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Agent Strategies for ABA-based Information-seeking and Inquiry Dialogues

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Abstract. Much research has been devoted to the use of argumentation to support inter-agent dialogues. Here, we contribute to this line of research by investigating the strategic behaviour of agents in argumentation-based dialogues, using Assumption-Based-Argumentation (ABA) as the underlying framework. We will focus on information-seeking and inquiry dialogues, giving formalisations thereof and showing how they can be supported by specific classes of *strategy-move functions* for agents to select suitable utterances.

1 Introduction

Much research in the area of argumentation-based dialogues in recent years [11, 8] has focused on the construction of dialogue frameworks and correctness, from an argumentation perspective, of dialogue outcomes, i.e. that the outcome is "acceptable" according to chosen argumentation semantics (e.g. [2, 7, 10]). Some of these works have developed dialogue frameworks suitable for particular dialogue types, e.g. for inquiry [2] or persuasion [10]. In this paper, we continue this overall research agenda but focus on identifying strategies for agents participating in information-seeking and inquiry dialogues, as understood in [12].

The main characteristics of information-seeking and inquiry dialogues are summarised in Table 1. Thus, in both information-seeking and inquiry, agents need to determine the appropriate information to disclose. We give strategies to help agents identify "suitable" utterances (and their content) in order to advance (information-seeking and inquiry) dialogues towards their goal. We define these strategies in terms of *strategy-move functions* for the dialogues defined in [7]. These dialogues allow agents to construct argumentation frameworks in the format of Assumption-Based-Argumentation (ABA) [4, 5] and to determine the acceptability of claims explored by the dialogues. Whereas the ABA-dialogues of [7] are defined in terms of *legal-move functions*, namely *public* protocols sanctioning allowed exchanges for ensuring the dialogues' integrity (i.e. acceptability), the strategy-move functions of this paper focus on agents' *private* beliefs and aims. We prove that ABA-dialogues where agents adopt specific classes of strategy-move functions are (i) sound and (ii) complete for information-seeking and inquiry, in that (i) the ABA-dialogues constructed with these strategy-move functions achieve the main goals of these dialogue types, starting from the initial situation, and (ii) the existence of (information-seeking and inquiry) dialogues achieving the goals guarantees the existence of ABA-dialogues, constructed with these strategy-move functions, also achieving these goals. We prove these results for two novel formulations of each of information-seeking and inquiry dialogues, formalising the definitions of Table 1.

Table 1. Information-seeking and inquiry dialogues (from [12]).

Information-seeking Dialogue
Initial Situation - Personal ignorance;
Main Goal - Spreading knowledge & revealing positions;
Participant's Aims - Gain, pass on, show or hide personal knowledge.
Inquiry Dialogue
Initial Situation - General ignorance;
Main Goal - Growth of knowledge & agreement;
Participant's Aims - Find a "proof" or destroy one.

There is a large body of work on studying multi-agent systems communication, e.g., concerning FIPA standardisation. Our dialogue model is orthogonal in that it concerns higher-level agent behaviour.

The paper is organised as follows. Section 2 gives background. Section 3 gives preliminary definitions. Section 4 introduces strategies-move functions and shows formal results for dialogues constructed using them. Section 5 presents our formalisations of information-seeking and inquiry dialogues and proves soundness and completeness of strategies resulting from strategy-move functions, using the earlier results. Section 6 discusses related work. Section 7 concludes.

2 Background

Our proposed approach relies upon Assumption-Based Argumentation (ABA), and ABA-dialogues. We briefly review these below.

An ABA framework [5] is a tuple $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ where

- $\langle \mathcal{L}, \mathcal{R} \rangle$ is a deductive system, with $\mathcal{L}$ the *language* and $\mathcal{R}$ a set of *rules* of the form $\beta_0 \leftarrow \beta_1, \ldots, \beta_m (m \geq 0)$ with $\beta_i \in \mathcal{L}$, and, if $m > 1$, then $\beta_i \neq \beta_j$ for $i \neq j, 1 \leq i, j \leq m$;
- $\mathcal{A} \subseteq \mathcal{L}$ is a (non-empty) set, referred to as *assumptions*;
- $\mathcal{C}$ is a total mapping from $\mathcal{A}$ into $2^{\mathcal{L}} - \{\{\}\}$, where each $\beta \in \mathcal{C}(\alpha)$ is a *contrary* of α, for $\alpha \in \mathcal{A}$.[2]

Given a rule ρ of the form $\beta_0 \leftarrow \beta_1, \ldots, \beta_m$, β_0 is referred to as the *head* (denoted $Head(\rho) = \beta_0$) and $\beta_1, \ldots, \beta_m$ as the *body* (denoted $Body(\rho) = \{\beta_1, \ldots, \beta_m\}$). An ABA framework is *flat* iff no assumption is the head of a rule.

In ABA, *arguments* are deductions of claims using rules and supported by sets of assumptions, and *attacks* are directed at the assumptions in the support of arguments. Informally, following [5]:

- *an argument for (the claim)* $\beta \in \mathcal{L}$ *supported by* $A \subseteq \mathcal{A}$ *(*$A \vdash \beta$ in short) is a (finite) tree with nodes labelled by sentences in $\mathcal{L}$ or by τ[3], the root labelled by β, leaves either τ or assumptions in A,

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[2] In standard ABA [5], contrary maps to a single sentence. This generalisation is equivalent to the standard version. Also, standard ABA does not require $\beta_i \neq \beta_j$ in rules, but this can be imposed with no loss of generality.

[3] $\tau \notin \mathcal{L}$ represents "true" and stands for the empty body of rules.

and non-leaves β' with, as children, the elements of the body of some rule with head β';
- *an argument* $A_1 \vdash \beta_1$ attacks an argument $A_2 \vdash \beta_2$ iff β_1 is a contrary of one of the assumptions in A_2.

Attacks between (sets of) arguments correspond in ABA to attacks between sets of assumptions, where *a set of assumptions A attacks a set of assumptions A'* iff an argument supported by a subset of A attacks an argument supported by a subset of A'.

With argument and attack defined for a given $\mathcal{F} = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$, standard argumentation semantics can be applied in ABA [5], e.g.:

- *a set of assumptions is admissible* (in $\mathcal{F}$) iff it does not attack itself and it attacks all $A \subseteq \mathcal{A}$ that attack it; *grounded* (in $\mathcal{F}$) iff it the least set (wrt. $\subseteq$) that is admissible and contains all assumptions it *defends*, where $A \subseteq \mathcal{A}$ defends $\alpha \in \mathcal{A}$ iff A attacks all sets of assumptions that attack α; *ideal* (in $\mathcal{F}$) iff it is the largest admissible set contained in all maximally admissible sets;
- *an argument $A \vdash \beta$ is admissible (grounded, ideal) supported (in $\mathcal{F}$) by $A' \subseteq \mathcal{A}$* iff $A \subseteq A'$ and A' is admissible (grounded, ideal, resp.); *a sentence is $\mathcal{S}$-acceptable* for $\mathcal{S} \in$ {admissible, grounded, ideal} (in $\mathcal{F}$) iff it is the claim of an argument that is $\mathcal{S}$ supported (in $\mathcal{F}$) by some $A \subseteq \mathcal{A}$.

ABA-dialogues [7] are conducted between two agents a_1 and a_2 that can be thought of as being equipped with ABA frameworks $\langle \mathcal{L}, \mathcal{R}_1, \mathcal{A}_1, \mathcal{C}_1 \rangle$ and $\langle \mathcal{L}, \mathcal{R}_2, \mathcal{A}_2, \mathcal{C}_2 \rangle$ resp., sharing a common language $\mathcal{L}$. An ABA-dialogue is made of *utterances* of the form $\langle a_i, a_j, T, C, ID \rangle$ (for $i, j = 1, 2, i \neq j$) where:

- C (the *content*) is one of: $claim(\beta)$ for some $\beta \in \mathcal{L}$ (a *claim*); $rl(\beta_0 \leftarrow \beta_1, \ldots, \beta_m)$ for some $\beta_0, \ldots, \beta_m \in \mathcal{L}$ (a *rule*); $asm(\alpha)$ for some $\alpha \in \mathcal{L}$ (an *assumption*); $ctr(\alpha, \beta)$ for some $\alpha, \beta \in \mathcal{L}$ (a *contrary*); a *pass* sentence $\pi \notin \mathcal{L}$;
- $ID \in \mathbb{N}$ (the *identifier*);
- $T \in \mathbb{N} \cup \{0\}$ (the *target utterance*) such that $T < ID$.

Utterances with content other than π or $claim(\_)$ are termed *regular-utterances*.[4] An utterance $\langle a_i, a_j, T, C, ID \rangle$ is *from a_i to a_j*.

Given this notion of utterances, a *dialogue* $\mathcal{D}^{a_i}_{a_j}(\chi)$ (*between agents a_i and a_j* for $\chi \in \mathcal{L}$), is a finite sequence $\delta = \langle u_1, \ldots, u_n \rangle$, $n \geq 0$, where each u_l, $l = 1, \ldots, n$, is an utterance from a_i or a_j, u_1 is an utterance from a_i, and (1) the content of u_l is $claim(\chi)$ iff $l = 1$; (2) the target of pass- and claim utterances in δ is 0; (3) for every $u_i = \langle \_, \_, T, \_, \_ \rangle$ with $i > 1$ and $T \neq 0$, there is a non-pass-utterance $u_k = \langle \_, \_, \_, C, T \rangle$ for $k < i$; (4) no two consecutive utterances in δ are pass-utterances, other than possibly the last two utterances, u_{n-1} and u_n. Intuitively, the identifier of an utterance represents the position of the utterance in a dialogue, and its target is the identifier of some earlier utterance in the dialogue. $\mathcal{D}^{a_i}_{a_j}(\chi)$ is referred to as *complete* iff its last two utterances are pass-utterances. Unless otherwise specified, dialogues in later discussion are all complete. Given a dialogue $\delta = \langle u_1, \ldots, u_n, \rangle$ and an utterance u, $\delta \circ u = \langle u_1, \ldots, u_n, u \rangle$.

The *framework drawn from a dialogue* $\delta = \langle u_1, \ldots, u_n \rangle$ is $F_\delta = \langle \mathcal{L}, \mathcal{R}_\delta, \mathcal{A}_\delta, \mathcal{C}_\delta \rangle$ where

- $\mathcal{R}_\delta = \{\rho | rl(\rho)$ is the content of some u_i in $\delta\}$;
- $\mathcal{A}_\delta = \{\alpha | asm(\alpha)$ is the content of some u_i in $\delta\}$;
- $\mathcal{C}_\delta(\alpha) = \{\beta | ctr(\alpha, \beta)$ is the content of some u_i in $\delta\}$.

Several restrictions can be imposed on dialogues so that they fulfil desirable properties, and in particular properties P1) the framework drawn from them is a flat ABA framework (i.e. with no assumption in the head of rules and such that all assumptions have contraries), and P2) utterances are "related to" their target utterances, where $u_j = \langle \_, \_, T, C_j, \_ \rangle$ is *related to* $u_i = \langle \_, \_, \_, C_i, ID \rangle$ iff $T = ID$ and one of the following cases holds:

- $C_j = rl(\rho_j)$, $Head(\rho_j) = \beta$ and either $C_i = rl(\rho_i)$ with $\beta \in Body(\rho_i)$, or $C_i = ctr(\_, \beta)$, or $C_i = claim(\beta)$;
- $C_j = asm(\alpha)$ and either $C_i = rl(\rho)$ with $\alpha \in Body(\rho)$, or $C_i = ctr(\_, \alpha)$, or $C_i = claim(\alpha)$;
- $C_j = ctr(\alpha, \_)$ and $C_i = asm(\alpha)$.

Properties P1) and P2) above can be enforced using the notion of *legal-move functions*, which are mappings $\lambda : \mathcal{D} \mapsto 2^{\mathcal{U}}$ (where $\mathcal{D}$ is the set of all possible dialogues and $\mathcal{U}$ is the set of all possible utterances)[5] such that, given $\delta = \langle u_1, \ldots, u_n \rangle \in \mathcal{D}$, for all $u \in \lambda(\delta)$: $\delta \circ u$ is a dialogue and if $u = \langle \_, \_, T, C, \_ \rangle$, then there exists no $i, 1 \leq i \leq n$, such that $u_i = \langle \_, \_, T, C, \_ \rangle$. We say that δ is *compatible with* λ. Thus, there is no repeated utterance to the same target in a dialogue compatible with a legal-move function. It is possible to define legal-move functions that guarantee P1 and P2 [7]: here, we will refer to complete dialogues fulfilling these properties as *coherent*.

Another property studied in [7] concerns the admissibility of the claim of a coherent dialogue in the ABA framework drawn from this dialogue. This is guaranteed for coherent and *successful dialogues* compatible with a *focused legal-move function* (Theorem 1 in [7]). Dialogues that are compatible with a focused legal-move function are called *focused dialogues*. Intuitively, in a focused dialogue, only a single way of proving or defending the topic is examined. We omit the formal definitions of successful and focused dialogues for lack of space, but we will use the result in Theorem 1 in [7], as well as the following extension (for the grounded semantics) thereof:

if a focused dialogue $\delta = \mathcal{D}^{a_i}_{a_j}(\chi)$ is successful
then χ is $\mathcal{S}$-acceptable in $\mathcal{F}_\delta$ for $\mathcal{S} \in$ {admissible, grounded}.

The extension to the grounded semantics is straightforward, as the original result is proven by extracting admissible dispute trees [6] from successful dialogues and using the result, in [6], that they compute admissible sets. Since dialogues are finite, the dispute trees are also finite, and thus grounded and computing grounded sets [6].

3 Preliminaries

Agents have private beliefs in some internal representation. However, when they interact within dialogues they exchange information in a shared language. Following [7], we assume that this language is that of ABA, namely agents exchange rules, assumptions and their contraries, expressed in some shared logical language $\mathcal{L}$. Thus, agents can be thought of as being equipped with ABA frameworks. We will often use the ABA framework an agent is equipped with to denote the agent itself. We will focus on the case of two agents, $a_1 = \langle \mathcal{L}, \mathcal{R}_1, \mathcal{A}_1, \mathcal{C}_1 \rangle$ and $a_2 = \langle \mathcal{L}, \mathcal{R}_2, \mathcal{A}_2, \mathcal{C}_2 \rangle$. Note that even though the language $\mathcal{L}$ is shared, $\mathcal{R}_1 \neq \mathcal{R}_2$, $\mathcal{A}_1 \neq \mathcal{A}_2$ and $\mathcal{C}_1 \neq \mathcal{C}_2$, in general.

We will use the term *frameworks* to describe tuples of the form $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ but where $\mathcal{C}$ is a mapping from $\mathcal{A}$ into $2^{\mathcal{L}}$. Obviously, ABA frameworks are frameworks but not vice versa.

We will often need to refer to the beliefs that the two agents have collectively, formalised by the following notion:

[4] Throughout, _ stands for an anonymous variable as in Prolog.

[5] In [7], legal-move functions have co-domain $\mathcal{U}$ instead of $2^{\mathcal{U}}$. Our definition is a useful generalisation indicating that there might be more than one utterance allowed by a legal-move function.

Definition 1. Given frameworks $\mathcal{F}_1 = \langle \mathcal{L}, \mathcal{R}_1, \mathcal{A}_1, \mathcal{C}_1 \rangle$ and $\mathcal{F}_2 = \langle \mathcal{L}, \mathcal{R}_2, \mathcal{A}_2, \mathcal{C}_2 \rangle$, the *joint framework* (of $\mathcal{F}_1$ and $\mathcal{F}_2$) is $\mathcal{F}_J = \mathcal{F}_1 \uplus \mathcal{F}_2 = \langle \mathcal{L}, \mathcal{R}_1 \cup \mathcal{R}_2, \mathcal{A}_1 \cup \mathcal{A}_2, C_J \rangle$, where $\mathcal{C}_J(\alpha) = \mathcal{C}_1(\alpha) \cup \mathcal{C}_2(\alpha)$, for all α in $\mathcal{A}_1 \cup \mathcal{A}_2$.[6] Given frameworks $\mathcal{F}_J$ and $\mathcal{F}_1$, $\mathcal{F}_1$ is a *sub-framework of* $\mathcal{F}_J$, written $\mathcal{F}_1 \sqsubseteq \mathcal{F}_J$, iff there exists $\mathcal{F}_2$ such that $\mathcal{F}_1 \uplus \mathcal{F}_2 = \mathcal{F}_J$. We use $\mathcal{F}_J$ also to denote $a_1 \uplus a_2$.

We will illustrate notions and results in the context of the following example, adapted from the movie *Twelve Angry Men*, an example of argumentation-based collaborative reasoning [1]. Here, we focus on the reasoning of two of the jurors: juror 8, played by Henry Fonda (a_1), and juror 9, played by Joseph Sweeney (a_2). These agents need to decide whether to condemn a boy, accused of murder, or acquit him, after a trial where two witnesses have provided evidence against the boy. According to the law, the jurors should acquit the boy if they do not believe that the trial has proven him guilty convincingly.

Example 1. Table 2 gives the ABA frameworks of a_1 and a_2 (as indicated in the rightmost column) as well as their joint framework $\mathcal{F}_J$ (given by the entire leftmost column). The components of these ABA frameworks should be self-explanatory. For example, the first rule says that the boy should be deemed to be innocent if it cannot be proven guilty. This can be assumed (as boy_not_proven_guilty $\in \mathcal{A}_1 = \mathcal{A}_2 = \mathcal{A}_J$) but can be objected to, by proving its contrary (boy_proven_guilty). The second and third rules provide ways to prove this contrary, and they rely upon assumptions in turn, etc.

Table 2. ABA frameworks for Example 1. $\mathcal{L}$ is implicit here and in all examples as it contains all sentences in rules, assumptions, and contraries.

Rules: ($\mathcal{R}_J$)	
boy_innocent ← boy_not_proven_guilty	a_1, a_2
boy_proven_guilty ← w1_is_believable	a_1, a_2
boy_proven_guilty ← w2_is_believable	a_1, a_2
w1_not_believable ← w1_contradicted_by_w2	a_1
w1_contradicted_by_w2 ←	a_1
w2_not_believable ← w2_has_poor_eyesight	a_1
w2_has_poor_eyesight ←	a_2
w2_is_blonde ←	a_2
w1_is_poor ←	a_2
Assumptions: ($\mathcal{A}_J$)	
boy_not_proven_guilty	a_1, a_2
w1_is_believable	a_1, a_2
w2_is_believable	a_1, a_2
Contraries: ($\mathcal{C}_J$)	
$\mathcal{C}$(boy_not_proven_guilty) = {boy_proven_guilty}	a_1, a_2
$\mathcal{C}$(w1_is_believable) = {w1_is_not_believable}	a_1, a_2
$\mathcal{C}$(w2_is_believable) = {w2_is_not_believable}	a_1, a_2

We will assume that a_1, a_2 and $\mathcal{F}_J$ are flat, in line with [5]. This is the case in example 1. We will use the notation $A \vdash_R \beta$ for an argument where β is the claim, A is the support, and R is the set of rules used to construct the argument, e.g., in example 1, given ρ=(boy_innocent←boy_not_proven_guilty): {boy_not_proven_guilty} $\vdash_{\{\rho\}}$ boy_innocent is an argument.

When studying dialogues, we will restrict attention to the agents' beliefs that are (directly and indirectly) *rule-related* and *related* (resp.) to that topic, as defined below.

Definition 2. Y is *directly rule-related* to X wrt. a framework $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ iff:

X is an assumption $\alpha \in \mathcal{A}$ and Y is α; or
X is a sentence $\beta \in \mathcal{L} \setminus \mathcal{A}$ and Y is a rule $\beta \leftarrow \_ \in \mathcal{R}$; or
X is a rule $\beta_0 \leftarrow \beta_1, \ldots, \beta_n \in \mathcal{R}$ with $n \geq 1$ and Y is
either a rule $\beta_i \leftarrow \_ \in \mathcal{R}$, if $\beta_i \notin \mathcal{A}$,
or an assumption $\beta_i \in \mathcal{A}$.

Let $\mathcal{O}_{rr}$ be (the monotonic operator) defined, for any $W \subseteq \mathcal{L} \cup \mathcal{R}$, as $\mathcal{O}_{rr}(W) = \{Y | Y$ is directly rule-related to $X \in W\}$. Then, Y is *(directly or indirectly) rule-related* to X wrt. a framework $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ iff Y belongs to the least fix-point of $\mathcal{O}_{rr}(\{X\})$.

Intuitively, rules and assumptions used to construct an argument are rule-related to the argument's claim.

Definition 3. Y is *directly related* to X wrt. a framework $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ iff:

X is an assumption $\alpha \in \mathcal{A}$ and Y is $\mathcal{C}(\alpha) = \_$; or
X is a sentence $\beta \in \mathcal{L} \setminus \mathcal{A}$ and Y is a rule $\beta \leftarrow \_ \in \mathcal{R}$; or
X is a rule, and Y is directly rule-related to X; or
X is $\mathcal{C}(\_) = B$ and Y is
either a rule $\beta \leftarrow \_ \in \mathcal{R}$, for some $\beta \in B$,
or an assumption $\alpha \in B \cap \mathcal{A}$.

Let $\mathcal{O}_r$ be (the monotonic operator) defined, for any $W \subseteq \mathcal{L} \cup \mathcal{R} \cup \{\mathcal{C}(\alpha) = B | \alpha \in \mathcal{A}, B \subseteq \mathcal{L}\}$, as $\mathcal{O}_r(W) = \{Y | Y$ is directly related to $X \in W\}$. Then, Y is *(directly or indirectly) related* to X wrt. a framework $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ iff Y belongs to the least fix-point of $\mathcal{O}_r(\{X\})$.

Intuitively, rules, assumptions, contraries used to build a "dispute" for an argument are related to the claim of the argument.

The following lemma is trivially true by definitions 2 and 3.

Lemma 1. For all arguments $A \vdash_R \chi$, if $X \in A \cup R$, $X \neq \{\}$, then X is related to χ.

The notions of rule-related and related can be used to identify suitable sub-frameworks of frameworks, as follows:

Definition 4. Given a framework $\mathcal{F} = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ and a sentence $\chi \in \mathcal{L}$, let $Y = \{X | X$ is rule-related to χ wrt. $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle\}$. The *$\chi$-rule-related framework* of $\mathcal{F}$ is $\mathcal{F}^{\chi r} = \langle \mathcal{L}, \mathcal{R}^{\chi r}, \mathcal{A}^{\chi r}, \mathcal{C}^{\chi r} \rangle$, with $\mathcal{R}^{\chi r} = Y \cap \mathcal{R}$, $\mathcal{A}^{\chi r} = Y \cap \mathcal{A}$, and $\mathcal{C}^{\chi r}(\alpha) = \{\}$ for each $\alpha \in \mathcal{A}^{\chi r}$.

Namely, the $\chi-$rule-related framework is a sub-framework with all rules and assumptions used in arguments for χ, as illustrated next:

Example 2. (Continuation of example 1) Let χ= boy_proven_guilty. Then $\mathcal{F}^{\chi r}$ is $\langle \mathcal{L}, \mathcal{R}^{\chi r}, \mathcal{A}^{\chi r}, \mathcal{C}^{\chi r} \rangle$ with $\mathcal{C}^{\chi r}(\alpha) = \{\}$ for each α and

$\mathcal{R}^{\chi r} = \{$boy_proven_guilty ← w1_is_believable;
boy_proven_guilty ← w2_is_believable$\}$
$\mathcal{A}^{\chi r} = \{$w1_is_believable, w2_is_believable$\}$

Note that χ-rule-related frameworks are generally not ABA frameworks since they define the contrary of every assumption as empty.

Similarly, we can define topic-related frameworks as follows.

Definition 5. Given a framework $\mathcal{F} = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ and a sentence $\chi \in \mathcal{L}$, let $Y = \{X | X$ is related to χ wrt. $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle\}$. Then, the *$\chi$-related framework* of $\mathcal{F}$ is $\mathcal{F}^{\chi} = \langle \mathcal{L}, \mathcal{R}^{\chi}, \mathcal{A}^{\chi}, \mathcal{C}^{\chi} \rangle$ with $\mathcal{R}^{\chi} = Y \cap \mathcal{R}$; $\mathcal{A}^{\chi} = Y \cap \mathcal{A}$; $\mathcal{C}^{\chi}$ is such that, for every $\alpha \in \mathcal{A}^{\chi}$, $\mathcal{C}^{\chi}(\alpha) = B$ iff $(\mathcal{C}(\alpha) = B) \in Y$.

Namely, the χ-related framework is a sub-framework that contains all information (directly or indirectly) related to χ, as illustrated next:

Example 3. (Continuation of example 1) Let χ= boy_innocent. Then w2_is_blonde ← and w1_is_poor ← are not related to χ. Therefore, the χ-related framework, $\mathcal{F}^{\chi}$, of $\mathcal{F}_J$ is $\mathcal{F}_J$ with these rules omitted.

Assumptions in χ-related frameworks admit non-empty contraries. Thus, for any ABA framework $\mathcal{F}$, $\mathcal{F}^{\chi}$ is an ABA framework.

[6] We assume that $\mathcal{C}_i(\alpha) = \{\}$ if $\alpha \notin \mathcal{A}_i$, for $i = 1, 2$.

Notation 1. We will say that an argument $A \vdash_R \beta$ is *in* $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$ iff $\beta \in \mathcal{L}$, $A \subseteq \mathcal{A}$, and $R \subseteq \mathcal{R}$. Moreover, given a dialogue $\delta \in \mathcal{D}$, we will say that $\texttt{Arg}$ is *in* δ and δ *contains* $\texttt{Arg}$ iff $\texttt{Arg}$ is in $\mathcal{F}_\delta$.

The following lemmas trivially hold by definitions 4 and 5.

Lemma 2. Given an ABA framework $\mathcal{F}$, an argument $\texttt{Arg} = A \vdash_R \chi$ is *in* $\mathcal{F}$ iff $\texttt{Arg}$ is *in* $\mathcal{F}^{\chi r}$.

Lemma 3. Given an ABA framework $\mathcal{F} = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$, $\chi \in \mathcal{L}$, then χ is $\mathcal{S}$-acceptable in $\mathcal{F}$ iff χ is $\mathcal{S}$-acceptable in $\mathcal{F}^\chi$, for $\mathcal{S} \in$ {admissible, grounded, ideal}.

Finally, we will adopt the following notation: $\mathcal{U}^i$ stands for all utterances from a_i in $\mathcal{U}$, namely of the form $\langle a_i, \_, \_, \_, \_ \rangle$, and, for any utterance $\langle a_i, \_, \_, \_, \_ \rangle = u$, we also say that u is *made by* a_i.

4 Strategy-move Functions

In ABA dialogues, agents make utterances that contains rules, assumptions and contraries. The selection of utterances must satisfy the integrity of the dialogue and the aims of the agents. Legal-move functions (see Section 2) are used to keep the integrity. Here, we introduce *strategy-move functions* to specify agents' behaviours that are suitable for their aims and for the aims of the dialogues they are engaged in. We use Λ to denote the set of all legal-move functions.

Definition 6. A *strategy-move function* for agent a_i ($i = 1, 2$) is a mapping $\phi : \mathcal{D} \times \Lambda \mapsto 2^{\mathcal{U}^i}$, such that, given $\lambda \in \Lambda$ and $\delta \in \mathcal{D}$: $\phi(\delta, \lambda) \subseteq \lambda(\delta)$.

Given a coherent dialogue $\mathcal{D}^{a_i}_{a_j}(\chi) = \delta = \langle u_1, \ldots, u_n \rangle$ compatible with a legal-move function λ (see Section 2) and a strategy-move function ϕ for a_k ($k = i, j$), if, for all $u_m = \langle a_k, \_, \_, \_, \_ \rangle$, $1 < m \leq n$, $u_m \in \phi(\langle u_1, \ldots, u_{m-1} \rangle, \lambda)$, then we say that δ is *constructed with* ϕ wrt. a_k and a_k *uses* ϕ in δ. Furthermore, if a_i and a_j both use ϕ, then we say that δ is *constructed with* ϕ.

We use Φ to denote the set of all strategy-move functions.

In the remainder of this section we define a number of strategy-move functions that we will then use for information-seeking and inquiry. The first strategy-move function characterises the "truthfulness" of agents. If a dialogue is constructed with a *truthful strategy-move function* wrt. a_k, then a_k only utter rules, assumptions, and contraries it believes (namely, from its ABA framework).

Definition 7. A *truthful strategy-move function* $\phi \in \Phi$ for agent a_k ($k \in \{1, 2\}$) is such that, given a dialogue $\delta \in \mathcal{D}$ and a legal-move function $\lambda \in \Lambda$, for all $u \in \phi(\delta, \lambda)$ made by a_k, the content C of u is such that: if $C = rl(\rho)$, then $\rho \in \mathcal{R}_k$, if $C = asm(\alpha)$, then $\alpha \in \mathcal{A}_k$, if $C = ctr(\beta, \beta')$, then $\beta' \in \mathcal{C}_k(\beta)$. With an abuse of notation, we refer to a generic truthful strategy-move function as ϕ_t.

The second strategy-move function we define characterises the "completeness" of an agent's utterances: the *thorough strategy-move function* specifies that agents must not utter π if there is any other "truthful" utterance allowed by the given legal-move function.

Definition 8. A *thorough strategy-move function* $\phi \in \Phi$ for agent a_k ($k \in \{1, 2\}$) is such that, given $\delta \in \mathcal{D}$ such that δ is constructed with a truthful strategy-move function wrt. a_k, given $\lambda \in \Lambda$, for all $u \in \phi(\delta, \lambda)$ made by a_k, if u is a pass-utterance then there exists no regular utterance $u \in \lambda(\delta) \cap \mathcal{U}^k$ such that $\delta \circ u$ is constructed with a truthful strategy-move function. We refer to a generic thorough strategy-move function as ϕ_h.

We further define the notion of *non-attack strategy-move function*, specifying that agents do not utter contraries. Hence, agents that use the non-attack strategy can only construct arguments.

Definition 9. A *non-attack strategy-move function* $\phi \in \Phi$ for agent a_k ($k \in \{1, 2\}$) is such that given $\delta = \langle u_1, \ldots, u_n \rangle$ constructed with a_k using ϕ, then there is no utterance $u_i, 1 \leq i \leq n$ of the form $\langle a_k, \_, \_, ctr(\_, \_), \_ \rangle$ in δ. We refer to a generic non-attack strategy-move function as ϕ_n.

We also use *non-attack-thorough strategy-move functions*, generically indicated as ϕ_{nh}. Intuitively, an agent that uses ϕ_{nh} attempts to utter all rules and assumptions from its ABA framework.

Agents that use a *pass strategy-move* function may initiate dialogues but do not utter any other information throughout them:

Definition 10. A *pass strategy-move function* $\phi \in \Phi$ for agent a_k ($k \in \{1, 2\}$) is such that given $\mathcal{D}^{a_i}_{a_j}(\chi) = \delta \in \mathcal{D}$ and $\lambda \in \Lambda$, if $i = k$ then (for $j \neq i, j = 1, 2$):

$$\phi(\delta, \lambda) = \begin{cases} \{\langle a_i, a_j, 0, claim(\chi), 1 \rangle\} & \text{if } \delta = \langle\rangle; \\ \{\langle a_i, a_j, 0, \pi, ID \rangle | ID \in \mathbb{N}\} & \text{otherwise.} \end{cases}$$

We refer to a generic pass strategy-move function as ϕ_p.

We give a number of properties for strategy-move functions. The non-attack and thorough strategy-move functions jointly give an agent disclosing all rules and assumptions in arguments for the topic.

Proposition 1. Given a coherent dialogue $\mathcal{D}^{a_i}_{a_j}(\chi) = \delta$ for $a_i, a_j \in \{a_1, a_2\}$ constructed using ϕ_{nh} wrt. $a_k, k \in \{i, j\}$, then for all arguments $\texttt{Arg} = A \vdash \chi$ in a_k, $\texttt{Arg}$ is in $\mathcal{F}_\delta$.

Proof. For any argument $A \vdash_R \chi$, for all $\alpha \in A$ and $\rho \in R$, α and ρ are related to χ (lemma 1). Given that δ is coherent and constructed with ϕ_{nh} wrt. a_k, all such α and ρ in a_k must be disclosed in δ, i.e., there are utterances of the form $\langle \_, \_, \_, rl(\rho), \_ \rangle$ or $\langle \_, \_, \_, asm(\alpha), \_ \rangle$ in δ. (It is uncertain which agent makes these utterances though, as both agents can make them. However, it is certain that if the other agent does not make such utterances, a_k will.) Therefore if $A \vdash_R \chi$ is in a_k, it is also in $\mathcal{F}_\delta$. □

Note that proposition 1 does not specify a strategy-move function for the other agent $a'_k \in \{a_i, a_j\}, a'_k \neq a_k$. Hence proposition 1 describes a situation where, regardless of the strategy a'_k uses, as long as a_k uses ϕ_{nh}, then all $A \vdash \chi$ in a_k are disclosed in δ.

Proposition 2. Given a coherent dialogue $\mathcal{D}^{a_i}_{a_j}(\chi) = \delta$, constructed with ϕ_t, for $a_i, a_j \in \{a_1, a_2\}$, it holds that $\mathcal{F}_\delta \sqsubseteq \mathcal{F}_J$.

Proof. From definition 7, if both agents only utter information from their ABA frameworks, then obviously $\mathcal{F}_\delta$ is a sub-framework of the joint ABA framework of the two agents. □

Proposition 3. If $\mathcal{F}_J$ is flat and $\mathcal{D}^{a_i}_{a_j}(\chi) = \delta$ is a coherent dialogue constructed with ϕ_h, then $\mathcal{F}_\delta$ is flat.

Proof. Every rule, assumption and contrary in $\mathcal{F}_\delta$ is also in $\mathcal{F}_J$ (proposition 2), so the flatness of $\mathcal{F}_J$ implies the flatness of $\mathcal{F}_\delta$ (since trivially any sub-framework of a flat ABA framework is flat). □

Since ϕ_h represents truthfulness and thoroughness, coherent dialogues constructed with ϕ_h contain all information about the dialogue topic from the two agents. In this case, the ABA framework drawn from a dialogue and the topic-related framework obtained from the joint framework of the two agents are the same. Formally:

Lemma 4. Given a coherent dialogue $\delta = \mathcal{D}^{a_i}_{a_j}(\chi)$ constructed with ϕ_h, if the χ-related framework of $\mathcal{F}_J$ is $\mathcal{F}^\chi$, then $\mathcal{F}^\chi = \mathcal{F}_\delta$.

Proof. We need to show that $\nexists W$, such that W is either a rule, assumption, or contrary in $\mathcal{F}_J$ and W is (directly and indirectly) related to χ but W is not the content of any utterance in δ. Such W cannot exist because δ is constructed with ϕ_h, hence both agents are bound to utter all rules, assumptions, and contraries that are (directly and indirectly) related to χ from their ABA frameworks. □

We link acceptability in the framework drawn from a dialogue constructed with ϕ_h and the joint ABA framework.

Theorem 1. Given a coherent dialogue $\mathcal{D}^{a_i}_{a_j}(\chi) = \delta$, for $a_i, a_j \in \{a_1, a_2\}$, constructed with ϕ_h, χ is $\mathcal{S}$-acceptable in $\mathcal{F}_J$, for $\mathcal{S} \in \{\text{admissible, grounded, ideal}\}$, iff χ is $\mathcal{S}$-acceptable in $\mathcal{F}_\delta$.

Proof. By lemma 3, the acceptability of χ is the same in $\mathcal{F}_J$ and $\mathcal{F}^\chi$, the χ-related framework of $\mathcal{F}_J$. By lemma 4, given a coherent $\delta \in \mathcal{D}$ constructed with ϕ_h, we have $\mathcal{F}_\delta = \mathcal{F}^\chi$. Hence the lemma holds. □

However, the acceptability of the topic in the joint framework can sometimes be assessed with a sub-framework of $\mathcal{F}^\chi$.

Theorem 2. Given a focused dialogue $\mathcal{D}^{a_i}_{a_j}(\chi) = \delta$ constructed with ϕ_h, for $a_i, a_j \in \{a_1, a_2\}$, if δ is successful, then χ is $\mathcal{S}$-acceptable in $\mathcal{F}_J$, for $\mathcal{S} \in \{\text{admissible, grounded}\}$.

Proof. Let $\mathcal{F}_\delta$ be $\langle \mathcal{L}, \mathcal{R}_\delta, \mathcal{A}_\delta, \mathcal{C}_\delta \rangle$ and let $\mathcal{F}_J$ be $\langle \mathcal{L}, \mathcal{R}_J, \mathcal{A}_J, \mathcal{C}_J \rangle$.

(1) Since δ is focused and successful, χ is $\mathcal{S}$-acceptable in $\mathcal{F}_\delta$. Then there is $A \vdash \chi$ and a set of $\mathcal{S}$-acceptable assumptions $\mathcal{A} \subseteq \mathcal{A}_\delta$ (in $\mathcal{F}_\delta$), such that $A \subseteq \mathcal{A}$ (theorem 1 of [7]). Hence there does not exist $A' \subseteq \mathcal{A}_\delta$ such that A' attacks $\mathcal{A}$ and A' is not attacked by $\mathcal{A}$.

(2) Since δ is a focused and constructed with ϕ_h, then for all assumptions $A^* \subseteq \mathcal{A}_J$, if A^* attacks $\mathcal{A}$ in $\mathcal{F}_J$, then $A^* \subseteq \mathcal{A}_\delta$.

By (1) and (2), there is no $A^* \subseteq \mathcal{A}_J$, such that A^* attacks $\mathcal{A}$ and A^* is not attacked by $\mathcal{A}$. Hence $\mathcal{A}$ and χ are $\mathcal{S}$-acceptable in $\mathcal{F}_J$. □

Theorem 2 is useful as if the agents want to justify the acceptability (under admissible and grounded semantics) of a topic in the joint framework, then it is sufficient to justify the topic using a focused dialogue, thus requiring less disclosure of agents' beliefs. Note that theorem 2 does not hold for the ideal semantics as focused dialogues do not compute it. Also, the converse of theorem 2 is not true: given that δ is a focused dialogue constructed with ϕ_h, if δ is not successful, then χ may or may not be $\mathcal{S}$-acceptable in $\mathcal{F}_J$, as illustrated next:

Example 4. Let $\mathcal{F}_J = \langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \mathcal{C} \rangle$, with $\mathcal{R} = \{\chi \leftarrow a; \chi \leftarrow b; b \leftarrow\}$ and $\mathcal{A} = \{\}$. Then $\langle \langle a_1, a_2, 0, claim(\chi), 1\rangle, \langle a_2, a_1, 1, rl(\chi \leftarrow a), 2\rangle, \langle a_2, a_1, 0, \pi, 3\rangle, \langle a_1, a_2, 0, \pi, 4\rangle \rangle$ is focused but non-successful, even if χ is $\mathcal{S}$-acceptable in $\mathcal{F}_J$, for $\mathcal{S} \in \{\text{grounded, admissible}\}$.

5 Strategies for Dialogues

We draw two formulations for each of information-seeking and inquiry dialogues from the given Walton & Krabbe's description, and link these formulations to strategy-move functions.

Information-Seeking Dialogues. In table 3, we model information-seeking dialogues as engaging a *questioner* agent a_1 posing a topic, χ, and an *answerer* agent a_2 uttering information of relevance to χ. The purpose is to spread knowledge about arguments for χ. We assume that the questioner contributes no information, apart from initiating the dialogue; and the answerer is interested in conveying information *for* χ, but not *against*. Thus, there is an asymmetric distribution of information, in line with the original specification. IS-Type I dialogues convey all arguments whereas IS-Type II dialogues convey only one argument.

Table 3. Two formulations of information-seeking dialogues.

Information-seeking Dialogue:	
IS-Type I:	Initial Situation: some $A \vdash \chi$ in a_2 which is not in a_1. Main Goal: find δ s.t. all $A \vdash \chi$ in a_2 are in $\mathcal{F}_\delta$.
IS-Type II:	Initial Situation: some $A \vdash \chi$ in a_2 but none in a_1. Main Goal: find δ s.t. one $A \vdash \chi$ in a_2 is in $\mathcal{F}_\delta$.

The following result sanctions the soundness, for IS-Type I information-seeking, of the questioner using ϕ_p and the answerer using ϕ_{nh} to construct coherent dialogues.

Proposition 4. Let $A \vdash \chi$ be in a_2 but not in a_1. Then, if a coherent dialogue $\delta = \mathcal{D}^{a_1}_{a_2}(\chi)$ is constructed by a_1 using ϕ_p and a_2 using ϕ_{nh}, then $\mathcal{F}_\delta$ contains all $A' \vdash \chi$ in a_2.

Proof. Directly from proposition 1 (where a_1 uses ϕ_p, rather than an unspecified strategy-move function). □

The next result sanctions completeness, for IS-Type I information-seeking, of coherent dialogues with the answerer using ϕ_{nh}.

Proposition 5. Let $A \vdash \chi$ be in a_2 but not in a_1. Then, if there is $\delta = \mathcal{D}^{a_1}_{a_2}(\chi)$ such that $\mathcal{F}_\delta$ contains all $A' \vdash \chi$ that are in a_2, then there exists a coherent dialogue δ' constructed by a_1 using ϕ_p and a_2 using ϕ_{nh} such that $\mathcal{F}_{\delta'}$ contains all $A' \vdash \chi$ that are in a_2.

Proof. δ' can be constructed as follows. Given that a_1 uses ϕ_p, a_1 will utter the claim, but not contribute any rule, assumption, or contrary to δ'. Given that there exists $A_1 \vdash_{R_1} \chi, \ldots, A_n \vdash_{R_n} \chi$ in a_2, δ' can be constructed in a way such that for every $\alpha \in A_1 \cup \ldots \cup A_n$ and $\rho \in R_1 \cup \ldots \cup R_n$, there is an utterance of the form $\langle a_2, a_1, \_, rl(\rho), \_\rangle$ or $\langle a_2, a_1, \_, asm(\alpha), \_\rangle$, resp., in δ'; and there is no other regular utterance made by a_2. The resulting δ' is coherent, as rules and assumptions in an argument are related. Moreover, a_2 uses ϕ_{nh}, as a_2 utters no contraries. □

The following result sanctions the completeness, for IS-Type II information-seeking, of the questioner using ϕ_p and the answerer using ϕ_{nh} to construct focused dialogues.

Proposition 6. Let $\texttt{Arg} = A \vdash \chi$ be in a_2, and a_1 be such that there is no argument $A' \vdash \chi$ in a_1. Then if there is a dialogue $\mathcal{D}^{a_1}_{a_2}(\chi) = \delta$ such that $\texttt{Arg}$ is in $\mathcal{F}_\delta$, then there exists a focused dialogue δ' constructed by a_1 using ϕ_p and a_2 using ϕ_{nh} such that $\texttt{Arg}$ is in $\mathcal{F}_{\delta'}$.

The proof of this proposition is similar to the one of proposition 5, except that there is only one argument constructed in the dialogue.

Note that for the reasons illustrated in example 4, given that there is $\texttt{Arg} = A \vdash \chi$ in a_2, it is not the case that all focused dialogues $\mathcal{D}^{a_1}_{a_2}(\chi)$ constructed with a_1 using ϕ_p and a_2 using ϕ_{nh} contain $\texttt{Arg}$.

An information-seeking dialogue constructed with ϕ_{nh} and ϕ_p is shown in Table 4, in which the questioner queries about w1_not_believable. Note that all rules used here are known by the answerer only. Since there is a single argument for the topic, the dialogue is both focused and coherent. There is no difference between IS-Type I and IS-Type II here. Note that in this example a_2 is the questioner and a_1 is the answerer.

Inquiry Dialogues. We formulate inquiry dialogue in two ways, shown in table 5, where $\mathcal{S} \in \{\text{admissible, grounded, ideal}\}$. Note that here agents contribute to dialogues symmetrically.

The next corollary of theorem 1 sanctions soundness and completeness, for I-Type I inquiry, of ϕ_h to construct coherent dialogues.

Table 4. Information-seeking dialogue for the two agents in example 1.

$\langle a_2, a_1, 0, claim(w1\_not\_believable), 1\rangle$	
$\langle a_1, a_2, 1, rl(w1\_not\_believable \leftarrow w1\_contradicted\_by\_w2), 2\rangle$	
$\langle a_1, a_2, 2, rl(w1\_contradicted\_by\_w2 \leftarrow), 3\rangle$	
$\langle a_1, a_2, 0, \pi, 4\rangle$	$\langle a_2, a_1, 0, \pi, 5\rangle$

Table 5. Two formulations of inquiry dialogues.

	Inquiry Dialogue
I-Type I:	Initial Situation: it is uncertain if χ is $\mathcal{S}$-acceptable in $\mathcal{F}_J$ Main Goal: testing the $\mathcal{S}$-acceptability of χ in $\mathcal{F}_J$
I-Type II:	There is no argument $A \vdash \chi$ in either a_1 or a_2. Main Goal: testing whether $A \vdash \chi$ is in $\mathcal{F}_J$

Proposition 7. To test the $\mathcal{S}$-acceptability of χ in $\mathcal{F}_J$ is to test the $\mathcal{S}$-acceptability of χ in $\mathcal{F}_\delta$ for a coherent $\delta \in \mathcal{D}$ constructed using ϕ_h.

The following result sanctions the soundness and completeness for I-Type II inquiry of using ϕ_{nh} to construct coherent dialogues.

Proposition 8. If there is no $A \vdash \chi$ in either a_1 or a_2, to test whether $\mathtt{Arg} = A \vdash \chi$ is in $\mathcal{F}_J$ is to test whether $\mathtt{Arg}$ is in a coherent dialogue constructed using ϕ_{nh}.

Proof. We show that $\mathtt{Arg} = A \vdash_R \chi$ is in $\mathcal{F}_J$ iff $\mathtt{Arg}$ is in $\mathcal{F}_\delta$, where δ is coherent and constructed using ϕ_{nh}. (1) Since δ is constructed using ϕ_{nh}, a_1 and a_2 are truthful, therefore all arguments $A_1 \vdash \chi, \ldots, A_n \vdash \chi$ in $\mathcal{F}_\delta$ are in $\mathcal{F}_J$. (2) We show by contradiction that all arguments $\mathtt{Arg}_1 = A_1 \vdash \chi, \ldots, \mathtt{Arg}_n = A_n \vdash \chi$ in $\mathcal{F}_J$ are in $\mathcal{F}_\delta$. Suppose $\mathtt{Arg}' = A' \vdash_{R'} \chi$ is in $\mathcal{F}_J$ but not in $\mathcal{F}_\delta$, then $\exists X \in A' \cup R', X \neq \{\}$, such that X is not the content of any regular utterance in δ. But this cannot be, by lemma 1, as X is related to χ; and, for all such X, there is an utterance $u = \langle \_, \_, \_, CT(X), \_\rangle$ in δ, where $CT(\_)$ is $rl(\_)$ or $asm(\_)$, as δ is coherent and constructed with ϕ_{nh}. Hence we have a contradiction. □

An I-Type I inquiry, coherent dialogue constructed with ϕ_h is shown in Table 6[7]. Clearly, $\mathcal{F}_\delta$ is topic-related framework of F_J, and the $\mathcal{S}$-acceptability of the topic can be examined in $\mathcal{F}_\delta$.

6 Related Work

Argumentation dialogues have been studied by various researchers (e.g, see [8, 11]). The dialogue model of our work uses elements from the model presented in [7]. However, [7] has focused on presenting the dialogue model and proving its soundness, whereas this work introduces strategy-move functions and studies the behaviour of agents participating in information-seeking and inquiry dialogues.

Black and Hunter [2] present a formal system for inquiry dialogues based on DeLP as the underlying argumentation framework. Our work differs in several ways. Firstly, we attempt formal definition of the goals of information-seeking and inquiry dialogues. Secondly, we have studied information-seeking dialogues whereas they focused solely on inquiry. Thirdly, the underlying dialogue framework we use is generic rather than tailored to inquiry. Lastly, we describe agent strategies as compositions of strategy-move functions, rather than give a specific strategy-move per dialogue type.

Boella et al [3] use the MacKenzie dialogue system to map some dialogue protocols into strategies. Our work is orthogonal as we fix the dialogue framework and study strategies that apply in it.

Parsons et al [9] present a study on information-seeking, inquiry and persuasion dialogues, focusing on complexity results. They use classical logic as the base for argumentation and specify dialogue protocols for each dialogue type, in an algorithmic manner. Finally, they do not compare dialogue outcomes with the joint knowledge held by the two agents.

Table 6. Inquiry dialogue for the two agents in example 1.

$\langle a_1, a_2, 0, claim(boy\_innocent), 1\rangle$	
$\langle a_2, a_1, 1, rl(boy\_innocent \leftarrow boy\_not\_proven\_guilty), 2\rangle$	
$\langle a_1, a_2, 2, asm(boy\_not\_proven\_guilty), 3\rangle$	
$\langle a_2, a_1, 3, ctr(boy\_not\_proven\_guilty, guilty), 4\rangle$	
$\langle a_1, a_2, 4, rl(guilty \leftarrow W1), 5\rangle$	
$\langle a_2, a_1, 5, asm(W1), 6\rangle$	
$\langle a_2, a_1, 6, ctr(W1, not\_W1), 7\rangle$	
$\langle a_1, a_2, 7, rl(not\_W1 \leftarrow contradicted), 8\rangle$	
$\langle a_1, a_2, 8, rl(contradicted \leftarrow), 9\rangle$	
$\langle a_2, a_1, 4, rl(guilty \leftarrow W2), 10\rangle$	
$\langle a_1, a_2, 10, asm(W2), 11\rangle$	
$\langle a_2, a_1, 11, ctr(W2, not\_W2), 12\rangle$	
$\langle a_1, a_2, 12, rl(not\_W2 \leftarrow W2\_has\_poor\_eyesight), 13\rangle$	
$\langle a_2, a_1, 13, rl(W2\_has\_poor\_eyesight \leftarrow), 14\rangle$	
$\langle a_1, a_2, 0, \pi, 15\rangle$	$\langle a_2, a_1, 0, \pi, 16\rangle$

7 Conclusions

We have studied some dialogue strategies agents can use in information-seeking and inquiry dialogues. We have also presented some formal interpretations of information-seeking and inquiry dialogues. We have shown that the specified dialogue strategies are suitable for these interpretations.

Using the dialogue model proposed in [7], we have shown that introducing strategy-move functions is a viable means of defining agent behaviours in dialogues. We have shown that, in information-seeking dialogues, the answerer should be truthful and disclose directly related information about this topic, whereas, in inquiry dialogues, both agents should be truthful and disclose directly or indirectly related information about the topic.

Future work includes studying strategies for other dialogue types, such as persuasion, and results for other argumentation semantics.

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[7] Here, guilty, W1, not_W1, contradicted, W2, not_W2 are shorthand for boy_proven_guilty, w1_is_believable, w1_not_believable, w1_contradicted_by_w2, w2_is_believable, w2_not_believable, resp..