Multi-party Dialogue Games for Dialectical Argumentation

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***Abstract*—This paper concerns a distributed argumentation system where different agents are equipped with argumentative knowledge base (henceforth referred as KB) within which conflict arguments are represented using attacking relations. This paper proposes the notion of "defensibility" of an argument in a distributed argumentation system and a multi-party dialogue game to compute the defensibility of an argument. In our multi-party dialogue game framework, we have proposed the notion of critical factor, legal move function and critical countermeasure, which act as the mechanism for avoiding idle attack and invalid attack in the course of dialogue games. Theoretically, the paper has also proved the soundness and completeness of multi-party dialogue games conducted by legal move and countermeasure function. It is anticipated that this research will contribute to argumentation research in MAS.**

***Index Terms*—argumentation; distributed argumentation system; multi-party dialogue games; multi-agent system**

I. Introduction

Belief conflicts are inevitable among different agents inhabiting in environments with imperfect information (such as incomplete, inconsistent or imprecise information). Finding effective ways for agents to reconciling conflicts is an active research area in multi-agent system (MAS). One mechanism of reducing conflicts is through argumentation where each agent presents arguments for or against the initial thesis and tries to convince each other during the argumentation or dialogical process[1] .

Much of recent work on argumentation dialogues[2-4], are usually based on static and centralized argumentation framework[5], which means that arguments and their attacking relationships are prescribed together in advance and unchangeable during the argumentation process. As our world is dynamic and distributed, this assumption doesn't normally hold and it is difficult to establish a complete argumentation framework in advance. In a dynamic situation, argumentation framework w.r.t. a certain proposition is gradually emerged during the argument process. It is therefore difficult to know whether an admissible set is preferred extension.

In this paper, we consider a distributed argumentation system, where arguments are stored in different agents' knowledge base as fragments of information and the attacking relationship exists between arguments with conflict information (e.g. "Chris is a female" and "Chris is a male"). To resolve conflicts among agents, we adopt an argumentation approach to enable agents engaging in dialogue with each other. Typically, we propose a multi-party dialogue game to facilitate such dialogue interaction. We introduce the notions of defensibility for arguments, and a multi-party dialogue game for computing defensibility of an argument. The multi-party dialogue game is established on the notions of critical factor, eligible legal move function and critical countermeasure.

The remainder of this paper is organized as follows. Distributed argumentation system is briefly introduced in Section 2 where the notation of defensibility of an argument is proposed. We then introduce our proposed multi-party dialogue games in Section 3 where some key notations, e.g. critical factor, legal move function and critical countermeasure are introduced. Section 4 contains an algorithm we have proposed for computing critical factors and the defense set of a defensible proposition in a multi-party dialogue. Section 5 provides an example illustrating our proposed approach in action. We finally discuss some related work in the area and our planned further work.

II. Distributed Argumentation System

Over the last decade, a number of argumentation systems have been proposed to formally represent argumentation[5-7]. The most influential one is Dung's argumentation framework[5], which defines a set of atomic arguments together with a set of attack relationship. Generally speaking, these frameworks are based on the assumption that all arguments and attack relationship are prefixed. Following Dung's abstract argumentation framework, we propose a distributed argumentation system as follows.

Distributed argumentation system is established on several knowledge bases of participating agents (henceforth referred as participants). During the process of argumentation, participants are able to generate the initial arguments for a given topic, advance arguments for or against a position with the aim of convincing each other (including users) to adopt a certain proposition. The distributed argumentation system is defined as follows.

Definition 1. (Consistency) Let a set KB of program clauses, if there does not exist literal φ satisfies both

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$KB \vdash \varphi$ and $KB \vdash \neg\varphi$, KB is said to be consistent.

Here, it is notable that φ and $\neg\varphi$ are two conflicting literal, such as "Chris is a female" and "Chris is a male".

Let a set $PAR = \{par_i \mid i \in \mathbb{N}\}$ of participants, the knowledge base KB_i of each participant $par_i \in PAR$ is a finite set of logical sentences. It is assumed that each agent's knowledge base is consistent, but conflicts may exist among different agents' knowledge bases, i.e. $\exists\varphi.(KB_i \vdash \varphi) \wedge (KB_j \vdash \neg\varphi)$, $i \neq j$.

Definition 2. (Distributed argumentation system) A distributed argumentation system established on knowledge bases of all participants $PAR = \{par_i \mid i \in \mathbb{N}\}$ is a tuple $DAF = (\mathrm{A}, \mathrm{R})$, in which:

① $\mathrm{A} = \bigcup_{par_i \in PAR} \mathrm{A}_i$, A_i be a set of arguments generated from the knowledge base of par_i;

② $\mathrm{R} = \bigcup_{i,j=1}^{n} \mathrm{R}_{ij}$, R_{ij} is a set of binary (attack) relationship from A_i to A_j, i.e. $\mathrm{R}_{ij} \subseteq \mathrm{A}_i \times \mathrm{A}_j$, $\mathrm{R}_{ii} = \varnothing$.

Given two arguments $a \in \mathrm{A}_i$ and $b \in \mathrm{A}_j$, $(a,b) \in R$ (or $aR\,b$) means a attacks b; $(a,b) \notin R$ represents a and b are conflict-free. $R_+(a)$ denotes the set of arguments attacked by argument a, i.e. $R_+(a) = \{b \in A \mid aR\,b\}$; and $R_-(a)$ the set of arguments attacking argument a, i.e. $R_-(a) = \{b \in A \mid bR\,a\}$. A set S of arguments attacks an argument a if there is some argument b in S, such that $(b,a) \in R$. And an argument a attacks a set S of arguments if there is some argument b in S, such that $(a,b) \in R$. Let a set S of arguments, similarly, $R_\omega(S) = \bigcup_{a \in S} R_\omega(a)$ ($\omega \in \{+,-\}$) denotes the set of arguments which attacks or is attacked by S.

A set S of arguments is conflict-free iff for any arguments $a, b \in S$, it follows $(a,b) \notin R$. For a conflict-free set S of arguments, S is called admissible iff for any argument $a \in R_-(S)$, there exists an argument $b \in S$ such that $(b,a) \in R$.

With the assumption of consistency of each participant's knowledge base, it follows that, for each $par_i \in PAR$, A_i is conflict-free.

In a distributed argumentation setting, it is usually difficult to decide whether an admissible set is a preferred extension. Thus we introduce a notion of defensibility for an argument.

Definition 3. (Defensibility[8]) An argument $a \in \mathrm{A}$ of $DAF = (\mathrm{A}, \mathrm{R})$ is a defensible w.r.t. an admissible set $S \subseteq \mathrm{A}$, iff $\forall x \in \mathrm{A}.(x\mathrm{R}\,a \rightarrow x \in \mathrm{R}_+(S))$.

If argument a is defensible w.r.t. admissible set $S \subseteq \mathrm{A}$, then S is said to be a's defense set.

Example 1. Let $\{a,e\}$, $\{b,d\}$ and $\{c\}$ are sets of arguments derived from KB_1, KB_2 and KB_3 respectively, such that $R = \{(b,a),(d,a),(c,b),(c,d),(e,b)\}$. Then a is defensible on $DAF = (\mathrm{A}, \mathrm{R})$ established on KB_1, KB_2 and KB_3, and whose defense set is $\{a, c, e\}$.

III. MULTI-PARTY DIALOGUE GAMES

Multi-party dialogue game is a suitable mechanism for the implementation of distributed argumentation. In a multi-party dialogue, each participant par_i puts forward their own proposition ϕ_i for a given topic *t*, then we get a collection $\Phi = \{\phi_i \mid par_i \in PAR\}$ of propositions. For each proposition $\phi \in \Phi$, there exists a multi-party dialogue starting by an initial move that contains ϕ, in which all participants make moves to attack or defend the initial one. The proponents win the multi-party dialogue if the opponents have no moves to change the status of the initial move, the status of the initial move is labeled as 1 when the opponents run out all valid moves to expand the multi-party dialogue, and labeled as 0 when the proponents has no valid moves to expand the dialogue tree. A formal definition of the status of an argument is given in Definition 9 below.

Traditionally, a move is tuple $m = (par_i, arg)$ [9], in which $par_i \in PAR$ is the player of the move, denoted by $\mathrm{Par}(m)$; and $arg \in \mathrm{A}_i$ the (counter-)argument expressed with move, denoted by $\mathrm{Arg}(m)$. Meanwhile, for convenience, let $M_i = \{m \mid \mathrm{Arg}(m) \in \mathrm{A}_i\}$ be the set of moves held by participant par, and $M = \{m \mid \mathrm{Arg}(m) \in \mathrm{A}\}$ the set of moves in $DAF = (\mathrm{A}, \mathrm{R})$, i.e. $M = \bigcup_{par_i \in PAR} M_i$. In addition, $\mathrm{Arg}(m_i)\mathrm{R}\,\mathrm{Arg}(m_j)$ is also simplified by $m_i \mathrm{R}\, m_j$ which is called move m_i attacks m_j.

Definition 4. (Multi-party dialogue type) A multi-party dialogue type is a tuple $MDT = (PAR, DAF, \psi)$, where $PAR = PAR_P \cup PAR_O \cup PAR_N$ is the set of participants with three different positions to a certain proposition (i.e. proponents PAR_P, opponents PAR_O, and neutrals PAR_N); $DAF = (\mathrm{A}, \mathrm{R})$ is a distributed argumentation system established on these participants' knowledge base; and $\psi : \mathcal{P}(M) \rightarrow \mathcal{P}(M)$ is legal move function, in which $\mathcal{P}(M)$ represents the power set of M.

For $\forall par \in PAR_P \cup PAR_O$, $\mathrm{C}(par)$ means the complement of the set that par belongs to, e.g., for a move m if $\mathrm{Par}(m) \in PAR_P$, then $\mathrm{C}(\mathrm{Par}(m)) = PAR_O \cup PAR_N$.

A multi-party dialogue is a sequence of moves $d : m_0, m_1, \ldots, m_n, \ldots$, in which players make moves to attack those moves made by the opposing party. It can be defined formally as follows.

Definition 5. (Multi-party dialogue) A multi-party dialogue is a sequence of moves $d : m_0, m_1, \ldots, m_n, \ldots$ satisfying: ① $\mathrm{Par}(m_0) \in PAR_P$, and $\mathrm{Arg}(m_0) \in \Phi$; and ②for any move m_n in d, such that $m_n \in \psi(\{m_0, m_1, \ldots, m_{n-1}\})$, where ψ is legal move function.

The first condition says that multi-party dialogues always start with an argument in question, i.e. the proposition w.r.t. a given topic; and the second condition states all moves in dialogue games should be legal as defined in definition 6 below.

For convenience, $m \in_i d\,(i = 0,1,2,\ldots)$ denotes move m appears in d at *ith* position (*i-appear* for short).

Definition 6. (Legal move function) A legal move function for multi-party dialogue games is defined as $\psi : \mathcal{P}(M) \to \mathcal{P}(M)$ that satisfies:

$$\psi(\overline{d}) = \begin{cases} M_\Phi, & if\ \overline{d} = \varnothing \\ \bigcup_{m \in_i d} (\mathrm{R}_{\flat}(m, M) \setminus \mathrm{R}_{\flat}(m, \overline{d})), & otherwise \end{cases}$$

where $\overline{d} = \{m \mid m \in_i d\}$ represents the set of all moves appear in d; $M_\Phi = \{m_0 | \mathrm{Arg}(m_0) \in \Phi\}$ represents the set of moves only containing the initial argument; and $\mathrm{R}_{\flat}(m, S) = \{m' \in S \mid m' \mathrm{R}\, m \wedge \mathrm{Par}(m') \in \mathrm{C}(\mathrm{Par}(m))\}$ the set of moves attacking m in set S, $S \in \{M, \overline{d}\}$.

This definition suggests that for each move $m \in_i d (i = 1, 2, ...)$ (i.e. except for m_0), there exists a move attacked by m in multi-party dialogue, and it is not allowed to use one move attacking the same move more than once.

For a move m, $\mathrm{R}_{+\flat}(m, S) = \{m' \in S \mid m \mathrm{R}\, m'\}$ indicates the set of moves in S attacked by m. In multi-party dialogue d, it follows $\mathrm{R}_{+\flat}(m_0, d) = \varnothing$.

Definition 7. (Extension) Let d and d' be two multi-party dialogues, d' be an expansion of d, iff for any $m \in_i d$, it also holds $m \in_i d'$;

Definition 8. (Legal extension) Let d' is an expansion of d, and there exists a set of moves $\mathrm{E} = \{m \mid m \in_i d' \wedge m \notin_i d\} \neq \varnothing$. If $\mathrm{E} \subseteq \psi(\overline{d})$, then d' be a legal expansion of d with E under ψ. E is also said a *legal expansion factor* of d under ψ.

Definition 9. (Move status function) Move status function $label : \overline{d} \to \{0,1\}$, such that for any $m \in_i d$, it can be recursively defined as:

$$label(m \mid d) = \begin{cases} 0, & if\ \omega \geq 1 \\ 1, & if\ \mathrm{R}_{\flat}(m, \overline{d}) = \varnothing\ or\ \omega = 0 \\ undefined, & otherwise \end{cases}$$

where $\omega = \sum_{m' \in \mathrm{R}_{\flat}(m, \overline{d})} label(m' \mid d)$, $label(m \mid d)$ denotes the status of m in d.

From above definition, each move in multi-party dialogue can be labeled either as 0 or 1. The definition also suggests a backward labeling procedure, through which we are able determine the status of the initial move m_0.

Let $Win(d) = \{m \in_i d \mid label(m \mid d) = 1\}$ indicates the set of moves labeling as 1 in a multi-party dialogue d, and $Def(d) = \{m \in_i d \mid label(m \mid d) = 0\}$ the set of moves labeling 0.

Definition 6 provides a set of legal moves from the attacking relationship and repetition points of view. Further, we do not want to extend a multi-party dialogue with invalid moves (e.g. moves already been defeated by the opposing party) or useless moves (has no effect on the status of the initial move of dialogue game). In a dialogue game, each party hopes to achieve its goal with the least number of moves. Specifically, the proponents try to prove the rationality of initial argument by attacking all attacks from the opponents; while the opponents attempt to disprove the initial argument by attacking the proponents' argument. Intuitively, some moves play critical role in a multi-party dialogue, since they have direct effect on the initial move. From this point of view, both the proponents and opponents could propose an optimal set of attackers aiming at critical moves. Critical factor depicts these moves playing a critical role in a multi-party dialogue.

Let $PRO(d) = \{m \in_i d \mid \mathrm{Par}(m) \in PAR_P\}$ be the set of moves presented by the proponents in d, and $OPP(d) = \{m \in_i d \mid \mathrm{Par}(m) \in PAR_O\}$ the set of moves presented by the opponents.

Definition 10. (Critical factor) Let multi-party dialogue d, and the initial move $m_0 \in_0 d$.

(1) If $label(m_0 \mid d) = 1$, $CF_{PRO}(d) \subseteq PRO(d) \cap Win(d)$ be a set of moves executed by the proponents in d, $CF_{PRO}(d)$ is called a pro critical factor iff the following conditions hold: ① If $\sum_{m \in CF_{PRO}(d)} label(m \mid d) = 0$, then $label(m_0 \mid d) = 0$; and ② $CF_{PRO}(d)$ is minimal w.r.t. set inclusion.

(2) If $label(m_0 \mid d) = 0$, $CF_{OPP}(d) \subseteq OPP(d) \cap Win(d)$ be a set of moves executed by the opponents in d, $CF_{OPP}(d)$ is called a con critical factor, iff the following conditions hold:①If $\sum_{m \in CF_{OPP}(d)} label(m \mid d) = 0$, then $label(m_0 \mid d) = 1$; and ② $CF_{OPP}(d)$ is minimal w.r.t. set inclusion.

By Definition 10, if $label(m_0 \mid d) = 1$, the pro critical factor $CF_{PRO}(d)$ represents a minimal set of moves, such that if all moves in $CF_{PRO}(d)$ are defeated, then $label(m_0 \mid d) = 0$; and if $label(m_0 \mid d) = 0$, the con critical factor $CF_{OPP}(d)$ indicates a minimal set of moves such that if all moves in $CF_{OPP}(d)$ are defeated, then $label(m_0 \mid d) = 1$. Obviously, the pro (con) critical factor provides guidelines for the opponents (proponents) to attack proponents' (opponents') move.

Generally, there may be several critical factors in a multi-party dialogue, let $SCF_{PRO}(d)$ and $SCF_{OPP}(d)$ denote the set of pro and con critical factors respectively. Sometimes, pro critical factor and con critical factor are collectively called critical factor, denoted by $CF_{PO}(d)$ ($PO \in \{PRO, OPP\}$ from now on), which represents the minimal set of critical moves that makes $label(m_0 \mid d) = 1$ or $label(m_0 \mid d) = 0$. The element in critical factor is called *critical element*, it is obvious that for any critical element m, it follows $label(m \mid d) = 1$.

Example 2. Figure 1 depicts a multi-party dialogue. At the beginning, a proponent makes the initial move (m_0), following Definition 9, it holds that $d_{(a)}$ contains a single move (as Fig.1 (a)) and $label(m_0 \mid d_{(a)}) = 1$. Then, the only pro critical factor is $\{m_0\}$, which means that only when m_0 is attacked will its status changes. Suppose the opponents makes moves m_1 and m_2 attacking m_0 (as Fig.1 (b)), it is obvious that $d_{(b)} : m_0, m_1, m_2$ and $label(m_0 \mid d_{(b)}) = 0$. For the proponents, they have to counterattack both m_1 and m_2 in order to achieve $label(m_0)=1$, as the con critical factor is $\{m_1, m_2\}$. Suppose the proponents make moves $\{m_3, m_4\}$ attacking critical factor $\{m_1, m_2\}$ (as Fig.1 (c)), then it is easy to know that $d_{(c)}: m_0, m_1, m_2, m_3, m_4$ and $label(m_0 \mid d_{(c)})=1$ and $SCF_{PRO}(d_{(c)}) = \{\{m_0\},\{m_3\},\{m_4\}\}$ is the set of pro critical factors, and so on.

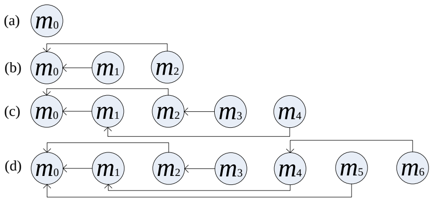

Figure 1. Multi-party dialogues

Proposition 1. Let a multi-party dialogue d, and the initial move $m_0 \in_0 d$.

1) If $label(m_0 \mid d)=1$, then $\{m_0\}$ is a pro critical factor;

2)If $label(m_0 \mid d)=0$, then $\mathrm{R}\underline{\mathrm{b}}(m_0,\overline{d}) \cap Win(d)$ is a con critical factor.

Definition 11. (Critical dependence) Let a multi-party dialogue d, and a critical element $m \in PO(d)$, such that $\mathrm{R}\underline{\mathrm{b}}(m,\overline{d}) \neq \varnothing$. The move m is critically dependent on $CD \subseteq PO(d) \cap Win(d)$, iff following conditions hold: ①If $\sum_{m' \in CD} label(m' \mid d)=0$, then $label(m \mid d)=0$;② CD is minimal w.r.t. set inclusion.

The set of moves CD is also called a critical dependence of move m, denoted by m ¨ CD. Specially, it is said that m has no critical dependence if $\mathrm{R}\underline{\mathrm{b}}(m,\overline{d}) = \varnothing$.

Theorem 1. Let $m \in_i d$ is a critical element in critical factor $CF_{PO}(d)$ of d, and $\mathrm{R}\underline{\mathrm{b}}(m,\overline{d}) \neq \varnothing$. If m is critically dependent on CD, then $(CF_{PO}(d) \setminus \{m\}) \cup CD$ is also a critical factor of d.

Proof. For convenience, and without loss of generality, let $PO = PRO$, i.e. $CF_{PRO}(d)$ be a pro critical factor in d.

For critical element $m \in_i d$ in $CF_{PRO}(d)$, let $CF^+_{PRO}(d) = (CF_{PRO}(d) \setminus \{m\}) \cup CD$ where CD is a critical dependence of m. By Definition 11, it holds that if $\sum_{m' \in CF^+_{PRO}} label(m' \mid d)=0$, then $label(m_0 \mid d)=0$. Because m is a critical element in $CF_{PRO}(d)$ and critically dependent on CD (i.e. m ¨ CD).

Then it remains to show that $CF^+_{PRO}(d)$ is minimal. Suppose $CF^+_{PRO}(d)$ is not minimal, thus there exist $CF^*_{PRO}(d)$ Ö $CF^+_{PRO}(d)$, such that if $\sum_{m' \in CF^+_{PRO}(d)} label(m' \mid d)=0$, then $label(m_0 \mid d)=0$. In other words, there exists at least one move $m*$ which holds $m* \in CF^+_{PRO}(d)$ but $m* \notin CF^*_{PRO}(d)$. There are two cases:

1) $m*$ be a critical element in $CF_{PRO}(d)$ (i.e. $m* \in CF_{PRO}(d)$), then it follows that there exists a set $CF^-_{PRO}(d) = CF_{PRO}(d) \setminus \{m*\}$ of moves, such that if $\sum_{m' \in CF^-_{PRO}(d)} label(m' \mid d)=0$, then $label(m_0 \mid d)=0$. This violates the minimality of critical factor $CF_{PRO}(d)$.

2) $m*$ be an element in CD (i.e. $m* \in CD$), then it holds that there exists a set $CD^- = CD \setminus \{m*\}$ satisfying if $\sum_{m' \in CD^-} label(m' \mid d)=0$, then $label(m \mid d)=0$. It violates the minimality of critical dependence CD. Therefore $CF^+_{PRO}(d)$ is minimal w.r.t. set inclusion.

Thus, $CF^+_{PRO}(d) = (CF_{PRO}(d) \setminus \{m\}) \cup CD$ is a critical factor of d. □

Definition 11 states the substitutability of critical element, in other words, for any critical factor $CF_{PRO}(d)$, a new critical factor can be established from $CF_{PRO}(d)$ by substituting a critical element with one of its critical dependences. And Theorem 1 suggests an approach to computing the set of critical factors (it remains to details later).

Proposition 2. Let a multi-party dialogue d, if $label(m_0 \mid d)=1$, then m_0 critically depends on all pro critical factors.

Theorem 2. For each critical element $m \in_i d$, if $\mathrm{R}\underline{\mathrm{b}}(m,\overline{d}) \neq \varnothing$, then $m \cong \underline{\mathrm{b}}(m',\overline{d}) \cap Win(d)$, where $m' \in \mathrm{R}\underline{\mathrm{b}}(m,\overline{d})$.

Proof. For convenience, and without loss of generality, we assume that $m \in CF_{PRO}(d)$, then it follows that $m \in PRO(d) \cap Win(d)$, i.e. $label(m \mid d)=1$. By Definition 9, it follows $\sum_{m' \in \mathrm{R}\underline{\mathrm{b}}(m,\overline{d})} label(m' \mid d)=0$, because $\mathrm{R}\underline{\mathrm{b}}(m,\overline{d}) \neq \varnothing$, i.e. $\mathrm{R}\underline{\mathrm{b}}(m,d) \subseteq OPP(d) \cap Def(d)$. Hence, for any $m' \in \mathrm{R}\_(m,\overline{d})$, it easy to see that $\mathrm{R}\underline{\mathrm{b}}(m',\overline{d}) \neq \varnothing$ and $\sum_{m'' \in \mathrm{R}\underline{\mathrm{b}}(m',\overline{d})} label(m'' \mid d) \geq 1$ (otherwise $label(m' \mid d)=1$, it follows $label(m \mid d)=0$ from Definition 9. Contradiction.).

Let $CD = \mathrm{R}\underline{\mathrm{b}}(m',\overline{d}) \cap Win(d)$, it is obvious that if $\sum_{m* \in CD} label(m* \mid d)=0$, then $label(m' \mid d)=1$. Therefore $label(m \mid d)=0$, in other words, critical element $m \in_i d$ and the set of moves CD satisfy condition ① in Definition 11.

Thus it remains to show that CD is minimal w.r.t. set inclusion. Suppose CD is not minimal set, i.e. there exists CD^- Ö CD, such that if $\sum_{m* \in CD^-} label(m* \mid d)=0$, it holds $label(m \mid d)=0$. It follows $CD^- \supseteq \mathrm{R}\underline{\mathrm{b}}(m',\overline{d}) \cap Win(d)$. Therefore $CD^- = CD$, i.e. $CD = \mathrm{R}\underline{\mathrm{b}}(m',\overline{d}) \cap Win(d)$ is minimal w.r.t. set inclusion. □

From Theorem 1 and Theorem 2, it is easy to see that:

Corollary 1. Let $m \in_i d$ be critical element. For any $m' \in \mathrm{R}\underline{\mathrm{b}}(m,\overline{d})$, there exists at least one critical factor $CF_{PO}(d)$ of d, such that $\mathrm{R}\underline{\mathrm{b}}(m',\overline{d}) \cap Win(d) \subseteq CF_{PO}(d)$.

Corollary 2. Let a set CF be a critical factor with single critical element m, then for any $m' \in \mathrm{R}\underline{\mathrm{b}}(m,\overline{d})$,

$\mathrm{R}\underline{\mathrm{b}}(m',\overline{d})\cap Win(d)$ is also a critical factor.

Corollary 1 and Corollary 2 shows that for each critical dependence CD of critical element, there exists critical factor $CF_{PO}(d)$, such that $CD \subseteq CF_{PO}(d)$. Theoretically, following these ideas, we can acquire all critical factors (it remains to discuss in section 4).

By Definition 10, both pro and con critical factors are those moves that take direct effects on the initial move of multi-party dialogues. They provide guidelines for participants making targeted and valid moves. From another angle of view, critical factors suggest a novel approach to avoiding invalid and useless moves in dialogue games.

Definition 12. Let a multi-party dialogue d, the legal move function $\psi_E : \mathcal{P}(M) \to \mathcal{P}(M)$ is eligible iff

$$\psi_E(\overline{d}) = \begin{cases} M_\Phi,\ if\ \overline{d} = \varnothing \\ \psi(\bigcup_{CF_{PRO} \in SCF_{PRO}} CF_{PRO}) \setminus Def(d), \\ \quad if\ \overline{d} \neq \varnothing\ and\ label(m_0 \mid d) = 1 \\ \psi(\bigcup_{CF_{OPP} \in SCF_{OPP}} CF_{OPP}) \setminus Def(d), \\ \quad if\ \overline{d} \neq \varnothing\ and\ label(m_0 \mid d) = 0 \end{cases}.$$

It can be seen that eligible legal move function ψ_E finds attack move based on critical factors. That is to say each move suggested by ψ_E is aiming to a critical element of multi-party dialogue.

Definition 13. (Critical countermeasure) Let CF_{PO} be a critical factor of d, a set $CM \subseteq \psi_E(\overline{d})$ of moves is said to be critical countermeasure to CF_{PO}, denoted by $CM\,\underline{\mathrm{R}}\,CF_{PO}$, iff following conditions hold: ①for any move m in CF_{PO}, CM has move m' attacking m; ② CM is minimal w.r.t. set inclusion.

By Definition 13, a critical countermeasure is a minimal set of moves which can be used to attack a critical factor $CF_{PO}(d)$ such that $\sum_{m \in CF_{PO}(d)} label(m \mid d) = 0$. For example, as in Fig 1 (c), $SCF_{PRO}(d_{(c)}) = \{\{m_0\},\{m_3\},\{m_4\}\}$ is a set of critical factors, and in Fig.1(d), it is clear that $\{m_5\}$, $\{m_6\}$ are critical countermeasures aiming to $\{m_0\}$, $\{m_4\}$ respectively.

Definition 14. (Countermeasure function) Let a set $SCF_{PO}(d)$ of critical factors of d, countermeasure function $\Theta : \mathcal{P}(M) \to \mathcal{P}(\mathcal{P}(M))$ defined as：

$$\Theta(\overline{d}) = \begin{cases} \{CM \in \mathcal{P}(M_\Phi) \mid |CM| = 1\}, & if\ \overline{d} = \varnothing \\ \{CM \mid \exists CF \in SCF_{PO}(d), \text{ s.t. } CM\,\underline{\mathrm{R}}\,CF\}, & if\ \overline{d} \neq \varnothing \end{cases}$$

Countermeasure function suggests a set of critical countermeasures from which the proponents or opponents can select to reach their goal. Because all moves provided by eligible legal move function aim at critical factor, there exit no idle and invalid moves in each critical countermeasure. And each critical countermeasure suggested by countermeasure function is also minimal.

Following the critical countermeasure and M extension (see 错误！未找到引用源。), we are now considering whether both the proponents and opponents can expand multi-party dialogues with critical countermeasure in the course of dialogue games.

Definition 15. (Critical extension) Given an eligible legal move function ψ_E and countermeasure function Θ. d' is said a critical extension of d under (ψ_E, Θ), if there exists $\mathrm{E}_C \in \Theta(\overline{d})$ such that d' is a legal extension of d with E_C.

It is also said that E_C is a *critical extension factor* from d to d'. Obviously, any critical extension is legal extension under ψ_E.

Definition 16. (Termination and outcome) (1) A multi-party dialogue d terminates if there exists no critical extension factor for d under (ψ_E, Θ).

(2) Let multi-party dialogue d terminates. For any $m \in_i d$, if $label(m \mid d) = 1$, then argument $\mathrm{Arg}(m)$ included in m is said to be vindicable in d; otherwise argument $\mathrm{Arg}(m)$ is defeated if $label(m \mid d) = 0$.

(3) A terminating multi-party dialogue d is said to be successfully terminated by the proponents if $label(m_0 \mid d) = 1$; otherwise it is successfully terminated by the opponents.

Next, the soundness and completeness of multi-party dialogue game conducted by (ψ_E, Θ) are discussed.

Definition 17. (Soundness and completeness) Given a finite distributed argumentation system $DAF = (\mathrm{A}, \mathrm{R})$, and a multi-party dialogue d w.r.t. argument $\phi \in \mathrm{A}$.

(1) A multi-party dialogue game is sound if the set $DS = \{\mathrm{Arg}(m) \mid m \in \bigcup_{CF \in SCF_{PRO}(d)} CF\}$ of a multi-party dialogue d, which is successfully terminated by the proponents with this game, is a defense set of ϕ.

(2) A multi-party dialogue game is said to be complete if for each defensible argument ϕ in $DAF = (\mathrm{A}, \mathrm{R})$, there exists multi-party dialogue d w.r.t. ϕ which is successfully terminated by the proponents, and the set $DS = \{\mathrm{Arg}(m) \mid m \in \bigcup_{CF \in SCF_{PRO}(d)} CF\}$ is a defense set of ϕ.

Theorem 3. Let ψ_E, Θ are eligible legal move function and countermeasure function respectively, then：

(1) Multi-party dialogue game conducted by (ψ_E, Θ) is sound;

(2) Multi-party dialogue game conducted by (ψ_E, Θ) is complete.

Proof.(1)Soundness part.

Let multi-party dialogue d conducted by (ψ_E, Θ) is successfully terminated by the proponent. Then, we want to show that $DS = \{\mathrm{Arg}(m) \mid m \in \bigcup_{CF \in SCF_{PRO}(d)} CF\}$ is a defense set for ϕ. In other words, we need prove that DS is admissible and $\phi \in DS$ (see Definition 3).

Since the proponents successfully terminate d, hence $label(m_0 \mid d) = 1$, i.e. $\phi \in DS$ (see 0);

It remains to show that DS counterattacks every attack against it.

For each argument $a \in \mathrm{A}$ attacking an argument $b \in DS$, then let move $m^a = (par, a)$, $m^b = (par, b)$, it follows that $m^a \mathrm{R}\, m^b$. The move m^b is critical element because $b \in DS$. Also by Theorem 2, it holds $m^b \cong \underline{b}(m^a, d) \cap Win(d)$ since $m^a \in \mathrm{R}\,\underline{b}(m^b, d) \neq \varnothing$. By Corollary 1, it follows that there exists critical factor $CF_{PRO}(d) \in SCF_{PRO}(d)$, such that $\mathrm{R}\,\underline{b}(m^a, \overline{d}) \cap Win(d) \subseteq CF_{PRO}(d)$. Then it is obvious that $\mathrm{R}\,\underline{b}(m^a, \overline{d}) \cap Win(d) \subseteq \bigcup_{CF \in SCF_{PRO}(d)} CF$, i.e. there exists $m \in \bigcup_{CF \in SCF_{PRO}(d)} CF$ satisfying $m \mathrm{R}\, m^a$. In other words, DS counterattacks every attack against it.

DS is conflict-free. Otherwise, suppose that there are moves $m, m' \in \bigcup_{CF \in SCF_{PRO}(d)} CF$ satisfying $m \mathrm{R}\, m'$. It is easy to see that $label(m \mid d) = 1$, because move m is critical element in mdg. By Definition 9, hence $label(m' \mid d) = 0$. However, we are informed that $label(m' \mid d) = 1$, because m' is also critical element in d. Contradiction! So, DS is a conflict-free set.

Thus, DS is defense set of ϕ.

(2)Completeness part.

Let $\phi \in \mathrm{A}$ is defensible in $DAF = (\mathrm{A}, \mathrm{R})$, i.e. there exists admissible set $S \subseteq \mathrm{A}$ such that $\phi \in S$. Let multi-party dialogue d conducted by (ψ_E, Θ) starts by the initial move m_0 containing ϕ.Then there exists a dialogue d such that $PRO(d) \subseteq M_S$:

If d is successfully terminated by the proponent, then we are done, it holds the conclusion.

It is easy to see that d is not successfully terminated by the opponent either (otherwise it contradicts that admissible set S contains ϕ). It follows that d is not successfully terminated, i.e. there exists legal expansion factor $\mathrm{E} \in \psi_E(\overline{d})$ for d under ψ_E. Specially, there are two cases:

Case 1: $label(m_0 \mid d) = 1$. For the set $SCF_{PRO}(d)$ of pro critical factors, there exists legal expansion factor $\mathrm{E} \in \psi_E(\overline{d})$ under ψ_E for the opponent.

Case 2: $label(m_0 \mid d) = 0$. For the set $SCF_{OPP}(d)$ of con critical factors, there exists legal expansion factor $\mathrm{E} \in \psi_E(\overline{d}) \subseteq M_S$ under ψ_E for the proponent.

Since the distributed argumentation system DAF is finite, then it is easy to see that the multi-party dialogue w.r.t. ϕ is successfully terminated by the proponents finally (Otherwise it violates the defensibility of argument ϕ). Meanwhile, $DS = \{\mathrm{Arg}(m) \mid m \in \bigcup_{CF \in SCF_{PRO}(d)} CF\} \subseteq S$ is defense set of argument ϕ by the soundness theorem. □

IV. Critical Factor and the Defensibility of Argument

From previous sections, it can be seen that critical factor, a significant notion in multi-party dialogue games, plays as both the guideline for the proponents and opponents to make moves and the component of the defense set of initial move (for a multi-party dialogue terminated by the proponents successfully). From Definition 11 and Theorem 1, the substitutability of critical element suggests an approach to computing the set of critical factors.

For any multi-party dialogue d, it follows that if $label(m_0 \mid d) = 1$, then $\{m_0\}$ is one of the pro critical factors, i.e. $\{m_0\} \in SCF_{PRO}(d)$ (by 0 (1)); and it analogously holds that if $label(m_0 \mid d) = 0$, then the set $\mathrm{R}\,\underline{b}(m_0, \overline{d}) \cap Win(d)$ is one of the con critical factors, i.e. $\mathrm{R}\,\underline{b}(m_0, \overline{d}) \cap Win(d) \in SCF_{OPP}(d)$ (by 0 (2)). Intuitively, the set of pro (or con) critical factors can be established from $\{m_0\}$ (or $\mathrm{R}\,\underline{b}(m_0, \overline{d}) \cap Win(d)$) with substitutability of critical element in critical factor depicted in Theorem 1.

Therefore, starting by $\{m_0\}$ (or $\mathrm{R}\,\underline{b}(m_0, \overline{d}) \cap Win(d)$), algorithm 1 exposits the computation of all pro (or con) critical factors of multi-party dialogue with DFS (depth-first search).

Algorithm 1. COMPUTE_SETOFCRITICALFACTORS

Input: multi-party dialogue d;
Output: a set of critical factors $SCF_{PO}(d)$;

if $label(m_0 \mid d) = 1$
  let $SCF_{PRO}(d) \leftarrow \{\{m_0\}\}$
  /*initialize the set of pro critical factors*/
  $CF_{PRO}(d) \leftarrow \{m_0\}$
  CriticalDependence($m_0, CF_{PRO}(d), SCF_{PRO}(d)$);
else if $label(m_0 \mid d) = 0$
  let $SCF_{OPP} \leftarrow \{\mathrm{R}\,\underline{b}(m_0, d) \cap Win(d)\}$;
  /*initialize the set of con critical factors*/
  $CF_{OPP}(d) \leftarrow \mathrm{R}\,\underline{b}(m_0, d) \cap Win(d)$
    for all $m \in CF_{OPP}(d)$
      CriticalDependence($m, CF_{OPP}(d), SCF_{OPP}(d)$);
Function CriticalDependence($m, CF_{PO}(d), SCF_{PO}(d)$)
if $\mathrm{R}\,\underline{b}(m, d) \neq \varnothing$
  $SCD = \{\mathrm{R}\,\underline{b}(m', d) \cap Win(d) \mid m' \in \mathrm{R}\,\underline{b}(m, d)\}$;
  /* critical dependences of m */
  for all $CD \in SCD$
    $newCF_{PO}(d) \leftarrow (CF_{PO}(d) \setminus \{m\}) \cup CD$;
    /* $newCF_{PO}(d)$ is critical factor established by replacing m in CF_{PO} with its critical dependence */
    $SCF_{PO}(d) \leftarrow SCF_{PO}(d) \cup \{newCF_{PO}(d)\}$;
    for all $m^* \in CD$
      CriticalDependence($m^*, newCF_{PO}(d), SCF_{PO}(d)$);
else if $\mathrm{R}\,\underline{b}(m, d) = \varnothing$ /* m has no critical dependence*/
  return *null*;

Proposition 3. (Termination) For any finite multi-party dialogue d, algorithm 1 is guaranteed to terminate returning a set of pro or con critical factors of d.

For any terminated multi-party dialogue d, $label(m_0 \mid d) = 1$ represents that the proponents successfully terminate d and $\phi = \mathrm{Arg}(m_0)$ is defensible; contrarily $label(m \mid d) = 0$ means that the opponents successfully terminate d and thus $\phi = \text{Arg}(m_0)$ is defeated.

For a multi-party dialogue d terminated by the proponents successfully, then we usually consider the defense set of the initial argument. This can be solved by Definition 17 and Theorem 3, which state that all arguments contained in pro critical factors of d constitute the defense set of $\phi = \text{Arg}(m_0)$.

V. Related Work and Comparison

With the development of abstract argument systems in the last decade, more and more researchers are devoted to the computation of the credulous and skeptical semantics of an abstract argumentation framework. One method adopted widely is through the use of dialogue games (or argument games), in which agents present arguments for or against a certain proposition (i.e. argument in question) by attacking those arguments proposed by the opponents. The TPI-disputes (Two Party Immediate Response Disputes) constructs disputes between the proponent and opponent, in which the players try their best to attack each other's most recent argument alternately[3]. In addition, Prakken has discussed the notion of relevance of arguments in the dialogues[10]. He argued that each move executed in the dialogue should have effect on the status of the initial move. In [11], PADUA (Protocol for Argumentation Dialogue Using Association Rules) is elaborated for classification of a new example through persuasion dialogue between two agents. Based on PADUA, the same authors propose PISA (Pooling Information from Several Agents) which allows more than two protagonists arguing from experience according a classification question[4]. To our best knowledge, PISA is the only existing multi-party dialogue game.

The work reviewed above however put their focus on solving semantic of a static and centralized argumentation system where arguments and attack relationship are known and stored in one location. Using Defeasible Logic Programming(DeLP), Thimm et al. proposed distributed argumentation in multi-agent systems, called ArgMAS[12]. In their framework, agent is capable of generating arguments for a given query and counterarguments against the arguments of other agents. All arguments are monitored by a role called moderator, which is similar to a judge overlooking the defender and accuser in a legal case. But they did not consider how to guide the agents making valid moves during the argumentation process. This paper provides a multi-party dialogue game, established on the notions of critical factor and critical countermeasures, for distributed argumentation. Critical factor is a minimal set of moves which play critical role in a multi-party dialogue game. It provides a guideline for participants making the most helpful moves to change the status of the initial move. Critical countermeasure is a minimal set of moves attacking a critical factor so as to change the status of the initial move. Obviously, critical countermeasure is analogical to the notion of relevance proposed by Prakken in [10].

VI. Conclusions

Belief conflicts are inevitable among different agents under imperfect information environment. Multi-party dialogue game is a useful means for heterogeneous agents to resolve conflicts in a distributed setting where agents put forward their arguments to, convince each other the truth of a certain proposition.

In this paper, we concern argumentation in a distributed scenario where both the proponents and opponents consist of several participating agents. Each agent is equipped with ability to generate initial argument for a given topic, and to propose counterarguments to attack arguments made by the opponents. We have proposed the notions of critical factor and critical countermeasure, and legal move and countermeasure functions for eliminating repeated, idle and invalid moves in a multi-party dialogue game. With these notions, the mechanism of multi-party dialogue game is discussed for computing the defense set of a defensible argument. We have also proved the soundness and completeness of multi-party dialogue game for a defensible argument in a distributed argumentation system. In addition, we have specified an algorithm for computing the set of pro (or con) critical factors of multi-party dialogue by DFS.

Our immediate further work is to implement our proposed multi-party dialogue game and then study the consequence. We will then explore the strategies for individual agents making high quality argument contributions along the line of [13]. We are also planning to explore different applications of our distributed argumentation system, e.g. in cloud computing and arguing agent competition [14].

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