Efficient Ordering and Parameterization of Multi-Linked Negotiation *

Xiaoqin Zhang
Computer and Information Science Department
University of Massachusetts at Dartmouth
x2zhang@umassd.edu

Victor Lesser
Computer Science Department
University of Massachusetts at Amherst
lesser@cs.umass.edu

Sherief Abdallah
Computer Science Department
University of Massachusetts at Amherst
shario@cs.umass.edu

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1. INTRODUCTION

Multi-linked negotiation deals with multiple negotiations when these negotiations are interconnected. In a multi-task, resource sharing environment, an agent may need to deal with multiple related negotiations about multiple subjects. The potential relationships among multiple negotiations can be classified as two types. One type of relationship is the *directly-linked* relationship: negotiation 2 affects negotiation 1 directly because the subject in negotiation 2 is a necessary resource (or a subtask) of the subject in negotiation 1. The characteristics (such as cost, duration and quality) of subject 2 directly affect the characteristics of subject 1. Another type of relationship is the *indirectly-linked* relationship: negotiation 1 relates to negotiation 2 because the subjects in these negotiations compete for use of a common resource.

How can the agent deal with these multiple related negotiations? Two questions need to be answered here. The first question is in what order should these negotiations be performed. How should the agent orders multiple related negotiations? Should all the negotiations be performed concurrently or in sequence? If in sequence, in what sequence? The second question is how the agent assigns values for those attributes (also referred as "features") in negotiation to minimize the conflicts and maximize the utility. In this work, we develop a decision-making process that enables an agent to manage the multi-linked negotiations and choose the appropriate negotiation solution based on the knowledge about each negotiation and the interrelationships among them.

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2. MODEL OF THE PROBLEM

A multi-linked negotiation problem occurs when an agent has multiple negotiations that are interrelated.

DEFINITION 2.1. *A* **multi-linked negotiation problem** *is defined as an undirected graph (more specifically, a forest as a set of rooted trees): $\mathcal{M} = (V, E)$, where $V = \{v\}$ is a finite set of negotiations, and $E = \{(u, v)\}$ is a set of binary relations on V. $(u, v) \in E$ denotes that negotiation u and negotiation v are directly-linked. The relationships among the negotiations are described by a forest, a set of rooted trees $\{T_i\}$. There is a relation operator associated with every non-leaf negotiation v (denoted as $\rho(v)$), which describes the relationship between negotiation v and its children. This relation operator has two possible values: AND and OR.*

DEFINITION 2.2. *A negotiation v is* **successful** *if and only if a commitment has been established and confirmed for the subject in this negotiation by those agents which are involved in this negotiation.*

DEFINITION 2.3. *A leaf node v is* **task-level successful** *if and only if v is successful; A non-leaf node v is* **task-level successful** *if and only if the following conditions are fulfilled:*

- *v is successful;*
- *all its children are task-level successful if $\rho(v) = AND$; or at least one of its children is task-level successful, if $\rho(v) = OR$.*

Each negotiation $v_i (v_i \in V)$ is associated with a set of attributes $\mathcal{A}_i = \{a_{ij}\}$. Each attribute a_{ij} either already has been determined or needs to be decided. There are two types of attributes: the attributes (of the subject) in negotiation (the features of the subject to be negotiated, such as task deadline, reward, etc.), which are domain dependent; and the attributes of negotiation itself, which describe the negotiation process and they are domain in-dependent, including negotiation duration, negotiation start time, negotiation deadline, success probability.

Given this multi-linked negotiation problem $\mathcal{M} = (V, E)$, an agent needs to make a decision about how the negotiations should be performed. The decision concerns the negotiation ordering and the feature assignment, and they are interleaving. The values assigned to some attributes, such as reward and flexibility, would affect the success probability of negotiation, hence would affect the ordering of the negotiations.

DEFINITION 2.4. *A negotiation solution (ϕ, φ) is a combination of a negotiation ordering ϕ and a valid feature assignment φ. A* **negotiation ordering** *ϕ is a directed acyclic graph (DAG), $\phi = (V, E_\phi)$. If $e : (v_i, v_j) \in E_\phi$, then negotiation v_j can only start after negotiation v_i has been completed. $e : (v_i, v_j)$ is being referred to as a* **partial order relationship (POR),** *e. A negotiation ordering can be represented as a set of* **POR***s, $\{e\}$. A feature assignment φ is a mapping function that assigns a value μ_{ij} to each attribute a_{ij} that needs to be decided in the negotiation. A feature assignment φ is* **valid** *if given the assigned values of those attributes, there exists at least one feasible local schedule for all tasks and negotiation subjects. A partial order scheduler and a related toolkit are used to test if a feature assignment is valid.*

The evaluation of a negotiation solution is based on the expected task-level successful rewards and decommitment penalties given all possible negotiation outcomes for each negotiation. A negotiation has two possible outcomes: **success** and **failure**.

DEFINITION 2.5. *A negotiation outcome χ for a set of negotiations $\{v_j\}, (j = 1, ..., n)$ is a set of numbers $\{o_j\}(j = 1, ..., n), o_j \in \{0, 1\}$. $o_j = 1$ means v_j is successful, $o_j = 0$ means v_j fails. There are a total of 2^n different outcomes for n negotiations, denoted as $\chi_1, \chi_2, ...\chi_{2^n}$.*

DEFINITION 2.6. *The expected value of a negotiation solution (ϕ, φ), denoted as $\mathcal{EV}(\phi, \varphi)$, is defined as: $\mathcal{EV}(\phi, \varphi) = \sum_{i=1}^{2^n} P(\chi_i, \varphi) * (R(\chi_i, \varphi) + C(\chi_i, \phi, \varphi))$*

$P(\chi_i, \varphi)$ denotes the probability of the outcome χ_i given the feature assignment φ.
$P(\chi_i, \varphi) = \prod_{j=1}^{n} p_{ij}(\varphi)$

$$p_{ij}(\varphi) = \begin{cases} p_s(v_j), (p_s(v_j) = \zeta_j(\varphi)) & \text{if } o_j \in \chi_i = 1 \\ 1 - p_s(v_j) & \text{if } o_j \in \chi_i = 0 \end{cases}$$

$R(\chi_i, \varphi)$ denotes the agent's utility increase given the outcome χ_i and the feature assignment φ. $R(\chi_i, \varphi) = \sum_j \gamma_\varphi(v_j)$, v_j is a root of a tree and v_j is task-level successful according to the outcome χ_i.

$C(\chi_i, \phi, \varphi))$ denotes the decommitment penalty according to the outcome χ_i, the negotiation ordering ϕ and the feature assignment φ. $C(\chi_i, \phi, \varphi)) = \sum_j \beta_\varphi(v_j)$, v_j represents every negotiation that fulfills all the following conditions:

1. *v_j is successful according to χ_i;*
2. *the root of the tree that v_j belongs to isn't task-level successful according to χ_i;*
3. *according to the negotiation ordering ϕ, there is no such negotiation v_k existing that fulfills all the following conditions:*
   (a) *v_k and v_j belong to the same tree;*
   (b) *v_k gets a failure outcome according to the outcome χ_i;*
   (c) *v_k makes it impossible for $root(v_j)$ to be task-level successful;*
   (d) *the negotiation finish time of v_k is no later than the negotiation start time of v_j according to the negotiation ordering ϕ.*

3. DESCRIPTION OF THE ALGORITHM

Based on the above definition, we first developed a complete search algorithm, it evaluates each pair of negotiation ordering and valid feature assignment $\mathcal{EV}(\phi_i, \varphi_k)$, and finds an optimal negotiation solution for a multi-linked negotiation problem $\mathcal{M} = (V, E)$. The exponential complexity of the complete algorithm prevents it from being used for real-time applications when the number of negotiations and the number of valid feature assignments are large; hence a heuristic search algorithm has been developed. The heuristic search for the optimal negotiation solution includes two parts. One is to find the optimal negotiation schedule; the other one is to find the optimal feature assignment for a given negotiation schedule. The search for the optimal negotiation schedule is based on the simulated annealing idea. The search for the best feature assignment is based on a hill climbing approach. After considering the characteristics of this problem, some heuristics have been added to these search processes. Experiments show that the heuristic search saves a large amount search effort compared to the complete search when the number of negotiation issues and the number of possible feature increase.

4. SUMMARY AND RELATED WORK

We presented a formalized model of the multi-linked negotiation problem enables the agent to represent and reason about the relationships among different negotiations explicitly. A heuristic search algorithm finds the nearly-optimal approach in affordable time. Experimental work shows that this management technique for multi-linked negotiation leads to improved performance. To our knowledge, there is no other work that has addressed the *directly-linked* relationship in the negotiation process. There is some work that takes into account the *indirectly-linked* relationship among multiple negotiation issues such as the distributed meeting scheduling [2] problem and the distributed resource allocation problem [1]. However, those problems are different from our problem in the following ways: the negotiation is cooperative by nature and the agent can altruistically withdraw its request to help others succeed; the tasks are simple, no need for subcontracting; no time pressure on negotiation and no penalty for decommitment.

5. REFERENCES

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