# Holistic Argumentation: A Logic Programming Approach

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**Abstract.** In this report, we introduce the notion of holistic arguments. A holistic argument is formed by two arguments, an argument $a$ and an argument $h(a)$ which says something about $a$. This means that $h(a)$ is a *meta-argument* of $a$. In order to manage the relations between holistic arguments, an extension of Dung's argumentation frameworks is presented. This extension will be called *holistic argumentation frameworks*. We present an application of holistic argumentation frameworks in a medical scenario. In particular, we define an argumentation approach for modeling medical diagnosis. For capturing the knowledge of the medical scenario, normal and abductive logic programs are used.

**Keywords.** Argumentation Theory, Medical Diagnosis, Logic Programming.

## 1. Introduction

Different reasoning strategies are usually applied in complex and incomplete knowledge domains when humans reason towards decisions about e.g., medical diagnosis [8]. These can be seen as supplementary methods to create a base for a decision, and may be limited and of less quality when applied in solitude. In practice, the situation may involve more than one agent with different reasoning methods possibly due to level of expertise, type of profession, speciality or the use of different medical sources, but with the aim to collaboratively create a stable base for a decision. In a wider perspective, the aim is to accomplish a *holistic*[2] assessment, taking both different interpretations of observations into account as well as a range of different phenomenon as target for observations.

When different perspectives are combined they are typically separated into distinct arguments in an argumentation-based dialogue about a topic in applied examples in literature (one example is the argumentation schemes, which explicitly distinguish between chosen reasoning pattern [10]). We propose an alternative approach for the purpose to illuminate the different perspectives that generates strengths of an argument, which may follow humans' reasoning in a more intuitive way. We motivate the approach by examples from the medical domain.

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[2]The concept *holistic* is defined in Oxford American Dictionaries the following way: "characterized by comprehension of the parts of something as intimately interconnected and explicable only by reference to the whole". http://www.oxfordlanguagedictionaries.com/

The knowledge used when reasoning about a medical diagnosis is ideally based on evidence-based medical knowledge generalizable over a large population. However, this knowledge is translated into diagnostic criteria based on consensus among researchers in order to become applicable to a single individual and of practical use in the encounter with a patient. These different types of sources of knowledge make use of different reasoning strategies, which are co-existing and observable in medical professionals' decision making (e.g., causal and diagnostic reasoning) [8]. We acknowledge this, and propose the notion of *holistic argumentation*, meaning that there is at least two supporting perspectives for each claim, where the supplementary part of the holistic argument may be considered being a *meta*-argument, providing strength based on contextual information. An illustrating example is the following: consider the situation where there are diagnostic criteria for a disease, which a patient partly fulfills considering the available observations. An argument can be formed with a strength selected among a set of values. However, since the available knowledge is incomplete, a verification is made using an evidence-based medical study where the diagnosis can be supported based on a population study conducted in the area where the patient is living. This supplementary support is possibly measured using a different set of values.

Against this background, we outline the argumentation approach called *holistic argumentation*, for aggregating information from different sources as composite arguments. By considering holistic arguments, the concept of holistic argumentation framework is defined. We show that these holistic argumentation frameworks are a natural generalization of Dung's argumentation frameworks [6]. In order to show the applicability of holistic argumentation frameworks, these argumentation frameworks are instantiated by using two kinds of arguments, *i.e.*, deductive and abductive arguments. For building these arguments, normal logic programs and the well-found semantics ([**?**]) are considered.

We use in this paper as a running example the case when a patient shows symptoms that can be evaluated using more than one knowledge source and the diagnosis that is supported by more knowledge sources is preferred.

The rest of the paper is divided as follows: In the following section, some basic concepts of logic programs are presented. After this, the holistic argumentation frameworks are defined as an extension of Dung's argumentation frameworks [6]. An application of the holistic argumentation frameworks in the context of medical diagnosis in presented in the subsequent section. In the last section, an outline of our conclusions and future work is presented.

## 2. Background

In this section, some basic concepts of logic programs are presented. In particular, the syntaxis of extended normal logic programs is presented. For capturing the semantics of these programs, the well-founded semantics ([**?**]) is presented.

### *2.1. Normal Logic Programs*

The language of propositional logic has an alphabet consisting of

**(i)** propositional symbols: $p_0, p_1, ...$
**(ii)** connectives : $\vee, \wedge, \leftarrow, \neg,\ not, \top$

**(iii)** auxiliary symbols : ( , ).

in which $\vee, \wedge, \leftarrow$ are 2-place connectives, $\neg$, $not$ are 1-place connectives and $\top$ is a 0-place connective. The propositional symbols, $\top$, and the propositional symbols of the form $\neg p_i$ ($i \geq 0$) stand for the indecomposable propositions, which we call *atoms*, or *atomic propositions*. Atoms negated by $\neg$ will be called *extended atoms*. We will use the concept of atom without paying attention to whether it is an extended atom or not. The negation sign $\neg$ is regarded as the so called *strong negation* by the ASP's literature and the negation $not$ as the *negation as failure*. A literal is an atom, $a$ (called positive literal), or the negation of an atom $not\ a$ (called negative literal). Given a set of atoms $\{a_1, ..., a_n\}$, we write $not\ \{a_1, ..., a_n\}$ to denote the set of literals $\{not\ a_1, ..., not\ a_n\}$.

An extended normal clause, *C*, is denoted:

$$a \leftarrow b_1, \ldots, b_j, not\ b_{j+1}, \ldots, not\ b_{j+n} \tag{1}$$

where $j + n \geq 0$, $a$ is an atom and each $b_i$ ($1 \leq i \leq j + n$) is an atom. When $j + n = 0$ the clause is an abbreviation of $a \leftarrow \top$ such that $\top$ is the propositional symbol that always evaluates to true. In a slight abuse of notation, we sometimes write the clause 1 as $a \leftarrow \mathcal{B}^+, not\ \mathcal{B}^-$, where $\mathcal{B}^+ := \{b_1, \ldots, b_j\}$ and $\mathcal{B}^- := \{b_{j+1}, \ldots, b_{j+n}\}$. An extended normal program $P$ is a finite set of extended normal clauses. When $n = 0$, the clause is called *extended definite clause*. *An extended definite logic program* is a finite set of extended definite clauses. By $\mathcal{L}_P$, we denote the set of atoms in the signature of $P$. Let $Prog_{\mathcal{L}}$ be the set of all normal programs with atoms from $\mathcal{L}$.

We will manage the strong negation ($\neg$) in our logic programs as it is done in ASP [3]. Basically, each atom of the form $\neg a$ is replaced by a new atom symbol $a'$ which does not appear in the language of the program. For instance, let $P$ be the extended normal program:

$$a \leftarrow q. \qquad \neg q \leftarrow r. \qquad q \leftarrow \top. \qquad r \leftarrow \top.$$

Then replacing the atom $\neg q$ with a new atom symbol $q'$, we will have:

$$a \leftarrow q. \qquad q' \leftarrow r. \qquad q \leftarrow \top. \qquad r \leftarrow \top.$$

In order not to allow inconsistent models from logic programs, a normal clause of the form $f \leftarrow q, q', f$ such that $f \notin \mathcal{L}_P$ is added.

### *2.2. Well-Founded Semantics*

In this section, we present a standard definition of the well-founded semantics in terms of rewriting systems. We start by presenting a definition *w.r.t.* a 3-valued logic semantics.

**Definition 1 (SEM)** *[?] For a normal logic program P, we define HEAD($P$) := $\{a|\ a \leftarrow \mathcal{B}^+,\ not\ \mathcal{B}^- \in P\}$ — the set of all head-atoms of P. We also define SEM($P$) = $\langle P^{true}, P^{false}\rangle$, where $P^{true} := \{p|\ p \leftarrow \top \in P\}$ and $P^{false} := \{p|\ p \in \mathcal{L}_P \backslash HEAD(P)\}$. SEM($P$) is also called a model of P.*

In order to present a characterization of the well-funded semantics in terms of rewriting systems, we define some basic transformation rules for normal logic programs.

**Definition 2 (Basic Transformation Rules)** *[?] A transformation rule is a binary relation on $Prog_{\mathcal{L}}$. The following transformation rules are called* basic. *Given a program $P \in Prog_{\mathcal{L}}$ we define:*

**RED$^+$:** *This transformation can be applied to $P$, if there is an atom $a$ which does not occur in HEAD(P). **RED$^+$** transforms $P$ to the program where all occurrences of $not\ a$ are removed.*

**RED$^-$:** *This transformation can be applied to $P$, if there is a rule $a \leftarrow \top \in P$. **RED$^-$** transforms $P$ to the program where all clauses that contain $not\ a$ in their bodies are deleted.*

**Success:** *Suppose that $P$ includes a fact $a \leftarrow \top$ and a clause $q \leftarrow body$ such that $a \in body$. Then we replace the clause $q \leftarrow body$ by $q \leftarrow body \setminus \{a\}$.*

**Failure:** *Suppose that $P$ contains a clause $q \leftarrow body$ such that $a \in body$ and $a \notin HEAD(P)$. Then we erase the given clause.*

**Loop:** *We say that $P_2$ results from $P_1$ by* $\text{Loop}_A$ *if, by definition, there is a set $A$ of atoms such that:*

1. *for each rule $a \leftarrow body \in P_1$, if $a \in A$, then $body \cap A \neq \emptyset$,*
2. $P_2 := \{a \leftarrow body \in P_1 | body \cap A = \emptyset\}$,
3. $P_1 \neq P_2$.

Let $CS_0$ be the rewriting system containing the basic transformation rules: **RED$^+$**, **RED$^-$**, **Success**, **Failure**, and **Loop**.

We denote the uniquely determined normal form of a program $P$ with respect to the rewriting system $CS_0$ by $norm_{CS_0}(P)$. $CS_0$ induces a semantics $\text{SEM}_{CS_0}$ as follows:

$$\text{SEM}_{CS_0}(P) := \text{SEM}(norm_{CS_0}(P))$$

In order to illustrate the basic transformation rules, let us consider the following example.

**Example 1** *Let $P$ be the following normal logic program:*

$$b \leftarrow\ not\ a. \qquad c \leftarrow\ not\ b. \qquad c \leftarrow a.$$

*Now, let us apply $CS_0$ to $P$. Since $a \notin HEAD(P)$, then we can apply **RED$^+$** to $P$. Thus we get:*

$$b \leftarrow \top. \qquad c \leftarrow\ not\ b. \qquad c \leftarrow a.$$

*Observe that now we can apply **RED$^-$** to the new program, thus we get:*

$$b \leftarrow \top. \qquad\qquad c \leftarrow a.$$

*Finally, we can apply **Failure** to the new program, thus we get:*

$$b \leftarrow \top.$$

*This last program is called the* normal form *of $P$ w.r.t. $CS_0$, because none of the transformation rules from $CS_0$ can be applied.*

WFS was introduced in [**?**] and it was characterized in terms of rewriting systems in [**?**]. This characterization is defined as follows:

**Lemma 1** *[**?**] $CS_0$ is a confluent rewriting system. It induces a 3-valued semantics that is the well-founded semantics.*

Given a normal logic program $P$, by $WFS(P)$, we denote the well-founded model of $P$.

**Example 2** *Let $P$ be the normal logic program introduced in Example 1. As we saw in Example 1, $norm_{CS_0}(P)$ is:*

$$b \leftarrow \top.$$

*This means that $WFS(P) = \langle \{b\}, \{a, c\} \rangle$*

**Example 3** *We illustrate a normal logic program with an example from the dementia domain (simplified due to space reasons). A summary of the clinical guidelines which are used in the dementia example given here can be found in [7] and includes [1]. We use the following abbreviations:*

$$
\begin{aligned}
AD &= \textit{Alzheimer's disease} \\
DLB &= \textit{Lewy body type of dementia} \\
VaD &= \textit{Vascular dementia} \\
epiMem &= \textit{Episodic memory dysfunction} \\
fluctCog &= \textit{Fluctuating cognition} \\
fn &= \textit{Focal neurological signs} \\
prog &= \textit{Progressive course} \\
radVasc &= \textit{Radiology exam shows vascular signs} \\
slow &= \textit{Slow, gradual onset} \\
extraPyr &= \textit{Extrapyramidal symptoms} \\
visHall &= \textit{Visual hallucinations}
\end{aligned}
$$

*By considering the previous abbreviations as propositional atoms, let $P$ be a normal logic program formed by the following set of normal clauses.*

1. $VaD \leftarrow fn,\ not\ AD,\ not\ DLB$
2. $VaD \leftarrow radVasc,\ not\ AD,\ not\ DLB$
3. $AD \leftarrow slow, prog, epiMem,\ not\ VaD,\ not\ DLB$
4. $DLB \leftarrow extraPyr, visHall, not\ fn$
5. $DLB \leftarrow fluctCog, visHall, not\ fn$
6. $DLB \leftarrow fluctCog, extraPyr, not\ fn$
7. $VaD \leftarrow fn, radVasc$

*These normal clauses will be considered for building argument in the following section.*

## 3. Holistic Argumentation Frameworks

In this section, the first part of our main results are presented. In particular, the notions of a holistic argument and an extension of Dung's argumentation frameworks are defined. So, we start by presenting the Dung's argumentation framework definition.

**Definition 3** *[6] An argumentation framework is a pair $AF = \langle AR, attacks\rangle$, where* AR *is a finite set of arguments, and* attacks *is a binary relation on* AR*,* i.e.attacks $\subseteq$ $AR \times AR$*.*

For two arguments $a$ and $b$, we say that $a$ *attacks* $b$ (or $b$ is attacked by $a$) if $attacks(a, b)$ holds. it only tells us the relation of two conflicting arguments. Now, let us to define the idea of holistic argument.

**Definition 4** *Let $AR$ and $AR_h$ be sets of arguments.*

- *A holistic argument $a_h$ is a pair of the form $\langle a, h(a)\rangle$ such that $a \in AR$, $h(a) \in AR_h$, and $h : AR \longmapsto AR_h$ is a relation. $\mathcal{AR}_h$ denotes the induced holistic arguments from $AR$ and $AR_h$.*
- *A holistic preference relation $\preceq_h$ is binary relation on $\mathcal{AR}_h$ such that it is reflexive, antisymmetry and transitive.*

Observe that a holistic argument is formed by two *common* arguments, *i.e.* $a$, $h(s)$, which are related by a relation, $h : AR \longmapsto AR_h$. The basic idea is that given an argument $a$ there is an argument $h(a)$ which says something about $a$. For instance, $h(a)$ can be a preference numerical value about $a$ or $h(a)$ can be an other argument (no a numerical value) which adds information about $a$. Hence, the combination of $a$ and $h(a)$ aggregates information with respect to a common topic between $a$ and $h(a)$. A holistic preference relation $\preceq_h$ defines an partial order between the information which is aggregated by holistic arguments. Hence, a holistic argumentation framework is defined as follows:

**Definition 5** *A holistic argumentation framework is a tuple of the form:*

$$\langle AR, attacks, AR_h, \mathcal{AR}_h, \preceq_h\rangle$$

*where $AR$, $attacks$ are as in Definition 3, $AR_h$ is a set of arguments such that $AR \cap AR_h = \emptyset$, $\mathcal{AR}_h$ is the set of holistic arguments induced by $AR$ and $AR_h$, $\preceq_h$ is a holistic preference relation on $\mathcal{AR}_h$.*

Given that a holistic argument is formed by two arguments, a relation of *defeat* between two holistic arguments is defined as follows:

**Definition 6** *Given a holistic argumentation framework $AF_h = \langle AR,\ attacks,\ AR_h, \mathcal{AR}_h, \preceq_h\rangle$ and $a_h, b_h \in \mathcal{AR}_h$ such that $a_h = \langle a, h(a)\rangle$ and $b_h = \langle b, h(b)\rangle$.*

- *$a_h$ attacks $b_h$ iff $(a, b) \in attacks$*
- *$a_h$ defeats $b_h$ iff $(a, b) \in attacks$ and it is not the case that $b \succ a$.*

One see that given this definition of *defeat* between holistic arguments one can follow the idea of acceptability by using abstract argumentation semantics, *i.e.*, grounded, preferred, *etc.*[6]. We only introduce the simple generalization of admissible sets and preferred extensions with respect to holistic argumentation frameworks.

**Definition 7** *Let* $AF_h = \langle AR,\ attacks,\ AR_h,\ \mathcal{AR}_h, \preceq_h \rangle$ *and* $a_h, b_h \in \mathcal{AR}_h$ *be a holistic argumentation framework and* $S \subseteq \mathcal{AR}_h$*:*

- $S$ *is conflict free iff there are not* $a_h, b_h \in S$ *such that* $a_h$ *attacks* $b_h$
- $a_h \in \mathcal{AR}_h$ *is acceptable with respect to* $S$ *if: for all* $b_h \in \mathcal{AR}_h$ *which attacks* $a_h$ *there exists* $c_h \in S$ *such that* $c_h$ *defeats* $b_h$.
- $S$ *is an admissible set iff* $S$ *is conflict free and for all* $a_h \in S$ *is acceptable with respect to* $S$.
- $S$ *is a preferred extension iff* $S$ *is an admissible set and* $S$ *is maximal with respect to set inclusion.*

A natural property of the holistic argumentation frameworks is that they generalize Dungt's argumentation frameworks. We show this property by considering admissible sets. Let us recall that stable, grounded, complete and preferred extensions (introduced in [6]) are admissible sets.

**Proposition 1** *Let* $AF_h = \langle AR,\ attacks,\ AR_h,\ \mathcal{AR}_h, =_h \rangle$ *be a holistic argumentation framework such that* $AR_h = \{\top\}$*, for all* $a \in AR$*,* $h(a) = \top$ *and* $=_h$ *is the equal relation.* $E$ *is an admissible set of* $AF_h$ *iff* $E' = \{a | \langle a, \top \rangle \in E\}$ *is an Dung-admissible set of* $AF = \langle AR, attacks \rangle$*. The Dung-admissible set follows the well-know definition of admissible sets introduced in [6].*

Proof. (Sketch) One can see that the definition of admissible sets is the same (Definition 7 and Dung-admissible sets) when all the arguments are equal preferable Hence, the proof is straightforward by the definition of holistic argument and the definition of defeat between holistic arguments. ■

At this point, we want to point out that the holistic argumentation frameworks are not a simple extension of the Dung's argumentation frameworks. Let us recall that we motivate the necessity of holistic arguments by the need of aggregating information from different sources. In the following section, we will see that by using holistic arguments, we merge arguments from two different knowledge bases which support a common claim.

As a final comment of this section, one can see that the holistic argumentation frameworks have common points with at least the value-based argumentation frameworks [4] and the preference-based argumentation framework [2] . By lack of space, we will explore these common points in the long version of this paper.

## 4. An application of Holistic Argumentation Frameworks

In this section, we instantiate holistic argumentation frameworks (HAFs) in a practical application. In particular, we use HAFs for modeling an argumentation framework which tries to capture medical diagnosis. To this end, two kinds arguments are defined: *deductive arguments* and *abductive arguments*. The idea is that given a set of observations a deductive argument will infer a conclusions. On the other hand, given the conclusion of the deductive argument, an abductive argument will support the conclusion of the given deductive argument. Let us start defining deductive arguments.

### *4.1. Deductive Arguments*

An deductive argument will be defined by considering normal logic programs and the well-found semantics.

**Definition 8 (Deductive argument)** *Let $P$ be a normal logic programs and $O \subseteq \mathcal{L}_P$. $A_D = \langle S, O, c \rangle$ is a deductive argument if the following conditions holds:*

- *$c \in T$ such that $WFS(S \cup O') = \langle T, F \rangle$*
- *$S \subseteq P$ (respectively $O' \subseteq O$) such that $S$ is a minimal set among the subsets of $P$ (respectively $O'$ is a minimal set among the subsets of $O$) satisfying* 1.

*$\mathcal{A}^D(P, O)$ denotes the set of deductive arguments built from $AF$ and $O$.*

**Example 4** *Let $P$ be the normal program introduced in Example 3 and $O = \{fn,$ $extraPyr,$ $fluctCog\}$. Some deductive arguments which one build from $P$ and $O$ are:*

$$\begin{aligned} Arg_D^1 = & \quad \langle \{\}, \{fn\}, fn \rangle \\ Arg_D^2 = & \quad \langle \{DLB \leftarrow fluctCog, extraPyr, not\ fn\}, \\ & \quad \{fluctCog, extraPyr\}, DLB \rangle \\ Arg_D^3 = & \quad \langle \{VaD \leftarrow fn,\ not\ AD,\ not\ DLB\}, \{fn\}, VaD \rangle \end{aligned}$$

*From these arguments, we can believe that the given patient could be diagnosed with* Lewy body type dementia *(DLB) or* Vascular dementia *(VaD).*

Once we have defined the structure of a deductive argument, the attack relation between these arguments is defined as follows:

**Definition 9 (Attack relation between deductive arguments)** *Let $A = \langle S_A, O_A, c_A \rangle$, $B = \langle S_B, O_B, c_B \rangle$ be two deductive arguments, $WFS(S_A \cup O_A) = \langle T_A, F_A \rangle$ and $WFS(S_B \cup O_B) = \langle T_B, F_B \rangle$. We say that $A$ attacks $B$ if one of the following conditions holds:*

- *$a \in T_A$ and $\neg a \in T_B$.*
- *$a \in T_A$ and $a \in F_B$.*

*$At_d(S)$ denotes the set of attack relations between the deductive arguments which belong to a set of deductive arguments $S$.*

Observe that the first condition of the definition is capturing the standard idea of rebut and the second condition is capturing the standard idea of undercut.

**Example 5** *Let us consider the three deductive arguments which were introduced in Example 4. One can see the following relations of attack:*

*$Arg_D^1$ attacks $Arg_D^2$* *$Arg_D^2$ attacks $Arg_D^3$*

*4.2. Abductive Arguments*

Now let us introduce the definition of abductive arguments. To this end, the class of abductive programs is defined.

**Definition 10 (Abductive Program)** *Let $P$ an extended logic program. An abductive logic program is a pair $\langle P, H\rangle$ where the following conditions hold:*

1. *$H \subset \mathcal{L}_P$, $H$ will be called hypothesis.*
2. *$P$ is an extended normal logic program such $HEAD(P) \cap H = \emptyset$.*

This definition follows the ideas of abductive programs introduced in [9]. Hence, by considering this definition an abductive argument is defined as follows:

**Definition 11 (Abductive Argument)** *Let $P_{Ab} = \langle P, H\rangle$ be an abductive logic program and $A$ a set of atoms. An abductive argument with respect to an atom $a \in A$ is $A^{Ab}(a) = \langle S, E, a\rangle$ such that the following conditions holds:*

- *$a \in T$ such that $WFS(S \cup E) = \langle T, F\rangle$*
- *$S \subseteq P$, $E \subseteq H$ and both $S, E$ are minimal amount the subsets of P and E respectively.*

*$\mathcal{A}^{Ab}(P_{Ab}, A)$ denotes the set of abductive arguments built from $P_{Ab}$ and $A$.*

One can see that an abductive argument is an explanation of a given atom.

**Example 6** *By considering the propositional atoms introduced in Example 3, let $P_{Ab} = \langle P', H\rangle$ be an abductive program such that $H = \{DLB, VaD, AD\}$, and $P'$ the following set of normal clauses:*

1. $extraPyr \leftarrow DLB$
2. $fluctCog \leftarrow DLB$
3. $visHall \leftarrow DLB$
4. $fn \leftarrow VaD$
5. $radVasc \leftarrow VaD$
6. $epiMem \leftarrow AD$

*Let us consider $O = \{fn,\ extraPyr,\ fluctCog\}$. Hence, some abductive arguments from $P_{Ab}$ and $O$ are:*

*The next argument argues that* extrapyramidal symptoms *($extraPyr$) can be* explained by Lewy body type of dementia *($DLB$):*

$$Arg_1^{Ab} = \langle \{extraPyr \leftarrow DLB\}, \{DLB\}, extraPyr\rangle$$

*The following argument have easy readings:*

$$Arg_2^{Ab} = \langle \{fluctCog \leftarrow DLB\}, \{DLB\}, fluctCog\rangle$$
$$Arg_3^{Ab} = \langle \{fn \leftarrow VaD\}, \{VaD\}, fn\rangle$$

*4.3. Holistic arguments*

Now that we have defined deductive and abductive arguments, the definition of a holistic argument based on deductive and abductive arguments is presented.

**Definition 12** *Let $P$ be a normal logic program, $P_{Ab} = \langle P', H\rangle$ be an abductive program, $O \subseteq \mathcal{L}_P$. A holistic argument $a_{h^\circ}$ is of the form $\langle a^d, h^\circ(a^d)\rangle$ such that $a^d \in \mathcal{A}^D(P, O)$, $a^d = \langle S, O', c^D\rangle$ and*

$$h^\circ(a^d) := P \cup \begin{cases} a^{Ab} & \textit{if } \ a^{Ab} \in \mathcal{A}^{Ab}(O), \\ & a^{Ab} = \langle S, H, c^{Ab}\rangle, c^D \in H \textit{ and } c^{Ab} \in O' \\ \langle \{\}, \{\}, \top\rangle & otherwise \end{cases}$$

One can see that a holistic argument according to Definition 12 is formed by a deductive argument which claims a conclusion $c$ and this this claim is supported by an abductive argument. An important point to observe is that in case that $c$ cannot be supported by an abductive argument from $\mathcal{A}^{Ab}(O)$, the second part of the given holistic argument will be the empty-abductive argument, *i.e.*, $\langle \{\}, \{\}, \top\rangle$.

**Example 7** *Let us consider the deductive arguments which were introduced in Example 4 and the abductive arguments which were introduced in Example 6. From these arguments, one can build the following holistic arguments:*

$$Arg_h^1 = \langle Arg_D^1, \langle \{\}, \{\}, \top\rangle\rangle$$
$$Arg_h^2 = \langle Arg_D^2, Arg_1^{Ab}\rangle$$
$$Arg_h^3 = \langle Arg_D^2, Arg_2^{Ab}\rangle$$
$$Arg_h^4 = \langle Arg_D^3, Arg_3^{Ab}\rangle$$

*By considering the relations of attack identified in Example 5, we can see that: $Arg_h^1$ attacks $Arg_h^2$, $Arg_h^1$ attacks $Arg_h^3$, $Arg_h^2$ attacks $Arg_h^4$, $Arg_h^3$ attacks $Arg_h^4$.*

Once we have defined the structure of the holistic arguments, the last element which is required for defining a holistic argumentation framework is an order delation between holistic arguments. This order relation can be defined in several forms. For instance,

1. To consider the number of assumptions (atoms negated by negation as failure) which appear in each holistic arguments and define an order relation by using this number..
2. To consider possibilistic knowledge bases for building the deductive and abductive arguments; hence, to consider the possibilistic values for defining a preference-order between holistic arguments.

In order to simplify the presentation of the paper, the preference order in this paper will only consider as preferred arguments those arguments which their abductive arguments are different to the empty abductive argument.

Let $a_{h^\circ} = \langle a, h^\circ(a)\rangle$, $b_{h^\circ} = \langle b, h^\circ(b)\rangle$ be two holistic arguments. $a_{h^\circ} \succ_{h^\circ} b_{h^\circ}$ holds iff ($h^\circ(a) \neq \langle \{\}, \{\}, \top\rangle$ and $h^\circ(b) = \langle \{\}, \{\}, \top\rangle$) or ($a = \langle \{\}, S, c\rangle$). On the other hand, $a_{h^\circ} =_{h^\circ} b_{h^\circ}$ holds iff $h(a)^\circ \neq \langle \{\}, \{\}, \top\rangle$ and $b_{h^\circ} \neq \langle \{\}, \{\}, \top\rangle$.

In formally speaking, $\preceq_{h^\circ}$ prefers claims which are supported by two knowledge bases (the deductive argument and the abductive argument).

**Example 8** *By considering the holistic arguments and the relations of attack identified in Example 7, and the the relation $\succeq_{h^\circ}$, one can see that there is an admissible set of holistic arguments which is: $\{Arg_h^1, Arg_h^4\}$.*

The example shows that the approach allows for assessing vascular dementia based on the available observations and based on four different knowledge sources sorted into two knowledge bases. The example could also be extended with additional sources, giving stronger support to the alternative diagnosis (DLB).

Since the construction of the deductive arguments is based on the well-founded semantics, the set of conclusions of the deductive arguments which belong to an admissible set is a subset of the true atoms of the well-founded model of $P^{\mathcal{A}^D}$. $P^{\mathcal{A}^D}$ is defined as follows: Given a set of deductive arguments $\mathcal{A}^D$, the normal program $P^{\mathcal{A}^D} = \{S \cup O | \langle S, O, c\rangle \in \mathcal{A}^D\}$. Observe that $P^{\mathcal{A}^D}$ basically is the union of the sub-programs which belong to each deductive argument that belongs to $\mathcal{A}^D$.

**Proposition 2** *Let $P$ be a normal logic program, $P_{Ab}$ be an abductive program, $O \subseteq \mathcal{L}_P$ and $AF_{h^\circ} = \langle \mathcal{A}^D(P,O), At_d(\mathcal{A}^D(P,O)), \mathcal{A}^{Ab}(P_{Ab},O), \mathcal{AR}_{h^\circ}, \preceq_{h^\circ}\rangle$ be a holistic argumentation framework. If $E$ is admissible set of $AF_{h^\circ}$ then $T' \subseteq T$ such that $T' = \{c | \langle\langle S, O', c\rangle, \top\rangle \in E\}$ and $WFS(P^E) = \langle T, F\rangle$.*

Proof. (Sketch) The proof follows by the fact that the well-founded semantics satisfies the property of relevance [5]. ■

## 5. Conclusions

In this paper, we have motivated and introduced an argumentation approach (called *holistic argumentation*) for aggregating information from different sources. In particular, given an argument $a$, we identify an other argument $h(a)$ which suggests something about $a$. Indeed, we can regard $h(a)$ as a meta-argument of $a$.

The motivation of this framework is diverse. There are qualitative properties built into the context of an argument that can be challenged or behave as supportive features, besides the strength of the argument. The following are examples: 1) the characteristics of the knowledge source that gives the knowledge base for the argument (sensitivity, specificity, etc), 2) the reasoning strategy built into the knowledge source (causal, deductive, adductive, etc), 3) the reliability of the premises, 4) the confidence the mediator agent has who proposes the claim, 5) obligations imposed by an external actor to use certain knowledge source, and 6) the potential benefit (or risk) that may come out of the selected decision. It is not obvious how these different properties should be evaluated, and it may be the case that depending on the situation, these different factors may have different degree of influence. Looking closer into these factors, it is clear that the focus shifts from the topic of the original argument towards other but related topics.

An example is when the argument is supporting a hypothetical diagnosis based on a particular clinical guideline, and the meta-argument gives the support for using the clinical guideline, *e.g.*, as a preference expressed by a medical organization, or as a measure of the guideline's sensitivity to detect the disease.

We have showed that the holistic argumentation frameworks generalize the Dung's argumentation frameworks. There are several argumentation approaches which are related to holistic argumentation, *i.e.*, the value-based argumentation frameworks [4] and the preference-based argumentation framework [2]. Part of our future work will be to explore the common points among these argumentation frameworks and holistic argumentation.

By considering logic programs with negation as failure, we have instantiated holistic argumentation in order to define an argumentation approach for supporting medical diagnosis. We considered the well-founded semantics for building two kinds of arguments: deductive and abductive arguments. In the literature, there are several logic programming semantics for capturing the semantics of normal logic programs; however, it well-know that the well-founded semantics satisfies a good number of properties ([5]) which take relevance in the process of building arguments, *i.e.*, it is polynomial time computable, it satisfies relevance, etc.

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