Modelling Imprecise Arguments in a Weighted Argument System

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***Abstract*—The paper applies the newly proposed weighted argument systems (WAS) and the associated notion of inconsistency budget [3]. Fuzzy theory and ontological knowledge are used to supply WAS with the required weights, whilst the weighted argument systems provide a beautiful and simple principle to decide which fuzzy logic to use for reasoning, given an argumentation set.**

***Keywords*-weighted argument systems; fuzzy reasoning; description logic; knowledge representation;**

I. Introduction

From the practical perspective, the argumentative-based applications are still very limited. One reason for the lack of a large scale proliferation is the gap between the low level provided by the existing argumentation frameworks and the level of expressivity and flexibility required by human agents.

During the past years, the research on argumentation theory has focused on i) identifying and formalizing the most adequate technical instrumentation for modeling argumentation and ii) specifying standards for changing arguments between agents. Defeasible reasoning has its strong points for the modelling issue, whilst Argument Interchange Format (AIF) ontology fulfils the requirements for arguments interchange in multi-agent systems.

Argumentation schemes and diagrammin reasoning based on conceptual maps have been introduced in order to provide support for human argumentation. One line of research consists in developing hybrid approaches that combine the advantages of formal (logic-based) and informal (argumentation schemes-based, diagramming reasoning) ideas.

The seminal work of Dung [2] with his abstract argumentation framework paved the way towards identifying many theoretical insights of the argument bases. We have focused on the newly formalized WAS [3], as an extension of the Dung's model. The attacks are associated with a *weight*, indicating the relative strength of the attack. The notion of *inconsistency budget* is used to characterise how much inconsistency one is prepared to tolerate in an argumentation base. Our proposal exploits fuzzy theory and ontological knowledge in order to supply WAS with the required weights.

(A) It may be very hard to reverse the trend of eating junk food that can be achieved by education alone.
(B) It is cheap and easy for people to eat junk food, opposite to the nutrition food.
(C) At the store where I shop, a candy bar costs less than a dollar and is ready to eat.
(D) Candy bar can be classified as junk food.
(E) Fresh fruits and vegetables tend to be inconveniently packaged and cost more.
(F) Fresh fruits and vegetables can be classified as nutritious foods.
(G) It is also highly profitable for manufacturers because
(H) junk food has a long shelf life in the retail outlet.

Figure 1. Mix of fuzzy and ontological knowledge in arguments.

II. Motivation

Real arguments are a mixture of fuzzy linguistic variables and ontological knowledge. This section advocates the use of fuzzy description logic (FDL) as the technical instrumentation aiming to fill the gap between software and human arguments. The DL component contributes to the current vision of the World Wide Argument Web [5], while the fuzzy component helps agents to exploit the arguments conveyed by humans.

Consider the example in figure 1, where A is the final conclusion, B is supported by several premises C, D, E, F, while G gives additional reasons to support B. The conclusion A contains the linguistic variable *Hard*, meaning that the point to be proved is a fuzzy concept. It also contains the modifier *very* which can be seen as a function which alters the membership function of the fuzzy concept *Hard*. Two other fuzzy variables, *Cheap* and *Easy*, appear in the sentence B. Here we meet the concept *People* which is linked by the role *eat* with the concept *JunkFood*. The concept *NutritionFood* is disjointed with the concept *JunkFood*. Both of them are subsumed by the more general concept *Food*.

One might consider how clear is the delimitation between junk and nutrition food? The definition of junk food is applied to some food which has little nutritional value, or to products with nutritional value but which also have ingredients considered unhealthy:

$$JunkFood = Food \sqcap (\exists\, hasNutritionalValue.Little \sqcup \exists\, hasIngredients.Unhealthy)$$

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Operation	Lukasiewicz Logic	Godel Logic
Intersection	$max\{\alpha+\beta-1,0\}$	$min\{\alpha,\beta\}$
Union	$min\{\alpha+\beta,1\}$	$max\{\alpha,\beta\}$
Negation	$1-\alpha$	$1,\ if\ \alpha=0,\ 0,\ otherwise$
Implication	$min\{1,1-\alpha+\beta\}$	$1, if \alpha \leqslant \beta, \beta, otherwise$

Figure 2. Operators in Fuzzy Logics.

In this definition there are two roles which points to the fuzzy concepts *Little* and *Unhealthy*. Take the common example of pizza. Can it be categorized as junk or nutrition food? Associated with some food outlets, it is labelled as "junk", while in others it is acceptable and trendy. One can rather consider that it belongs to both concepts with different degrees of truth.

The sentence D introduces the subconcept *CandyBar* subsumed by the concept *JunkFood* ($CandyBar \sqsubseteq JunkFood$), while the sentence C instantiates a candy bar which costs less than a dollar. The terms *Fresh* and *Inconveniently* in the sentence E are also fuzzy concepts, while the statement F introduces new ontological knowledge: $FreshFruits \sqsubseteq NutritionalFood$, $Vegetables \sqsubseteq NutritionalFood$. The fuzzy modifier *highly* appears in the sentence G, and additionally, the fuzzy concept *Long* in H. The point that we want to bear out here, is that humans consistently use both fuzzy and ontological knowledge when they convey arguments.

From the technical perspective, one issue regards what type of inference one can apply between two fuzzy arguments, i.e. B and A. What about the case in which B is supported by two independent reasons? Should one take into consideration the strongest argument, or both of them may contribute to the degree of truth? One advantage of fuzzy logic is that it provides technical instrumentation (Lukasiewicz semantics, Godel semantics) to handle all the above cases in an argumentative debate. The interpretation of Godel operators maps the *weakest link principle* in argumentation, which states that an argument supported by a conjunction of antecedents α and β, is as good as the weakest premise. The reason behind this principle is the fact that the opponent of the argument will attack the weakest premise in order to defeat the entire argumentation chain. This situation suits perfectly the semantics of the Godel operator for intersection (figure 2). When several reasons to support a consequent are available, each having the strength and β, the strongest justification is chosen to be conveyed in a dialog protocol, which can be modelled by the Godel union operator ($max\{\alpha,\beta\}$).

The Lukasiewicz semantics fits better to the concept of *accrual of arguments*. In some cases, independent reasons supporting the same consequent provide stronger arguments in favor of that conclusion. Under the Lukasiewicz logic, the strength of the premises (α,β) contributes to the confidence of the conclusion, given by $max\{\alpha+\beta-1,0\}$. For instance, the testimony of two witnesses is required in judicial cases. Similarly, several reasons against a statement act as a form of collaborative defeat.

One issue related to appling Lukasiewicz operators to argumentation regards the difficulty to identify independent reasons. Thus, an argument presented in different forms contributes with all its avatars to the alteration of the current degree of truth. For instance, an argument subsumed by a more general concept would also contribute to the amendment of the degree of truth. Consider $Pizza \sqcap NutritionalFood \Rightarrow AcceptableFood$ and that a particular instance of pizza, belongs with a degree of $\alpha=.95$ to the concept *Pizza* and with $\beta=.5$ to the *NutritionalFood* concept. Given the Lukasiewicz intersection operator, the degree of truth for the considered pizza to be an *AcceptableFood* is: $max\{\alpha+\beta-1,0\}=.45$

The requirement of the accrual principle, that the premises should be independent, is violated: the degree of truth for a particular pizza to belong to the concept *AcceptableFood* is altered by the fact that the concept *Pizza* is already subsumed with a degree of 0.3 by the concept *NutritionalFood*. Thus, the description logic provides the technical instrumentation needed to identify independent justifications, whilst Lukasiewicz semantics offer a formula to compute the accrual of arguments. The accrual of dependent arguments is not necessarily useless. Changing the perspective, this case can be valuable in persuasion dialogs, where an agent, by repeatedly posting the same argument in different forms, will end in convincing his partner to accept it.

The nature of the argumentative process itself indicates that the subject of the debate cannot be easily categorised as true or false. The degree of truth for an issue (α) and its negation ($1-\alpha$) are continuously changed during the lifetime of the dispute. Thus, the different levels of truthfulness (and falsity) from fuzzy logic can be exploited when modelling argumentation.

Of great importance is the fact that the argument bases are characterised by a degree of inconsistency. Rules supporting both a consequent and its negation co-exist in the knowledge base. This inconsistency is naturally accommodated in fuzzy logic, where the intersection between the fuzzy concept A and its negation is not zero: $A \wedge \neg A \neq 0$.

III. Weighted Argument Systems

WASs [3] extend the Dung abstract argument systems [2] by adding numeric weights to every edge in the argument graph. The weights correspond to the relative strengths of different attacks between arguments.

Definition. A Dung abstract argument system is a pair

$D = \langle X, A \rangle$ where $X = \alpha_1, ..., \alpha_k$, is a finite set of arguments, and $A \subseteq X \times X$ is a binary attack relation.

In this model, given the attack relation $(\alpha_1, \alpha_2) \in A$ if one accepts α_1, it would be inconsistent to accept α_2. In a Dung argument system $D = \langle X, A \rangle$ and $S \subseteq X$ we say that S is *consistent* if $\nexists \alpha_1 \in S$ such that $\exists\, \alpha_2 \in X$ and $(\alpha_1, \alpha_2) \in A$. It happens that the only consistent set of arguments to be the empty set. The WASs refine the model in order to deal with such trivial solutions.

Definition. A WAS is a triple $W = \langle X, A, w \rangle$, where $\langle X, A \rangle$ is a Dung abstract argument system, and $w : A \rightarrow \mathbb{R}_{\leq 0}$ is a function assigning positive real valued weights to attacks [3].

The inconsistency budget $\beta \in [0, 1]$ characterises how much inconsistency one is willing to tolerate within the argument base. Given this value, the attacks up to a total weight of β can not be taken into consideration in the weighted argument system W [3].

Fuzzy Description Logic (FDL) has been proposed as an extension to classical DL with the aim to deal with fuzzy and imprecise concepts, and it is based on the *SHIF(D)* version of the description logic. The complete formalisation can be found in [1].

IV. Running scenario

The following arguments taken from [3] fit perfectly to our purpose of modelling imprecise arguments:

- α_1: The house is in good location, it is large enough for our family and it is affordable: we should buy it.
- α_2: The house suffers from subsidence, which is prohibitively expensive to fix: we shouldn't buy it.

The arguments α_1 and α_2 attack each other, expressed as $A = \{(\alpha_1, \alpha_2), (\alpha_2, \alpha_1)\}$, where A is the binary attack relation. Within a Dung argumentation framework only the empty solution exists, as the grounded extension is the empty set. In order to compute β-solutions, firstly, one has to estimate the relative weights of the attack relations. Secondly, the set of arguments which require the smallest inconsistency budget is preferred to take the decision of buying the house or not.

A. Computing the strength of the arguments

This section shows how FDL can be used both to formalize and to compute the degree of truth of the above arguments. The proof of concept scenario is formalised in the *FuzzyDL* reasoner [1].

Firstly, we need to specify the ontological knowledge of the house selling domain. We start by introducing the relevant attributes of the subject of the dispute. Thus, the *isLocated* feature limits the distance between the center of the town and the current house to an integer value between 0 and 20 kilometers (line 1 in figure 3).

```
1.(define-concrete-feature isLocated *integer* 0 20)
2.(define-concrete-feature hasPrice *integer* 0 100000)
3.(define-concrete-feature hasArea *integer* 0 150)
4. (define-fuzzy-concept GoodLocation trapezoidal(0,10,1,2,4,5))
5. (define-fuzzy-concept Affordable
                        left-shoulder(0,100000,50000,70000))
6. (define-fuzzy-concept Large right-shoulder(0,150,70,80))
7. (define-concept ShouldBuy
             (and House (some isLocated GoodLocation)
                        (some hasPrice Affordable)
                        (some hasArea Large)))
8. (instance house1 (and House (= isLocated 2)
                        (= hasPrice 55000) (= hasArea 80)
                        (= hasPeriodOfInhabitation 3)))
```

Figure 3. Formalizing the Argument α_1 in FDL.

Similarly, the price lies in the interval [0, 100000] (line 2), whilst the area of the house is between 0 and 150 square meters (line 3). Usually, these information for a particular house are available during the argumentation and exactly specified, therefore they are modelled as crisp values in the current framework.

We continue by defining in line 4 what a good location means. The concept is a fuzzy one, represented by the trapezoidal membership function $(0, 10, 1, 2, 4, 5)$. If the distance between center and the considered house is within the interval $[2, 4]$ kilometers, the degree of membership to the *GoodLocation* concept is one, if the distance is in $(1, 2)$ or $(4, 5)$, the membership is less than one, and it is considered 0, for the other values in the interval $[0, 10]$. Based on the definition in line 5, a house is considered *Affordable* with the degree of 1 if the price is less then 50000, with a subunit degree if the price is within 50000 and 70000, and zero for any other value within the interval $[0, 100000]$. In line 6, an entity belongs to the fuzzy concept *Large* if the area is at least 70.

Line 7 formalises the first argument α_1 based on the fuzzy relationships introduced so far. Thus, the concept *ShouldBuy* is defined as a house situated in a *GoodLocation*, having an *Affordable* price and a *Large* area. A particular instance (line 8) $house_1$ is located at a distance of 2 km from the downtown, has a selling price of 55000, and an area of 80 square meters. Based on the trapezoidal membership function of the fuzzy concept *GoodLocation*, $house_1$ is an instance of this concept with a degree of truth $\alpha = max - instance?\ house_1\ GoodLocation) = 1$. The price of 55000 leads to a degree of $\beta = .75$ to the concept *Affordable*, whilst the value 79 square meters contributes to the membership of the *Large* concept with a degree $\gamma = .9$. Under the Lukasiewicz semantics, the answer to the query $(max - sat?\ ShouldBuy\ house_1)$ is computed as $\alpha_1^L = max\{max\{\alpha + \beta - 1, 0\} + \gamma - 1, 0\} = .65$

Here, both the price value (.75) and the area (.9) have affected the cognitive state of the buyer, leading to the decreasing of the weight of the *ShouldBuy* action. If the most dissonant factor with the client's preferences has

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9.(define-concrete-feature hasPeriodOfInhabitation *integer* 0 10)
10. (define-fuzzy-concept Subsidence right-shoulder(0,10,1,4))
11. (define-concept ExpensiveToFix (and House
        (some hasPeriodOfInhabitation Subsidence)))
12. (define-concept ShouldNotBuy (and House ExpensiveToFix))
13. (instance house1 (= hasPeriodOfInhabitation 3)) 0.9)
14. (functional attack)
15. (related ShouldBuy ShouldNotBuy attack 0.65)
16. (related ShouldNotBuy ShouldBuy attack 0.667)
```

Figure 4. Formalizing the Argument α_2 in FDL.

Semantics/Argument	α_1	α_2
Lukasiewicz Logic	$\alpha_1^L = 0.65$	$\alpha_2^L = 0.667$
Godel Logic	$\alpha_1^G = 0.75$	$\alpha_2^G = 0.667$

Figure 5. The strengths of the arguments α_1 and α_2.

affected the decision, then the price is the only one that contributes to the strength of the conclusion. In this case, the weight is computed based on the Godel semantics: $\alpha_1^G = min\{min\{\alpha, \beta\}, \gamma\} = 0.75$. The ontological knowledge needed to represent the argument α_2 is introduced in the figure 4. Here, the role *hasPeriodOfInhabitation* represents the number of years in which the house was not inhabited, which can be between 0 and 10 years according to line 9. The fuzzy concept *Subsidence* states the a house suffers from subsidence if the number of years in which it was not inhabited is greater than 1, within a degree computed based on the right-shoulder membership function. Any house which suffers from subsidence would be expensive to fix, is defined as an implication in line 11. Line 12 formalises the second argument α_2, stating that we should not buy a house which is expensive to fix. Finally, the newly available piece of information is introduced: it seems that the house was not inhabited for three years (line 13). Opposite to the features introduced in line 8, this information cannot be verified with certainty. A factor of 0.9 is used to model this uncertainty.

The a-box $house_1$ belongs to the *ExpensiveToFix* concept within a degree of 0.567. Thus, it belongs to the concept *ShouldNotBuy* with $\alpha_2^L = max(0.567 + 1 - 0.9, 0) = 0.667$ under the Lukasiewicz semantics and with the degree $\alpha_2^G = min(0.667, 0.9) = 0.667$ under the Godel semantics.

B. Computing the β-solutions

Table 5 sumarises the degree of truth obtained so far, for both viewpoints α_1 and α_2, under the Lukasiewicz and Godel semantics. The attack set for $\beta = 0$ is $A^L_{\beta=0} = \{(\alpha_1, \alpha_2)_{0.65}, (\alpha_2, \alpha_1)_{0.67}\}$ for the first case, and $A^G_{\beta=0} = \{(\alpha_1, \alpha_2)_{0.75}, (\alpha_2, \alpha_1)_{0.67}\}$, for the second one. Under the Lukasiewicz logic the support for α_2 is greater, leading to the not buying decision. Quite the opposite, the support is stronger for the α_1 under the Godel logic, supporting the decision to buy.

The inconsistency budget provides us the principle to decide one side or the other. Based on it, *the argument that requires the smallest inconsistency budget is preferred.* If $\beta < 0.65$ no attack relation can be disregarded from A^L and A^G. For $\beta \in [0.65, 0.667)$ the relation $(\alpha_1, \alpha_2)_{0.65}$ can be eliminated from A^L. For $\beta \geq 0.667$ the attack relations become $A^L_{\beta \geq 0} = A^G_{\beta \geq 0} = \varnothing$. Therefore, $\beta = 0.65$ is the smallest inconsistency budget which leads to a non empty solution. The solution is given under the Lukasiewics semantics $A^L_{\beta=0.65} = \{(\alpha_2, \alpha_1)_{0.667}\}$, and it corresponds to the not buying decision.

V. Related Work and Conclusion

Rahwan and Banihashemi demonstrated the use of automated DL reasoning over argument structures, the arguments being represented in the AIF ontology. Our work is rather complementary, by focusing on the interaction between human and software arguments. Fuzzy Argumentation Frameworks (FAF) were proposed as an extension of traditional Dung argumentation framework to enrich the expressivity of the argumentation model [4]. Our approach benefits from the supplementary expressive power provided by the DL component, being committed to the idea of supporting large scale argumentation as envisaged by the argumentative web [5].

We advocated the use of fuzzy reasoning and DL in argumentation systems, aiming to fill the gap between human arguments and software agents arguments. We identified some links between fuzzy reasoning and some issues in the argumentation theory (such as *the weakest link principle* and *the accrual of arguments*); What makes fuzzy logic adequate as a tool to represent argument bases, is the capacity to implicitly tolerate a level of inconsistency, inconsistency which is the main feature of the argument bases. The paper is one of the first that applies the newly proposed WASs and the notion of inconsistency budget.

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