Agent Based Risk Management Methods for Speculative Actions

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Abstract. In multiagent systems, a cooperative action requires the mutual agreement of multiple agents which is generally achieved by exchanging messages. Any delay in message transfer will, however, delay the realization of agreement, and this may reduce the effectiveness of the cooperative action. One solution is to use speculative actions, actions taken before agreement is reached with the goal being to "lock in" the benefits of the cooperative action; its downside is the penalty incurred in unwinding the speculative actions if indeed the agents do not reach agreement. In this framework, we have two risks; the risk of losing the benefits of the cooperative action and the risk of unwinding the speculative actions. It is clear that some form of risk management is needed. In this paper, we propose two risk management methods, the hybrid method and the leveled method, which are viewed as a single agent approach and a multiagent approach, respectively. We discuss their advantages using the meeting room reservation problem.

1 Introduction

Generally speaking, concluding a cooperative action between multiple agents requires agreement and the agreement is normally achieved by exchanging messages among the agents[5, 6]. Agreement may, however, be delayed by either communication in the channels connecting the agents or by the agents themselves.

The first problem reflects the congestion or interruption of the communication channels that connect the agents. The second one is more subtle. In multiagent systems, we often assume that each agent behaves autonomously and rationally to maximize its profit. When the profit to the agent depends on the reply, it may take some time to gather all the information needed to maximize its profit.

This paper considers only the second problem and focuses on cases where the delay reduces the effectiveness or value of the cooperative action. For example, consider the meeting room reservation problem in which a host agent and a member agent must reach agreement about when to have a meeting; the room for the meeting is to be reserved in advance by the host agent. When they succeed in having a meeting, the host agent receives a reward from some external party and the member agent receives some share of the reward from the host agent. We assume that the more time the agents take to reach agreement, the more difficult it is to reserve a room, and that a cost is charged when an agent cancels a reserved room. In this problem, if the agents take a long time to reach agreement (when to hold a meeting), they risk having no room in which to meet.

Speculative action [4] is one solution to the delay in reaching agreement. It is an action taken before agreement is reached later that attempts to lock-in the reward of having the meeting. If agreement is reached, the speculative action is effective. On the other hand, if agreement is not reached, the action should be cancelled or rolled back which would, we assume, incur some penalty. For example, in the problem considered, let us assume that the host agent reserves a room as a speculative action before reaching agreement with the member agent. If agreement is reached, the two agents can have the meeting without the need to worry about the room reservation. On the other hand, if no agreement is reached, the host agent has to cancel the reserved room and pay a cancellation charge. When an agent takes a speculative action, it accepts the risk of needing to cancel the action. This illustrates the need for an effective risk management method.

This paper proposes two risk management methods for speculative actions: the hybrid method and the leveled method. In the hybrid method, the host agent estimates the probability of agreement and decides whether to initiate a speculative action. This method can be viewed as a single agent approach because the decision is made by a single agent. In the leveled method, the host agent concludes a pre-agreement with the member agent and either agent can cancel the pre-agreement by paying a penalty. This method can be viewed as a multi-agent approach because it is based on pre-agreement among the agents involved.

In Section 2, we define the meeting room reservation problem and two fundamental agreement methods called the basic method and the speculative method and discuss these methods from the viewpoint of expected profit. Section 3 introduces the hybrid method and the leveled method and discusses the circumstances under which the agents would accept the leveled method. We mention related works in Section 4 and conclude this paper in Section 5.

2 Meeting Room Reservation Problem

2.1 Definition

To make the discussion of speculative action concrete, we use the meeting room reservation problem. There exist a host agent and a member agent, and they negotiate to decide when to have a meeting in a room to be reserved in advance by the host agent.

For the negotiation, the agents exchange messages following a protocol like the Contract Net Protocol [5]. Initially, the host agent sends an announcement of the meeting date to the member agent. The member agent sends a reply of agreement or disagreement to the host agent. Finally the host agent reserves a meeting room if they reached agreement as to when to have the meeting.

The host agent receives a reward a from some external party when the meeting takes place and the member agent receives a share, value ρ, of the reward from the host agent. The value amount is specified in the announcement message. The member agent receives announcements not only from the host agent but also other agents, and decides whether it accepts to have a meeting with the host agent considering the shares offered by the other agents. Announcements sequentially reach the member agent, and the probability of getting a better share monotonically increases as the time goes by. Hence, the member agent does not reply promptly to the host agent, but rather waits as long as possible to increase its profit, which delays the agreement. If the agents follow the Contract Net Protocol, the host agent can set an time limit for receiving replies to the announcement and the member agent sends a reply within the limit. For convenience, we fix the time interval of expiration to T. Hence, after the member agent receives an announcement, it waits T for to receive announcements from the other agents. The probability, P_m, that the member agent agrees with the host agent to have the meeting on the date specified is given by

$$P_m = \int_0^\rho f(b)db, \tag{1}$$

where b is the best share offered by the other agents up to the expiration time, $f(b)$ is the probability distribution function of b, and is the share offered by the host agent.

We assume that the probability of successfully reserving a meeting room decreases as time goes by. For convenience, we set the probability to be 1 when the host agent sends the announcement, and P_r when the host agent receives a reply after time interval T.

2.2 Agreement formation for meeting room reservation problem

We discuss two naive agreement formation methods, the basic method and the speculative method, for the meeting room reservation problem.

In the basic method, shown in Fig. 1(a), the host agent first sends an announcement message which indicates the date and share ρ to the member agent. After it receives an agreement message from the member agent, it tries to reserves a meeting room and succeeds with probability P_r.

In the basic method, after the member agent agrees to have the meeting, the host agent may fail to reserve a room because of the delay. When it fails in this manner, the host agent must pay share ρ to the member agent.

In the speculative method, shown in Fig. 1(b), the host agent sends the same announcement message as well as reserving a room. We assume that this reservation will always succeed. If the reply is 'agree', then the meeting will be held. Otherwise, the host agent has to cancel the reservation and pay cancellation charge c.

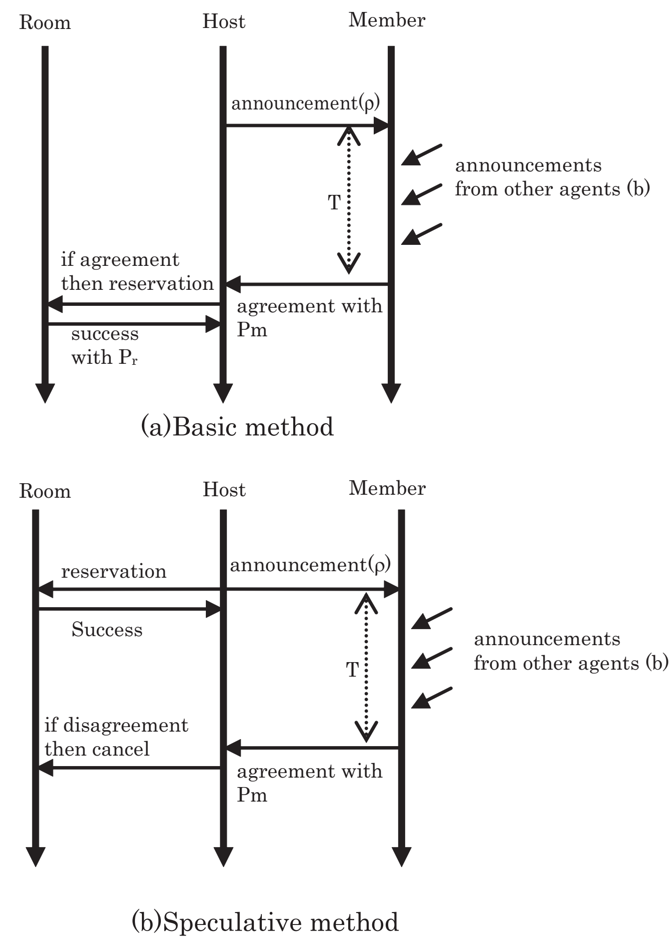

Fig. 1. Basic method and speculative method.

2.3 Expected profit of agents in meeting room reservation problem

The profit tree in Fig. 2 shows the expected profits of the host and member agents in the meeting room reservation problem. If the host agent and the member agent agree to have a meeting by using the speculative method, the host agent receives reward a and pays share ρ to the member agent, so the profit of the host agent is $a-\rho$ while that of the member agent is ρ. If the member agent does not agree, the host agent has to pay c to cancel the meeting room, so the profit of the host agent is $-c$ and that of the member agent is 0. Hence, the expected profit of the host agent and the member agent using the speculative method is calculated as

$$profit^h_{SM} = P_m \cdot (a-\rho) + (1-P_m) \cdot (-c) \tag{2}$$

and

$$profit^m_{SM} = P_m \cdot \rho \tag{3}$$

respectively.

If the host agent and the member agent agree to have a meeting and the host agent succeeds to reserve a meeting room by using the basic method, the host agent receives reward a and pays share ρ to the member agent, so the profit of the host agent is $a-\rho$ while that of the member agent is ρ. If the host agent fails to reserve a meeting room, it receives no reward and pay ρ, so the profit of the host agent is $-\rho$ while that of the member agent is ρ. Hence, the expected profit of the host and member agents using the basic method is calculated as

$$profit^h_{BM} = P_m \cdot P_r \cdot (a-\rho) + P_m \cdot (1-P_r) \cdot (-\rho) \tag{4}$$

and

$$profit^m_{BM} = P_m \cdot \rho \tag{5}$$

respectively.

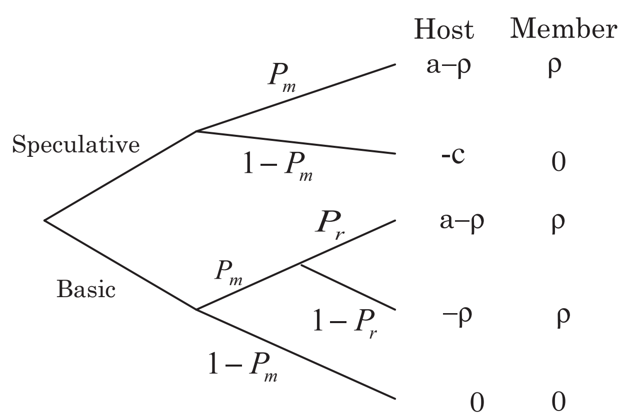

Fig. 2. Profit tree of the host and member agents.

Fig. 3 shows the expected profit of the host agent using the basic and speculative methods with $a = 50$, $\rho = 35$, and $c = 10$.

In the basic method, when P_r is large, the profit of the host agent increases with P_m. When P_r is small, it is difficult to reserve a room, which negates the value of the member agent's agreement. The profit of the host agent decreases as P_m increases because it has to pay ρ to the member agent even though it receives no reward.

The speculative method never fails to reserve a meeting room, and the profit of the host monotonically increases as the probability of the member's agreement increases. However, if the probability is low, the host agent has to pay the cancellation charge.

In conclusion, the speculative method has no risk of failing to reserve a room, but has the risk of canceling the reservation. Especially when the probability of agreement is low and $c > 0$, the basic method returns a better profit than the speculative method. Hence, we need a risk management method for speculative actions that can increase the profit. To that end, we propose two methods in the next section.

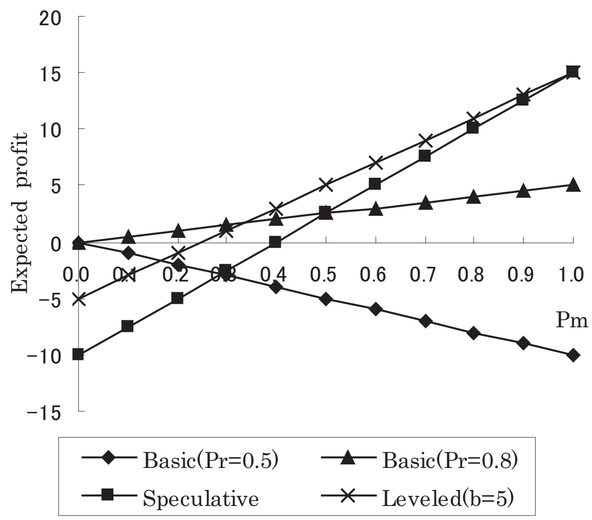

Fig. 3. Expected profit of the host agent versus P_m.

3 Risk Management Methods for Speculative Actions

The speculative method eliminates the risk of causing the failure of the cooperative action, while creating the risk of having to unwind the speculative action. We here propose two risk management methods called the hybrid method and the leveled method to balance these two risks according to the situation.

3.1 Hybrid method: a single agent approach

As shown in Fig. 3[[ALWAYS TRUE??]], the speculative method should be used if the probability of the member's agreement is high while the basic method should be used if the probability is low. The hybrid method switches between the speculative method and the basic method by estimating the probability of the member's agreement. If the probability is estimated to be high, it uses the speculative method, otherwise the basic method. Because it is based on an estimation performed by the host agent, it is viewed as a single agent approach.

In this method, it is important to decide the timing to switch from one method to another. The condition in which the speculative method is superior to the basic method is given as

$$P_m \cdot (a - \rho) + (1 - P_m) \cdot (-c) \geq P_m \cdot P_r \cdot (a - \rho) + P_m \cdot (1 - P_r) \cdot (-\rho), \quad (6)$$

considering the expected profit of each method.

When we pay attention to the probability, P_m, of the member's agreement, the inequality can be rewritten as

$$P_m \geq \frac{c}{(1 - P_r) \cdot a + c}. \quad (7)$$

Fig. 4 shows the expected profit of the host agent using the hybrid method when $a = 50$, $\rho = 35$, $c = 10$, and $P_m = 0.5$. If the host agent can accurately estimate P_m, the hybrid method returns a better profit regardless of P_r than the basic method or the speculative method. If, however, the host estimates P_m incorrectly, the profit decreases. For example as shown in Fig. 4, if the host agent wrongly estimates P_m* to be 0.3, it uses the speculative method in the interval of $0.53 < P_r < 0.8$ inappropriately which reduces the profit. Likewise, if P_m is wrongly estimates to be 0.7, the host agent uses the basic method in the interval of $0.8 < P_r < 0.91$ inappropriately and the profit reduces.

We need to discuss how the host agent estimates the probability of the member's agreement. As suggested in Section 2, the probability can be estimated from ρ, the share given by the host, and $f(b)$, the probability distribution function of the maximum shares offered by other agents. The host agent does not know $f(b)$ accurately. However, it may be able to estimate $f(b)$ by using the history of past agreements.

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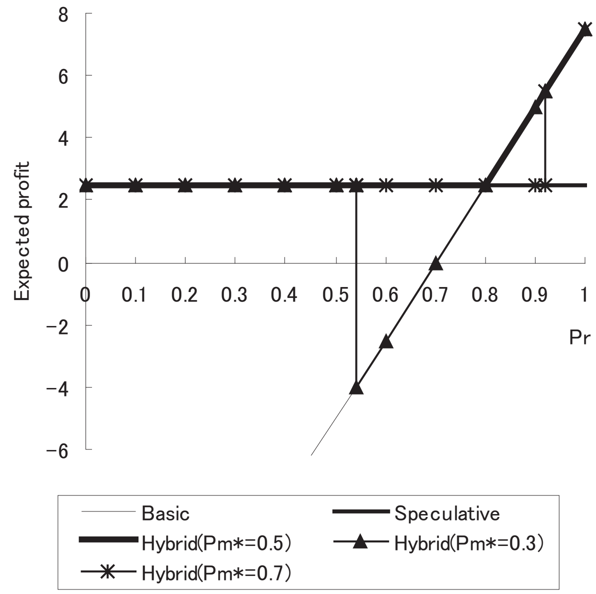

Fig. 4. Expected profit in the hybrid method. P_m* means the estimated value of P_m.

3.2 Leveled method: a multi-agent approach

In the leveled method, the host agent and the member agent make a pre-agreement, and either can cancel it by paying a penalty. By making a pre-agreement, the host agent can reduce the risk of unwinding the speculative action when the member agent disagrees. The leveled method is a risk management method based on a pre-agreement made by the host and member agents and so is viewed as a multi-agent approach.

The protocol of the leveled method is shown in Fig. 5. The host agent initiates the speculative action after it concludes the pre-agreement. When the expiration limit of the main agreement is reached, the member agent replies whether it agrees or not to the host agent. If the member agent disagrees, the member agent pays penalty d and the host agent cancels the room by paying cancellation charge c. The profit tree of the leveled method is shown in Fig. 6.

The profit of the host agent in the leveled method, given as

$$profit^h_{LM} = P_m \cdot (a - \rho) + (1 - P_m) \cdot (d - c) \tag{8}$$

is more than that in the speculative method for $(1 - P_m) \cdot d$. This is because the member agent offsets some of the cancellation charge. Fig. 3 shows that the expected profit of host agent with the leveled method is better than that with the speculative method at any P_m. When P_m is low, the basic method is superior

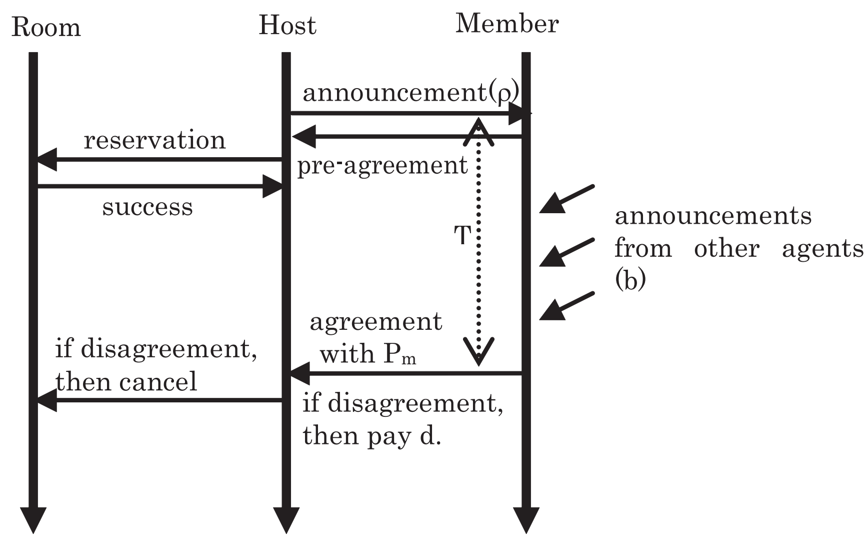

Fig. 5. The leveled method.

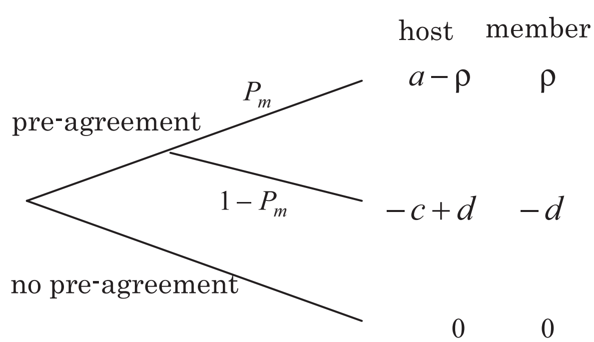

Fig. 6. The profit tree of the leveled method.

to the leveled method. If we can estimate P_m properly, we can switch between the basic method and the leveled method as in the hybrid method.

If we increase d, the expected profit of the host agent increases but that of the member agent decreases. Since this obviously involves a tradeoff, the next section examines the conditions under which the host and the member agents enter into the pre-agreement.

3.3 Entering into pre-agreement

In the leveled method, the condition under which the host agent should accept the pre-agreement is given as

$$profit^h_{LM} \geq 0. \tag{9}$$

That for the member agent is given as

$$profit^m_{LM} \geq E[b], \tag{10}$$

and only if both conditions are satisfied, the host and member agents make pre-agreement.

For example, let us consider a case when $a = 45$, $c = 10$, and

$$f(b) = \begin{cases} 0.01 & (0 \leq b \leq 100) \\ 0 & (\text{otherwise}) \end{cases} \tag{11}$$

If b is less than ρ, the member agent keeps the pre-agreement, otherwise, it breaks it, so the host's expected profit is calculated as

$$\begin{aligned} profit^h_{LM} &= (45 - \rho) \int_0^\rho f(b)db + (d - 10) \int_\rho^{100} f(b)db \\ &= (45 - \rho) \cdot \frac{\rho}{100} + (d - 10) \cdot \frac{100 - \rho}{100} \end{aligned} \tag{12}$$

The member's expected profit is calculated as

$$\begin{aligned} profit^m_{LM} &= \rho \int_0^\rho f(b)db + \int_\rho^{100} (b - d) \cdot f(b)db \\ &= \frac{\rho^2}{100} + \frac{1}{100}[(5000 - 100d) - (\frac{\rho^2}{2} - d\rho)] \\ &= \frac{1}{200}(\rho^2 + 2d\rho + 10000 - 200d) \end{aligned} \tag{13}$$

Fig. 7 and Fig. 8 depict the condition in which both agents are happy with the pre-agreement. Fig. 7 shows the expected profit graph when we fix $d = 10$ and change share ρ. Fig. 8 shows that when we fix $\rho = 40$ and change penalty d. These figures show that the agents will accept the pre-agreement only in a limited range of ρ or d.

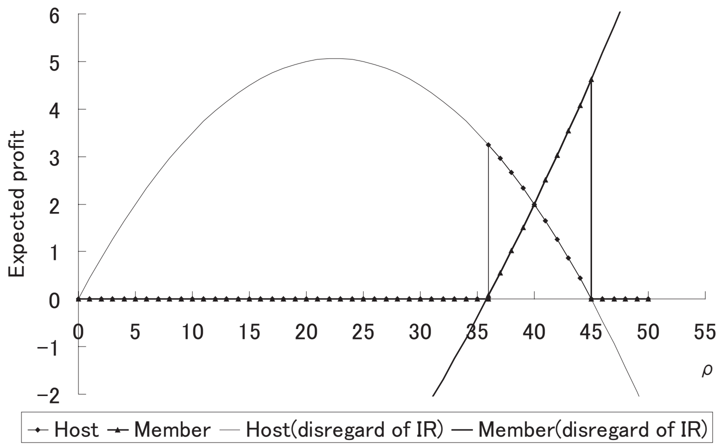

Fig. 7. Share ρ that balances agents' profits.

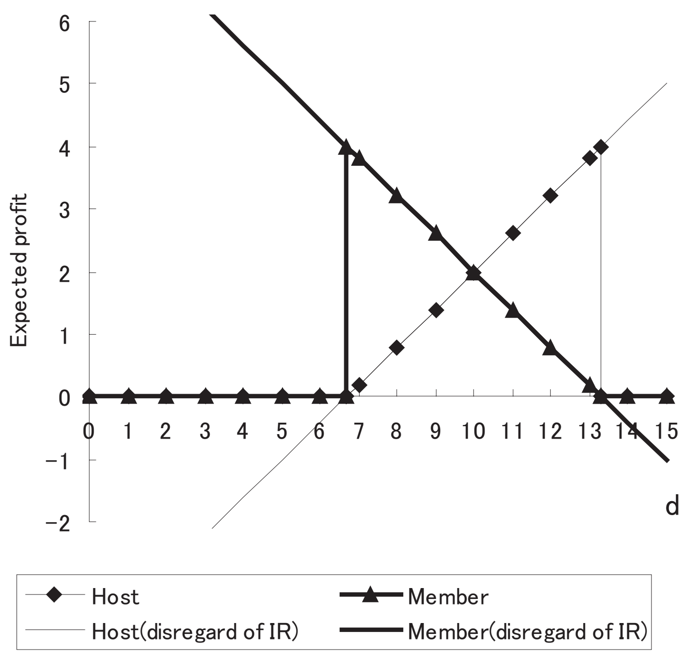

Fig. 8. Penalty d that balances agents' profits.

Fig. 7 shows that the host agent maximizes its profit if the pre-agreement uses $\rho = 45/2$. This, unfortunately, imposes a loss on the member agent, who would thus reject the pre-agreement. Pre-agreement is feasible only when $34.20 < \rho < 45$.

A similar discussion can be made for d. When d is too large, the member agent is not satisfied, and when too small, the host agent is not satisfied. Fig. 8 shows that the pre-agreement is possible when $6.67 < d < 13.33$.

4 Related Work

The idea of speculative action is based on the work on speculative computation [2, 1]. Speculative computation has been proposed as a method to accelerate the processing speed of pipelined parallel computers. A pipelined parallel computer can pre-fetch as many commands as there are processors and execute them in parallel. However, if a branch command is included in the pre-fetched commands, the following sequence of commands to be executed changes depending on the result of the branch command. Speculative computation attempts to choose the most plausible command and to execute it speculatively. It runs the risk of choosing a wrong command, which must be canceled or rolled back.

Satoh et al. [4] introduced the idea of speculative computation into the field of multi-agent systems. They discussed the issue of communication delay in multi-agent systems and dealt with it by using a default reasoning technique, which is viewed as a variant of speculative computation.

In previous works, the failure of speculative computation is recovered simply by canceling the computation and no side effects are assumed to occur. In this paper, we assume that unwinding a speculative action has a cost. The leveled method described here is based on the leveled commitment method proposed by Toumas Sandholm et al. [3].

5 Conclusions and Future Work

Speculative actions are effective if agreement cannot be reached rapidly. Since we assume that unwinding them incurs a cost, they are not a universal palliative. We proposed two methods in this paper to reduce the risk of unwinding a speculative action: the hybrid method, which switches between the speculative method and the basic method based on the estimated probability of agreement; and the leveled method, which makes the host and the member agents enter a pre-agreement and forces them to pay a penalty when they break the pre-agreement. We showed the advantages and disadvantages of these methods by using the example of the meeting room reservation problem. The hybrid method has better performance than either of its constituents, the basic method and the speculative method, if the probability of agreement is correctly estimated. Otherwise, its performance is degraded, so estimation accuracy is a critical issue. The leveled method is based on establishing a pre-agreement between the two agents, so the logic of why the agents would accept the pre-agreement is a critical issue. We discussed the settings in which the two agents would accept a pre-agreement.

In this paper, we used the meeting room reservation problem as a case study to discuss speculative actions, but we need to further discuss how we can apply the proposed methods in more general contexts. We also need to deal with cases where there are more than two agents.

Acknowledgement

This work is partly supported by the Grant-in-Aide for Scientific Research (No.13358004) from Japan Society for the Promotion of Science. We would to like to show our thanks to Ken Satoh, Chiaki Sakama, Katsumi Inoue, Koji Iwanuma, and anonymous reviewer for their helpful comments.

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