodes. The higher the nodes' active degrees, the more knowledge services are sold.

Figure 8 compares the amount of purchased knowledge services of each node. The amounts are also related to the active degrees, but the distributions of points are not the same as that in figure 7. This is because whether a node can buy the knowledge services is also related to the amount of its virtual money and its reputation. The results demonstrate that the higher active degree can lead to higher possibility to buy knowledge services.

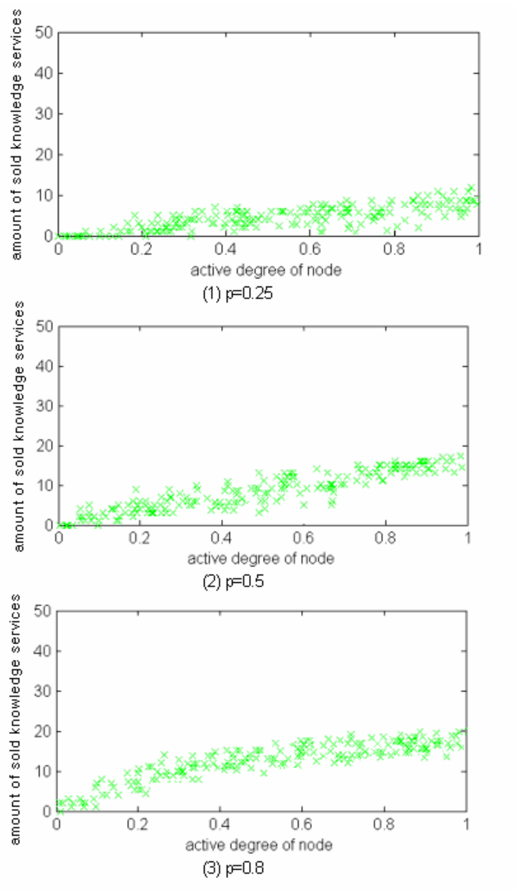

Figure 7. Comparison of sold knowledge services

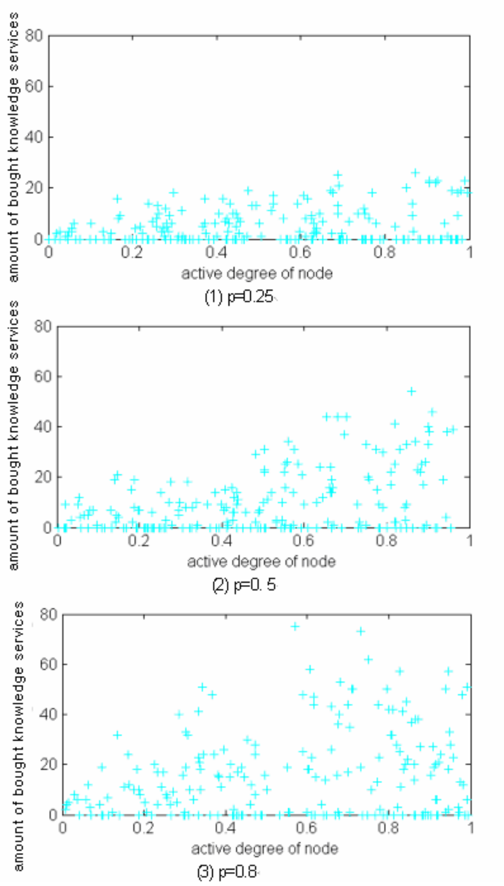

Figure 8. Comparison of bought knowledge services

Figure 9 compares the reputation increment of nodes. Points in figures show that reputations changes with the active degrees of nodes. But the increments of reputation do not linearly depend on active degrees, because the growths caused by different knowledge services are not equal.

Figure 10 compares the average changes of reputation of the three teams. It shows that the third team of the largest proportion of active nodes performs the best and the first team with the smallest proportion performs the worst.

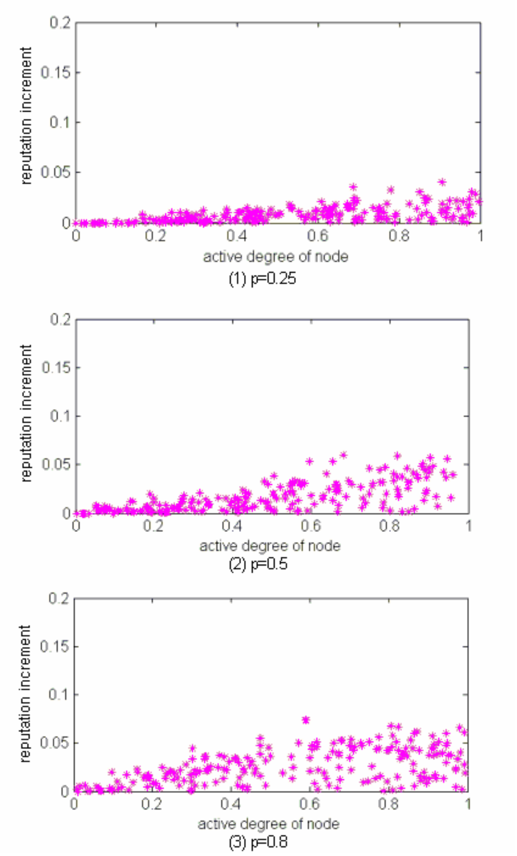

Figure 9. Comparison of reputation increment

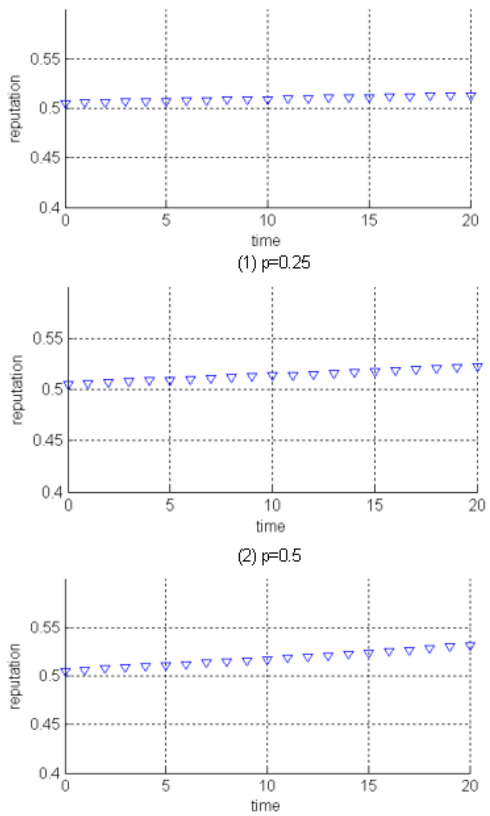

Figure 10. Comparison of teams' average reputation changes

This experiment shows that:

1) The higher active degree nodes are, the more their knowledge services trade and the more their reputations change.
2) The more active nodes in the organization and the higher their active degrees, the more the knowledge services supply and the better the organization performs.

The three experiments show that knowledge service market has the following features:

(1) The auction market mechanism can make larger quantity of knowledge service trades than the uniform price mechanism and that without incentive measures.

(2) Motivations and behaviors of nodes influence the trade effects.

(3) Knowledge service markets are influenced by the active degree of nodes.

4. CONCLUSION

Establishing knowledge service market mechanism over knowledge flow network is an important way to realize effective knowledge sharing. The knowledge service market has the following effects:

1. It can stimulate cooperation. Virtual money earned from selling knowledge services can qualify nodes to buy when they needed, which is a kind of indirect reciprocity. With the expectation of future gain, nodes tend to sell knowledge services.
2. Both seller and buyer can benefit from the knowledge service trades: buyers can obtain needed knowledge service to accomplish their tasks and sellers can promote the reputation and friendship degree that can affect the possibility of win the auction and buy knowledge services at a lower price in bargaining.
3. It can realize more pay for more labor. The quantity of virtual money and the degree of reputation reflect the contribution of nodes. More contribution can earn more rewards, and can thus buy more knowledge services. Those never provide services for others will not be served, so free-riding can be avoided.

The virtual knowledge service market can be the high-level architecture of the Knowledge Grid — an intelligent and sustainable Internet application environment that enables people or virtual roles to effectively capture, publish, share and manage explicit knowledge resources. It also provides on-demand services to support innovation, cooperative teamwork, problem-solving and decision making. It incorporates epistemology and ontology to reflect human cognition characteristics; exploits social, ecological and economic principles; and adopts the techniques and standards developed during efforts toward the next-generation web [16, 19].

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