Argumentation-based Normative Practical Reasoning

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Abstract. Reasoning about what is best for an agent to do in a particular situation is a challenging task. What makes it even more challenging in a dynamic environment is the existence of norms that aim to regulate a self-interested agent's behaviour. Practical reasoning is reasoning about what to do in a given situation, particularly in the presence of conflicts between the agent's practical attitude such as goals, plans and norms. In this paper we: (i) introduce a formal model for normative practical reasoning that allows an agent to plan for multiple and potentially conflicting goals and norms at the same time (ii) identify the best plan(s) for the agent to execute by means of argumentation schemes and critical questions (iii) justify the best plan(s) via an argumentation-based persuasion dialogue for grounded semantics.

1 Introduction

Autonomous agents operating in a dynamic environment must be able to reason and make decisions about actions in pursuit of their goals. In addition, in a normative environment an agent's actions are not only directed by the agent's goals, but also by the norms imposed on the agent. Norms are a well understood approach for declaratively specifying desirable behaviour by stating under which circumstances the performance of which actions or reaching which states are obliged or prohibited. When modelled as soft constraints, norms allow more flexible behaviour by defining a reward and punishment associated with compliance and violation. To avoid punishment, agents must comply with norms while pursuing their goals. However, if complying with a norm hinders a more important goal or norm, the agent should consider violating it. In order to decide what to do, an agent performing normative practical reasoning therefore needs to constantly weigh up the importance of goal achievement and norm compliance against the cost of goals being ignored and norms being violated, in different plans.

Although practical reasoning frameworks that take norms into account exist (e.g. [1, 2, 3], there has been little attention paid to the explanation and justification of agents' decision making in such frameworks. The conflicts that arise between the practical attitudes of agents, such as goals, plans and norms, can make explaining the agent's decision making process very complicated. Argumentation has been shown to be a promising means for reasoning in the presence of inconsistent information [4]. In addition to assisting agents' reasoning, argumentation supports explaining agents' decision making via argumentation-based dialogues (e.g. [5]). Argumentation has previously been applied in practical reasoning and in the justification of the agent's decision making (e.g. [6, 7, 8]). However, the existing approaches suffer from at least one of the following problems: (i) the normative aspects of the agents operating in a dynamic environment are not taken into consideration [6, 7]; (ii) the planning aspects of the practical reasoning problem is either abstracted away, or is not computationally implemented [6, 7, 8]; (iii) the conflicts identified between actions, goals, norms and plans are static and disregard the temporal essence of conflict [6].

In this paper we aim at presenting a model that integrates normative reasoning into practical reasoning. The model is implemented formally in a way that handles *durative* actions and time explicitly, hence enriching reasoning about conflicts. In order to develop a pattern of arguments to reason about conflicts in such a model, we use *argument schemes* and their associated *critical questions* [9]. Argument schemes are reasoning patterns expressed in natural language and critical questions are situations in which the scheme does not apply and are used to question the arguments constructed based on the schemes. These argument schemes employed in an argumentation framework (AF) enable the agent to identify and justify the best course of action. Although all of the existing approaches mentioned earlier use argumentation to identify the best course of actions for the agent to take, to the best of our knowledge our framework is the first one that uses the argumentation-based persuasion dialogue in [10] to engage in an internal dialogue to justify this choice.

The paper is organised as follows. After describing the formal model in the next section, we discuss arguments and their relations in Section 3. Section 4 demonstrates the dialogue used in this work, followed by an illustrative example in Section 5. Related work and conclusions are discussed in sections 6 and 7, respectively.

2 A Formal Model for Normative Practical Reasoning

This section offers a formal model and its semantics for normative practical reasoning. The foundation of this model is classical planning in which an agent is presented with a set of actions and a goal. Any sequence of actions that satisfies the goal is a solution for the planning problem. In section 2.1 we extend the classical planning problem by substituting a single goal with a set of potentially inconsistent goals G and a corresponding set of norms N. A solution for such a problem is any sequence of actions that satisfies at least one goal. The agent has the choice of violating or complying with triggered norms, while satisfying its goals.

2.1 The Model

A normative temporal planning system is a tuple $P = (FL, \Delta, A, G, N)$ where FL is a set of fluents, Δ is the initial state, A is a set of durative STRIPS-like [11] actions, G denotes the set of agent goals and N denotes a set of norms imposed on the agent actions, that define what an agent is obliged or forbidden to do under certain conditions. We now describe each of these elements in more details.

Fluents FL is a set of domain fluents that accounts for the description of the domain the agent operates in. A literal l is a fluent or its negation i.e. $l = \mathit{fl}$ or $l = \neg \mathit{fl}$ for some $\mathit{fl} \in FL$. For a set of literals L, we define $L^+ = \{\mathit{fl} | \mathit{fl} \in L\}$ and $L^- = \{\mathit{fl} | \neg \mathit{fl} \in L\}$ to denote the set of positive and negative fluents in L respectively. L is well-defined if there exists no fluent $\mathit{fl} \in FL$ such that $\mathit{fl} \in L$ and $\neg \mathit{fl} \in L$, i.e. if $L^+ \cap L^- = \emptyset$.
The semantics of the model are defined over a set of states S. A state $s \subseteq FL$ is determined by set of fluents that hold *true* at a given time, while other fluents (those not present) are considered false. A state $s \in S$ satisfies fluent $\mathit{fl} \in FL$ (i.e. $s \models \mathit{fl}$) if $\mathit{fl} \in s$ and it satisfies its negation $\neg \mathit{fl}$ if $\mathit{fl} \notin s$. This notation can be extended to a set of literals as follows: the set X is satisfied in state s, where $s \models x$, when $\forall x \in X \cdot s \models x$.

Initial State The set of fluents that hold at the initial state is denoted by $\Delta \subseteq FL$.

Actions A is a set of durative STRIPS-like actions, that is actions with preconditions and postconditions that take a non-zero duration of time to have their effects in terms of their postconditions. A durative action $a = \langle pr, ps, d \rangle$ is composed of well-defined sets of literals $pr(a), ps(a)$ to represents a's preconditions and postconditions and a positive number $d(a) \in \mathbb{N}$ for its duration. Postconditions are further divided into a set of add postconditions $ps(a)^+$ and a set of delete postconditions $ps(a)^-$. An action a can be executed in a state s if its preconditions hold in s (i.e. $s \models pr(a)$. The postconditions of a durative action are applied in the state s at which the action ends (i.e. $s \models ps(a)^+$ and $s \not\models ps(a)^-$) .
The model allows concurrency unless there is a concurrency conflict between some actions, which prevents them from being executed in an overlapping period of time. Two actions a_1 and a_2 are in a concurrency conflict if the preconditions or postconditions of a_1 contradicts the preconditions or postconditions of a_2 [12].

Goals G denotes a set of (possibly inconsistent) goals. Goals identify the state of affairs in the world that an agent wants to satisfy. Each goal $g \in G$ is defined as a well-defined set of literals, that should hold in order to satisfy the goal. Goal g is satisfied in the state s when $s \models g$. A set of goal $G_i \subseteq G$ is consistent iff $\nexists g_1, g_2$ s.t. $g_1 \cup g_2$ is not well-defined.

Norms N denotes a set of event-based norms to which the agent is subject. Each norm is a quadruple of the form $\langle d\_o, a_1, a_2, \mathit{dl} \rangle$, where

- $d\_o \in \{o, f\}$ is the deontic operator determining the type of norm, which can be an obligation or prohibition.
- $a_1 \in A$ is the action that counts as the norm activation condition.
- $a_2 \in A$ is the action that is subject to obligation or prohibition.
- $\mathit{dl} \in \mathbb{N}$ is the norm deadline that is a time instant defined relative to the activation of the norm through the execution of a_1.

An obligation norm expresses that taking action a_1 obliges the agent to take action a_2 within dl time units of norm activation. Such an obligation is complied with if the agent starts executing a_2 before the deadline and is violated otherwise. A prohibition norm expresses that taking action a_1 prohibits the agent from taking action a_2 within dl time units of norm activation. Such a prohibition is complied with if the agent does not take a_2 before the deadline and is violated otherwise.

2.2 Semantics of The Model

Suppose that $P = (FL, \Delta, A, G, N)$ is a normative planning problem with the syntax given previously. A plan is represented by a sequence of actions taken at certain times, denoted as: $\pi = \langle (a_0, t_0), \cdots, (a_n, t_n) \rangle$, which means that action a_i is executed at time $t_i \in \mathbb{Z}^+$ s.t. $\forall i < j$ we have $t_i < t_j$. The total duration of a plan, $Makespan(\pi)$, is calculated by the relation: $Makespan(\pi) = max(t_i + d(a_i))$. The evolution of a sequence of actions for a given starting state $s_0 = \Delta$ is a sequence of states $\langle s_0, \cdots s_m \rangle$ for every discrete time interval from t_0 to m, where $m = Makespan(\pi)$. The transition relation between two states is defined by Equation 1. If an action a_j ends at time t_i, state s_i results from removing all negative postconditions and adding all positive postconditions of action a_j to state s_{i-1}. If there is no action ending at s_i, s_i remains the same as s_{i-1}.

$$\forall i > 0: \; s_i = \begin{cases} (s_{i-1} \setminus ps(a_j)^-) \cup ps(a_j)^+ & i = t_j + d(a_j) \\ s_{i-1} & \text{otherwise} \end{cases} \tag{1}$$

A sequence of actions π satisfies a goal, $s \models g$, if there is at least one state s_i in the sequence of states caused by the sequence of actions in π, such that $s_i \models g$. We therefore have $\pi \models G_j$ iff $\forall g \in G_j, \exists \; i \in [1, m]$ such that $s_i \models g$. An obligation $n_1 = \langle o, a_i, a_j, \not{d} \rangle$ is complied with in plan π (i.e. $\pi \models n_1$) if the action that is the norm activation condition has occurred ($(a_i, t_i) \in \pi$), and the action that is the subject of the obligation occurs ($(a_j, t_j) \in \pi$) between when the condition holds and when the deadline expires ($t_j \in (t_i, \not{d} + t_i)$). If a_i has occurred but a_j does not occur at all or occurs in a period other than the one specified, the obligation is violated (i.e. $\pi \not\models n_1$). In the case of prohibition $n_2 = \langle f, a_i, a_j, \not{d} \rangle$, compliance happens if the action that is the norm activation condition has occurred ($(a_i, t_i) \in \pi$) and the action that is the subject of the prohibition does not occur in the period between when the condition holds and when the deadline expires ($\nexists (a_j, t_j) \in \pi$ s.t. $t_j \in (t_i, \not{d} + t_i)$). If a_i has occurred and a_j occurs in the specified period, the prohibition norm is violated (i.e. $\pi \not\models n_2$).

Two obligation norms $n_1 = \langle o, a_1, a_2, \not{d} \rangle$ and $n_2 = \langle o, b_1, b_2, \not{d}' \rangle$ are in conflict in the context of plan π iff: (1) their activation conditions hold, (2) the obliged actions a_2 and b_2 have a concurrency conflict and (3) a_2 is in progress during the entire period over which the agent is obliged to take action b_2. On the other hand, a norm of type obligation $n_1 = \langle o, a_1, a_2, \not{d} \rangle$ and a norm of type prohibition $n_2 = \langle f, b_1, a_2, \not{d}' \rangle$ are in conflict in the context of plan π iff: (1) their activation conditions hold and (2) n_2 forbids the agent from taking action a_2 during the entire period over which n_1 obliges the agent to take a_2.

A norm of type obligation $n = \langle o, a_1, a_2, \not{d} \rangle$ and a goal g are in conflict, if taking action a_2 that is the subject of the obligation, brings about postconditions that are in conflict with the requirements of goal g. In addition, a norm of type prohibition $n = \langle f, a_1, a_2, \not{d} \rangle$ and a goal g are in conflict, if the postconditions of a_2 contribute to satisfying g, but taking action a_2 is prohibited by norm n.
Sequence of actions $\pi = \langle (a_0, t_0), \cdots, (a_n, t_n) \rangle$ is a valid plan[1] and solution for P iff:

[1] We assume that plans are given by a sound planning system and make no further assumption about the implementation.

1. all the fluents in Δ hold at time t_0.
2. for each i, the preconditions of action a_i holds at time t_i, as well as through the execution of a_i.
3. a non-empty consistent subset of goals (i.e. $G_j \subseteq G$ and $G_j \neq \emptyset$) is satisfied in the path from initial state s_0 to the state holding at time t_m, where $m = Makespan(\pi)$.
4. there is no concurrency conflict between actions that are executed concurrently.
5. there is no conflict between any of the norms complied with.
6. there is no conflict between goals satisfied and norms complied with.

3 Argument Scheme and Critical Questions

The formal model explained in the previous section defines all possible plans Π that the agent can execute to satisfy at least one of its goals. Regarding norms, when the course of actions in a plan triggers a norm, the possible outcomes of violating or complying with that norm are generated separately. In order to identify the best plan(s) for the agent to execute, if any, we first augment the tuple $P = \langle FL, \Delta, A, G, N \rangle$ with a partial, irreflexive and transitive preference relation $Pref_{gn}$ that expresses agent's preferences over goals and norms: $Pref_{gn} \subseteq (G \cup N) \times (G \cup N)$. If the agent prefers satisfying goal α (or complying with norm α) over satisfying goal β (or complying with norm β), we have $(\alpha, \beta) \in Pref_{gn}$. The preference relation over plans, on the other hand, comes from the fact that the lesser number of violations is always preferred over more. Thus, plan π_1 is preferred over plan π_2, iff they satisfy the same set of goals, while π_1 has fewer violations. Assuming that the sets $satisfied_i$ and $violated_i$ define the set of satisfied goals and violated norms in plan π_i: $satisfied_i = \{g_j | g_j \in G, \pi_i \models g_j\}$ and $violated_i = \{n_k | n_k \in N, \pi_i \not\models n_k\}$, we have: iff $satisfied_1 = satisfied_2, violated_1 \subsetneq violated_2$ then $(\pi_1, \pi_2) \in Pref_{\pi}$.

Having defined the preference relations $Pref_{gn}$ and $Pref_{\pi}$, we now use argument schemes and critical questions [9] to construct and evaluate a set of arguments involved in practical reasoning. The arguments and their relationships defined through arguments schemes and critical questions, respectively, plus arguments preferences that result from agent preferences discussed above, form a preference-based argumentation framework (PAF) [13]. The evaluation of such a PAF according to grounded semantics results in an unique extension containing a set of arguments that are justified in all senses. The choice of grounded semantics for sceptical reasoning has pragmatic and philosophical reasons that are discussed in details in [14]. By using a persuasion dialogue for the grounded semantics [10] in the next section, we justify how the plan argument(s) included in the grounded extension identify the best plan(s) for the agent to execute.

Definition 1. *A PAF is a triplet (Arg, Att, Pr) where Arg is a set of arguments, Att is a binary attack relation between arguments, $Att \subseteq Arg \times Arg$, and Pr is a (partial or complete) preordering on $Arg \times Arg$. Argument a is preferred over argument b iff $(a, b) \in Pr$ and $(b, a) \notin Pr$. The defeat relation between two argument $Def \subseteq Arg \times Arg$ is therefore defined as: $\forall a, b \in Arg, a$ defeats b iff $(a, b) \in Att$ and $(b, a) \notin Pr$.*

The arguments, Arg, in the created PAF consists of three disjoint sets of arguments Arg_{π}, Arg_g, and Arg_n, obtained from three separate argument schemes defined in Section 3.1. The attack relation, Att, between arguments is instantiated through the application of six critical questions described in Section 3.2. The preference relations, Pr, between goal arguments and norm arguments results from the preference relations expressed by the agent over goals and norms: iff $(\alpha, \beta) \in Pref_{gn}$ then $(Arg_\alpha, Arg_\beta) \in Pr$. The same applies to plan arguments: iff $(\gamma, \lambda) \in Pref_\pi$ then $(Arg_\gamma, Arg_\lambda) \in Pr$.

3.1 Formal Model of Arguments

We now express three argumentation schemes in order to construct a set of arguments for normative practical reasoning: plan arguments, goal arguments and norm arguments. These arguments will be used to conduct the dialogue between a proponent that aims at convincing an opponent to accept why a particular plan should be executed. An opponent can question the proponent claim by asking why a certain goal was not satisfied in the proposed plan, or why a certain norm was violated.

AS1: This argument scheme results in constructing an argument for each plan (Arg_π) obtained from our formal model and is used by the agent to put forward a sequence of actions and as a proponent claims that the proposed sequence should be executed:

- In the initial state Δ
- The agent should perform sequence of actions $\pi = \langle (a_1, t_1), \cdots, (a_n, t_n) \rangle$
- which will realise set of goals G' ($\pi \models G'$) and complies with set of norms N' ($\pi \models N'$) and violates set of norms N'' ($\pi \not\models N''$)

AS2: This argument scheme results in constructing an argument for each goal that is *feasible*. A goal is feasible if it is satisfied in at least one plan. If a goal in not feasible, a rational agent should not adopt it or try to justify its adoption (for more details see [15]). A goal argument (Arg_g) is used by an opponent to explore why a goal is not satisfied in a plan, or to address the conflict between two goals or a goal and a norm:

- Goal g is a feasible goal of the agent
- Therefore, satisfying g is required.

AS3: This argument scheme results in constructing an argument for each norm (Arg_n) that is activated in at least one plan and is used by an opponent to explore why a norm is violated in a plan. It is also used to address the conflict between two norms or a goal and a norm. An activated norm is not necessarily activated in all plans. To allow reasoning about norms only in the context of the plans they are activated in, the norm (e.g. n_k) is augmented as (e.g. n_{ki}) where i is the index of the plan in which n_k is activated. Note that, this operation does not effect the preference relations discussed earlier. For instance, if the agent prefers satisfying g_2 to complying with norm n_1, $g_2 \succ n_1$, argument for this goal, Arg_{g_2}, is preferred to all the arguments for norm $Arg_{n_{1i}}$, where i is represents the plans in which norm n_1 was activated.

- Norm n_k is an activated norm imposed to the agent in plan π_i
- Therefore, complying with n_{ki} is required

3.2 Argument Interactions

The six critical questions in this section describe the ways arguments built in the previous section can attack each other. These CQs are associated to one or more AS, which are listed after each CQ.

CQ1 (AS2): Does a goal conflict with another goal? This CQ results in an attack between arguments for conflicting goals. Attacks caused by CQ1 are by definition symmetric and irreflexive. This can be formulated as:
Iff $g_1 \cup g_2$ is not well-defined then $(Arg_{g_1}, Arg_{g_2}), (Arg_{g_2}, Arg_{g_1}) \in Att$.

CQ2 (AS3): Does a norm conflict with another norm? Conflict between two norms is contextual based, the context being defined as the plan the norms are activated in. For instance, norms n_1 and n_2 might be in conflict in plan π_i (i.e., $Arg_{n_{1i}}$ and $Arg_{n_{2i}}$ attack each other) while they are conflict-free in plan π_j. Similar to CQ1, attacks caused by CQ2 are by definition symmetric and irreflexive. It is defined in Section 2.2 what it means for two norms to be conflicting. The definitions are formulated as follows.
Two obligation norms $n_1 = \langle o, a_1, a_2, d \rangle$ and $n_2 = \langle o, b_1, b_2, d' \rangle$ are in conflict in the context of plan π_i:
Iff $(a_1, t_{a_1}), (b_1, t_{b_1}), (a_2, t_{a_2}) \in \pi_i,$ s.t. $t_{a_2} \in (t_{a_1}, t_{a_1} + d)$ and $(t_{b_1}, t_{b_1} + d') \subseteq (t_{a_2}, t_{a_2} + d(a_2))$ then $(Arg_{n_{1i}}, Arg_{n_{2i}}), (Arg_{n_{2i}}, Arg_{n_{1i}}) \in Att$.
A norm of type obligation $n_1 = \langle o, a_1, a_2, d \rangle$ and a norm of type prohibition $n_2 = \langle f, b_1, a_2, d' \rangle$ are in conflict in the context of plan π_i:
Iff $(a_1, t_{a_1}), (b_1, t_{b_1}) \in \pi_i$ s.t. $(t_{a_1}, t_{a_1} + d) \subseteq (t_{b_1}, t_{b_1} + d')$ then
$(Arg_{n_{1i}}, Arg_{n_{2i}}), (Arg_{n_{2i}}, Arg_{n_{1i}}) \in Att$.

CQ3 (AS1): Is there any other preferred plan available? This CQ results in an attack from plan argument Arg_{π_1} to plan argument Arg_{π_2}, when plan π_1 is preferred over plan π_2. Attacks caused by CQ3 are by definition asymmetric and irreflexive:
Iff $(\pi_1, \pi_2) \in Pref_\pi$ then $(Arg_{\pi_1}, Arg_{\pi_2}) \in Att$.

CQ4 (AS1): Is there any conflict between a goal and a plan? This CQ results in an attack from a goal argument to a plan argument, when the goal is not satisfied in the plan. Attacks caused by CQ4 are by definition asymmetric and are formulated as:
Iff $\pi_i \not\models g_j$ then $(Arg_{g_j}, Arg_{\pi_i}) \in Att$.

CQ5 (AS2-AS3): Is there any conflict between a norm and a goal? The conflict between a norm and a goal is defined in Section 2.2 and is formulated below. Attacks caused by CQ5 are by definition symmetric.
A norm of type obligation $n_1 = \langle o, a_1, a_2, d \rangle$ and a goal g_j are in conflict:
iff $ps(a_2) \cup g_j$ is not well-defined then $\forall n_{1i},$ s.t. $\pi_i \in \Pi$:
$(Arg_{n_{1i}}, Arg_{g_j}), (Arg_{g_j}, Arg_{n_{1i}}) \in Att$.
A norm of type prohibition $n_2 = \langle f, a_1, a_2, d \rangle$ and a goal g_j are in conflict:
iff $ps(a_2) \cap g_j \neq \emptyset$ then $\forall n_{2i},$ s.t. $\pi_i \in \Pi : (Arg_{n_{2i}}, Arg_{g_j}), (Arg_{g_j}, Arg_{n_{2i}}) \in Att$.

CQ6 (AS1): Is there any conflict between a norm and a plan? This CQ results in an attack from a norm argument to a plan argument, when the norm is violated in the plan. This asymmetric attack is formulated as: Iff $\pi_i \not\models n_j$ then $(Arg_{n_{ji}}, Arg_{\pi_i}) \in Att$.

3.3 Grounded Extension and Properties of Plan Arguments

We organise the instantiation of the arguments and their relations, as presented in the previous section, within a $PAF = (Arg, Att, Pr)$, which, based on Definition 1, can be mapped to a Dung $AF = (Arg, Def)$. The grounded extension of the AF, Gr, determines if a plan should be identified as a basis for the agent's action execution.

Property 1. For any plan π, $Arg_\pi \in Gr$ iff there is no plan better than π.

Property 2. Let ARG_π be the set of all plan arguments in the grounded extension: $ARG_\pi = \{Arg_\pi | Arg_\pi \in Gr\}$.

- if $ARG_\pi = \emptyset$, then a unique best plan does not exist.
- if $card(ARG_\pi) = 1$, then $Arg_\pi \in ARG_\pi$ is the best plan for the agent to execute.
- if $card(ARG_\pi) > 1$, then the preference information available is insufficient to identify a single best plan. Thus all $Arg_\pi \in ARG_\pi$ are the best plans and the agent can choose any of them as the basis of what to execute.

Property 3. If $card(ARG_\pi) = 1$ and Arg_π is the best plan then $\forall g_j \in G, n_k \in N$ s.t. $\pi \models g_j, \pi \models n_k$, we have: $Arg_{g_j}, Arg_{n_k} \in Gr$.

4 Persuasion Dialogue for Grounded Semantics

This section demonstrates a persuasion dialogue game for grounded semantics. The main motivation behind the development of argumentation-based dialogues is to bring the mathematical intuition behind the semantics closer to human way of interacting when trying to convince one another of their perspective. However, these dialogues have rarely been used in practice. The contribution of this paper is not in introducing a new dialogue, but instead is in applying an existing dialogue game to a practical reasoning problem, where the agent engages in this internal dialogue to justify why a plan(s) is the best plan(s) to execute. The purpose of the dialogue is to show that if a plan argument is in the grounded extension of an AF, the agent can dialectically point out the reason for why this particular course of action should be executed. The dialogue is based on Caminada's *complete and grounded labelling* that is stated in the following definition taken from [16].

Definition 2. *Let (Arg, Def) be a Dung argumentation framework, a (partial) argument labelling is a (partial) function $lab : Arg \rightarrow \{in, out, undec\}$. A non-partial argument labelling is called a complete labelling iff for each argument $a \in Arg$ it holds that a is labelled 'in' iff each attacker of a is labelled 'out' and a is labelled 'out' iff there exists an attacker of a that is labelled 'in'.*

A complete labelling is called the (unique) grounded labelling $\mathcal{L}_{gr}$ iff its set of in-labelled arguments is minimal (or equivalently, iff its set of out-labelled arguments is minimal, or iff its set of undec-labelled arguments is maximal among all complete labellings.

The persuasion dialogue for grounded semantics is defined such that for any argument $a \in Arg$ there exists a grounded discussion that is won by a proponent iff $\mathcal{L}_{gr}(a) = in$. A discussion move in this dialogue is a triple $\mathcal{M} = (\mathcal{P}, \mathcal{T}, \mathcal{L})$, where $\mathcal{P}$ is the player: $\mathcal{P} \in \{proponent, opponent\}$, $\mathcal{T}$ is one of the following moves: $\mathcal{T} \in \{claim, why, because, concede\}$ and $\mathcal{L}$ is a partial labelling. $claim$ is always the first move in the dialogue put forward by proponent to claim that an argument is labelled in; why is a move available to the opponent to question the proponent about why an argument is labelled in or out; $because$ is a move with which the proponent describes why a questioned argument is labelled in a particular way; and $concede$ is the move uttered by the opponent to concede an argument being labelled in or out by the proponent earlier. The opponent is assumed to be maximally sceptical, conceding an argument is in, if it is already committed that all attackers are out and it concedes an argument is out if it is committed that at least one attacker is in.

The dialogue starts by the proponent (P) putting forward a claim that an argument is in $claim\ in(a)$. The proponent (P) and opponent (O) then take turns, while each turn for P contains a single $because$ move, whereas in each turn O can play more than one $concede$ and why move. However, O can question with why just one argument at a time. P gets committed to arguments used in $claim$ and $because$ moves, while O gets committed to $concede$ moves. These moves can only be played if new commitment does not contradict a previous one. P uses the $because$ move to provide reasons for why moves, put forward by O. The reason for an argument being labelled in can be provided only if all its attackers are labelled out and the reason for an argument being labelled out can be provided when at least one of its attackers is labelled in. When P or O cannot make any more moves the dialogue terminates. If on termination, O conceded the claim argument then P wins, otherwise O is the winner.

Using the dialogue described above, if there exists $Arg_\pi \in Arg$ s.t. $\mathcal{L}_{gr}(Arg_\pi) = in$, the proponent starting the discussion by move $claim\ in(Arg_\pi)$ is guaranteed a winning strategy to justify plan π. The example in the following section shows the dialogue in action.

5 Illustrative Example

In this section, we provide a brief example that, for sake of space, just highlights the most important features of the proposed model. Let us consider an agent with the actions presented in Table 1. Apart from $attend\_interview$ that has duration two, the duration of all other actions is one. The agent has two goals namely, getting some qualification and going on strike. Getting the qualification requires the agent to pay the fee for the test, do an online theory test and attend an interview for oral examination: $g_1 = \{fee\_paid, test\_done, interview\_attended\}$. Going on strike on the other hand, requires the agent to be a member of union, not to go to work nor to attend any meeting on behalf of the company: $g_2 = \{union\_member, \neg office, \neg meeting\}$. Two of the agent's actions, $comp\_funding$ and $attend\_interview$, have normative consequences captured in the two following norms:

$n_1 = \langle o, comp\_funding, attend\_meeting, 2\rangle$: This norm expresses that if the agent uses company funds to pay the fee for the test she wants to take, she is obliged to attend a meeting on behalf of the company within 2 time units of execution of $comp\_funding$.

$n_2 = \langle f, attend\_interview, attend\_meeting, 3\rangle$: This norm expresses that attending the interview prohibits the agent from attending the meeting within 3 time units of taking action $attend\_interview$.

Table 2 shows five plans for the agent, including the goal(s) satisfied and norms complied with or violated in each plan. The positive or negative signs next to each norm means the norm is being complied with or violated in the respective plan. The argumentation graph in Figure 1 shows the arguments associated with plans, goals and norms in table 2. Arguments $Arg_{\pi_1} - Arg_{\pi_5}$ are built based on $AS1$, Arg_{g_1} and Arg_{g_2} are based on $AS2$, and $Arg_{n_{11}} - Arg_{n_{25}}$ are based on $AS3$. The attack between arguments is labelled with the relevant critical question.

To show the role of agent preferences in reducing the two-way attacks to a one-way defeat, we assume two different set of preferences, Pr_1 and Pr_2 , for a PAF with set of Arg and Att in Figure 1. Table 3 shows the agent preferences in the first column, while the second column translates the agent preferences to preferences between arguments. Finally, the grounded extension, Gr, of the argumentation graph based on each set of preferences is computed in the third column. In this specific example, each grounded extension includes a single plan, π_5 in Gr_1 and π_1 in Gr_2, that according to Property 2, is the best plan for the agent to execute.

Figures 2 and 3 show how by putting forward the argument for the best plan, that is Arg_{π_5} on the left hand side dialogue and Arg_{π_1} on the right hand side dialogue, the proponent can convince the opponent to accept this plan as the basis of what to do. Note that the dialogue is conducted after applying the preference information in Table 3 to the framework in Figure 1. Moreover, these two dialogues are not the only possible dialogues. For example, in Figure 3 instead of stating $because\ in(Arg_{n_{11}})$, the proponent could have put forward $because\ in(Arg_{n_{12}})$, or $because\ in(Arg_{n_{13}})$, or $because\ in(Arg_{n_{15}})$.

6 Related Work

Current work on argumentation-based practical reasoning can be broadly divided into two categories: logic-based (e.g. [6, 15, 17, 18]) and scheme-based (e.g. [7, 8]) approaches. In the former category (see details below) Dung's AF is used to generate a subset of consistent desires and plans to achieve them that are optimised in some sense. Whereas, in the approach proposed in this paper argumentation techniques, i.e. argument schemes and critical questions, are applied to a different step of the practical reasoning process, namely to identify and justify the best plan(s) out of a set of generated plans. Plans are generated by enabling the agent to plan for multiple goals together, which not only ensures the consistency of plans, it also gives a precise account of how the agent should execute the actions in those plans (e.g. in which order, in what

Table 1. Agent Actions

Preconditions	Actions	Postconditions
$\neg fee\_paid$	$comp\_funding$	fee_paid
$\neg test\_done, fee\_paid$	$take\_test$	$test\_done$
$\neg interview\_attended, fee\_paid$	$attend\_interview$	$interview\_attended$
$\neg meeting\_attended, office, fee\_paid$	$attend\_meeting$	$meeting\_attended$
$\neg union\_member$	$join\_union$	$union\_member$

Table 2. Agent Plans

Plans	Goals	Norms
$\pi_1 = \langle (comp\_funding, 0), (attend\_meeting, 1), (take\_test, 2), (attend\_interview, 3) \rangle$	g_1	$+n_{11}, +n_{21}$
$\pi_2 = \langle (comp\_funding, 0), (attend\_interview, 1), (take\_test, 2) \rangle$	g_1	$-n_{12}, +n_{22}$
$\pi_3 = \langle (comp\_funding, 0), (attend\_interview, 1), (attend\_meeting, 2), (take\_test, 3) \rangle$	g_1	$+n_{13}, -n_{23}$
$\pi_4 = \langle (join\_union, 0) \rangle$	g_2	N/A
$\pi_5 = \langle (join\_union, 0), (comp\_funding, 1), (attend\_interview, 2), (take\_test, 3) \rangle$	g_1, g_2	$-n_{15}, +n_{25}$

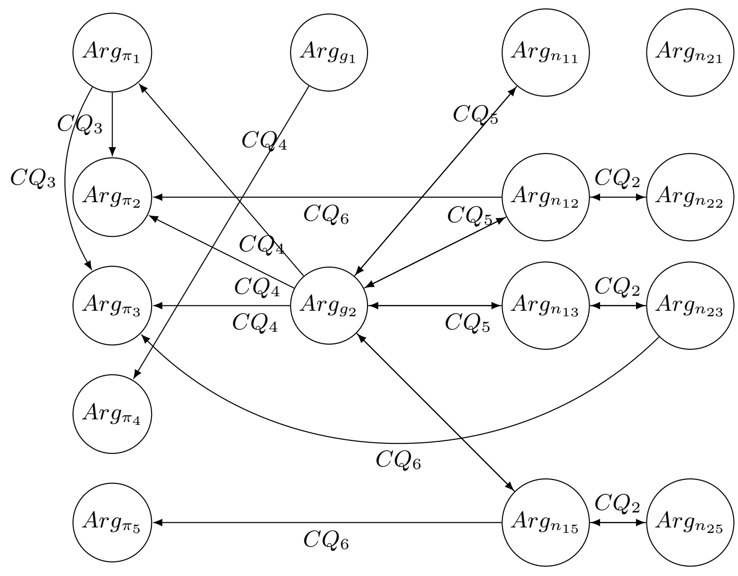

Fig. 1. Argumentation Framework of The Example

Table 3. Grounded Extensions of Graph 1

Agent Preferences	Argument Preferences	Grounded extension
$Pref_1 = \{(g_2, n_1), (n_1, n_2)\}$	$Pr_1 = \{(Arg_{g_2}, Arg_{n_{11}}), (Arg_{g_2}, Arg_{n_{12}}), (Arg_{g_2}, Arg_{n_{13}}), (Arg_{g_2}, Arg_{n_{15}}), (Arg_{n_{11}}, Arg_{n_{21}}), (Arg_{n_{12}}, Arg_{n_{22}}), (Arg_{n_{13}}, Arg_{n_{23}}), (Arg_{n_{15}}, Arg_{n_{25}})\}$	$Gr_1 = \{Arg_{g_1}, Arg_{g_2}, Arg_{n_{21}}, Arg_{n_{22}}, Arg_{n_{23}}, Arg_{n_{25}}, Arg_{\pi_5}\}$
$Pref_2 = \{(n_1, n_2), (n_2, g_2)\}$	$Pr_2 = \{(Arg_{n_{11}}, Arg_{n_{21}}), (Arg_{n_{12}}, Arg_{n_{22}}), (Arg_{n_{13}}, Arg_{n_{23}}), (Arg_{n_{15}}, Arg_{n_{25}}), (Arg_{n_{21}}, Arg_{g_2}), (Arg_{n_{22}}, Arg_{g_2}), (Arg_{n_{23}}, Arg_{g_2}), (Arg_{n_{25}}, Arg_{g_2})\}$	$Gr_2 = \{Arg_{g_1}, Arg_{n_{11}} Arg_{n_{21}}, Arg_{n_{12}}, Arg_{n_{13}}, Arg_{n_{15}}, Arg_{\pi_1}\}$

1. P: $claim\ in(Arg_{\pi_5})$
2. O: $why\ in(Arg_{\pi_5})$
3. P: $because\ out(Arg_{n_{15}})$
4. O: $why\ out(Arg_{n_{15}})$
5. P: $because\ in(Arg_{g_2})$
6. O: $concede\ in(Arg_{g_2})$
7. O: $concede\ out(Arg_{n_{15}})$
8. O: $concede\ in(Arg_{\pi_5})$

Fig. 2. Persuasion Dialogue for π_5 in Gr_1

1. P: $claim\ in(Arg_{\pi_1})$
2. O: $why\ in(Arg_{\pi_1})$
3. P: $because\ out(Arg_{g_2})$
4. O: $why\ out(Arg_{g_2})$
5. P: $because\ in(Arg_{n_{11}})$
6. O: $concede\ in(Arg_{n_{11}})$
7. O: $concede\ out(Arg_{g_2})$
8. O: $concede\ in(Arg_{\pi_1})$

Fig. 3. Persuasion Dialogue for π_1 in Gr_2

time, consequently or concurrently, etc.). In what follows we provide a summary of [6] and [18] as examples of logic-based approaches, followed by two examples of scheme-based approaches, [7] and [8]. We also mention how the approach offered in this paper compared with existing works.

Rahwan and Amgoud [6] offer an instantiation of Dung's AF for generating consistent desires and plans for BDI agents. They consider three different Dung style AFs for arguing about beliefs and their truth value, about desires and justification of their adoption and about intentions. Arguing about intention, i.e. what is the best course of actions to achieve desires, is based on the utility of desires and resources required to achieve them. Continuing the work of [6], Amgoud et al. [15] propose a constrained argumentation system that takes arguing about desires further by excluding the possibility of adopting desires that are not feasible. Unlike [6], there is no mechanism to compare various sets of justified and feasible desires. Hulstijn and van der Torre [18], unlike Amgoud [6, 17], do not use multiple argumentation frameworks to capture the conflicts between beliefs, desires/goals and intentions/plans. Instead, they extract goals by reasoning forward from desires, followed by deriving plans for goals, using planning rules. Goals that have a plan associated with them, can be modelled as an argument consisting of a claim and its necessary support. These arguments form an AF for planning, in which there is an attack between conflicting plans. They then look for an extension of this AF that maximises the number of achieved desires as opposed to considering the quality or utility of these desires that is the base of comparison in [6].

The criticism about logic-based approaches is that the plan generation is not discussed and the main focus is on identifying a subset of consistent desires and their plans. However, it is not clear how, i.e. when and in which orders, the agent should execute those plans. More importantly and as it is discussed in [19], it is difficult to distinguish between states and actions, which results in the intrinsic worth of actions being neglected.

The most well-known scheme-based approach is the practical reasoning approach offered by Atkinson and Bench-Capon [7]. The approach uses Action-based Alternating Transition System (AATS) [20], which is instantiated based on the agent's knowledge of actions with pre- and post-conditions, and the values they promote. Using this AATS along with a set of arguments schemes and critical questions, arguments are generated for each available action. These arguments are then organised in a value-based argumentation framework (VAF) [21], where the preference between arguments is defined according to the values they promote and the goals they contribute to. Having said that there is no measurement of how much a value is promoted. The approach proposed by Oren [8] is also based on AATS and argumentation scheme and adopts several ideas from [7], however, unlike [7], it permits practical reasoning in the presence of norms. As a result preferences between arguments are defined based on considering all possible interactions between norms and goals instead of values and goals [7]. The work done in [5] also considers norms in collaborative planning, but unlike our work and [8], the norms are simply regimented, limiting the agent's normative reasoning capability to complying always with the imposed norms, without considering the possibility of violation. Permitting violation, allows the agent to weigh up outcomes of disregarding or adhering to a norm prior to committing to compliance or violation.

In order to avoid the shortcomings of logic-based approaches discussed in the third paragraph of this section, we have used scheme-based practical reasoning. Closest to our work is the approach in [8], however, instead of using AATS and evaluating all possible evolutions of the system, we approach this problem from a planning perspective, where only those evolutions that satisfy at least one goal are evaluated. The other difference is that [8] assumes that the conflict between different entities is inferred form paths, rather than being formulated in advance as it is in this work. Goal conflict for instance arises due to the fact that certain actions may achieve one but not another. Whereas, argument schemes and critical questions proposed here are based on the conflict formulated in the formal model level. Therefore, knowing that two goal conflict is used in the dialogue to explain why one was satisfied in a plan and the other one was not. In addition, in our approach, the justification of evaluation of plans to identify the best plan(s), is formulated using a persuasion dialogue game, in which the agent argues why a course of action should be taken.

7 Conclusion and Future Work

This paper proposes a formal framework for normative practical reasoning that is able to generate consistent plans for a set of conflicting goals and norms. The conflict between plans, goals and norms is managed by constructing arguments for these entities and instantiating an AF according to their relations. In order to bring transparency to the agent decision-making process when deciding which plan to execute, a persuasion dialogue is employed. Such a dialogue dialectically points out the reasons why (i) a goal/norm is or is not satisfied in a plan, (ii) a particular plan that pursues certain goals while violating and complying with some norms, should be the course of actions for the agent to execute. The main focus of future work is implementing the formal model.

Another area of future work is to extend the normative reasoning capability of the model by allowing state based norms. Such an extension would allow the expression of obligation and prohibitions to achieve or avoid some state before some deadline. A combination of event and state based norms (e.g. [22]) enriches the norm representation as well as normative reasoning. Furthermore, the normative reasoning can be extended by modelling permission norms as exceptions to obligation and prohibition norms (see [23] for more details).

Regarding the dialogue, at the moment, the preference-based AF constructed based on argument schemes and critical questions is converted to Dung's AF before being subjected to the persuasion dialogue. As a result the preference information is abstracted away in the dialogue. For instance, the reason for a goal not being satisfied in a plan could be because another goal that is in conflict with the former was satisfied in the plan. Knowing that the attack relation between two goals is symmetric, there must have been a preference relation that reduced the symmetric attack between the two goal arguments to an asymmetric one which is not explicit in the dialogue. We plan to make the dialogue game more informative by including information about preferences.

Traditionally, preferred semantics are used for practical reasoning because they preserve the agent's choices in case of unresolvable conflict between available courses of actions. By allowing multiple plans in the grounded extension, this choice is available to the agent. Having said that, as a part of future work, we are planning to apply preferred semantics to the problem presented in this paper and compare the result with grounded semantics.

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