Towards Argument-based Foundation for Sceptical and Credulous Dialogue Games

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Abstract. We propose an argument-based foundation for dialogue games capable of modelling protocols for exchange of arguments in dialogues to prove or disprove propositions. We introduce structure into dialogue states by modelling them as dialogue trees coupled with appropriate annotation mechanisms. We model dialogue locutions as transformations between dialogue states. Viewing dialogues as proofs, we study conditions for them to be sound under the grounded semantics and the credulous semantics in argumentation. Thank to annotation mechanisms, we could handle backtracking of proponent in dialogue games.

Keywords. Agent, Argumentation, Dialogue Games.

1. Introduction

Dialogue games have attracted much attention lately in the literature as a form of practical argumentation [3,9,1,11,7] (see [10] for an overview). In this paper we restrict ourselves to a kind of dialogue games between a proponent and an opponent in which the proponent (resp. opponent) tries to persuade (resp. dissuade) a third person (like a judge, members of audience or the parties themselves) to accept (resp. reject) some proposition. For illustration, consider a court case example.

Example 1.1 *(Modified slightly from [14]) The central issue of this court case is to determine whether there is a valid sale contract between two parties. Plaintiff (proponent) asserts that they concluded a valid sale contract with an affidavit signed by both parties. Defendant (opponent) counter-argues that it is not an affidavit as a lab report has stated that the signatures are not authentic. As the plaintiff can not present other evidence, he retracts his original claim.*

The proponent starts a dialogue by asserting a proposition. During the dialogue, the proponent and opponent could introduce new rules to construct their arguments by uttering appropriate locutions. Our dialogue model does not focus on a particular type of dialogues. In adversarial dialogues like disputes between plaintiff and defendant in a court of laws, or debates between presidential candidates, a party takes either the proponent role or the opponent role throughout

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a dialogue. However in collaborative settings like information seeking, persuasion or discovery, a party could play both roles at different times.

In many domains the third party can play an active role. In the legal domain, for instance, judges act as referees in deciding which evidence is allowed, which common knowledge and social norms or argumentation schemas are accepted. Hence before the court, dispute parties can only deploy evidence and rules that are accepted by the court as permissible. For simplicity in our dialogue model we assume that the proponent and opponent present only permissible evidence and rules, so we can view the third party as purely representing a knowledge base of which both parties have only a *partial* knowledge. Viewing successful dialogues as proofs for the acceptability of initial propositions, we study conditions for them to be sound wrt to the common knowledge base (aka commitment store) that consists of the evidence and rules exposed in the exchanged locutions. To do so we use assumption-based frameworks to structure commitment stores.

One of early known work of argument-based dialogue games is the one in [3] which aims at providing game-theoretical semantics and dialectical proof procedures for logic programming. There, a logic program is viewed as a common knowledge base of which both dispute parties have *full* knowledge, and a successful dialogue of a given proposition represents a proof that needs to be searched by proof procedures in order to establish the acceptability of the proposition. Since in a dialogue, participants can only have full knowledge of the common commitment store when the dialogue terminates, dialectical proof procedures can be viewed as representing the semantics of dialogue models. In fact our dialogue model could be viewed as a continuation of the dialectical proof procedures for logic programming in [3], for assumption-based argumentation in [5], and especially the dialogue models in [6,8]. We generalize the results and also overcome several shortcomings of [8]. First, we deal with both the grounded semantics and credulous semantics while Fan and Toni [8], as well as many others, only deal with the grounded semantics. Secondly, we extend to conceding and retracting locutions to allow dialogue participants to backtrack among different lines of disputes. Thirdly, our framework, even without the extra locutions, captures a much larger class of dialogues which are not captured in [8] due to their various constraints. Finally, our technical framework deploys a novel notion of dialogue trees which improves on the dispute trees [5] used in [8], to provide a theoretically simple and conceptually elegant mechanism for backtracking and make it possible to deploy various notions that naturally capture the rationality of dialogue participants.

The paper is structured as follows. Section 2 recalls the basic background on assumption-based argumentation. Section 3 introduces our theory of dialogue games. Section 4 defines credulous and sceptical games and studies their properties. Section 5 concludes.

2. Assumption-based argumentation

This section recalls **assumption-based argumentation framework** (ABF, see [5,2] for details). Assuming a language $\mathcal{L}$, an ABF is defined as a triple $(\mathcal{R}, \mathcal{A}, \overline{})$ where $\mathcal{R}$ is a set of inference rules of the form $l_0 \leftarrow l_1, \ldots, l_n$ (for $n \geq 0$), and $\mathcal{A} \subseteq \mathcal{L}$

is a set of assumptions, and $\overline{}$ is a (total) one-to-one mapping from $\mathcal{A}$ into $\mathcal{L}$, where $\overline{x}$ is referred to as the *contrary* of x. Assumptions in $\mathcal{A}$ do not appear in the heads of rules in $\mathcal{R}$. Contraries of assumptions are not assumptions. For a rule $r : l_0 \leftarrow l_1, \ldots, l_n$, define $head(r) = l_0$ and $body(r) = \{l_1, \ldots l_n\}$.

A proof tree for a conclusion (claim) $\gamma \in \mathcal{L}$ supported by a set of premisses $S \subseteq \mathcal{L}$ is a tree with nodes labelled by sentences in $\mathcal{L}$ or by the symbol "*true*", such that: the root is labelled by γ; S is the set of sentences labelling the leaves; and for every internal node N labelled by sentence l, there is an inference rule r such that $head(r) = l$ and: for each $b \in body(r)$, N has a child labelled by b, or $body(r) = \emptyset$ and N has a single child labelled by "*true*".

Given $S \subseteq \mathcal{L}$ and $l \in \mathcal{L}$, $S \vdash_{\mathcal{F}} l$ stands for "there exists a proof tree for l supported by a subset of S" wrt ABF $\mathcal{F}$. An argument in favour of $x \in \mathcal{L}$ supported by a set of assumptions S is a proof tree for x supported by S.

A set of assumptions X attacks an assumption α iff $X \vdash_{\mathcal{F}} \overline{\alpha}$; and X defends α iff X attacks any set of assumptions Y attacking α. A set of assumptions X is

- admissible iff X does not attack itself and X attacks every set of assumptions Y attacking X.
- complete iff X is admissible and X contains all assumptions that X defends.
- a preferred extension iff X is maximally complete (wrt set inclusion).
- a grounded extension iff X is minimally complete.

A proposition π is said to be a credulous/grounded consequence of $\mathcal{F}$ if there exists a preferred/grounded extension E of $\mathcal{F}$ such that $E \vdash_{\mathcal{F}} \pi$.

3. Dialogue Games

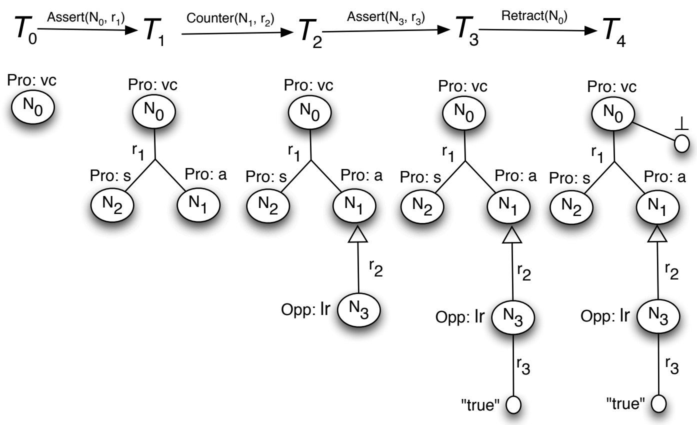
In essence, a dialogue is a sequence of locutions $m_0 m_1 \ldots m_n$, each of which transforms the dialogue from one state to another. In our formalism, a dialogue state is represented by a dialogue tree. Hence a dialogue is represented by a sequence of dialogue tree transformations $\mathcal{T}_0 \xrightarrow{m_0} \mathcal{T}_1 \ldots \mathcal{T}_n \xrightarrow{m_n} \mathcal{T}_{n+1}$, in which each dialogue tree $\mathcal{T}_i$ is obtained from $\mathcal{T}_{i-1}$ by adding children to some node to represent the effects of m_{i-1}. For illustration let's revisit example 1.1.

Example 3.1 *Our language includes vc = "valid contract", s = "document supposedly signed by both parties"; a = "authentic document"; lr = "lab report", where a is an assumption with $\overline{a} = \neg a$. Let $r_1 : vc \leftarrow s, a$; $r_2 : \neg a \leftarrow lr$; and $r_3 : lr \leftarrow$. The dialogue is illustrated in Fig. 1.*

- *$\mathcal{T}_0$ consists of only root node N_0 labelled by "$Pro : vc$" representing the proponent's claim for a valid contract.*
- *Proponent's assertion can be represented by locution $Assert(N_0, r_1)$. Transformation $\mathcal{T}_0 \xrightarrow{Assert(N_0,r_1)} \mathcal{T}_1$ adds to N_0 two child nodes N_1 and N_2, which are labelled by $\langle a, r_1 \rangle$ and $\langle s, r_1 \rangle$ respectively to indicate that N_1 and N_2 together provides a reason for N_0 following the inference rule r_1.*
  Note that for ease of visualization, in figures we often "place" inference rules on edges of dialogue trees.

- *Opponent's counter-argument begins with locution $Counter(N_1, r_2)$ and continues with locution $Assert(N_3, r_3)$.*
- *Transformation $\mathcal{T}_1 \xrightarrow{Counter(N_1,r_2)} \mathcal{T}_2$ adds to N_1 a child node N_3 labelled by "$Opp : lr$". Edge N_3N_1 is directed to represent an attack.*
- *Transformation $\mathcal{T}_2 \xrightarrow{Assert(N_3,r_3)} \mathcal{T}_3$ adds to N_3 a child node labelled by a special sentence "true" in order to say that r_3 is a fact.*
- *Proponent's retraction at the end is represented by locution $Retract(N_0)$. Transformation $\mathcal{T}_3 \xrightarrow{Retract(N_0)} \mathcal{T}_4$ adds to N_0 a child node labelled by a sentence $\perp$ to say that the proponent gives up proving the initial claim.*

Figure 1. A dialogue.



Definition 3.1 *A dialogue tree $\mathcal{T}$ for a proposition π is such that:*

1. *Each non-root node of $\mathcal{T}$ is labelled by*

   (a) *a pair $\langle \gamma, r \rangle$ where r is an inference rule such that $\gamma \in body(r)$, or*
   (b) *"true" or $\perp$.*

2. *Each node satisfying 1(a) is assigned the type of either proponent or opponent. The root is a proponent node labelled by π.*

If player X stands for the proponent (resp. opponent) then $\overline{X}$ is the opponent (resp. proponent). For a node N, if the label of N contains an assumption (resp. non-assumption), then N is called an **assumption** (resp. **non-assumption**) **node**.

We now define locutions and how they transform dialogue trees.

Definition 3.2 *A locution is one of the form*

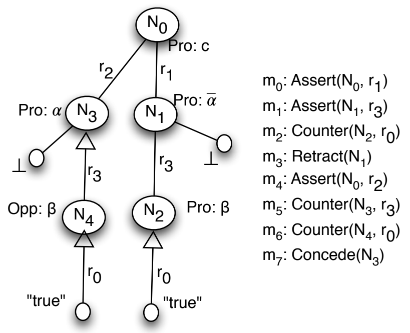
1. *$Assert(N, r)$, where N is a non-assumption node and r is a rule whose head occurs in the label of N.*
2. *$Counter(N, r)$, where N is an assumption node and r is a rule whose head is the contrary of the assumption in the label of N.*

3. *Retract*(N)*, where* N *is a non-assumption node.*
4. *Concede*(N)*, where* N *is an assumption node.*

A player who moves $Assert(N, r)$ tries to prove the sentence labelling N with r as a reason, while a player who moves $Counter(N, r)$ tries to disprove the assumption labelling N by using r. A player moving $Retract(N)$ gives up proving the sentence labelling N, while a player moving $Concede(N)$ gives up disproving the assumption labelling N. Note that we do not represent the player of a locution syntactically, as she can be easily inferred from the node therein. Concretely, if N is a non-assumption node of type X, then $Assert(N, r)$ and $Retract(N)$ are moved by player X because X wants to prove the sentence labelling N. If N is an assumption node of type X, $Counter(N, r)$ and $Concede(N)$ are moved by player $\overline{X}$ because $\overline{X}$ wants to disprove the assumption labelling N. Note that without *Retract* and *Concede* locutions, we can not capture dialogues where the proponent wants to backtrack among different lines of disputes, like the following.

Example 3.2 *Consider a discovery dialogue between agent* B *whose initial knowledge base consists of only one rule* $r_0 : \overline{\beta} \leftarrow$*; and agent* A *whose initial knowledge base consists of three rules* $r_1 : c \leftarrow \overline{\alpha}$*;* $r_2 : c \leftarrow \alpha$*;* $r_3 : \overline{\alpha} \leftarrow \beta$ *where* α, β *are assumptions. Agent* A*, in order to discover the truth of* c*, builds an argument for* c *based on assumption* β *using* r_1 *and* r_3*. Agent* B *then counters* β *with* r_0*. If the dialogue stops here, two agents must admit that* c *is not acceptable. However, agent* A *can establish another argument for* c *based on assumption* α *using* r_2*. Although agent* B *could attack assumption* α *of this argument by using rule* r_3*, agent* A *can counter-attack by using* r_0*. Hence at the end two agents discover that* c *is acceptable. Note that before presenting the second argument for* c*, agent* A *should retract* a *because* a *is the contrary of assumption* α *backing the argument. In our framework, the dialogue has sequence of locutions* $m_0 m_1 \ldots m_7$ *and the final dialogue tree shown in Fig. 2.*

Figure 2. An example of proponent's backtracking.



Definition 3.3 *Let* $\mathcal{T}$ *and* $\mathcal{T}'$ *be dialogue trees, and* m *be a locution. We say* $\mathcal{T}'$ *is obtained from* $\mathcal{T}$ *by* m*, written* $\mathcal{T} \xrightarrow{m} \mathcal{T}'$*, if one of the following conditions holds:*

1. *m is $Assert(N, r)$ and $\mathcal{T}'$ is obtained from $\mathcal{T}$ by adding to N, for each $\sigma \in body(r)$, a child of the same type as N and labelled by $\langle\sigma, r\rangle$. If $body(r) = \emptyset$, then a single child node of N labelled by "true" is added.*
2. *m is $Counter(N, r)$ and $\mathcal{T}'$ is obtained from $\mathcal{T}$ by adding to N, for each $\sigma \in body(r)$, a child of the different type from N and labelled by $\langle\sigma, r\rangle$. If $body(r) = \emptyset$, then a single child node of N labelled by "true" is added.*
3. *m is $Retract(N)$ or $Concede(N)$, and $\mathcal{T}'$ is obtained from $\mathcal{T}$ by adding to N a child labelled by $\perp$.*

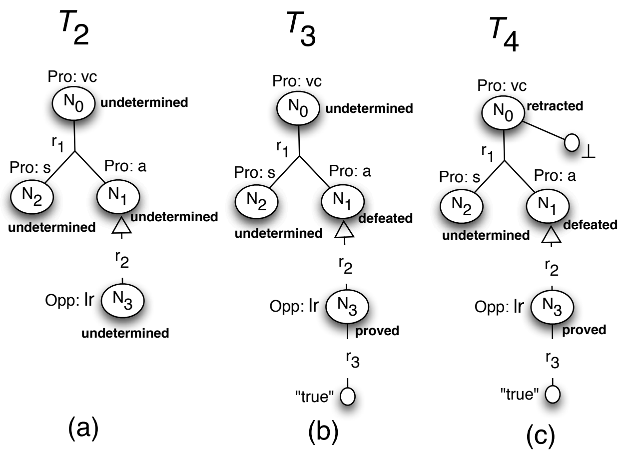
A dialogue of a proposition π is a sequence of transformations $\mathcal{T}_0 \xrightarrow{m_0} \mathcal{T}_1 \dots \mathcal{T}_i \xrightarrow{m_i} \mathcal{T}_{i+1} \dots$, where $\mathcal{T}_0$ consists of a root node N_0 labelled by π and m_0 is of the form $Assert(N_0, r)$ or $Counter(N_0, r)$. A **derivable** dialogue tree is a dialogue tree in some dialogue.

Given a node N of a derivable dialogue tree $\mathcal{T}$, $RULE_{\mathcal{T}}(N)$ denotes the set of rules occurring in the labels of children of N; and $CHILD_{\mathcal{T}}(N, r)$ where $r \in RULE_{\mathcal{T}}(N)$, denotes the set of children of N whose labels contain r. Elements of $CHILD_{\mathcal{T}}(N, r)$ are said to be *siblings*. It is obvious that there is an one-to-one correspondence between nodes in $CHILD_{\mathcal{T}}(N, r)$ and sentences in $body(r)$[2].

The notion of annotation is introduced to represent node statuses.

Example 3.3 *In $\mathcal{T}_4$ (Fig. 3(c)), N_3 can be said to have been "proved" by r_3. As edge N_3N_1 represents an attack, N_1 can be said to have been "defeated". N_0 is considered as "retracted" as the proponent has explicitly specified. Finally, N_2 can be considered as "undetermined" since two parties have not discussed about it yet.*

Figure 3. Dialogue tree annotations.



Intuitively, for a non-assumption node of type X, **undetermined** status says that player X is still trying to prove the sentence there, while **proved** status says

[2]Note that here *siblings not only are children of the same parent but also contain the same inference rule.*

that he has succeeded and **retracted** status says that he has given up the task. Similarly, for an assumption node of type X, **undetermined** status says player $\overline{X}$ is still trying to disprove the assumption there, while **defeated** status says $\overline{X}$ has succeeded and **accepted** status says $\overline{X}$ has given up the task.

Definition 3.4 *An* **annotation** *of a dialogue tree is a mapping that assigns to each of its non-assumption nodes one of three statuses:* **undetermined***,* **retracted***,* **proved***; and each of its assumption nodes one of three statuses:* **undetermined***,* **defeated***,* **accepted**[3]*.*

We say that a node has status *determined* if it does not have status undetermined.

A dialogue tree can have different annotations, some of them are rather counter-intuitive. For example, an annotation assigning to node N_3 of $\mathcal{T}_4$ (Fig. 3 c) status retracted is rather counter-intuitive. An annotation is said to be coherent if it reflects the structure of its dialogue tree, as follows.

Definition 3.5 *An annotation of a derivable dialogue tree $\mathcal{T}$ is* **coherent** *if the following conditions hold:*

1. *for each non-assumption node N,*
   (a) *N has status proved iff N has a child labelled by "true" or $\exists r \in RULE_{\mathcal{T}}(N)$ s.t. each of $CHILD_{\mathcal{T}}(N, r)$ has status proved or accepted.*
   (b) *N has status retracted iff N has a child labelled by $\perp$.*
   (c) *N has status undetermined iff the above two cases do not hold.*
2. *for each assumption node N,*
   (a) *N has status defeated iff N has a child labelled by "true" or $\exists r \in RULE_{\mathcal{T}}(N)$ s.t. each of $CHILD_{\mathcal{T}}(N, r)$ has status proved or accepted.*
   (b) *N has status accepted iff N has a child labelled by $\perp$.*
   (c) *N has status undetermined iff the above two cases do not hold.*

A **coherent dialogue tree** is a derivable dialogue tree that has a unique coherent annotation. From now on, by the annotation of a coherent dialogue tree, we mean the unique coherent annotation of the tree.

Lemma 3.1 *Each derivable dialogue tree has at most one coherent annotation.*

Proof (Sketch) We prove by induction on the height of given derivable dialogue tree $\mathcal{T}$. The base case, i.e. $\mathcal{T}$ consists of only the root node, is obvious. From the induction hypothesis, it follows that there is maximally one coherent annotation for each subtree with root as a child of the root of $\mathcal{T}$. If some of this subtree has no coherent annotation then $\mathcal{T}$ has none either. Suppose all of them have an unique coherent annotation. If the status of the root could be uniquely determined according to definition 3.5, we have determined an unique coherent annotation for $\mathcal{T}$. Otherwise $\mathcal{T}$ has no coherent annotation. □

Dialogue participants utter locutions to determine the statuses of their claims. Hence we expect that uttered locutions target at nodes of status undetermined.

[3]Note that we do not need explicitly to annotate nodes that are labelled by "true" or $\perp$.

Even more, *a rational player does not utter at such nodes if it is clear that the changes of their statuses do not contribute to proving or disproving the proposition the proponent wants to prove.*

Example 3.4 *In state $\mathcal{T}_3$ (Fig. 3b), suppose the proponent has two rules: $r_4 : s \leftarrow$ (the signed document indeed exists) and $r_5 : vc \leftarrow cd$ (the conduct of the parties could prove the existence of a valid contract). Since both N_0 and N_2 have status undetermined, the proponent may utter $Assert(N_0, r_5)$ or $Assert(N_2, r_4)$. While $Assert(N_0, r_5)$ may help the proponent win the dialogue, $Assert(N_2, r_4)$ is useless since N_1 already has status defeated, i.e. the document is not authentic anyway.*

Definition 3.6 *Let N be a node of a coherent dialogue tree. N is said to be* **irrelevant** *if N has status undetermined and one of conditions below holds*

1. *N has a retracted or defeated sibling.*
2. *The parent of N has status determined or is irrelevant.*

N is said to be **relevant** *if N is not irrelevant*[4]*.*

It is sensible to expect that players should only utter locutions targeting at relevant nodes that have status undetermined. Moreover, for $Concede(N)$ and $Retract(N)$, a rational player would utter them in $\mathcal{T}$ only if for each $r \in RULE_{\mathcal{T}}(N)$, some node in $CHILD_{\mathcal{T}}(N, r)$ has status retracted or defeated.

Example 3.5 *For dialogue tree $\mathcal{T}_2$ (Fig. 3a), N_0 and N_2 are relevant nodes that the proponent could consider a retraction because both of them have status undetermined. While $Retract(N_2)$ is sensible, $Retract(N_0)$ is not because following r_1, N_0 still can become proved if N_2 becomes proved and N_1 becomes accepted.*

However, for $\mathcal{T}_3$ (Fig. 3b), $Retract(N_0)$ is sensible as N_1 has been defeated.

We incorporate the above intuition into the following definition.

Definition 3.7 *Let m be a locution that could be uttered in a coherent dialogue tree $\mathcal{T}$ (i.e. there exists $\mathcal{T}'$ s.t. $\mathcal{T} \xrightarrow{m} \mathcal{T}'$). We say that m is* **s-rational** *(sceptically rational) in $\mathcal{T}$ if one of the following conditions is satisfied.*

1. *m is of the form $Assert(N, r)$ or $Counter(N, r)$, where N is a relevant node of $\mathcal{T}$ and has status undetermined.*
2. *m is of the form $Concede(N)$ or $Retract(N)$, where N is a relevant node of $\mathcal{T}$ and has status undetermined, and for each rule $r \in RULE_{\mathcal{T}}(N)$, some node of $CHILD_{\mathcal{T}}(N, r)$ has status defeated or retracted.*

Definition 3.8 *A dialogue $d = \mathcal{T}_0 \xrightarrow{m_0} \mathcal{T}_1 \ldots \mathcal{T}_{n-1} \xrightarrow{m_{n-1}} \mathcal{T}_n$ is said to be:*

1. **s-terminated** *if for each $0 \leq i \leq n-1$, m_i is s-rational in $\mathcal{T}_i$, and there is no s-rational locution for both proponent and opponent in $\mathcal{T}_n$.*
2. **successful** *if the root node of $\mathcal{T}_n$ has status proved or accepted.*

[4]Note that once a node becomes determined at a dialogue state it stays in that determined status in all subsequent states. Hence once a node becomes irrelevant at some dialogue state, it is irrelevant in all subsequent states.

3. **s-successful** *if d is s-terminated and successful.*

The following lemma says if a dialogue is s-terminated, then it has an outcome.

Lemma 3.2 *Let $\mathcal{T}_0 \xrightarrow{m_0} \mathcal{T}_1 \ldots \mathcal{T}_{n-1} \xrightarrow{m_{n-1}} \mathcal{T}_n$ be a s-terminated dialogue.*

1. *Each dialogue tree $\mathcal{T}_i$, $0 \leq i \leq n$ is coherent.*
2. *The root node of $\mathcal{T}_n$ has a determined status.*

Proof(Sketch) The second assertion follows directly from the first and the definition of s-termination and s-rationality. The first assertion is proved by case analysis of each of the s-rational locution. For each case, a double induction, first on i, then on the height of the trees will yield the expected claim. □

4. Soundness

In dialogues where both the proponent and opponent present only permissible evidence and rules, third parties (like judges, members of audience) can be seen as neutral observers who continuously observe the exchanges of locutions between the proponent and opponent, and are then persuaded by the proponent to accept his claim or dissuaded by the opponent to reject it. While observing, third parties gradually build the common commitment store of the proponent and opponent by accumulating the evidence and rules exposed in the uttered locutions.

Definition 4.1 *Given a dialogue tree $\mathcal{T}$, the common commitment store at $\mathcal{T}$, denoted $\mathcal{F}_{\mathcal{T}}$, is the assumption-based framework consisting of all inference rules in $\mathcal{T}$ together with the associated assumptions and contraries.*

The common commitment store of a dialogue d, denoted $\mathcal{F}_d$, is the common commitment store at the final dialogue state of d.

Third parties consider a successful dialogue about proposition π as a proof for π. However since a dialogue participant can win because he takes advantages of his opponent's mistakes, and can lose because he makes mistakes, third parties may or may not consider a successful dialogue as a sound proof. The third parties' notion of soundness for a successful dialogue is formalised as follows.

Definition 4.2 *A successful dialogue d of a proposition π is said to be groundedly (resp. credulously) sound if π is a grounded (resp. credulous) consequence of $\mathcal{F}_d$.*

It is well established that different argumentation semantics capture different sceptical attitudes of reasoners, with the grounded semantics capturing the most sceptical attitude and the credulous semantics capturing the least sceptical attitude [4]. Hence a reasoner may adopt different semantics for different reasoning tasks. In the legal domain, for instance, often the more serious the allegation, the less likely that it is that the allegation is correct and hence judges adopt the more sceptical semantics for the proof of the allegation. Because the grounded semantics and the credulous semantics delineates the range of possible sceptical attitudes, we want to study conditions for a successful dialogue to be sound under these two semantics in order to argue for the usefulness of our dialogue model.

4.1. Grounded soundness

Intuitively, a successful dialogue is sound if in a supposedly replayed game with hindsight where the opponent could advance any evidence and rules in the final common commitment store, the proponent still wins. Formally,

Definition 4.3 *Let d be a successful dialogue with final state $\mathcal{T}$. The opponent is said to be* **considerate** *in d if there is no opponent non-assumption or proponent assumption node N of $\mathcal{T}$ such that*

1. *N has a child labelled by $\perp$, and*
2. *there is $r \in \mathcal{F}_{\mathcal{T}}$ that can be used to expand N, i.e. $r \notin RULE_{\mathcal{T}}(N)$ and $head(r)$ occurs as the non-assumption or the contrary of the assumption in the label of N.*

Theorem 4.1 *If d is a s-successful dialogue of a proposition π in which the opponent is considerate, then π is a grounded consequence of $\mathcal{F}_d$.*

Proof (Sketch) By induction on the height of the final dialogue tree $\mathcal{T}$. Base case, where $\mathcal{T}$ consists of only the root N_0 with a single child labelled by "true" or $\perp$, is obvious. For the inductive case, there are two possibilities: a) π is a non-assumption and labels the root N_0 with status proved. From the definition of proved status in a coherent annotation, there is $r \in RULE_{\mathcal{T}}(N_0)$ s.t. each node in $CHILD_{\mathcal{T}}(N_0, r)$ has status proved or accepted. From induction hypothesis, each sentence labelling a node in $CHILD_{\mathcal{T}}(N_0, r)$ is a grounded consequence in $\mathcal{F}_d$. Hence π is a grounded consequence $\mathcal{F}_d$. b) π is an assumption and labels the root N_0 with status accepted. From the definition of s-rationality and that the opponent is considerate, it follows that for any argument $S \vdash_{\mathcal{F}_d} \overline{\pi}$ that attacks π, there is an assumption $\alpha \in S$ such that α labels an opponent node N of $\mathcal{T}$ with status defeated. From the definition of defeated status in a coherent annotation, there is $r \in RULE_{\mathcal{T}}(N)$ s.t. each node in $CHILD_{\mathcal{T}}(N, r)$ has status proved or accepted. From induction hypothesis, each sentence labelling a node in $CHILD_{\mathcal{T}}(N, r)$ is a grounded consequence in $\mathcal{F}_d$. Hence π is a grounded consequence $\mathcal{F}_d$. □

4.2. Credulous soundness

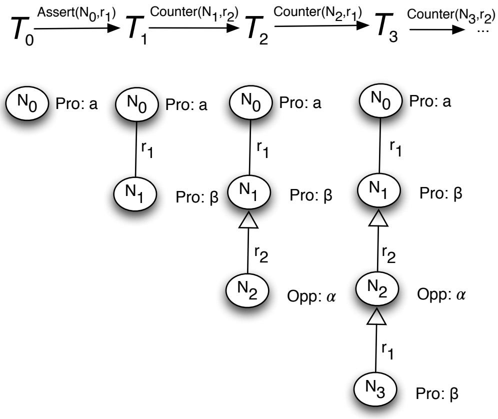
Consider the following dialogue.

Example 4.1 *Proponent asserts a using $r_1 : a \leftarrow \beta$ where $\overline{\beta} = b$, then opponent attacks assumption β by using $r_2 : b \leftarrow \alpha$ where $\overline{\alpha} = a$, then proponent counter-attacks assumption α by using r_1, then the opponent again attacks assumption β by using r_2, ad infinitum (see Fig. 4). Hence the proponent can not win.*

As a is not a grounded consequence of $\mathcal{F}$, the common commitment store consisting of just r_1 and r_2, the proponent should not win under the grounded semantics. However as a is a credulous consequence of $\mathcal{F}$, we expect that the proponent wins in a terminated dialogue under the credulous semantics.

To ensure credulous soundness, all possible counter locutions of the opponent must be accounted for. But if such a counter locution targets an assumption

Figure 4. An infinite dialogue.



already targeted by an opponent's previous counter locution (e.g. $Counter(N_3, r_2)$ in Fig. 4 of example 4.1 targets at assumption β which is already targeted by $Counter(N_1, r_2)$), then deploying it will not help the opponent wins the dialogue. This kind of counter locutions is deemed as c-redundant in the following definition.

Definition 4.4 *We say that locution m is* **c-redundant** *(credulously redundant) in state $\mathcal{T}$ if*

1. *m is of the form $Counter(N, r)$ where N is a proponent node and there is a proponent ancestor of N that contains the same assumption as N.*
2. *m is of the form $Counter(N, r)$ where N is an opponent node and there is a relevant proponent node N' that contains the same assumption as N.*

In general forbidding the opponent to move c-redundant locutions ensures the termination of dialogues when the participants stop introducing new rules into the commitment store. Note that forbidding the proponent to move c-redundant locutions ensures that the proponent is conflict-free.

We say that a locution m is **c-rational** in dialogue tree $\mathcal{T}$ if m is s-rational but not c-redundant in $\mathcal{T}$.

Definition 4.5 *A dialogue $d = \mathcal{T}_0 \xrightarrow{m_0} \mathcal{T}_1 \dots \mathcal{T}_{n-1} \xrightarrow{m_{n-1}} \mathcal{T}_n$ is said to be*

1. **c-terminated** *if for each $0 \leq i \leq n-1$, locution m_i is c-rational in $\mathcal{T}_i$ and there is no c-rational locution for both proponent and opponent in $\mathcal{T}_n$.*
2. **c-successful** *if d is c-terminated and successful.*

Theorem 4.2 *If d is a c-successful dialogue about π and the opponent is considerate in d, then π is a credulous consequence of $\mathcal{F}_d$.*

Proof (Sketch) From the considerate property, we can show that the opponent has deployed all possible attacks against the proponent's assumptions in the final dialogue tree. From property 2 in definition 4.4, we can prove that the set of proponent assumptions does not attack itself (again by showing by induction that the set of proponent assumptions in each dialogue tree in the dialogue is conflict-free). Hence the set of proponent assumptions is admissible. It is not difficult to see that there is an argument for the proposition labelling the root from this set.

5. Related work and conclusion

In this paper we present an argument-based foundation for dialogue games with grounded and credulous semantics, in settings that disputes parties present only permissible evidence and rules. Our technical framework is developed on the notion of dialogue trees which remain as simple and elegant as their predecessors, the dispute trees in [5], but are more general and flexible. We obtain two semantics for our dialogues with different notions of locution rationality. The simplicity and elegance of the framework enables us to deal with backtracking via the notion of relevance.

Our work, as well as much in the line of work aiming at developing argumentation dialogue models can be seen as originating from the work in [3] which aims at providing game-theoretical semantics and dialectical proof procedures for logic programming. There, a logic program is viewed as a common knowledge base of which both dispute parties have *full* knowledge, and a successful dialogue of a given proposition represents a proof that needs to be searched by proof procedures in order to establish the acceptability of the proposition. Since in a dialogue, participants can only have full knowledge of the common commitment store when the dialogue terminates, dialectical proof procedures can be viewed as representing the semantics of dialogue models. Hence our dialogue model could be seen as a continuation of the view in [3] and especially its developments in [5,6,8]. In particular, a dialogue in [8], for our purpose of comparison, could be viewed as a sequence $\langle 0, -1, Assert(\pi, \_)\rangle, \langle 1, ta_1, C_1\rangle, \ldots, \langle i, ta_i, C_i\rangle \ldots$ where C_i is of the form $Assert(\gamma, r)$ or $Counter(\gamma, r)$. Here γ is a non-assumption in the first case, and assumption in the second case, instead of a tree node as in our model. The meaning of i^{th} locution $\langle i, ta_i, C_i\rangle$ is that the rule r in C_i is used to expand the sentence γ introduced in the locution with index $ta_i < i$. This locution syntax could serve a syntactic sugar for our dialogue model because we can easily define an appropriate syntactic translation from this syntax to ours. However in [8] dialogue states are represented by dispute trees [5,2] alone, while in our model they are represented by dialogue trees with annotations, which provide a theoretically simple and conceptually elegant mechanism for backtracking and make it possible to deploy the notion of considerate opponent, instead of the blanket notion of exhaustiveness [8] for both proponent and opponent. Because this notion of exhaustiveness unnecessarily prevents many dialogues actually won by the proponent from being considered as successful, the class of successful dialogues in Fan and Toni's model [8] is smaller than that in our model even without considering conceding and retracting locutions.

On the roles of relevance in dialogues, Parson et al. [12] work on the level of abstract argumentation to examine how the notion impact agents choose arguments and attacks. Since our locutions are at the level of assumptions and inference rules, it is interesting to see how the results of [12] could be translated into our dialogue model. In [13], a soundness result for the nonmonotonic part of dialogues games without retract, concede locutions is given. Attitudes of agents have been studied in [1]. As the agent attitudes depend on their goals and domain, it would be interesting to see how the ideas of [1] could be incorporated into the domain of adversarial dialogues.

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