Extracting the core of a persuasion dialog to evaluate its quality

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Abstract: A persuasion dialog is a dialog in which agents exchange arguments on a subject. In this kind of dialog, the agents disagree about the status of the subject and each one tries to persuade the other to change his mind. Several systems, grounded on argumentation theory, have been proposed in the literature for modeling persuasion dialogs. It is important to be able to analyze the quality of these dialogs. Hence, *quality criteria* have to be defined in order to perform this analysis.
This paper tackles this important problem and proposes one criterion that concerns the conciseness of a dialog. A dialog is concise if all its moves are relevant and useful in order to reach the same outcome as the original dialog. From a given persuasion dialog, in this paper we compute its corresponding "ideal" dialog. This ideal dialog is concise. A persuasion dialog is thus interesting if it is close to its ideal dialog.

1 Introduction

Persuasion is one of the main types of dialogs encountered in everyday life. A persuasion dialog concerns two (or more) agents who disagree on a state of affairs, and each of them tries to persuade the others to change their minds. For that purpose, agents exchange arguments of different strengths. Several systems have been proposed in the literature for allowing agents to engage in persuasion dialogs (e.g. [1, 2, 3, 4, 5, 6, 7]). A dialog system is built around three main components: i) a *communication language* specifying the locutions that will be used by agents during a dialog for exchanging information, arguments, etc., ii) a *protocol* specifying the set of rules governing the well-definition of dialogs such as who is allowed to say what and when? and iii) agents' strategies which are the different tactics used by agents for selecting their moves at each step in a dialog. All the existing systems allow agents to engage in dialogs that obey to the rules of the protocol. Thus, the only properties that are guaranteed for a generated dialog are those related to the protocol. For instance, one can show that a dialog terminates, the turn shifts equally between agents in that dialog (if such rule is specified by the protocol), agents can refer only to the previous move or are allowed to answer to an early move in the dialog, etc. The properties inherited from a protocol are related to the way the dialog is generated. However, the protocol is not concerned by the *quality* of that dialog. Moreover, it is well-known that under the same protocol, different dialogs on the same subject may be generated. It is important to be able to compare them w.r.t. their quality. Such a comparison may help to refine the protocols and to have more efficient ones.

While there are a lot of works on dialog protocols (eg. [8]), no work is done on defining criteria for evaluating the persuasion dialogs generated under those protocols, except a very preliminary proposal in [9]. The basic idea of that paper is, given a finite persuasion dialog, it can be analyzed w.r.t. three families of criteria. The first family concerns the quality of arguments exchanged in this dialog. The second family checks the behavior of the agents involved in this dialog. The third family concerns the dialog as a whole. In this paper, we are more interested by investigating this third family of quality criteria. We propose a criterion based on the conciseness of the generated dialog. A dialog is concise if all its moves (i.e. the exchanged arguments) are both *relevant* to the subject (i.e. they don't deviate from the subject of the dialog) and *useful* (i.e. they are important to determine the outcome of the dialog). Inspired from works on proof procedures that have been proposed in argumentation theory in order to check whether an argument is accepted or not [10], we compute and characterize a sub-dialog of the original one that is concise. This sub-dialog is considered as *ideal*. The closer the original dialog to its ideal sub-dialog, the better is its quality. This report contains all the proofs of the article [11] published in ECSQARU'09.

The paper is organized as follows: Section 2 recalls the basics of argumentation theory. Section 3 presents the basic concepts of a persuasion dialog. Section 4 defines the notions of relevance and usefulness in a dialog. Section 5 presents the concept of ideal dialog founded on an ideal argumentation tree built from the initial dialog.

2 Basics of argumentation systems

Argumentation is a reasoning model based on the construction and the comparison of arguments. Arguments are reasons for believing in statements, or for performing actions. In this paper, the origins of arguments are supposed to be unknown. They are denoted by lowercase Greek letters. In [12], an argumentation system is defined by:

Definition 1 (Argumentation system) *An* argumentation system *is a pair* $\mathsf{AS} = \langle \mathcal{A}, \mathcal{R} \rangle$, *where $\mathcal{A}$ is a set of arguments and $\mathcal{R} \subseteq \mathcal{A} \times \mathcal{A}$ is an attack relation. We say that an argument α attacks an argument β iff $(\alpha, \beta) \in \mathcal{R}$.*

Note that to each argumentation system is associated a directed graph whose nodes are the different arguments, and the arcs represent the attack relation between them.

Since arguments are conflicting, it is important to know which arguments are acceptable. For that purpose, in [12], different *acceptability semantics* have been proposed. In this paper, we consider the case of *grounded* semantics. Remaining semantics are left for future research.

Definition 2 (Defense–Grounded extension) *Let* $\mathsf{AS} = \langle \mathcal{A}, \mathcal{R} \rangle$ *and* $\mathcal{B} \subseteq \mathcal{A}$.

- $\mathcal{B}$ defends *an argument $\alpha \in \mathcal{A}$ iff $\forall\, \beta \in \mathcal{A}$, if $(\beta, \alpha) \in \mathcal{R}$, then $\exists \delta \in \mathcal{B}$ s.t. $(\delta, \beta) \in \mathcal{R}$.*
- *The* grounded extension *of* AS, *denoted by $\mathcal{E}$, is the least fixed point of a function $\mathcal{F}$ where $\mathcal{F}(\mathcal{B}) = \{\alpha \in \mathcal{A} \mid \mathcal{B}$ defends $\alpha\}$.*

When the argumentation system is finite in the sense that each argument is attacked by a finite number of arguments, $\mathcal{E} = \bigcup_{i>0} \mathcal{F}^i(\emptyset)$.
Now that the acceptability semantics is defined, we can define the status of any argument. As we will see, an argument may have two possible statuses: *accepted* or *rejected*.

Definition 3 (Argument status) *Let* $\mathsf{AS} = \langle \mathcal{A}, \mathcal{R} \rangle$ *be an argumentation system, and $\mathcal{E}$ its grounded extension. An argument $\alpha \in \mathcal{A}$ is* accepted *iff $\alpha \in \mathcal{E}$, it is* rejected *it is attacked by an accepted argument. We denote by* $\mathtt{Status}(\alpha, \mathsf{AS})$ *the status of α in* AS.

Property 1 ([10]) *Let* $\mathsf{AS} = \langle \mathcal{A}, \mathcal{R} \rangle$, *$\mathcal{E}$ its grounded extension, and $\alpha \in \mathcal{A}$.*

- *If $\alpha \in \mathcal{E}$, then α is* indirectly defended[1] *by non-attacked arguments against all its attackers.*
- *If α is rejected, then it is* indirectly attacked[2] *by a non-attacked argument.*

[1] An argument α is *indirectly defended* by β iff there exists a finite sequence of distinct arguments $a_1, \ldots, a_{2n+1}$ such that $\alpha = a_1$, $\beta = a_{2n+1}$, and $\forall i \in [\![1, 2n]\!]$, $(a_{i+1}, a_i) \in \mathcal{R}, n \in \mathbb{N}^*$.

[2] An argument α is *indirectly attacked* by β iff there exists a finite sequence of distinct arguments $a_1, \ldots, a_{2n}$ such that $\alpha = a_1$, $\beta = a_{2n}$, and $\forall i \in [\![1, 2n-1]\!]$, $(a_{i+1}, a_i) \in \mathcal{R}, n \in \mathbb{N}^*$.

3 Persuasion dialogs

This section defines persuasion dialogs in the same spirit as in [1]. A persuasion dialog consists mainly of an exchange of arguments between different agents of the set $\texttt{Ag} = \{a_1, \dots, a_m\}$. The subject of such a dialog is an argument, and its aim is to provide the status of that argument. At the end of the dialog, the argument may be either "accepted" or "rejected", this status is the output of the dialog. In what follows, we assume that agents are *only* allowed to exchange arguments.

Each participating agent is supposed to be able to recognize all elements of $\arg(\mathcal{L})$ and $\mathcal{R}_\mathcal{L}$, where $\arg(\mathcal{L})$ is the set of all arguments that may be built from a logical language $\mathcal{L}$ and $\mathcal{R}_\mathcal{L}$ is a binary relation that captures all the conflicts that may exist among arguments of $\arg(\mathcal{L})$. Thus, $\mathcal{R}_\mathcal{L} \subseteq \arg(\mathcal{L}) \times \arg(\mathcal{L})$. For two arguments $\alpha, \beta \in \arg(\mathcal{L})$, the pair $(\alpha, \beta) \in \mathcal{R}_\mathcal{L}$ means that the argument α attacks the argument β. Note that this assumption does not mean at all that an agent is aware of all the arguments. But, it means that agents use the same logical language and the same definitions of arguments and conflict relation.

Definition 4 (Moves) *A* move m *is a triple* $\langle S, H, \alpha\rangle$ *such that:*

- $S \in \texttt{Ag}$ *is the agent that utters the move,* $\texttt{Speaker}(m) = S$
- $H \subseteq \texttt{Ag}$ *is the set of agents to which the move is addressed,* $\texttt{Hearer}(m) = H$
- $\alpha \in \arg(\mathcal{L})$ *is the content of the move,* $\texttt{Content}(m) = \alpha$*.*

During a dialog several moves may be uttered. Those moves constitute a sequence denoted by $\langle m_1, \dots, m_n\rangle$, where m_1 is the initial move whereas m_n is the final one. The empty sequence is denoted by $\langle\rangle$. These sequences are built under a given protocol. A protocol amounts to define a function that associates to each sequence of moves, a set of valid moves. Several protocols have been proposed in the literature, like for instance [1, 6]. In what follows, we don't focus on particular protocols.

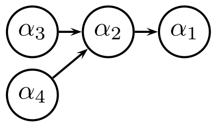
Definition 5 (Persuasion dialog) *A* persuasion dialog D *is a non-empty and finite sequence of moves* $\langle m_1, \dots, m_n\rangle$ *s.t. the* subject *of* D *is* $\texttt{Subject}(D) = \texttt{Content}(m_1)$*, and the* length *of* D*, denoted* $|D|$*, is the number of moves:* n*. Each sub-sequence* $\langle m_1, \dots, m_i\rangle$ *is a* sub-dialog D^i *of* D*. We will write also* $D^i \sqsubset D$*.*

To each persuasion dialog, one may associate an argumentation system that will be used to evaluate the status of each argument uttered during it and to compute its output.

Definition 6 (AS of a pers. dialog) *Let* $D = \langle m_1, \dots, m_n\rangle$ *be a persuasion dialog. The* argumentation system *of* D *is the pair* $\mathsf{AS}_D = \langle \texttt{Args}(D), \texttt{Confs}(D)\rangle$ *such that:*
- $\texttt{Args}(D) = \{\texttt{Content}(m_i) \mid i \in [\![1, n]\!]\}$
- $\texttt{Confs}(D) = \{(\alpha, \beta) \mid \alpha, \beta \in \texttt{Args}(D)$ *and* $(\alpha, \beta) \in \mathcal{R}_\mathcal{L}\}$

In other words, $\texttt{Args}(D)$ and $\texttt{Confs}(D)$ return respectively, the set of arguments exchanged during the dialog and the different conflicts among those arguments.

Example 1 *Let D_1 be the following persuasion dialog between two agents a_1 and a_2.* $D_1 = \langle\langle a_1, \{a_2\}, \alpha_1\rangle, \langle a_2, \{a_1\}, \alpha_2\rangle, \langle a_1, \{a_2\}, \alpha_3\rangle, \langle a_1, \{a_2\}, \alpha_4\rangle, \langle a_2, \{a_1\}, \alpha_1\rangle\rangle$. *Let us assume that there exist conflicts in $\mathcal{R}_\mathcal{L}$ among some of these arguments. Those conflicts are summarized in the figure below.*



Here, $\texttt{Args}(D_1) = \{\alpha_1, \alpha_2, \alpha_3, \alpha_4\}$ *and* $\texttt{Confs}(D_1) = \{(\alpha_2, \alpha_1), (\alpha_3, \alpha_2), (\alpha_4, \alpha_2)\}$.

Property 2 *Let $D = \langle m_1, \ldots, m_n\rangle$ be a persuasion dialog. $\forall D^j \sqsubset D$, it holds that* $\texttt{Args}(D^j) \subseteq \texttt{Args}(D)$, *and* $\texttt{Confs}(D^j) \subseteq \texttt{Confs}(D)$.

Proof Let $D = \langle m_1, \ldots, m_n\rangle$ be a persuasion dialog, and let $D' = \langle m'_0, \ldots, m'_k\rangle$. Assume that $D' \sqsubset D$, this means that each m'_i is also in the sequence of D, thus, $Content(m'_i) \in \texttt{Args}(D)$. Consequently, $\texttt{Args}(D') \subseteq \texttt{Args}(D)$. Moreover, $\texttt{Confs}(D') \subseteq \texttt{Confs}(D)$. ■

The output of a dialog is the status of the argument under discussion (i.e., the subject):

Definition 7 (Output of a persuasion dialog) *Let D be a persuasion dialog. The* output *of D, denoted by* $\texttt{Output}(D)$, *is* $\texttt{Status}(\texttt{Subject}(D), \mathsf{AS}_D)$.

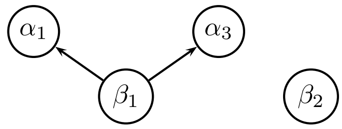
4 Criteria for Dialog quality

In this paper, we are interested in evaluating the conciseness of a dialog D which is already generated under a given protocol. This dialog is assumed to be *finite*. Note that this assumption is not too strong since a main property of any protocol is the termination of the dialogs it generates [13]. A consequence of this assumption is that the argumentation system AS_D associated to D is finite as well. In what follows, we propose two criteria that evaluate the importance of the moves that are exchanged in D, then we propose a way to compute the "ideal" dialog that reaches the same outcome as D.

In everyday life, it is very common that agents deviate from the subject of the dialog. The first criterion evaluates to what extent the moves uttered are in relation with the subject of the dialog. This amounts to check whether there exists a path from a move to the subject in the graph of the argumentation system associated to the dialog.

Definition 8 (Relevant and useful move)
Let $D = \langle m_1, \ldots, m_n\rangle$ be a persuasion dialog. A move m_i, $i \in [\![1, n]\!]$, is relevant *to D iff there exists a path (not necessarily directed) from* $\texttt{Content}(m_i)$ *to* $\texttt{Subject}(D)$ *in the directed graph associated with AS_D. m_i is* useful *iff there exists a directed path from* $\texttt{Content}(m_i)$ *to* $\texttt{Subject}(D)$ *in this graph.*

Example 2 *Let D_2 be a persuasion dialog. Let* $\texttt{Args}(D_2)$ = $\{\alpha_1, \alpha_3, \beta_1, \beta_2\}$. *The conflicts among the four arguments are depicted in the figure below.*



Suppose that $\texttt{Subject}(D_2) = \alpha_1$. *It is clear that the arguments α_3, β_1 are relevant, while β_2 is irrelevant. Here β_1 is useful, but α_3 is not.*

Property 3 *If a move m is useful in a dialog D, then m is relevant to D.*

Proof Let m be a given move in a persuasion dialog D. If m is useful then there exists a directed path from $\texttt{Content}(m)$ to $\texttt{Subject}(D)$, thus m is relevant to D. ■

On the basis of the notion of relevance, one can define a measure that computes the percentage of moves that are relevant in a dialog D. In Example 2, $\texttt{Relevance}(D_2)$ = 3/4. It is clear that the greater this degree is, the better the dialog. When the relevance degree of a dialog is equal to 1, this means that agents did not deviate from the subject of the dialog. The useful moves are moves that have a more direct influence on the status of the subject. However, this does not mean that their presence has an impact on the result of the dialog, i.e., on the status of the subject. The moves that have a real impact on the status of the subject are said "decisive".

Definition 9 (Decisive move) *Let D = $\langle m_1, \ldots, m_n\rangle$ be a persuasion dialog and* AS_D *its argumentation system. A move m_i ($i = 1, \ldots, n$) is* decisive *in D iff*

$$\texttt{Status}(\texttt{Subject}(D), \mathsf{AS}_D) \neq \texttt{Status}(\texttt{Subject}(D), \mathsf{AS}_D \ominus \texttt{Content}(m_i))$$

where $\mathsf{AS}_D \ominus \texttt{Content}(m_i)$ = $\langle A', R'\rangle$ *s.t.* A' = $\texttt{Args}(D) \setminus \{\texttt{Content}(m_i)\}$ *and* R' = $\texttt{Confs}(D) \setminus \{(x, \texttt{Content}(m_i)), (\texttt{Content}(m_i), x) \mid x \in \texttt{Args}(D)\}$.

It can be checked that if a move is decisive in a dialog, then it is useful. This means that there exists a directed path from the content of this move to the subject of the dialog in the graph of the argumentation system associated with the dialog.

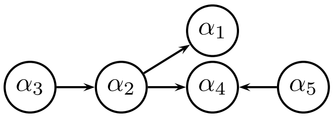
Property 4 *If a move m is decisive in a persuasion dialog D then m is useful in D.*

Proof Let us suppose that m is decisive in D, and that $\texttt{Subject}(D)$ is accepted in AS_D. Since m is decisive, $\texttt{Subject}(D)$ is rejected in $\mathsf{AS}_D \ominus \texttt{Content}(m)$. According to Property 1, $\texttt{Subject}(D)$ is indirectly attacked by a non-attacked argument in $\mathsf{AS}_D \ominus \texttt{Content}(m)$, say β. β is necessarily attacked in AS_D since $\texttt{Subject}(D)$ is accepted in AS_D. It can only be attacked by $\texttt{Content}(m)$ since it is the only argument in AS_D which is not in $\mathsf{AS}_D \ominus \texttt{Content}(m)$. This means that there is a directed path between $\texttt{Content}(m)$ and $\texttt{Subject}(D)$ in AS_D.

If $\texttt{Subject}(D)$ is rejected in AS_D, according to Property 1 $\texttt{Subject}(D)$ is indirectly attacked by a non-attacked argument in AS_D, say β. Since m is decisive, $\texttt{Subject}(D)$ is accepted in $\mathsf{AS}_D \ominus \texttt{Content}(m)$, it means that the argument removed in AS_D belongs to the path from β to $\texttt{Subject}(D)$. Hence there is a directed path between $\texttt{Content}(m)$ and $\texttt{Subject}(D)$ in AS_D. ■

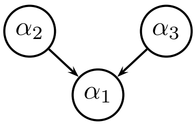
From the above property, it follows that each decisive move is also relevant. Note that the converse is not true as shown in the following example.

Example 3 *Let D_3 be a dialog whose subject is α_1 and whose graph is the following:*



The set $\{\alpha_1, \alpha_3, \alpha_5\}$ is the only grounded extension of AS_{D_3}. It is clear that the argument α_4 is relevant to α_1, but it is not decisive for D_3. Indeed, the removal of α_4 will not change the status of α_1 which is accepted.

Example 4 *Let D_4 be a dialog whose subject is α_1, and whose graph is the following:*



In this example, neither α_2 nor α_3 is decisive in D_4. However, this does not mean that the two arguments should be removed since the status of α_1 depends on at least one of them (they are both useful).

On the basis of the above notion of decisiveness of moves, we can define the degree of decisiveness of the entire dialog as the percentage of moves that are decisive.

5 Computing the ideal dialog

As already said, it is very common that dialogs contain redundancies in the sense that some moves are uttered but these are useless for the subject, or have no impact on the output of the dialog. Only a subset of the arguments is necessary to determine the status of the subject. Our aim is to compute the subset that returns exactly the same status for the subject of the dialogue as the whole set of arguments, and that is sufficient to convince that this result holds against any attack available in the initial dialog. That subset will form the "ideal" dialog. In what follows, we will provide a procedure for finding this subset and thus the ideal dialog.

A subset of arguments that will be convenient for our purpose contains those arguments that belong to a proof tree leading to the status of the subject. This is due to the fact that a proof tree contains every necessary argument for obtaining the status of the subject. When the subject is accepted, the proof tree contains defenders of the subject against any attack. When the subject is rejected, the proof tree contains at least every non attacked attacker. Hence, proof trees seem adequate to summarize perfectly the dialog. However, it is important to say that not any proof theory that exists in the literature will lead to the ideal dialog. This is due to the fact that some of them are not concise. In [10], a comparison of proof theories for grounded semantics shows that the one used here is the most concise.

5.1 Canonical dialogs

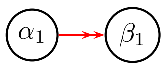
Let us define a sub-dialog of a given persuasion dialog D that reaches the same output as D. In [10], a proof procedure that tests the membership of an argument to a grounded extension has been proposed. The basic notions of this procedure are revisited and adapted for the purpose of characterizing canonical dialogs.

Definition 10 (Dialog branch) *Let D be a persuasion dialog and $\mathsf{AS}_D = \langle \mathtt{Args}(D), \mathtt{Confs}(D) \rangle$ its argumentation system. A* dialog branch *for D is a sequence $\langle \alpha_0, \ldots, \alpha_p \rangle$ of arguments s. t. $\forall i, j \in [\![0, p]\!]$*

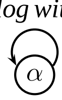
1. $\alpha_i \in \mathtt{Args}(D)$
2. $\alpha_0 = \mathtt{Subject}(D)$
3. *if $i \neq 0$ then $(\alpha_i, \alpha_{i-1}) \in \mathtt{Confs}(D)$*
4. *if i and j are even and $i \neq j$ then $\alpha_i \neq \alpha_j$*
5. *if i is even and $i \neq 0$ then $(\alpha_{i-1}, \alpha_i) \notin \mathtt{Confs}(D)$*
6. *$\forall \beta \in \mathtt{Args}(D)$, $\langle \alpha_0, \ldots, \alpha_p, \beta \rangle$ is not a dialog branch.*

Intuitively, a dialog branch is a kind of partial sub-graph of AS_D in which the nodes contains arguments and the arcs represents inverted conflicts. Note that arguments that appear at even levels are not allowed to be repeated. Moreover, these arguments should strictly attack[3] the preceding argument. The last point requires that a branch is maximal. Let us illustrate this notion on examples.

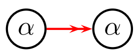
Example 5 *The only dialog branch that can be built from dialog D_2 is depicted below:*



Example 6 *Let D_5 be a persuasion dialog with subject α whose graph is the following:*



The only possible dialog branch associated to this dialog is the following:



Property 5 *A dialog branch is non-empty and finite.*

This result comes from the definitions of a dialog branch and of a persuasion dialog.

Proof

[3]An argument α strictly attacks an argument β in a argumentation system $\langle \mathcal{A}, \mathcal{R} \rangle$ iff $(\alpha, \beta) \in \mathcal{R}$ and $(\beta, \alpha) \notin \mathcal{R}$.

- A dialog branch is non-empty since the subject of the original persuasion dialog belongs to the branch.
- Let us assume that there exists an infinite dialog branch for a given persuasion dialog D. This means that there is an infinite sequence $\langle \alpha_0, \alpha_1, \ldots \rangle$ that forms a dialog branch. In this sequence, the number of arguments of even index and of odd index are infinite. According to Definition 5, the persuasion dialog D is finite, thus both sets $\texttt{Args}(D)$ and $\texttt{Confs}(D)$ are finite. Consequently, the set of arguments that belong to the sequence $\langle \alpha_0, \alpha_1, \ldots \rangle$ is finite. Hence, there is at least one argument that is repeated at an even index. This is impossible.

■

Moreover, it is easy to check the following result:

Property 6 *For each dialog branch $\langle \alpha_0, ..., \alpha_k \rangle$ of a persuasion dialog D there exists a unique directed path $\langle \alpha_k, \alpha_{k-1}, ..., \alpha_0 \rangle$ of same length[4] (k) in the directed graph associated to AS_D.*

Proof Let D be a persuasion dialog. Let $\langle \alpha_0, ..., \alpha_k \rangle$ be a dialog branch of the dialog tree D. From Definition 10.3, it follows that $(\alpha_i, \alpha_{i-1}) \in Confs(D)$. Hence there is a path of length k in AS_D from α_k to α_0. From Definition 10.2, $\alpha_0 = Subject(D)$. ■

In what follows, we will show that when a dialog branch is of even-length, then its leaf is not attacked in the original dialog.

Theorem 1 *Let D be a persuasion dialog and $\langle \alpha_0, \ldots \alpha_p \rangle$ be a given dialog branch of D. If p is even, then $\nexists \beta \in \texttt{Args}(D)$ such that $(\beta, \alpha_p) \in \texttt{Confs}(D)$.*

Proof Let D be a persuasion dialog and $\langle \alpha_0, \ldots \alpha_p \rangle$ be a given dialog branch of D. If $\exists \beta \in \texttt{Args}(D)$ s.t. $(\beta, \alpha_p) \in \texttt{Confs}(D)$ then $\langle \alpha_0, \ldots \alpha_p, \beta \rangle$ would be a dialog branch, which is forbidden by Definition 10.6. ■

Let us now introduce the notion of a dialog tree.

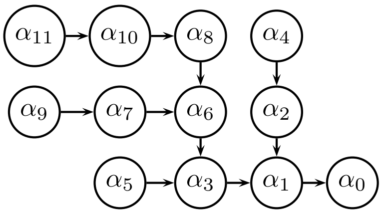
Definition 11 (Dialog tree) *Let D be a persuasion dialog and $\mathsf{AS}_D = \langle \texttt{Args}(D), \texttt{Confs}(D) \rangle$ its argumentation system. A* dialog tree *of D, denoted by D^t, is a finite tree whose branches are all the possible dialog branches that can be built from D.*

We denote by AS_{D^t} the argumentation system associated to D^t, $\mathsf{AS}_{D^t} = \langle A^t, C^t \rangle$ s.t. $A^t = \{\alpha \in \texttt{Args}(D)$ s.t. α appears in a node of $D^t\}$ and $C^t = \{(\alpha, \beta) \in \texttt{Confs}(D)$ s.t. (β, α) is an arc of $D^t\}$.

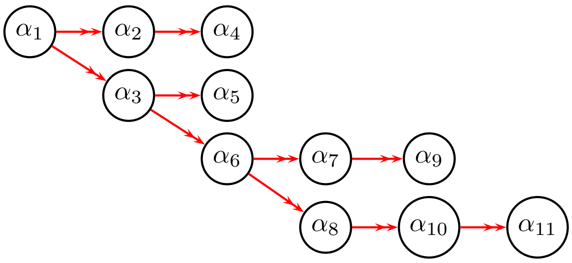
Hence, a dialog tree is a tree whose root is the subject of the persuasion dialog.

Example 7 *Let us consider D_6 whose subject is α_1 and whose graph is the following:*

[4] The length of a path is defined by its number of arcs.



The dialog tree associated to this dialog is depicted below:



Note that the argument α_0 does not belong to the dialog tree.

Property 7 *Each persuasion dialog has exactly one corresponding dialog tree.*

Proof This follows directly from the definition of the dialog tree. Indeed, the root of the tree is the subject of the persuasion dialog. Moreover, all the possible branches are considered. ■

An important result states that the status of the subject of the original persuasion dialog D is exactly the same in both argumentation systems AS_D and AS_{D^t} (where AS_{D^t} is the argumentation system whose arguments are all the arguments that appear in the dialog tree D^t and whose attacks are obtained by inverting the arcs between those arguments in D^t).

Theorem 2 *Let D be a persuasion dialog and AS_D its argumentation system. It holds that* $\texttt{Status}(\texttt{Subject}(D), \mathsf{AS}_D) = \texttt{Status}(\texttt{Subject}(D), \mathsf{AS}_{D^t})$.

Proof

- If $\texttt{Subject}(D)$ is accepted in AS_D then using Theorem 4 we get that there exists a canonical tree D_i^c such that $\texttt{Subject}(D)$ is accepted in $\mathsf{AS}_{D_i^c}$. Moreover, the way D_i^c has been constructed (by an AND/OR process) imposes that D_c^i contains every direct child of the subject in D^t. Furthermore, Theorem 3 shows that every branch of D_i^c is even. This means that every leaf of D_i^c is a non-attacked indirect defender of the subject in AS_{D^t} against each direct attacker in D^t. Hence the subject is accepted in AS_{D^t}.

- If $\texttt{Subject}(D)$ is rejected in AS_D then

– either there exists a non-attacked argument β that indirectly attacks the subject in AS_D, let $\langle \alpha_0, \dots \alpha_{2p+1} \rangle$ the sequence such that $\alpha_{2n+1} = \beta$ and $\alpha_0 = \texttt{Subject}(D)$ and $\forall i, 0 \leq i \leq 2n$, $(\alpha_{i+1}, \alpha_i) \in \texttt{Confs}(D)$. This sequence verifies Definition 10, bullets 1, 2, 3 and 6. If it does not verify bullet 4, then this means that there exist two even indexes i and j with $i < j$ such that $\alpha_i = \alpha_j$ then the sub-sequence $\alpha_{i+1}, \dots \alpha_j$ can be removed in order to obtain a new sequence $\langle \alpha_0, \dots \alpha_i, \alpha_{j+1} \dots \alpha_{2p+1} \rangle$ that satisfy again bullets 1, 2, 3 and 6 of Definition 10. This step can be repeated until bullet 4 is verified. If bullet 5 is not verified then this means that there exists an even index i such that $(\alpha_{i-1}, \alpha_i) \in \texttt{Confs}(D)$. In that case,

  * either $\langle \alpha_0, \dots \alpha_{i-1} \rangle$ verifies 11.6, it means that there is no other argument that attacks α_{i-1} than α_i, it means that α_{i-1} is not attacked in D^t .
  * or there is another attacker of α_{i-1} that must be defeated (else the subject would have been accepted in the dialog) hence the sequence defeating that argument will verify definition 11 (after repeating this reasoning).

  In both cases, there is a branch of odd length in D^t this branch proves the existence of a non-attacked indirect attacker of the subject in D^t

- either it does not exist non-attacked argument, by construction it means that D^t will contain an odd branch with a repeated odd argument, hence the subject will be indirectly attacked by a non-attacked argument in D^t.

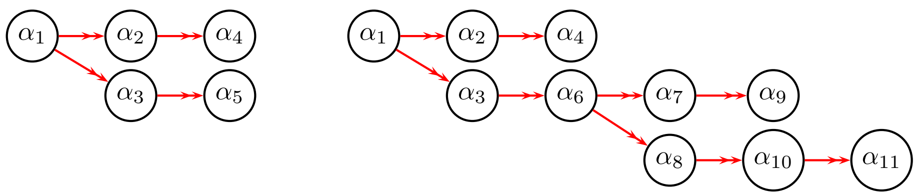
■

In order to compute the status of the subject of a dialog, we can consider the dialog tree as an And/Or tree. A node of an even level is an And node, whereas a node of odd level is an Or one. This distinction between nodes is due to the fact that an argument is accepted if it can be defended against all its attackers. A dialog tree can be decomposed into one or several trees called canonical trees.

Definition 12 (Canonical tree) *Let D be a persuasion dialog, and let D^t its dialog tree. A* canonical tree *is a subtree of D^t whose root is* $\texttt{Subject}(D)$ *and which contains all the arcs starting from an even node and exactly one arc starting from an odd node.*

It is worth noticing that from a dialog tree one may extract at least one canonical tree. Let $D_1^c, \dots, D_m^c$ denote those canonical trees. We will denote by $\mathsf{AS}_1^c, \dots, \mathsf{AS}_m^c$ their corresponding argumentation systems. It can be checked that the status of $\texttt{Subject}(D)$ is not necessarily the same in these different systems.

Example 8 *From the dialog tree of D_6, two canonical trees can be extracted:*



It can be checked that the argument α_1 is accepted in the argumentation system of the canonical tree on the left while it is rejected in the one of the right.

The following result characterizes the status of $\texttt{Subject}(D)$ in the argumentation system AS_i^c associated to a canonical tree D_i^c.

Theorem 3 *Let D be a persuasion dialog, D_i^c a canonical tree and AS_i^c its corresponding argumentation system.*

- $\texttt{Subject}(D)$ *is accepted in AS_i^c iff all the branches of D_i^c are of even-length.*
- $\texttt{Subject}(D)$ *is rejected in AS_i^c iff there exists a branch of D_i^c of odd-length.*

Proof Let D be a persuasion dialog, D_i^c a canonical tree and AS_i^c its corresponding argumentation system.
1) Let us show that $\texttt{Subject}(D)$ is accepted in AS_i^c iff all the branches of D_i^c are of even-length.

- Assume that $\texttt{Subject}(D)$ is accepted in AS_i^c, and that there is a branch of D_i^c whose length is odd. This means that the leaf of this branch, say α, indirectly attacks $\texttt{Subject}(D)$ (the root of the branch). However, according to Property 1, since $\texttt{Subject}(D)$ is accepted, i.e. it belongs to the grounded extension of AS_i^c, then $\texttt{Subject}(D)$ is defended by non-attacked arguments against its attackers. Thus, $\exists \alpha' \in \texttt{Args}(D)$ such that α' is not attacked and α' attacks α. This contradicts the fact that α is the leaf of the branch.
- Assume now that all the branches of D_i^c are of even length, and that $\texttt{Subject}(D)$ is rejected in AS_i^c. Since $\texttt{Subject}(D)$ is rejected, then from Property 1, $\exists \alpha \in D_i^c$ such that $\nexists \alpha' \in D_i^c$, $(\alpha', \alpha) \in \texttt{Confs}(D)$ and α indirectly attacks $\texttt{Subject}(D)$. This means that there is a branch of D_i^c whose leaf is α and of odd-length. Contradiction.

By contraposition of 1), we get that $\texttt{Subject}(D)$ is rejected in AS_i^c iff there exists a branch of D_i^c of odd-length. ■

The following result follows immediately from this Theorem and Theorem 1.

Corollary 1 *Let D be a persuasion dialog, D_i^c a canonical tree and AS_i^c its corresponding argumentation system.*
If $\texttt{Subject}(D)$ is accepted in AS_i^c, then all the leaves of D_i^c are not attacked in D.

Proof According to Theorem 3, since $\texttt{Subject}(D)$ is accepted in AS_i^c, then all its branches are of even-length. According to Theorem 1, the leaf of each branch of even-length is an argument that is not attacked in D. Thus, all the leaves of D_i^c are not attacked in D. ■

An important result shows the link between the outcome of a dialog D and the outcomes of the different canonical trees.

Theorem 4 *Let D be a persuasion dialog, D^c_1, ..., D^c_m its different canonical trees and $\mathsf{AS}^c_1, \ldots, \mathsf{AS}^c_m$ their corresponding argumentation systems.*
- $\texttt{Output}(D)$[5] is accepted iff $\exists\, i \in [\![1, m]\!]$ s.t. $\texttt{Status}(\texttt{Subject}(D), \mathsf{AS}^c_i)$ is accepted.
- $\texttt{Output}(D)$ is rejected iff $\forall j \in [\![1, m]\!]$, $\texttt{Status}(\texttt{Subject}(D), \mathsf{AS}^c_j)$ is rejected.

Proof Let D be a persuasion dialog, D^c_1, ..., D^c_n its different canonical trees and $\mathsf{AS}^c_1, \ldots, \mathsf{AS}^c_n$ their corresponding argumentation systems.

- Let us assume that there exists D^c_j with $1 \leq j \leq n$ and $\texttt{Status}(\texttt{Subject}(D)$, $\mathsf{AS}^c_j)$ is accepted. According to Theorem 3, this means that all the branches of D^c_j are of even length. From Corollary 1, it follows that the leaves of D^c_j are all not attacked in the graph of the original dialog D.

  Let $2i$ be the depth of D^c_j (i.e. the maximum number of moves of all dialog branches of D^c_j).

  We define the height of a node N in a tree as the depth of the sub-tree of root N.

  We show by induction on p that $\forall$ p such that $0 \leq o \leq i$, the set $\{y | y$ is an argument of even indice and in a node of height $\leq 2p$ belonging to $D^c_j\}$ is included in the grounded extension of AS^c_j).

  - Case $p = 0$. The leaves of D^c_j are not attacked (according to Corollary 1). Thus, they belong to the grounded extension of AS^c_j.
  - Assume that the property is true to an order p and show that it is also true to the order $p + 1$.
    It is sufficient to consider the arguments that appear at even levels and in a node of height $2p+2$ of D^c_j. Let y be such an argument. Since y appears at an even level, then all the arguments y' attacking y appear in D^c_j as children of y, and each y' is itself strictly attacked by one argument z appearing in D^c_j as a child of y'. Thus, each z is at an even level in D^c_j and appears as a node of height $2p$ of D^c_j. By induction hypothesis, each argument z is in the grounded extension of AS^c_j. Since all attackers of y have been considered, thus the grounded extension of AS^c_j defends y. Consequently y is also in this grounded extension.

- Let us assume that $\texttt{Status}(\texttt{Subject}(D), \mathsf{AS}_D)$ is accepted. Construct a tree with root $\texttt{Subject}(D)$. Let i be the smallest index ≥ 0 such that $\texttt{Subject}(D)$ $\in \mathcal{F}^i(\mathcal{C}$[6]). We show by induction on i that there exists a canonical tree whose root is $\texttt{Subject}(D)$ and its depth is $\leq 2i$.

  - Case $i = 0$: $\texttt{Subject}(D) \in \mathcal{C}$, the depth of the tree is 0.
  - Assume that the property is true at order i and consider the order $i + 1$. Then, $\texttt{Subject}(D) \in \mathcal{F}^{i+1}(\mathcal{C})$ and $\texttt{Subject}(D) \notin \mathcal{F}^j(\mathcal{C})$ with $j < i + 1$. Let x_1, ..., x_n be the attackers of $\texttt{Subject}(D)$. Consider an attacker x_j.

[5] Recall that $\texttt{Output}(D)$ = $\texttt{Status}(\texttt{Subject}(D), \mathsf{AS}_D)$.
[6] The set $\mathcal{C}$ contains all the arguments that are not attacked in D.

x_j attacks $\texttt{Subject}(D)$,
and $\texttt{Subject}(D) \in \mathcal{F}^{i+1}(\mathcal{C}) = \mathcal{F}(\mathcal{F}^i(\mathcal{C}))$.

According to Proposition 4.1 in [10], it exists y in the grounded extension of AS_D such that y attacks strictly x_j. Since y defends $\texttt{Subject}(D)$ (definition of $\mathcal{F}$) then $y \in \mathcal{F}^i(\mathcal{C})$. By induction hypothesis applied to y, there exists a canonical tree whose root is y and the depth is $\leq 2i$. The same construction is done for each x_j. So we get a canonical tree whose root is $\texttt{Subject}(D)$ and its depth is $\leq 2(i+1)$.

■

This result is of great importance since it shows that a canonical tree whose branches are all of even-length is sufficient to reach the same outcome as the original dialog in case the subject is accepted. When the subject is rejected, the whole dialog tree is necessary to ensure the outcome.

Example 9 *In Example 7, the subject α_1 of dialog D_6 is accepted since there is a canonical tree whose branches are of even length (it is the canonical tree on the left in Example 8). It can also be checked that α_1 is in the grounded extension $\{\alpha_1, \alpha_4, \alpha_5, \alpha_8, \alpha_9, \alpha_{11}\}$ of AS_D.*

So far, we have shown how to extract from a graph associated with a dialog its canonical trees. These canonical trees contain only useful (hence relevant) moves:

Theorem 5 *Let D_i^c be a canonical tree of a persuasion dialog D. Any move built on an argument of D_i^c is* useful *in the dialog D.*

Proof By construction of D_i^c, there is a path in this tree from the root to each argument α of the canonical tree. According to Property 6, we get that there exists a corresponding directed path in AS_D from α to $\texttt{Subject}(D)$, hence a move containing the argument α is useful in D. ■

The previous theorem gives an upper bound of the set of moves that can be used to build a canonical dialog, a lower bound is the set of decisive moves.

Theorem 6 *Every argument of a decisive move belongs to the dialog tree and to each canonical dialog.*

Proof If a move m is decisive then, as seen in the proof of property 4,

- if the subject is accepted in AS_D then it exists a sequence of odd length ending by an argument α in $\mathsf{AS}_D \ominus \texttt{Content}(m)$ such that α is attacked by $\texttt{Content}(m)$ in AD_D, every other possible indirect attack by an non attacked argument in $\mathsf{AS}_D \ominus \texttt{Content}(m)$ is not possible in AS_D, hence either there is no other possible attack or the possible indirect attackers are all attacked by $\texttt{Content}(m)$. Hence, either all the branches have $\texttt{Content}(m)$ as a leaf. It means that $\texttt{Content}(m)$ is in the dialog tree and in each canonical dialog.

- if the subject is rejected in AS_D then $\texttt{Content}(m)$ belongs to each path from a non-attacked indirect attacker to $\texttt{Subject}(D)$. It means that $\texttt{Content}(m)$ belongs to each branch of the dialog tree hence to each canonical dialog.

■

The converse is false since many arguments are not decisive, as shown in Example 4. Indeed, there are two attackers that are not decisive but the dialog tree contains both of them (as does the only canonical dialog for this example).

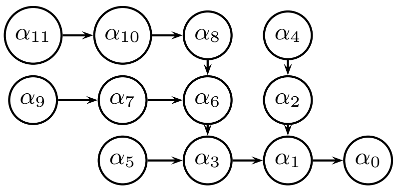
5.2 The ideal dialog

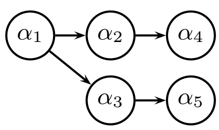
In the previous section, we have shown that from each dialog, a dialog tree can be built. This dialog tree contains direct and indirect attackers and defenders of the subject. From this dialog tree, interesting subtrees can be extracted and are called canonical trees. A canonical tree is a subtree containing only particular entire branches of the dialog tree (only one argument in favor of the subject is chosen for attacking an attacker while each argument against a defender is selected). In case the subject of the dialog is accepted it has been proved that there exists at least one canonical tree such that the subject is accepted in its argumentation system. This canonical tree is a candidate for being an ideal tree since it is sufficient to justify the acceptance of the subject against any attack available in the initial dialog. Among all these candidate we define the ideal tree as the smallest one. In the case the subject is rejected in the initial dialog, then the dialog tree contains all the reasons to reject it, hence we propose to consider the dialog tree itself as the only ideal tree.

Definition 13 (ideal trees and dialogs) *If a dialog D has an accepted output*
- then an ideal tree *associated to D is a canonical tree of D in which* $\texttt{Subject}(D)$ *is accepted and having a minimal number of nodes among all the canonical graphs that also accept* $\texttt{Subject}(D)$
- else the ideal tree *is the dialog tree of D.*

A dialog using once each argument of an ideal graph is called an ideal dialog.

Example 10 *An ideal Dialog for Dialog D6 (on the left) has the following graph (on the right):*





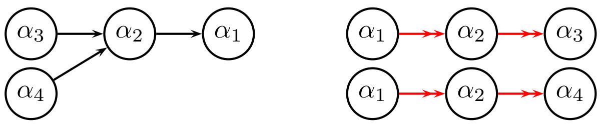
Given the above definition, an ideal dialog contains exactly the same number of moves that the number of nodes of the ideal graph.

Property 8 *Given a dialog D whose subject is accepted. An ideal dialog ID for D is the shortest dialog with the same output, and s.t. every argument in favor of the subject in ID (including $Subject(D)$ itself) is defended against any attack (existing in D).*

This property ensures that, when the subject is accepted in the initial dialog D, an ideal dialog ID is the more concise dialog that entails an acceptation. In other words, we require that the ideal dialog should contain a set of arguments that sumarize D.

Proof If the subject is accepted in D then, by construction, a canonical graph of D contains every argument existing in D that directly attacks the subject since they belongs to all the possible dialog branches that can be built from D. But for any of them it contains only one attacker that is in favor of the subject (this attacker is a son of an "OR" node in the dialog tree), for each chosen argument in favor of the subject, all the attackers are present in the canonical tree (they are the sons of an "AND" node in the dialog tree). Moreover, if the subject is accepted then every branch of the canonical graph is of even length. It means that the leafs are in favor of the subject and not attacked in the initial dialog D. This property is true for any canonical graph. Then since the ideal dialog correspond to the smallest canonical graph it means that it is the shortest dialog that satisfy this property. ■

Note that the ideal dialog exists but is not always unique. Here is an example of an argumentation system of a dialog which leads to two ideal trees (hence it will lead to at least two ideal dialogs).



So far, we have formally defined the notion of ideal dialog, and have shown how it is extracted from a persuasion dialog. It is clear that the closer (it terms of set-inclusion of the exchanged arguments) to its ideal version the dialog is, the better the dialog.

6 Conclusion

In this paper, we have proposed three criteria for evaluating the moves of a persuasion dialog with respect to its subject: relevance, usefulness and decisiveness. Relevance only expresses that the argument of the move has a link with the subject (this link is based on the attack relation of the argumentation system). Usefulness is a more stronger relevance since it requires a directed link from the argument of the move to the subject. Decisive moves have a heavier impact on the dialog, since their omission changes the output of the dialog.

Inspired from works on proof theories for grounded semantics in argumentation, we have defined a notion of "ideal dialog". More precisely, we have first defined a dialog tree associated to a given dialog as the graph that contains every possible direct and indirect attackers and defenders of the subject. From this dialog tree, it is then possible to extract sub-trees called "ideal trees" that are sufficient to prove that the subject is accepted or rejected in the original dialog and this, against any possible argument taken from the initial dialog. A dialog is good if it is close to that ideal tree. Ideal dialogs have nice properties with respect to conciseness, namely they contain only useful and relevant arguments for the subject of the dialog. Moreover for every decisive move its argument belongs to all ideal trees.

From the results of this paper, it seems natural that a protocol generates dialogs of good quality if (1) irrelevant and not useful moves are penalized until there is a set of arguments that relate them to the subject (2) adding arguments in favor of the subject that are attacked by already present arguments has no interest (since they do not belong to any ideal tree). By doing so, the generated dialogs are more *concise* (i.e. all the uttered arguments have an impact on the result of the dialog), and more *efficient* (i.e. they are the minimal dialogs that can be built from the information exchanged and that reach the goal of the persuasion).

Note that in our proposal, the order of the arguments has not to be constrained since the generated graph does not take it into account. The only thing that matters in order to obtain a conclusion is the final set of interactions between the exchanged arguments. But the criteria of being relevant to the previous move or at least to a move not too far in the dialog sequence could be taken into account for analyzing dialog quality. Moreover, all the measures already defined in the literature and cited in the introduction could also be used to refine the proposed preference relation on dialogs and finally could help to formalize general properties of protocols in order to generate good dialogs.

Furthermore, it may be the case that from the set of formulas involved in a set of arguments, new arguments may be built. This give birth to a new set of arguments and to a new set of attack relations called complete argumentation system associated to a dialog. Hence, it could be interesting to define dialog trees on the basis of the complete argumentation system then more efficient dialogs could be obtained (but this is not guaranteed). However, some arguments of the complete argumentation system may require the cooperation of the agents. It would mean that in an ideal but practicable dialog, the order of the utterance of the arguments would be constrained by the fact that each agent should be able to build each argument at each step.

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