# A Persuasive Dialogue Game for Coalition Formation

Luke Riley[1]

Department of Computer Science,
University of Liverpool,
L69 3BX, UK
{L.J.Riley@liverpool.ac.uk}

**Abstract.** In this paper, I propose a formal dialogue framework that enables autonomous agents to engage in a process of practical reasoning, in which they can propose to form coalitions that perform joint actions, using argumentation. An argumentation scheme is used to drive this coalition formation process that results in qualitative payoffs. This paper builds on existing work that uses value-based argumentation in the context of a dialogue system, which has been empirically verified. This framework is designed explicitly for closed cooperative systems where agents hold different preferences.

## Keywords

Multi-Agent Systems, Dialogue Games, Argumentation, Coalition Formation.

## 1 Introduction

Coalition formation is a major area within multi-agent systems research where agents form groups to achieve mutually shared goals to receive some payoff, often characterised in quantitative terms. However, not all situations allow for an obvious quantitative payoff and can be defined more explicitly in terms of goals that can be achieved or not. In qualitative coalition games an agent is satisfied if its goal is achieved or dissatisfied otherwise [14]. When forming teams, problems may occur, as it is not guaranteed all the agents of the system share the same views of the world and so disputes on what teams to form and why could arise.

Argumentation is a process where agents can reason about different beliefs to come to some logical conclusions. Recent work in argumentation suggests some agent systems can be more richly described with the inclusion of social values [2, 12] as opposed to just describing systems with goals. These values can be used to describe a social interest an agent has (for example, lowering taxes promotes entrepreneurship), which will be increased/decreased by moving from one state to another. In this work, the values (matched with an ordering over these values) will be used as the qualitative reasons for why agents form teams and prefer some teams to others.

Agents can communicate their arguments to each other through the use of dialogue games. Dialogue games are rule-governed interactions where each player moves by making utterances [9]. Dialogues frameworks have been previously used to form teams [7] but not from the approach of using agent argumentation from a persuasive context. Persuasion is one of the 6 main dialogue types defined by Walton and Krabbe in

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their influential model of human dialogues. It is described as one participant seeking to persuade another about something not currently accepted [13].

This paper shows how an argumentation scheme for practical reasoning (that consists of defeasible premises matched to a defeasible conclusion for a joint action) [2] paired with its associated critical questions (CQs) will drive the coalition formation process. The CQs can challenge the premises or conclusion of the scheme and so become collaborative learning aids for the agents to find the best coalitions. If a CQ is left unanswered then the instantiation of the argumentation scheme it attacks fails to hold [10]. Using argumentation schemes and critical questions has previously been shown to be a valid extension to dialogue games (e.g. [10, 4, 11]) but no work has been completed on using this method to form coalitions.

Agents join the coalitions using a pro-active approach. This pro-active approach requires the agents to volunteer for a coalition by making the appropriate utterance (See Table 1, Section 3). The overall aim of the dialogue game will be to partition agents into appropriate coalitions that take into account all the preferences of the agents in the system.

The paper is structured as follows. Section 2 recapitulates some elements of the dialogue system from [4] and gives an overview of the modifications to its argumentation model and dialogue framework, which were empirically evaluated in [11]. Section 3 details the dialogue framework proposed. Section 4 gives a dialogue example and shows how the new system proposed evaluates the arguments to reach a conclusion on the coalition structure (the collection of coalitions) to recommend. Section 5 concludes the paper.

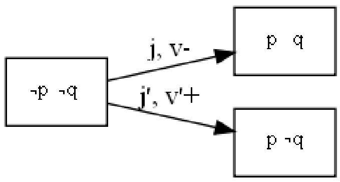


Fig. 1: Illustration of an agent's VATS (See Definition 1). $j$ and $j'$ are the joint-actions needed to move to another state, while $v$ and $v'$ are the values that are associated with these state changes. In this example $v$ is demoted and $v'$ is promoted.

## 2 Argumentation Model Used

For handling reasoning about the effects of actions, the following argumentation scheme for practical reasoning is used, modified from [4]. It is used to allow the agents to form arguments for coalitions, termed **coalition arguments**.

*In the current circumstances R, joint action J should be performed, by coalition C, which will result in the new circumstances S, which will promote/demote the value V.*

Circumstances *R* and *S* are represented as tuples of propositions, visualised in Figure 1. Joint action *J* is a tuple of single actions denoted $\langle \alpha_m, ..., \alpha_n \rangle$, Coalition *C* is a tuple of agent and single action pairs, where a pair is denoted $(x, \alpha)$, with the intended interpretation that if this coalition is agreed upon then each agent in *C* will perform the single action it is paired to, denoted $C^x_\alpha$. If no agent has yet been assigned the single action $\alpha$, this is denoted $C^?_\alpha$.

An agent may propose a joint-action including its justification, by instantiating this scheme. Agents can initially only add themselves to the coalition variable, until enough information is acquired about the other agents of the system so that accurate assumptions can be made. Other agents can then challenge instantiations by posing CQs associated with the scheme. The questions associated with the above scheme raise potential issues with: the validity of the elements instantiated in the scheme; the connections between the elements of the scheme and the side effects of the joint-actions [4]. Example CQs here are: *does doing the the joint action have a side effect which demotes another value?* and *assuming the circumstances does the joint action have the stated consequences?*.

A formally instantiated version of this scheme is denoted $\mathcal{A} = \langle q_x, j, c, q_y, v, s\rangle$ where $q_x$ is the current state, $j$ is the joint action, $c$ is the coalition of agents paired to single actions, $q_y$ is the new state, $v$ is the value associated with this state transition and $s$ (where $s = \{+, -, =\}$) is the sign indicating whether the value is promoted/demoted/not affected respectively. The coalition variable does not have to be completely instantiated upon the first utterance. This is to allow agents flexibility in their arguments, with the semantic meaning coming from the utterance that the instantiation is associated with (see Table 1, Section 3 for the full utterance list). An $\mathcal{A}$ will represent a proposal if $|c| < |j|$ as the coalition does not yet have a sufficient amount of members to carry out the joint action and so requires others to complete the proposal. $\mathcal{A}$ will represent an assertion if $|c| = |j|$ as the coalition now has enough members to carry out the joint action and is therefore ready to form. $\mathcal{A}$ will represent an objection if it is in the form of a CQ. A formalised CQ is instantiated as a modified version of $\mathcal{A}$ intended to reflect the question it represents in a logical form. The complete formalised CQ list is cut for space, but reflects the work of [11], expanded to incorporated the inclusion of the coalition and joint action variable.

To represent the agents' environment and help the agents create instantiations of the argumentation scheme a Value-Based Alternating Transition System (VATS) is used. It is a modified version of an Action-Based Transition System (AATS) [15], which is grounded in Alternating-time Temporal Logic (ATL). An example VATS diagram can be seen in Figure 1. Every agent in the system is assigned a VATS, which is a modified version of the one outlined in [4] and is summarised below:

***Definition 1:*** *The VATS formalism is as follows: A* **VATS** *for an agent $x$, denoted $S^x$, is a 12-tuple*
$\langle Q^x, q_0^x, Ac^x, Av^x, Ja^x, Ag^x, \rho^x, \tau^x, \Phi^x, \pi^x, \delta^x, \xi^x\rangle$ *s.t.:*

- $Q^x$ *is a finite set of* states*;*
- $q_0^x \in Q^x$ *is the designated* initial state*;*
- $Ac^x$ *is a finite set of* single actions*;*
- $Av^x$ *is a finite set of* values*;*
- $Ja^x$ *is a finite set of* joint actions*, where each joint action is composed of $m$ single actions where $m \in \mathbb{N}$;*
- $Ag^x$ *is a finite set of* agents*;*
- $\rho^x : Ja^x \mapsto 2^{Q^x}$ *is an* action precondition function*, which for each joint action $j \in Ja^x$ defines the set of states $\rho(j)$ from which $j$ may be executed;*

- $\tau^x : Q^x \times Ja^x \mapsto Q^x$ *is a partial* system transition function*, which defines the state $\tau^x(q, j)$ that would result by the performance of $j$ from state $q$. As this function is partial, not all joint actions are possible in all states;*
- $\Phi^x$ *is a finite set of* atomic propositions*;*
- $\pi^x : Q^x \mapsto 2^{\Phi^x}$ *is an interpretation function, which gives the set of primitive propositions satisfied in each state: if $p \in \pi^x(q)$, then this means that the propositional variable $p$ is satisfied (equivalently, true) in state $q$;*
- $\delta^x : Q^x \times Q^x \times Av^x \mapsto \{+, -, =\}$ *is a* valuation function *which defines the* status *(promoted (+), demoted (−), or neutral (=)) of a value $v \in Av^x$ ascribed by the agent to the transition between two states.*
- $\xi^x : Ag^x \times Ac^x \mapsto \{\top, \bot\}$ *is a partial agent capability function which defines if an agent can perform the single action ($\top$) or not ($\bot$). This function is partial as not all agents can perform all single actions.*

*Note,* $Q^x = \emptyset \leftrightarrow Ac^x = \emptyset \leftrightarrow Av^x = \emptyset \leftrightarrow \Phi^x = \emptyset$.

Each agent also has a preference order over its *values*, of the form $v_1 \succ ... \succ v_n$ where $n = |Av^x|$, that ranks the values into an order where $v_1$ is the most preferred and $v_n$ the least (termed an 'audience' in [3]). The set of all arguments that can be created from $S^x$ is denoted $A(S^x)$. $\Psi$ is a subset of all the possible arguments all the agents in the system can construct, denoted $\Psi \subseteq \bigcup_{\forall x_i \in \{x_1,...,x_n\}} A(S^{x_i})$ and represents the arguments $x$ believes to be true for the current state.

The coalition arguments and CQs uttered in the dialogue will be evaluated to determine their acceptability by placing them in a *Value-Based Argumentation Framework* (VAF) [3], which is an extended version of Dung's abstract Argumentation Framework (AF) [8]. An AF is defined as follows:

***Definition 2:*** *Dung's Argumentation Framework is a tuple AF = ($Args$, $R$) where $Args$ is a set of arguments and $R$ is a binary attack relation $R \subseteq Args \times Args$.*

A VAF extends an AF in the following manner:

***Definition 3:*** *A VAF is a 5-tuple: $\langle Args,\ R,\ V,\ val,\ P\rangle$ where $Args$ and $R$ remain the same as Definition 1, $V$ is a set of non-empty values, $val$ is a function mapping elements of $V$ to $Args$ and $P$ is a set of possible audiences.*

In a VAF an attack $arg_1 R arg_2$ only succeeds ($arg_1$ **defeats** $arg_2$) for an audience $p$ iff argument $arg_1$ is associated with the same or a higher value than argument $arg_2$ in audience $p$'s preference order, and $arg_1$ has not been defeated by another argument in the VAF.

A set of arguments $S$ is **acceptable** to an audience $p$ iff $\forall arg_x \in Args$ if $arg_x$ attacks an argument $arg_y$ where $arg_y \in S$ there $\exists arg_z \in S$ where $arg_z$ defeats $arg_x$ according to $p$'s preference order. $S$ is a **preferred extension** (PE) of a VAF for audience $p$ if $S$ is the maximal acceptable set of arguments for $p$.

## 3 Dialogue Framework

The underlying assumptions of this proposed dialogue framework are that agents in this system occupy a benevolent environment and are correctly aware of their starting state. When a dialogue commences, the number of agents in the system must remain fixed, but in between dialogues this number can change. Dialogues commence when an event triggers one agent to desire to move to another state. This agent should perform the **open** move detailed below and then start the dialogue protocol.

The protocol is similar to the one in [4] but cut for space. It finds all the legal moves that an agent can utter for its turn, given the current dialogue and the agent identifier. All these moves will then be uttered in unison. The moves available to the agents allow them to **object** to an argument with a critical question, **propose** an incomplete coalition, **assert** a complete coalition or attempt to **close** the dialogue.

Agents interact to find the best way to partition themselves into coalitions (which is a process known as coalition structure generation). Every agent asserts all the arguments and critical questions it can construct, given the union of their VATS and the other agents' utterances. Dialogues consist of a sequence of moves referred to as $[m_r, ..., m_t]$, collectively formalised to $\mathcal{D}_r^t$ where $r, t \in \mathbb{N}$ [4]. The first move of the dialogue is always the **open** move.

All agents' proposals, assertions and objections are stored in a publicly readable commitment store that grows monotonically over time until a new dialogue resets the commitment stores. For a dialogue, $\mathcal{D}_r^t$, with participants $\{x_1, \ldots, x_n\}$, for all $x \in \{x_1, \ldots, x_n\}$, the commitment store is denoted $CS_x^t$.

The moves that the agents in this framework can make are detailed further in Table 1 below, modified from [4] to allow for coalitions to be formed and CQs to be seperated from coalition arguments:

| Move | Format | Pre-conditions | Post-conditions |
|---|---|---|---|
| $open$ | $\langle x, open, \Lambda\rangle$ | No Dialogue open. $\Lambda = [x_1, ..., x_n]$ where $\Lambda$ is the available system agents. | Dialogue commenced. All agents in $\Lambda$ are committed to follow the dialogue protocol. |
| $propose$ | $\langle x, propose, \Psi\rangle$ | $\forall \mathcal{A} \in \Psi, \|c\| < \|j\|$ where $c, j \in \mathcal{A}$. | Commitment store updated. |
| $assert$ | $\langle x, assert, \Psi\rangle$ | $\forall \mathcal{A} \in \Psi, \|c\| = \|j\|$ where $c, j \in \mathcal{A}$. | Commitment store updated. All agents in $c$ are committed to perform the single action they are paired to. |
| $object$ | $\langle x, object, \Psi\rangle$ | $S^x$ conflicts with another argument. | Objection is stored in the commitment store. |
| $close$ | $\langle x, close\rangle$ | A Dialogue is open. | Dialogue closed **iff** all agents have performed a close move in a row (without another move inbetween). |

**Table 1.** The moves available to the agents

## 4 Dialogue Example and Argument Evaluation

Here is an abstract example for an agent system with 4 agents ($x_1, ..., x_4$), 7 arguments ($arg_1, ..., arg_7$), 5 states ($q_1, ..., q_5$), 3 joint actions ($j_1, j_2, j_3$), 2 values ($v_1$ and $v_2$) and 3 completely formed coalitions ($C1, C2, C3$). The purpose of the dialogue is to partition agents into coalitions that achieve the agents social values.

$x_1$ **- (proposes an instantiation of the argument scheme) -** $arg_1$**:** As we are in state $q_1$, joint action $j_1$, where $j_1 = \langle \alpha_1, \alpha_2\rangle$, will result in state $q_2$. $\mathrm{C1}_{\alpha_1}^{x_1}$ is proposed but $\mathrm{C1}_{\alpha_2}^{?}$ remains. This transition will promote value $v_2$.

$x_2$ **- (asserts an instantiation of the argument scheme that extends** $arg_1$**) -** $arg_2$**:** As we are in state $q_1$, joint action $j_1$, where $j_1 = \langle \alpha_1, \alpha_2 \rangle$, will result in state $q_2$. C$1^{x_1}_{\alpha_1}$ and C$1^{x_2}_{\alpha_2}$ are asserted. This transition will promote value $v_2$.
$x_3$ **- (proposes an instantiation of the argument scheme) -** $arg_3$**:** As we are in state $q_1$, joint action $j_2$, where $j_2 = \langle \alpha_1, \alpha_3 \rangle$, will result in state $q_4$. C$2^{x_3}_{\alpha_3}$ is proposed but C$2^{?}_{\alpha_1}$ remains. This transition will promote value $v_2$.
$x_4$ **- (asserts an instantiation of the argument scheme that extends** $arg_3$**) -** $arg_4$**:** As we are in state $q_1$, joint action $j_2$, where $j_2 = \langle \alpha_1, \alpha_3 \rangle$, will result in state $q_4$. C$2^{x_4}_{\alpha_1}$ and C$2^{x_3}_{\alpha_3}$ are asserted. This transition will promote value $v_2$.
$x_1$ **- (objects to** $arg_3$ **and** $arg_4$ **with a critical question) -** $arg_5$**:** As we are in state $q_1$, performing joint action $j_2$, where $j_2 = \langle \alpha_1, \alpha_3 \rangle$, will demote $v_1$.
$x_1$ **- (proposes an instantiation of the argument scheme) -** $arg_6$**:** As we are in state $q_1$, joint action $j_3$, where $j_3 = \langle \alpha_4, \alpha_5 \rangle$, will result in state $q_5$. C$3^{x_1}_{\alpha_5}$ is proposed but C$3^{?}_{\alpha_4}$ remains. This transition will promote value $v_1$.
$x_2$ **- (asserts an instantiation of the argument scheme that extends** $arg_6$**) -** $arg_7$**:** As we are in state $q_1$, joint action $j_3$, where $j_3 = \langle \alpha_4, \alpha_5 \rangle$, will result in state $q_5$. C$3^{x_1}_{\alpha_5}$ and C$3^{x_2}_{\alpha_4}$ are asserted. This transition will promote value $v_1$.

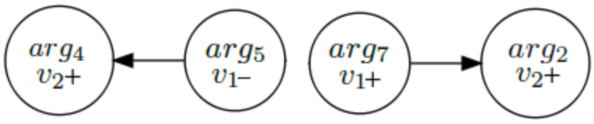


Fig. 2: Illustration of the VAF produced by the example dialogue.

From this dialogue the VAF is created. In the VAF are all the arguments uttered in an assert or objection move. The arguments uttered in a proposal move are not included as they hold incomplete coalitions that are not ready to form. The CQ arguments uttered in objection moves are in the VAF to determine the best coalitions to form. The attacks in the VAF come from coalition arguments that share an agent, coalition arguments that finish in conflicting states or conflicts that arise from the CQs.

To find the most preferred coalitions out of the remaining arguments one method that could be used is based on the borda count. Using this voting method all the agents of the dialogue have to summit their preference order to a centralised evaluating system which will then assign these preferences a score. The scoring method for a borda count is as follows: if there are $k$ total system values, the most preferred in each preference order will be assigned the score $k - 1$, the second most preferred assigned the score $k - 2$ continuing until the least preferred gets zero. Using these borda count scores the system will be able to find one overall value order that will be used to find the overall system's preferred extension. Once all the attacks have been analysed and the preferred extension found, the arguments remaining that recommend a coalition will form the coalition structure.

The VAF created by the example dialogue can be seen in Figure 2. With a value order $v_1 \succ v_2$ , $arg_5$ and $arg_7$ is the PE of the example VAF and so only C3 will form (as $arg_5$ doesn't recommend a coalition). A value order of $v_2 \succ v_1$ will mean the PE will contain $arg_2$ and $arg_4$ and so C1 and C2 will form. In this instance two coalitions are recommended as they are not conflicting. They do not conflict as they do not share an agent and the shared propositions of $q_4$ and $q_5$ have the same truth value. This can happen in systems where agents do not share all the same propositions to describe the system.

## 5 Conclusions, Related and Future Work

Forming coalitions via argumentation has been proposed previously (e.g. [1, 6, 5]) but no persuasive dialogue game and protocol has been defined that produces a coalition structure. The dialogue game outlined here differs from the one of Amgoud [1] as her dialogue game is only used to find out if a coalition is in the set of acceptable coalitions and it is not used to form them.

This paper details preliminary work produced to formalise a dialogue game for coalition structure generation that could be modified for environments that are dynamic and open. In future work, the dialogue framework will be implemented, different methods for determining the overall value order will be considered and situations where agents are not satisfied with the final recommended coalitions will be explored.

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