Utility-based Role Exchange

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Abstract. In this paper, we examine role exchange in multiagenty. After defining the utility that reflects an agent's orientation toward role exchange, I.e., Role Exchange Value (REV) and the agent's Individual Utility Gain (IUG), we present two theorems and two corollaries that capture properties of proposed utility-based role exchange. Then, we provide an algorithm that predicts IUG for each agent in role exchange. The algorithm is implemented and the results are discussed.

1 Introduction

In multiagent systems, a major issue is for self-interested agents to form coalitions in order to produce the most effective results. Self-interested agents care solely about their own benefits instead of considering the group benefits. Therefore, Pareto-optimality agents [8], which have cooperative characteristics, are preferred. Since "A team in which each boundedly rational player maximizes its individual expected utility does not yield the best possible team" [1], some agents need to sacrifice their individual utility for the sake of the community [6].

The relationship among agents is primarily reflected by their roles [9]. Ferber defines a role as "an abstract representation of an agent function, service or identification" [4]. Role is a common sense notion for agents in communities [5]. Said differently, here the consideration that helps form role selections is synonymous with the consideration that helps form a coalition of agents.

Careful selection of a pattern of roles for adoption is a key point for improving the group performance. We can use the concept of *individual utility* to measure each agent's performance in a specific role and use the *total utility* to represent the team's performance in the formation of roles.

Consider a group of distinct n agents, $A=\{a_1,a_2,...,a_n\}$, where a_i is the i th agent and a set of distinct n roles, $R=\{r_1,r_2,...,r_n\}$, where r_i is the i th role, such that $i \neq j \Rightarrow r_i \neq r_j$. For any agent a_i and role r_j, there is a utiltiy $U(a_i,r_j)=u_{ij}$, where u_{ij} stands for the utility of adopting role j by agent i and function $U(a_i,r_j)$ is to get

u_{ij}. Any formation F is a set of $\{ < a_i, r_j, u_{ij} > \mid where\ i, j \in [1..n]$, for any pair of $< a_i, r_j, u_{ij} >$ and $< a_k, r_l, u_{kl} >$, $a_i \neq a_j \Rightarrow r_k \neq r_l \}$ and each agent is assigned a single distinct role. The cardinality of this set is n. Agent i may adopt any of the other $n-1$ roles and its respective utility. In this model, there are the same number of roles as there are agents [11].

In this paper, we will present an algorithm called "utility-based role exchange". At first we will introduce the related works in the field of formation-based roles in section 2. Then we will provide some assumptions before defining the concept of role exchange value and the concept of utility gain in section 3.1. Then in section 3.2, we will discuss 2 theorems and 2 corollaries for the condition of role exchange. Based on the theorems and corollaries, we will present the utility-based role exchange algorithm in section 4 and the implementation of the algorithm with the results. In section 5, we will provide some concluding remarks.

2 Related Work

Formation as basis of collaboration among agents is introduced in [11]. A formation decomposes the task space into a set of roles. Formations include as many roles as there are agents in the team, so that each role is filled by a single agent. Furthermore, formations can specify sub-formations, or *units*, that do not involve the whole team. A unit consists of a subset of roles from the formation, a *captain*, and intra-unit interactions among those roles.

Formations are commonly found in the game of soccer or Robocup [12]. Agents adopt an initial assignment of roles, but this assignment may need to be revised as the situation changes. Therefore, re-assignment of roles or some role exchanges become necessary [7]. Formation-based role assignment ensures flexibility of role exchange, which was beneficial to the FC Portugal team [10]. In this team, each player exchanges not only its position (place in the formation), but also its assigned role in the current formation. After the exchange, the agent will be instantiated with a new role and corresponding new abilities and goals. Therefore, the team completely loses properties of its old roles. To our knowledge, beyond the game of Robocup, role exchange has not been explicitly addressed in the literature. Work on coalitions is related but the agent and its roles are not differentiated.

Role adoption is the initial state before role exchange takes place. Cavedon and Sonenberg introduced the notion that role adoption results in goal adoption to different degrees [2]. Fosli discussed the relationships among agents, roles, commitments, and obligations: an agent adopts a role, this role is associated with one or more social commitments, and obligations result from the adoption of roles ([3] in this volume).

3 The Assumptions and Properties for Role Exchange

Let's assume the agent is Pareto-optimality agent. In order to get the optimized *total utility*, some agents have to sacrifice their benefits to exchange roles. In order to determine which agent needs to sacrifice its benefit, we need to define a *Role Exchange Value* (REV) for the computation. From this value we present another concept of *Individual Utility Gain* (IUG) for each agent when considering role exchange in an agent pair. If IUG of each agent in the pair increases, role exchange will benefit the group. In some cases, the IUG of the agent may increase, while its individual utility after role exchange may decrease. At this time, we can say that the agent sacrifices its own benefit to maximize the pair utility.

Before presenting the detail of the algorithm of role exchange, we make the following assumptions:

1. With N agent and N roles, there is a one to one assignment of roles to agents.
2. Each agent has a unique utility per role. I.e., $V(A,R)$ is agent A's unique utility in role R.
3. An agent's adoption of a role will not affect the utility of another agent adopting another role.
4. The *total utility* of a number of agents is equal to the sum utilities from each of these agents. I.e. *Total Utility* = $\sum_{i=0}^{i=n} V(A_{i,} R_i)$ [1]**.**
5. The role exchange process takes place only between a pair of roles at one time.
6. If the margin of gain from a hypothetical role exchange is positive for a pair of agents, they are obliged to exchange. This is due to the Pareto-optimality cooperative agents.
7. The time consumption or utility loss due to the process of role exchange is assumed negligible and will not be considered.

3.1 Role Exchange Value and Utility Gain

REV involves a pair of agents and a pair of roles, i.e., agent A, agent B and role R1 and role R2. We will introduce the following concepts here:

1. $V(A,R1)$ represents the unique utility of agent A taking role R1.

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[1] We do not consider varying degrees of contribution. We consider uniform contribution by each agent. This means that we do not consider a weighted generalizing of this formula. Furthermore, individual agents do not have access to this total utility.

2. $V(A, R1, B, R2)$ represents the sum utility of agent A taking role R1 and agent B taking role R2. I.e., based on assumption 3 and 4, $V(A, R1, B, R2) = V(A, R1) + V(B, R2)$.
3. $REV_A(A, R1, B, R2)$ represents the role exchange value of agent A in the formation that agent A taking role R1 while agent B taking role R2. $REV_A(A, R1, B, R2)$ for role exchange involves $V(A, R1)$, $V(B, R2)$, $V(A, R2)$, and $V(B, R1)$.

We can assume that $V(A, R1)$ is the utility of agent A takes role R1 before role exchange, and $V(B, R2)$ is the utility of agent B takes role R2 before role exchange. The total utility of agent A and B before role exchange is $V(A, R1, B, R2)$. $V(A, R2, B, R1)$ is the total utility of agent A and agent B after role exchange. In role exchange for agent pair (A, B), we define the REV of agent A in the formation that agent A taking role R2 while agent B taking R2 as equation (1):

$$REV_A(A, R1, B, R2) = 0.5 * \{V(A, R1) + V(A, R2, B, R1) - V(B, R2)\} \quad (1)$$

The origin of this equation lies in the game theory where rewards are divided according to the relative contributions of each member. Here we have two agents and we adopt the Shapley value in the degenerate case of two agents. Since agents map one to one to roles, all exchanges are between pairs of agents and all concurrent exchanges can be pair-wise decomposed. This implies that no complex equation beyond (1) is needed for multiple exchanges. For agent A, the formula captures ½ the marginal gain A would contribute to working with B and ½ the gain it would make by itself. The multiplier 1/2 is used to divide the utility gain equally between two agents.

The *individual utility gain* for agent A in this role exchange formation is as equation (2):

$$IUG_A(A, R1, B, R2) = REV_A(A, R1, B, R2) - V(A, R1) \quad (2)$$

If REV is the gain after exchange, the agent must compare that to the gain when working alone. This will be basis of simple exchange. Based on equations (1) and (2), we use the following 3 conditions to check if role exchange is needed.

1. If $IUG_A(A, R1, B, R2) < 0$, role exchange will degrade to total utility for the entire group and original role formation is better.
2. If $IUG_A(A, R1, B, R2) = 0$, role exchange is not necessary. There is no difference between before and after role exchange.
3. If $IUG_A(A, R1, B, R2) > 0$, role exchange will be beneficial to the entire group.

Conditions for Role Exchange

3.2 Theorems

The following 2 theorems and 2 corollaries present the main properties of the utility-based role exchange using REV and IUG.

Theorem 1: Gains and losses of two agents in a role exchange are the same for either agent.

$$\forall i, j\ \forall k, l\ agent(i) \wedge agent(j) \wedge i \neq j \wedge role(k) \wedge role(l) \wedge k \neq l \Rightarrow$$
$$IUG_i(i,k,j,l) = IUG_j(i,k,j,l).$$

The predicate “agent” picks out agents whereas predicate “role” picks out roles.

> **Proof.** For agent pair A and B, agent A takes role R1, and agent B takes role R2. Let’s calculate the gain for agent A and B respectively after role exchange.
>
> $$IUG_A(A,R1,B,R2) = REV_A(A,R1,B,R2) - V(A,R1) =$$
> $$0.5 * \{V(A,R1) + [V(A,R2,B,R1) - V(B,R2)]\} - V(A,R1) =$$
> $$0.5 * [V(A,R2,B,R1) - V(A,R1) - V(B,R2)] \text{ and}$$
>
> $$IUG_B(A,R1,B,R2) = REV_B(A,R1,B,R2) - V(B,R2) =$$
> $$0.5 * \{V(B,R2) + [V(A,R2,B,R1) - V(A,R1)]\} - V(B,R2) =$$
> $$0.5 * [V(A,R2,B,R1) - V(A,R1) - V(B,R2)].$$
>
> From above equations, we can see that the utility gain of agent A is equal to utility gain of agent B.

The utility gain after each role exchange for each agent is the mutual gain for the pair of agent.

Corollary 1: If role exchange benefits either agent in a pair, it will also benefit the other agent.

$$\forall i, j\ \forall k, l\ agent(i) \wedge agent(j) \wedge i \neq j \wedge role(k) \wedge role(l) \wedge k \neq l \wedge IUG_i(i,k,j,l) > 0 \Rightarrow$$
$$IUG_j(i,k,j,l) > 0.$$

> **Proof.** Using Theorem 1.

Before role exchange, we calculate the utility gain of one agent in the agent pair, if its utility gain is positive, the other agent’s utility gain will also be positive. Therefore, role exchange will increase the total utility of the group.

Corollary 2: If role exchange does not benefit either agent in a pair, it will not benefit the other agent either.

$$\forall i, j\ \forall k, l\ agent(i) \wedge agent(j) \wedge i \neq j \wedge role(k) \wedge role(l) \wedge k \neq l \wedge IUG_i(i,k,j,l) < 0 \Rightarrow$$
$$IUG_j(i,k,j,l) < 0.$$

> **Proof.** Using Theorem 1.

Before role exchange, we calculate the utility gain of one agent in the agent pair, if its utility gain is negative, the other agent's utility gain will also be negative. Therefore, role exchange will not be performed.

Theorem 2: The marginal utility gain for the agent pair equals twice the IUG for one agent.

$$\forall i, j\ \forall k, l\ agent(i) \wedge agent(j) \wedge i \neq j \wedge role(k) \wedge role(l) \wedge k \neq l \Rightarrow$$

$$IUG_i(i, k, j, l) + IUG_j(i, k, j, l) = 2 * IUG_i(i, k, j, l).$$

Proof. Using Theorem 1.

From the IUG of one agent in a pair, we can simply calculate the total utility gain for the whole group. Since IUG is the mutual gain for both agents, therefore, the utility gain for the whole group during the current role exchange is twice IUG.

4 The Algorithm for Role Exchange

The algorithm for utility-based role exchange takes the following steps. In our algorithm, t is the time index. For instance, $t = 0$ is the time before any role exchange. $t = 1$ is the time at the 1st exchange. Function $add(< x, y, z >, S)$ adds the triple $< x, y, z >$ to set S. Function $delete(< x, y, z >, S)$ deletes the triple $< x, y, z >$ from set S. $stop$ stands for termination of the algorithm. Predicate "formation" picks out a specific formation, e.g., F.

1. There is no role adoption for any agent at the very beginning. $t = 0 \Rightarrow F = \varnothing$.

2. When role adoption starts, each agent adopts a role randomly, which means that the agent may adopt any role at first. $t = 1 \Rightarrow \forall i \exists j, agent(i) \wedge role(j) \wedge U(i, j) = u_{ij} \wedge add(< i, j, u_{ij} >, F)$.

3. Search the agent pairs from the first agent for role exchange. If the IUG of the given pair of agents is positive, the agent pair will make role exchange; otherwise search the next agent pair for role exchange.
$$\forall i, j \forall k, l \forall F, agent(i) \wedge agent(j) \wedge role(k) \wedge role(l) \wedge formation(F) \wedge < i, j, u_{ik} > \in F \wedge < i, j, u_{jl} > \in F \wedge$$
$$IUG_i(i, k, j, l) > 0 \Rightarrow add(< i, l, u_{il} >, F) \wedge add(< j, k, u_{jk} >, F) \wedge delete(< i, k, u_{ik} >, F) \wedge delete(< j, l, u_{jl} >, F)$$

4. Role exchanges will stop when the utility gain of any agent pair is no more than zero.
$$\forall i, j \forall k, l\ agent(i) \wedge agent(j) \wedge role(k) \wedge role(l) \wedge \sum_{i=1}^{n} IUG_i(i, k, j, l) \leq 0 \Rightarrow stop.$$

The Algorithm for Role Exchange

Consider the following example involving role exchanges with 2 agents and 2 roles, which are adopted by those 2 agents. We can use a matrix to model this problem. Based on assumption 1 and 2, suppose there are N agents and N roles, we can use N*N matrix to represent the relationship between agents and roles. The rows represent agents such as agent A0 and columns represent roles, such as role R0. The value at the intersection of an agent row and a role column, such as element (i, j), represents the utility that agent i adopting role j. In an implementation of this algorithm, we use a 10*10 matrix shown in Table 1, whose utilities are randomly generated.

According to the algorithm we discussed in above, no role has been adopted at first. So we may just assign each agent A_i with role R_i, as the entities highlighted in the table. Based on assumption 3 and 4, at this time, the initial total utility of the group is $\sum_{i=0}^{i=9} V(Ai, Ri) = 71$. Then based on assumption 5, 6 and 7, we will check each agent pair to decide if role exchange is necessary or not based on conditions we discussed in 2.1. The agent pair of role exchange and the exchange sequence is shown in Table 2.

Table 1. Agent-Role Table

	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9
A0	1	7	14	0	9	4	18	18	2	4
A1	5	5	1	7	1	11	15	2	7	16
A2	11	4	2	13	12	2	1	16	18	15
A3	7	6	11	1	8	9	12	7	19	15
A4	14	3	11	2	13	13	4	1	11	13
A5	8	7	4	2	17	17	19	3	1	9
A6	18	16	15	10	2	8	6	0	2	4
A7	8	6	5	10	9	10	10	6	1	13
A8	8	9	3	4	14	16	0	6	16	11
A9	8	4	19	6	3	17	18	18	2	9

Table 2. Role Exchange Pairs

Agent Pair	PairUtility Gain
A0, A1	6
A0, A2	9
A0, A6	14
A0, A7	5
A0, A2	1
A0, A6	12
A0, A7	8
A0, A9	3
A0, A1	12
A0, A2	12
A2, A8	5

The result for role exchange is shown in Figure 1. From the chart we can see that role exchange increases the total utility of the whole group from 71 to 154.

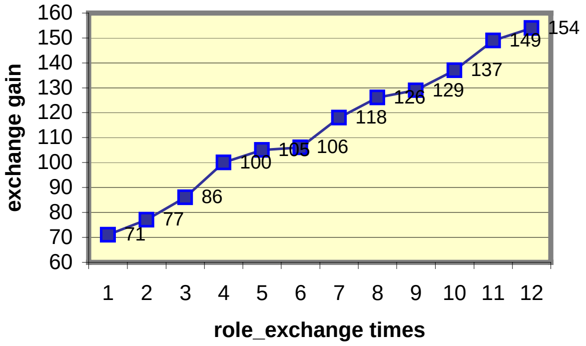

Figure 1. Utility Gain of Role Exchange

5 Ongoing Work

There are a number of possible avenues for future development related to utility-based role exchange. First, since in real world agents' role adoption is influenced by many factors, such as goals, abilities, commitments and etc, we can extend our considerations to other kinds of agent-role mapping relationships. For example, agents and roles are not mapped one by one. The algorithm for this example will be more complicated, i.e., one agent can take two or more roles at the same time. This aspect is not present in the current formalism. Second, in this paper, utility gains or losses are equally divided by a pair of agents since we assumed that every agent has the same priority toward the others. In the condition that agent's priority is not reciprocal, the gains and losses from role exchange will not be linear. Another issue is that when we make role exchanges, we consider all the other agents before making the decision. But some time, the agents do not have enough time to make full consideration, so partial consideration maybe "good enough". Based on the theorems and equations presented in this paper, elsewhere we have reported on two alternative algorithms for role exchange [13].

6 Conclusion

We examined role exchanges in general and suggested utility-based role exchange. We applied role exchange value to compute the utility gain for each agent in an agent pair. We also presented two theorem and two corollaries for utility-based role exchange and the method of computation for mutual gain. We provided the algorithm and conditions for role exchange based on the group utility gain. Finally, we discussed the implementation of the algorithm and analyzed that utility-based role exchange can benefit the group of agents.

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