# Argumentation-based decision making for selecting communication services in ambient home environments [1]

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**Abstract.** We propose here an Argumentation Framework (AF) for decision making in order to select services in ambient environments. A logic language is used as a concrete data structure for holding the statements like knowledge, goals, and actions. Different priorities are attached to these items. These concrete data structures consist of information providing the backbone of arguments. In this way, our AF selects some services but also provides an interactive and intelligible explanation of the choices.

## 1 INTRODUCTION

Service selection is the act of taking several material or immaterial products, and choosing some of them to meet the needs of a given customer. Indeed, when a user identifies her needs and specifies them with high-level and abstract terms, there should be a possibility to choosing some existing services. The related issues are being addressed by ongoing work in the area of the Semantic Web, Business Processes Workflow Management, and MultiAgent Systems (MAS). The latter offers solutions where the service selection could be performed dynamically by agents through negotiation [3].

Service selection requires MAS algorithms for negotiation, in order to select the best services taking account the user's constraints. Negotiation is a form of interaction in which a group of agents, with conflicting interests and a desire to cooperate, try to come to a mutually acceptable agreement [9]. Various decision mechanisms for automated negotiation have been proposed and studied. These include: game-theoretic analysis; heuristic-based approaches; and argumentation-based approaches. The main distinguishing feature of the latter is that it allows for more sophisticated forms of interaction. In this paper we present an Argumentation Framework (AF) for decision-making in order to perform the service selection. A logic language is used as a concrete data structure for holding the statements like knowledge, goals, and actions. Different priorities are attached to these items. These concrete data structures consist of information providing the backbone of arguments. In this way, our AF selects some solutions but also provides an interactive and intelligible explanation of the choices that could enrich the negotiation.

Section 2 introduces the walk-through example. In order to present our Argumentation Framework (AF) for decision making, we will browse the following fundamental notions. First, we define the *object language* (cf Section 3). Second, we will focus on the internal structure of *arguments* (cf Section 4). We present in Section 5 the *interactions* between them. These relations allow us to give a declarative model-theoretic *semantics* to this framework and we adopt a *dialectical proof procedure* to implement it (cf Section 6). Section 7 discusses some related works and draws some conclusions.

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## 2 WALK-THROUGH EXAMPLE

Ambient communication aims at enabling new forms on human communication in ambient home environments. Inspired by [11], we consider here a flexible system for selecting services in ambient communication environments. An agent is in charge of managing requirements and selecting some services.

The agent is responsible for selecting a suitable application, either based on explicit user needs or on context-based rules. She combines situation-specific constraints provided by devices and their knowledge on typical services. The main goal, that consists of selecting the services ($g_0$), is addressed by four decisions: the selection of the $\texttt{Audio}$, $\texttt{Video}$, $\texttt{Txt}$ and $\texttt{Content}$ channel. The assistant agent must select, for each decision, one alternative. For instance, $\texttt{Txt}(x)$ with $x \in \{\texttt{im}^3, \texttt{mobile}, \texttt{mail}, \texttt{none}\}$. The main goal ($g_0$) is split into sub-goals. The service must be adapted for 'important' ($g_1$), 'urgent' ($g_2$), and 'persistent' ($g_3$) communications. These high-level goals reveal the users'needs. The knowledge about the context is expressed with predicates such as: $\texttt{Loc}(\texttt{user}, \texttt{office})$ (the user is in her office space), or $\texttt{Ste}(\texttt{user}, \texttt{free})$ (the user is free).

Figure 1 provides a simple graphical representation of the decision problem called influence diagram [4]. The elements of the decision problem, i.e. *values* (represented by rectangles with rounded corners), *decisions* (represented by squares) and *knowledge* (represented by ovals), are connected by arcs where predecessors affect successors. We consider here a multiattribute decision problem captured by a hierarchy of values where the abstract value (represented by a rectangle with rounded corner and double line) aggregates the values in the lower level. While the influence diagram displays the structure of the decision, the object language reveals the hidden details of the decision.

## 3 THE OBJECT LANGUAGE

Since we want to provide a computational model of decision making and we want to instantiate it for our case study, we need to specify a particular logic.

The object language expresses rules and facts in logic-programming style. In order to address a decision making problem, we distinguish:

- a set of *goals*, i.e. some propositional symbols which represent the features that the decision must exhibit (denoted by $g_0, g_1, g_2, \ldots$);

[3] $\texttt{im}$ stands for instant messaging.

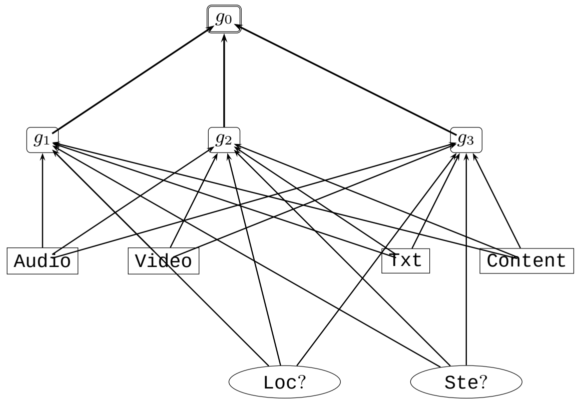


**Figure 1.** Influence diagram to structure the decision

- a *decision*, i.e. a predicate symbol which represents the action which must be performed (denoted by $D$);
- a set of *alternatives*, i.e. some constants symbols which represent the mutually exclusive solutions for the decision (eg `im`, `mail`);
- a set of *beliefs*, i.e. some predicate symbols which represent epistemic statements (denoted by words such as `Loc`, or `Ste`).

Since we want to consider conflicts in this object language, we need some form of negation. For this purpose, we only consider strong negation, also called explicit or classical negation[4]. A strong literal is an atomic formula, possible preceded by strong negation $\neg$. $\neg L$ says "L is definitely not the case". Since we restrict ourselves to logic programs, we cannot express in a compact way the mutual exclusion between alternatives. For this purpose, we define the incompatibility relation (denoted by $\mathcal{I}$ ) as a binary relation over atomic formulas which is transitive and symmetric. Obviously, $L \mathcal{I} \neg L$ for each atom $L$, and $D(a_1) \mathcal{I} D(a_2)$, $a_1$ and $a_2$ being different alternatives. Similarly, we say that a sentence $\phi_1$ is incompatible with a set of sentences $\Phi_2$ ($\phi_1 \mathcal{I} \Phi_2$) iff there is a sentence $\phi_2$ in $\Phi_2$ such as $\phi_1 \mathcal{I} \phi_2$. A theory gathers the statements about the decision making problem.

**Definition 1 (Theory)** *A* theory $\mathcal{T}$ *is an extended logic program, i.e a finite set of rules of the form* $R : L_0 \leftarrow L_1, \ldots, L_n$ *with* $n \geq 0$*, each* $L_i$ *being a strong literal. The literal* $L_0$*, called the* head *of the rule, is denoted by* $L_0 = head(R)$*. The finite set* $\{L_1, \ldots, L_n\}$*, called the* body *of the rule, is denoted by* $body(R)$*. The body of a rule can be empty. In this case, the rule is called a* fact*.* $R$*, called the name of the rule, is an atomic formula.*

Considering a decision making problem, we distinguish:

- *goal rules* of the form $R : g_0 \leftarrow g_1, \ldots, g_n$ with $n > 0$. Each $g_i$ is a goal. According to this rule, the head goal is reached if the goals in the body are reached;
- *epistemic rules* of the form $R : B_0 \leftarrow B_1, \ldots, B_n$ with $n \geq 0$. Each $B_i$ is a belief literal;
- *decision rules* of the form $R : g \leftarrow D, B_1, \ldots, B_n$ with $n \geq 0$. The head of this rule is a goal and the body includes a decision literal ($D$) and a possible empty set of belief literals. According to this rule, the goal can be eventually reached by the decision $D$, provided that conditions $B_1, \ldots, B_n$ are satisfied.

[4] Weak negation considered eg in [8] seems not to be useful in our applications.

Considering statements in the theory is not sufficient to take a decision, since some priorities between these pieces of information should be taken into account. For this purpose, we consider that the *priority* $\mathcal{P}$ is a (partial or total) preorder on $\mathcal{T}$. $R_1 \mathcal{P} R_2$ can be read "$R_1$ has priority over $R_2$". We define three priority relations:

- the priority over *goal rules* comes from their levels of *preference*. Let us consider two goal rules $R_1$ and $R_2$ with the same head ($g_0 = \text{head}(R_1) = \text{head}(R_2)$). $R_1$ has priority over $R_2$ if the achievement of the goals in the body of $R_1$ are more "important" than the achievement of the goals in the body of $R_2$ as far as reaching $g_0$ is concerned;
- the priority over *epistemic rules* comes from their levels of *certainty*. Let us consider, for instance, two facts $F_1$ and $F_2$. $F_1$ has priority over $F_2$ if the first is more likely to hold than the second one;
- the priority over *decision rules* comes from their levels of *credibility*. Let us consider two rules $R_1$ and $R_2$ with the same head. $R_1$ has priority over $R_2$ if the first conditional decision is more credible than the second one.

The goal theory, the epistemic theory (resp. the decision theory) are represented in Table 1 (resp. Table 2).

To simplify the graphical representation of the theories, they are stratified in non-overlapping subsets, i.e. different levels. The *ex æquo* rules are grouped in the same level. Non-comparable rules are arbitrarily assigned to a level. According to the goal theory, the achievement of $g_1$, $g_2$ and $g_3$ is required to reach $g_0$, but this constraint can be relaxed and the achievement of $g_3$ is more important than the achievement of $g_2$ which is is more important than the achievement of $g_1$ to reach $g_0$. According to the epistemic theory, the assistant agent does not know where the user is. Due to conflicting sources of information, the agent has conflicting beliefs about the state of the user. Since these sources of information are more or less reliable, $F_3^\beta \mathcal{P} F_1^\beta$. According to the decision theory, the user prefers instant messaging and mobile to mail and no text for urgent communications. However the credibility of these alternatives depends on the context: the location and the state of the user.

**Table 1.** The goal theory and the epistemic theory

| |
|---|
| $R_{012}^\alpha : g_0 \leftarrow g_1, g_2, g_3$ |
| $R_{023}^\alpha : g_0 \leftarrow g_2, g_3$<br>$R_{013}^\alpha : g_0 \leftarrow g_1, g_3$<br>$R_{012}^\alpha : g_0 \leftarrow g_1, g_2$ |
| $R_{03}^\alpha : g_0 \leftarrow g_3$ |
| $R_{02}^\alpha : g_0 \leftarrow g_2$ |
| $R_{01}^\alpha : g_0 \leftarrow g_1$ |

| |
|---|
| $F_1^\beta : \mathtt{Ste}(\mathtt{user}, \mathtt{free}) \leftarrow$ |
| $F_3^\beta : \neg\mathtt{Ste}(\mathtt{user}, \mathtt{free}) \leftarrow$ |

We will build now arguments in order to compare the alternatives.

## 4 ARGUMENTS

Due to the recursive nature of arguments (arguments are composed of subarguments, subarguments for these subarguments, and so on), we adopt and extend the tree-like structure for arguments proposed in [12].

**Table 2.** The decision theory

| | |
|---|---|
| $\uparrow$ | $R^{\delta}_{21} : g_2 \leftarrow \mathtt{Txt(im)}, \mathtt{Loc(user, office)}, \mathtt{Ste(user, free)}$ |
| | $R^{\delta}_{21} : g_2 \leftarrow \mathtt{Txt(mobile)}, \mathtt{Ste(user, free)}$ |
| | $R^{\delta}_{23} : g_2 \leftarrow \mathtt{Txt(mail)}, \neg\mathtt{Ste(user, free)}$ |
| | $R^{\delta}_{24} : g_2 \leftarrow \mathtt{Txt(none)}$ |

**Definition 2 (Argument)** *An argument has a conclusion, top rules, premises, suppositions, and sentences. These elements are abbreviated by the corresponding prefixes. An argument $A$ is:*

1. *a* supposal argument *built upon an unconditional ground statement. If $L$ is a ground literal such that there is no rule $R$ in $\mathcal{T}$ which can be instantiated in such a way that $L = head(R)$, then the argument, which is built upon this ground literal is defined as follows: $\mathtt{conc}(A) = L$, $\mathtt{top}(A) = \emptyset$, $\mathtt{premise}(A) = \emptyset$, $\mathtt{supp}(A) = \{L\}$, $\mathtt{sent}(A) = \{L\}$.*
*or*
2. *a* trivial argument *built upon an unconditional ground statement. If $F$ is a fact in $\mathcal{T}$, then the argument $A$, which is built upon the ground instance $F^g$ of $F$, is defined as follows: $\mathtt{conc}(A) = head(F^g)$, $\mathtt{top}(A) = F^g$, $\mathtt{premise}(A) = \{head(F^g)\}$, $\mathtt{supp}(A) = \emptyset$, $\mathtt{sent}(A) = \{head(F^g)\}$.*
*or*
3. *a* tree argument *built upon an instantiated rule such that all the literals in the body are the conclusion of subarguments. If $R$ is a rule in $\mathcal{T}$, we define the argument $A$ built upon a ground instance $R^g$ of $R$ as follows. Let $\{L_1, \ldots, L_n\}$ be the body of $R^g$ and $\mathtt{subarg}(A) = \{A_1, \ldots, A_n\}$ be a collection of arguments such that, for each $L_i \in body(R^g)$, $\mathtt{conc}(A_i) = L_i$ each $A_i$ is called a subargument of $A$. Then: $\mathtt{conc}(A) = head(R^g)$, $\mathtt{top}(A) = R^g$, $\mathtt{premise}(A) = body(R^g)$, $\mathtt{supp}(A) = \cup_{A' \in \mathtt{subarg}(A)} \mathtt{supp}(A')$, $\mathtt{sent}(A) = \cup_{A' \in \mathtt{subarg}(A)} \mathtt{sent}(A') \cup body(R^g)$.*
*Moreover, a tree argument must be consistent, i.e. $\mathtt{sent}(A)$ is neither incompatible with itself nor incompatible with $\mathtt{conc}(A)$.*

*The set of arguments built upon $\mathcal{T}$ is denoted $\mathcal{A}(\mathcal{T})$.*

As in [12], we consider *atomic* arguments (2) and *composite* arguments (3). Moreover, we distinguish *supposal* arguments (1) and *built* arguments (2/3). Notice that we add a technically essential constraint on arguments that is commonly assumed in the literature, namely that each argument is consistent. Due to the abductive nature of decision making, we define and construct arguments by reasoning backwards. Therefore, arguments are minimal, i.e. they do not include irrelevant information such as sentences not used to prove the conclusion. Notice that the different premises can be challenged and can be supported by composite arguments. In this way, arguments are intelligible explanations.

Triples of conclusions - premises - suppositions are simple representations of arguments. For example, some of the arguments concluding $g_2$ are the following:

$-A^2 = \langle g_2, (\mathtt{Txt(im)}, \mathtt{Loc(user, office)}, \mathtt{Ste(user, free)}), (\mathtt{Txt(im)}, \mathtt{Ste(user, free)})\rangle$;
$-B^2 = \langle g_2, (\mathtt{Txt(mobile)}, \mathtt{Ste(user, free)}), (\mathtt{Txt(mobile)}, \mathtt{Ste(user, free)})\rangle$;
$-C^2 = \langle g_2, (\mathtt{Txt(mail)}, \neg\mathtt{Ste(user, free)}), (\mathtt{Txt(mail)}, \neg\mathtt{Ste(user, free)})\rangle$;
$-D^2 = \langle g_2, (\mathtt{Txt(none)}), (\mathtt{Txt(none)})\rangle$.

Let us focus on $A^2$. This tree argument is built with two supposal arguments and one trivial argument:

$-A = \langle \mathtt{Txt(im)}, \emptyset, (\mathtt{Txt(im)})\rangle$;
$-B = \langle \mathtt{Loc(user, office)}, \emptyset, \emptyset\rangle$;
$-C = \langle \mathtt{Ste(user, free)}, \emptyset, (\mathtt{Ste(user, free)})\rangle$.

Due to their structure/nature, arguments interact with one another.

## 5 Interactions between arguments

The interactions between arguments may come from their nature, from the incompatibility of their sentences, and from the priority relation between the top rules of built arguments. We examine in turn these different sources of interaction.

Since sentences are conflicting, arguments interact with one another. For this purpose, we define the attack relation.

**Definition 3 (Attack relation)** *Let $A$ and $B$ be two arguments. $A$* attacks *$B$ (denoted by attacks $(A, B)$) iff $\mathtt{conc}(A)\ \mathcal{I}\ \mathtt{sent}(B)$.*

This attack relation, often called *undermining* attack, is indirect, i.e. directed to a "subconclusion". However, the direct attack, also called *rebuttal* attack, can also be obtained [7]. Since each argument is consistent, it does not attack itself. The attack relation is useful to build an argument which is an homogeneous explanation.

Since arguments have different natures (supposal or built) and the top rules of built arguments are more or less strong, they interact with one another. For this purpose, we define the strength relation.

**Definition 4 (Strength relation)** *Let $A_1$ be a supposal argument, and $A_2, A_3$ be two built arguments. 1) $A_2$ is stronger than $A_1$ (denoted $A_2\ \mathcal{P}^{\mathcal{A}}\ A_1$); 2) If $\mathtt{top}(A_2)\ \mathcal{P}\ \mathtt{top}(A_3)$, then $A_2\ \mathcal{P}^{\mathcal{A}}\ A_3$;*

Since $\mathcal{P}$ is a preorder on $\mathcal{T}$, $\mathcal{P}^{\mathcal{A}}$ is a preorder on $\mathcal{A}(\mathcal{T})$. Obviously, arguments built upon the existing knowledge are preferred to supposal arguments. When we consider two built arguments, we adopt the last link principle: the stronger the top rule is, the better the argument is. The strength relation is useful to choose (when it is possible) between homogeneous concurrent explanations, i.e. non conflicting arguments with the same conclusions.

The two previous relations can be combined to choose (if possible) between non-homogeneous concurrent explanations, i.e. conflicting arguments with the same conclusions.

**Definition 5 (Defeats)** *Let $A$ and $B$ be two arguments. $A$* defeats *$B$ (written defeats $(A, B)$) iff attacks $(A, B)$ and $\neg(B\ \mathcal{P}^{\mathcal{A}}\ A)$. Similarly, we say that a set $S$ of arguments defeats an argument $A$ if $A$ is defeated by one argument in $S$.*

Since $A^2$, $B^2$, $C^2$, and $D^2$ suggest incompatible alternatives, these arguments attack each other. Since the top rule of $A^2$ and $B^2$ (i.e. $R^{\delta}_{21}$ and $R^{\delta}_{22}$) have priority over the top rule of $C^2$ and $D^2$ (i.e. $R^{\delta}_{23}$ and $R^{\delta}_{24}$), $A^2$ and $B^2$ defeat $C^2$ and $D^2$. If we only consider these four arguments, the agent cannot decide what the best alternative is. However, $B^2$, which is composed of one supposal argument, is "better" than $A^2$, which is composed of two supposal arguments. Determining whether a service is ultimately selected requires a complete analysis of all arguments and subarguments.

## 6 SEMANTICS AND PROCEDURES

We can consider our AF abstracting away from the logical structures of arguments. This abstract AF consists of a set of arguments associated with a binary defeat relation. It can be equipped with various semantics, which can be computed by dialectical proof procedures.

Given an AF, "acceptable" sets of arguments[5] are defined as follows:

**Definition 6 (Semantics)** *An AF is a pair $\langle \mathcal{A},\ defeats\ \rangle$ where $\mathcal{A}$ is a set of arguments and $defeats\ \subseteq \mathcal{A} \times \mathcal{A}$ is the defeat relationship[5] for AF. For $A \in \mathcal{A}$ an argument and $S \subseteq \mathcal{A}$ a set of arguments, we say that:*

- $A$ *is* acceptable *with respect to* $S$ *(denoted* $A \in \mathcal{S}^S_{\mathcal{A}}$*) iff* $\forall B \in \mathcal{A},\ defeats\ (B, A)\ \exists C \in S\ \text{such that}\ defeats\ (C, B)$;
- $S$ *is* conflict-free *iff* $\forall A, B \in S\ \neg\ defeats\ (A, B)$;
- admissible *iff* $S$ *is conflict-free and* $\forall A \in S,\ A \in \mathcal{S}^S_{\mathcal{A}}$;
- preferred *iff* $S$ *is maximally admissible;*

The semantics of an admissible (or preferred) set of arguments is credulous, in that it sanctions a set of arguments as acceptable if it can successfully dispute every arguments against it, without disputing itself. However, there might be several conflicting admissible sets. Various sceptical semantics have been proposed for AF [5]. Since an ultimate choice amongst various admissible set of alternatives is not always possible, we adopt a credulous semantics. The decision $D(a_1)$ is *suggested* iff $D(a_1)$ is a supposition of one argument in an admissible set.

Since our practical application requires to specify the internal structure of arguments, we adopt the procedure proposed in [7] to compute admissible arguments. If the procedure succeeds, we know that the argument is contained in a preferred set. We have implemented our AF, called MARGO[6] (Multiattribute ARGumentation framework for Opinion explanation). For this purpose, we have translated our AF in an assumption-based AF (ABF for short). CaSAPI[7] computes the admissible semantics in the ABF by implementing the procedure proposed in [7]. Moreover, we have developed a CaSAPI meta-interpreter to relax constraints on the goals achievements and to make suppositions in order to compute the admissible semantics in our concrete AF. In this section, we have shown how arguments in the framework can be categorized in order to select some services.

## 7 RELATED WORKS AND CONCLUSIONS

The Belief-Desire-Intention (BDI) model of agency is the most famous model of agents for decision making. However, the simplifying assumptions made to implement modal logic specifications of BDI agents meant that they lack of a strong theoretical underpinning [10]. That is the reason why [6] proposes the KGP model [6] adopting Knowledge, Goals, and Plans as the main component of an agent state. However, this model deals only partially with priorities, as required by service selection, eg preferences between goals, reliability of knowledge, and credibility of possible actions. For this purpose, we have provided here a suitable revised representation of knowledge, goals and actions, Future investigations must make planning abilities available.

[8, 1] focus on AFs for selecting single actions. [1] (resp. [2]) is a mathematical (resp. philosophical) general approach of defeasible argumentation for practical reasoning. To the best of our knowledge, the existing AFs for decision making leave the underlying language unspecified contrary to our AF.

In this paper we have proposed a concrete AF for selecting services which provides an interactive and intelligible explanation of the choices made to reach such selection. Moreover we have implemented this AF and test it for this usecase. A logic language is used as a concrete data structure for holding the statements like knowledge, goals, and actions. Different priorities are attached to these items corresponding to the reliability of the knowledge, the preferences between goals, and the credibility of actions. These concrete data structures consist of information providing the backbone of arguments. Due to the abductive nature of decision making, arguments are built by reasoning backwards. To be intelligible, arguments are defined as tree-like structures. Since an ultimate choice amongst various admissible set of services is not always possible, we have adopted a credulous semantics. Future investigations must explore how to drive argumentation-based negotiations between agents.

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[5] Actually, in [5] the defeat relation is called attack.
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[7] http://www.doc.ic.ac.uk/∼dg00/casapi.html