Modelling Imprecise Arguments in Description Logic

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***Abstract*—Real arguments are a mixture of fuzzy linguistic variables and ontological knowledge. This paper focuses on modelling imprecise arguments in order to obtain a better interleaving of human and software agents argumentation, which might be proved useful for extending the number of real life argumentative-based applications. We propose Fuzzy Description Logic as the adequate technical instrumentation for filling the gap between human arguments and software agents arguments. A proof of concept scenario has been tested with the *fuzzyDL* reasoner.**

***Index Terms*—semi-structured argumentation, description logic, fuzzy logic**

I. INTRODUCTION

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

On the one hand, 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 software agents. Defeasible logic seems to be one answer to the modelling issue [2], whilst Argument Interchange Format (AIF) ontology fulfills the requirements for arguments interchange in multi-agent systems [10]. On the other hand, argumentation schemes [6] and diagrammatic reasoning [12] based on conceptual maps have been introduced in order to provide support for human argumentation.

The current trend consists of developing hybrid approaches that combine the advantages of formal (logic-based) and informal (argumentation schemes-based, diagramming reasoning) ideas [4]. In our viewpoint the software argumentation and human argumentation should not be treated separately. Even if the software agents skills of searching, comparing and identifying fallacies in argumentation chains are quite remarkable at the propositional level, many of the argumentative domains such as legal reasoning or medical argumentation rely mostly on the interaction with the human agent, which lacks the ability to easily interpret non-linguistic arguments. The focus on the interleaving of human and software agents might prove to be useful for extending the number of real life argumentative-based applications.

To meet these requirements, we propose fuzzy description logic as the technical instrumentation aiming to fill the gap between software and human arguments.

The description logic component contributes to the current vision [10] of developing the infrastructure for World Wide Argument Web (WWAW). The fuzzy component helps agents to exploit the real arguments conveyed by humans.

In the next section we illustrate the interleaving of fuzzy with ontological knowledge in real arguments. In section 3 we introduce Fuzzy Description Logic that we use to model imprecise arguments. Section 4 describes a running scenario based on fuzzy argumentation schemes. We end with related work and conclusions.

II. MOTIVATION

To illustrate this idea some examples follow. Firstly, in human argumentation, some attacks rely on fuzzy premises. Statements like "*the accused did not have a good relationship with the victim*" include the fuzzy notion of *good relationship*. Also, the sentence itself may be accepted only to a certain extent, as opposed to being either accepted or not.

1. *It may be very hard to reverse the trend of eating junk food that can be achieved by education alone.*
2. *It is cheap and easy for people to eat junk food, opposite to the nutrition food.*
3. *At the store where I shop, a candy bar costs less than a dollar and is ready to eat.*
4. *Candy bar can be classified as junk food.*
5. *Fresh fruits and vegetables tend to be inconveniently packaged and cost more.*
6. *Fresh fruits and vegetables can be classified as nutritious foods.*
7. *It is also highly profitable for manufacturers because*
8. *junk food has a long shelf life in the retail outlet.*

Figure 1. Imprecise argument with fuzzy variables and ontological knowledge.

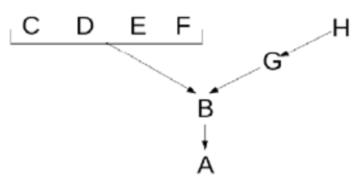

Figure 2. The structure of the argument

The example in figure 1 is adapted from [13]. The structure of the argument is depicted in figure 2, where *A* is the final conclusion. The sentence *B* is supported by several

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premises *C*, *D*, *E*, *F*, while *G* gives additional reasons to support *B*. Observe that 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 also introduced, which can be seen as disjoint with the concept *JunkFood*. Both of them are subsumed by the 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 is perceived to have little nutritional value, or to products with nutritional value but which also have ingredients considered unhealthy.

$$\text{JunkFood} = \text{Food} \sqcap (\exists \text{NutritionalValue.Little} \sqcup \exists \text{hasIngredients. Unhealthy}$$

Observe that in this definition there are two roles which point to the fuzzy concepts *Little* and *Unhealthy*. Let's take the common example of pizza. Can it be categorised as junk food or nutrition food? Associated with some food outlets, it is labelled as "junk", while in others it is seen as being acceptable and trendy. Rather, one can consider that it belongs to both concepts with different degree of truth, let's say 0.7 for *JunkFood* and 0.3 to *NutritionFood*.

$\text{Pizza} \sqsubseteq \text{JunkFood}\prec 0.7 \succ$

$\text{Pizza} \sqsubseteq \text{NutritionalFood}\prec 0.3 \succ$

The sentence *(D)* introduces the subconcept *CandyBar* subsumed by the concept *JunkFood*:

$\text{CandyBar} \sqsubseteq \text{JunkFood}$

The sentence *(C)* instantiates a particular 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:

$\text{FreshFruits} \sqsubseteq \text{NutritionalFood}$

$\text{Vegetables} \sqsubseteq \text{NutritionalFood}$

The fuzzy modifier *highly* appears in the sentence *(G)*, and additionally, the fuzzy concept *Long* is introduced in the sentence *(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 refers to what type of inference can one 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 concept? 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.

TABLE I. OPERATORS IN FUZZY LOGICS

Operators	**Luckasiewicz Semantics**	**Godel Semantics**
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 $\alpha<\beta$, ,β *otherwise*

Some observations regarding the usage of the fuzzy operators (table 1) in argumentation follow:

The interpretation of Godel operators suits the *weakest link principle* in argumentation. According to this principle, an argument supported by a conjunction of antecedents of confidence α and β is as good as the weakest premise. The reason behind this principle is due to the fact that the opponent of the argument will atack the weakest premise in order to defeat the entire argument. This situation maps perfectly the semantics of the Godel operator for intersection ($min\{\alpha,\beta\}$).

Similarly, when several reasons to support a consequent are available, each having the strenghts α, β , the strongest justification is chosen to be conveyed in a dialogue protocol, which can be modelled by the Godel union operator ($max\{\alpha,\beta\}$).

The interpretation of Lukasiewicz operators 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 semantics, the strenghts of the premises (α,β) contribute to the confidence of the conclusion, given by $max\{\alpha+\beta,1\}$. 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 [8].

One issue related to applying 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 argument would also contribute to the amendment of the degree of truth. Considering the argument

$\text{Pizza} \sqcap \text{NutritionalFood} \Rightarrow \text{AcceptableFood}$

a particular instance of pizza, belongs with a degree of $\alpha=0.95$ to the concept of *Pizza* and with $\beta=0.5$ to the *NutritionalFood* concept. Under the Lukasiewicz intersection operator, the degree of truth for the considered pizza to be an *AcceptableFood* is:

$max\{\alpha+\beta-1,0\}=max\{0.45.0\}=0.45$

The requirment 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 [9] is not necessarily useless. By changing the perspective, this case can be valuable in persuasion dialogues where an agent, by repeatedly posting the same argument in different representations, will end in convincing his partner to accept that sentence.

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.

Another important aspect regards the fact that argument bases are characterised by a degree of inconsistency [2]. Rules supporting both a consequent and its negation co-exist in the knowledge base. This inconsistency is naturally accomodated in fuzzy logic, as figure 3 bears out. Here, the intersection between the fuzzy concept A and its negation is not 0.

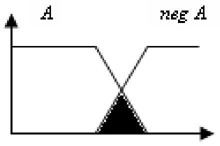

Figure 3. Negation in fuzzy logic accomodates inconsistency specific to argument bases ($A \wedge negA \neq 0$).

The following section formally presents the differences introduced by fuzzy reasoning on top of classical description logic. The complete formalisation of the fuzzy description logic can be found in [1].

III. Fuzzy Description Logic

Fuzzy Description Logic (FDL) has been proposed as an extension to classical description logic with the aim to deal with fuzzy and imprecise concepts, and it is based on the *SHIF(D)* version of the description logic [7].

From the syntactic viewpoint, FDL allows the definition of concepts with explicit fuzzy membership functions, as depicted in figure 4.

Fuzzy modifiers such as *very*, *more-or-less*, *slightly* can be applied to fuzzy sets to change their membership functions. They are defined in terms of linear hedges. For instance, one can define *very=linear (0.8)*.

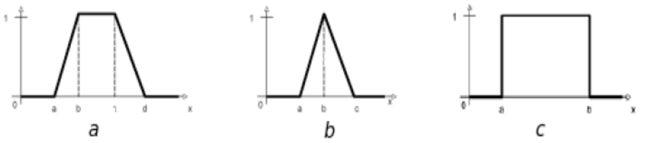

Figure 4. (a) Trapezoidal function; (b) Triangular function; (c) Crisp interval.

The syntax of fuzzy *SHIF* concepts [1] is as follows:

$$C,D = \bot \mid \top \mid A \mid C \sqcap_S D \mid C \sqcup_S D \mid C \rightarrow_S D \mid \neg_L C$$
$$= \forall R.C \mid \exists .R.C \mid m(C)$$

where *S={L, G, B}*, *L* comes from Lukasiewicz semantics (see table 1), *G* from Godel semantics, and B stands for classical logic. The modifier

m(C)=linear (a) | triangular(a,b,c)

can be used to alter the membership functions of the fuzzy concepts.

FDL extends *SHIF(D)* with additional constructs:

$$C, D = \forall T.d \mid \exists T.d \mid DR$$

$$d = crisp(a,b) \mid triangular(a,b,c) \mid trapezoidal(a,b,c,d)$$

$$DR = \geq t\ val \mid \leq t\ val \mid = t\ val$$

where *t* is a concrete functional role and *val* is an integer, real or string, depending on the range of *t*.

For instance, the complex concept *YoungPerson* is defined as a person whose age points to the concept *Young*:

YoungPerson = Person ⊓ hasAge.Young

where *Young* is a fuzzy concept represented as a triungular number *Young = triangular(10,20,30)* (in the figure 4b).

A fuzzy knowledge base $K = \langle A,T,R \rangle$, consists of a fuzzy asertional box (ABox) *A*, a fuzzy terminological box (TBox) *T*, and a fuzzy relational box (Rbox) *R* [1].

A fuzzy ABox *A* consists of a finite set of assertion axioms for fuzzy concepts $\langle x{:}C, \alpha \rangle$, and fuzzy roles $\langle (x,y){:}R, \alpha \rangle$, where $\alpha \in [0,1]$, *C* is a concept, and *R* a role. For instance, ⟨*david:SmallPerson, 0.8*⟩ states that *david* is a *SmallPerson* with degree at least 0.8, whilst ⟨*(david,goliat):attack, 0.7*⟩ says that *david* has attacked *goliat* with degree at least 0.7. If α is omitted, the maximum degree of 1 is assumed.

A fuzzy TBox *T* is a finite set of inclusion axioms $\langle C \sqsubseteq_S D, \alpha \rangle$, where $\alpha \in [0,1]$, *C, D* are concepts, and *S* specifies the implication function (Lukasiewicz, Godel) to be used. The axioms state that the subsumption degree between the concepts *C* and *D* is at least α.

A fuzzy RBox *R* is a finite set of role axioms of the form: ⟨*fun R*⟩, stating that the role *R* is functional; ⟨*trans R*⟩, stating the role *R* is transitive, $R_1 \subseteq R_2$, meaning the role R_1 is subsumed by the role R_2; and $\langle inv\ R_1\ R_2 \rangle$, stating the role R_1 is the inverse of the role R_2.

The main idea of the *semantics* of FDL is that concepts and roles are interpreted as fuzzy subsets of an interpretation's domain [1]. A fuzzy interpretation $I=(\Delta^I, \bullet^I)$ consists of a non empty set Δ^I (the domain) and a fuzzy interpretation function $\bullet^I$. The mapping $\bullet^I$ is extended to roles and complex concepts as specified in the figure 5.

$\bot^I(x) = 0$	$(m(C))^I = f_m(C^I(x)$
$\top^I(x) = 1$	$(\forall R.C)^I(x)=\inf_{y\in\Delta I} R^I(x,y) \rightarrow C^I(y)$
$(\neg C)^I(x)=\varnothing C^I(x)$	$(\exists R.C)^I(x)=\sup_{y\in\Delta I} R^I(x,y) \otimes C^I(y)$
$(C \sqcap D)^I(x)=C^I(x)\otimes D^I(x)$	$(\forall T.d)^I(x)=\inf_{y\in\Delta I} T^I(x,v) \rightarrow d^I(y)$
$(C \sqcap_G D)^I(x)=C^I(x)\otimes_G D^I(x)$	$(\exists T.d)^I(x)=\sup_{y\in\Delta I} T^I(x,v) \otimes d^I(y)$
$(C \sqcap_L D)^I(x)=C^I(x)\otimes_L D^I(x)$	$(nC)^I = n\, C^I(x)$
$(C \sqcup D)^I(x)=C^I(x)\oplus D^I(x)$	$(w_1C_1+w_kC_k)^I(x)=w_1C_1{}^I(x)+w_kC_k{}^I(x)$
$(C \sqcup_G D)^I(x)=C^I(x)\oplus D^I(x)$	$(C[\geq n])^I(x) = C^I(x),$ if $C^I(x) \geq n$; $0,$ otherwise
$(C \sqcup_L D)^I(x)=C^I(x)\oplus D^I(x)$	$(C[\leq n])^I(x) = C^I(x),$ if $C^I(x) \leq n$; $0,$ otherwise
$(C\rightarrow D)^I(x)=C^I(x)\rightarrow D^I(x)$	$(\geq t\ val)^I(x)=\sup_{c\in\Delta} t(x,v)= \otimes(v\geq val)$
$(C\rightarrow_G D)^I(x)=C^I(x)\rightarrow_G D^I(x)$	$(\leq t\ val)^I(x)=\sup_{c\in\Delta} t(x,v)= \otimes(v\leq val)$
$(C\rightarrow_L D)^I(x)=C^I(x)\rightarrow_L D^I(x)$	$(=t\ val)^I(x)=\sup_{c\in\Delta} t(x,v)= \otimes(v=val)$

Figure 5. Semantics of Fuzzy Description Logic.

IV. RUNNING SCENARIO

In this legal example, one person accuses the other of assault. There had been a fight between a small and weak man on one side, and a large and strong man on the other side, and the subject is who started it. The argument of the small and weak man is whether it is plausible that he would attack the large and strong man.

The plausible argument [13] is presented as an argumentation scheme in the figure 6. Here, we have the three premises A_1, A_2, A_3, the conclusion *C*, and the critical questions CQ_1-CQ_4, aiming to defeat the derivation of the consequent in case of exceptional situations. The premise A_1 contains the fuzzy qualifier *normally*, and thus the conclusion is subject to exceptions.

Argument from plausible explanation

A_1 : Normally, a small and weak person would not attack a large and strong person.
A_2 : David is small and weak.
A_3 : Goliat is large and strong.
C : It is implausible that David would attack Goliat .

CQ_1 : Is David generally aggressive?
CQ_2 : Is David a skillful fighter?
CQ_3 : Is Goliat somehow clumsy?
CQ_4 : Is Goliat non − aggressive?

Figure 6. Plausible Argumentation Scheme with Fuzzy Variables.

Computing the strength of the argument. This section shows how fuzzy description logic can be used to compute the degree of truth of the current argument. The proof of the concept scenario is formalised in the *FuzzyDL* reasoner[1] (see figure 8).

Firstly, we introduce the functional roles *weight* and *height* and some constraints attached to them, such as the *weight* should be an integer value between 0 and 200 (lines 1 and 2). Then, we define the fuzzy concepts *Small*, *Large* (see figure 7) , *Weak*, and *Strong*, by making use of the specific fuzzy membership functions triangle and trapezoidal (lines 3, 4, 5, and 6). We continue by defining complex concepts such as *SmallPerson*, which is a *Person* whose height is linked to the fuzzy concept *Small* (lines 7, 8, 9, and 10).

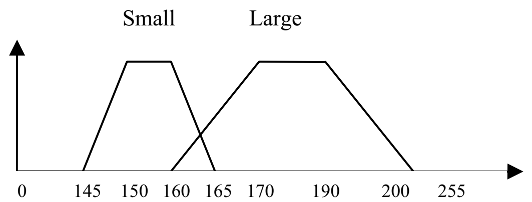

Figure 7. Trapezoidal membership functions for the concepts *Small* and *Large*.

*1. (define-concrete-feature height *integer* 0 250)*
*2. (define-concrete-feature weight *integer* 0 200)*
3. (define-fuzzy-concept Small trapezoidal(0,250,145,150,160,165))
4. (define-fuzzy-concept Large trapezoidal(0,250,160,170,190,200))
5. (define-fuzzy-concept Weak triangular(0,200,50,60,70))
6. (define-fuzzy-concept Strong triangular(0,200,75,100,125))
7. (define-concept SmallPerson (and Person (some height Small)))
8. (define-concept LargePerson (and Person (some height Large)))
9. (define-concept WeakPerson (and Person (some weight Weak)))
10. (define-concept StrongPerson (and Person (some weight Strong)))
11. (l-implies (and SmallPerson WeakPerson (some attack (and LargePerson StrongPerson))) ImplausibleAttack)
14. (instance david (and Person (= height 161) (= weight 63)) 1)
15. (instance goliat (and Person (= height 180)(= weight 98)) 1)
16. (related david goliat attack)

Figure 8. Plausible Argumentation scheme in Fuzzy Description Logic.

Next, we formalize under the Lukasiewicz implication the argument that a small and weak person with an attack role towards a large and strong person leads to an implausible situation (lines 11-13). Finnally, we specify instances by stating the knowledge that *david* is a person whose height is 161cm and his weight equals 63kg, and similarly for *goliat* (lines 14, 15).We assume that there is an *attack* relation from *david* towards *goliat* (line 16).

When querying the reasoner, the following answers are provided under the Lukasiewicz semantics (see table II).

TABLE II COMPUTING THE DEGREE OF TRUTH OF THE PLAUSIBLE ARGUMENTATION SCHEME UNDER THE LUKASIEWICZ SEMANTICS.

Id	Query	fuzzyDL response
Q_1	Is david instance of SmallPerson?	*≥ 0.8*
Q_2	Is david instance of WeakPerson?	*≥ 0.7*
Q_3	Is david instance of (and SmallPerson WeakPerson))	*≥ 0.5*
Q_4	Is goliat instance of LargePerson?	*≥ 1.0*
Q_5	Is goliat instance of StrongPerson?	*≥ 0.92*
Q_6	Is goliat instance of (and LargePerson StrongPerson))	*≥ 0.92*
Q_7	Is david instance of ImplausibleAttack?	*≥ 0.42*

Based on the trapezoidal membership function of the fuzzy concept *Small* (line 3 in figure 8), *david* is an instance of the concept *SmallPerson* with degree $\alpha = 0.8$ (query q_1) and of the concept *WeakPerson* with $\beta = 0.7$ (query q_2).

Under the Lukasiewicz semantics, *david* belongs to the intersection of the concepts *SmallPerson* and *WeakPerson* (query q_3) with the value of

$\alpha \otimes_L \beta = max\{\alpha + \beta - 1, 0\} = max\{0.8+0.7-1,0\}=0.5$

Similarly, *goliat* belongs to both fuzzy concepts *LargePerson* and *StrongPerson* (query q_6) with $max\{1.0 + 0.92 - 1, 0\}= 0.92$. The degree of truth for *david* to attack *goliat* (query q_7) equals $max\{0.5+0.92-1, 0\}= 0.42$.

Each phase of the dispute is governed by a standard of proof, which all the conveyed arguments should meet in order to be accepted in the trial. Consider the levels of proof defined in figure 9. Suppose, the active standard of proof is *resonableSuspicion*. In this case, because *david* belongs to the concept *ImplausibleAttack* with degree of 0.42, the argument is accepted. Consequently, the burden of proof is shifted to the opponent, who has to prove that he didn't attack the other person.

17. (define-truth-constant scintilaOfEvidence = 0.2)
18. (define-truth-constant resonableSuspicion = 0.4)
19.(define-truth-constant preponderenceOfEvidence=0.5)
20.(define-truth-constant clearConvincingEvidence= 0.8)
21. (define-truth-constant beyondResonableDoubt=0.95)

Figure 9. Standards of proof for accepting arguments.

[1] http://gaia.isti.cnr.it/~straccia/

Shifting the burden of proof. The interesting thing about this case is that the large and strong person can use a similar plausible argument to rebut the argument that made him appear guilty [13]. Thus, he claims that since it was obvious that he is the large and strong person, he would not assault the other person, especially if he was aware that the case might go to court. This argument is defined in lines 22-26 of the figure 10 as a Lukasiewicz implication.

22. (l-implies
23 (and LargePerson StrongPerson
24. (some attack (and SmallPerson WeakPerson))
25. (some aware LegalCase))
26. ImplausibleAttack)
27. (instance attackCase LegalCase)
28. (related goliat david attack)
29. (related goliat attackCase aware)

Figure 10. Shifting the burden of proof: supporting the opponent of the argument.

The following assertions are added to the knowledge base: Line 27 specifies that the *attack* event is an instance of the *LegalCase* concept. In the current phase of the dispute, the burden of proof belongs to *goliat*, who has to defeat the current state in which he is considered guilty of attack (line 28), while the line 29 states the information that the stronger person was aware that the case could be judged in court.

By asking if *goliat* is an instance of the *ImplausibleAttack* concept: the system provides based on the Lukasiewicz implication (recall table 1) a degree of truth of 0.42. Being equal to the support of the initial argument, it means that the stronger person was able to cancel the presumption of his guilt.

The expressivity of *fuzzyDl* allows to assign different degrees of truth both to an instance belonging to a concept, and also to roles linking instances. For example, one might say that i) the *attackCase* will lead to a trial with a degree of truth of 0.9:

(instance attackCase LegalCase 0.9),

or that (ii) the trust in the *aware* relationship between *goliat* and *atatckCase* is only 0.8:

(related goliat attackCase aware 0.8)

Therefore, in order for this counterargument to be successful, the lawyer must prove, beyond any resonable doubt, that the strong person was aware that the attack might end with a trial.

Instantiating critical questions. Of course, the conclusion of the implausible attack is based on the current incomplete information only, meaning that no evidence addressed in the critical questions $CQ_{1\text{-}4}$ has been put forward for the time being.

Now, consider that the evidence related to the CQ_2 has just been found out during the investigations. Specifically, it has been found that *david* has practised boxing for 11 years (lines 34-36 in figure 11).

30. (define-fuzzy-concept Long trapezoidal(0,50,5,10,20,25))
31. (define-concept Fighter
(and Person (some practice FightSport)))
32. (define-concept SkilledFighter
(and Fighter (some hasExperience Long)))
33. (l-implies SkilledFighter (not ImplausibleAttack))
34. (instance box FightSport)
35. (related david box practice)
36. (instance david (= hasExperience 11) 0.55)

Figure 11. Instantiating the critical question CQ_2.

Observe that the reliance on the information related to his experience is only 0.55 (line 36).

The ontological knowledge describes a *SkilledFighter* as a *Fighter* with long experience (line 32), where *Long* represents a fuzzy concept (line 30). The critical question CQ_2 states that if the weak person is a skillful fighter, the attack on the strong person is no longer implausible (line 28).

In the light of this new piece of evidence, querying the system *(min-instance? david Fighter)*, the reasoner finds that *david* is certainly a fighter (degree of 1.0, from lines 31, 34, and 35). He is a skillful fighter with degree of 0.55 (lines 30, 31, 36). It follows that the degree of truth for *david* to attack *goliat*

(min-instance? David (non ImplausibleAttack))

equals $max\{0.55 + 1 - 1, 0\} = 0.55$, which is greater than 0.42 supporting the concept *ImplausibleAttack*.

One relevant observation is that some level of conflict is tolerated in fuzzy argumentation: an instance might belong at the same time to opposite concepts with different degrees of truth. In this line, the system can be used to identify situations in which the pieces of evidence or the ontological knowledge are inconsistent, with respect to the level of conflict accepted.

For instance, if a fact A belongs to the concept C with a degree t_1, it also belongs to the opposite concept $\neg C$ with t_2, the current system will signal that the knowledge base is inconsistent only if $t_1+t_2 > 1$. In the current example, such a situation occurs when the level of confidence on the information related to experience (line 36) is greater then 0.58. In this case *david* would belong to the concepts *ImplausibleAtack* and *¬ImplausibleAtack* with a summed degrees of truth greater then 1.

V. DISCUSSION AND RELATED WORK

Rahwan and Banihashemi demonstrated in [10] the use of automated Description Logic reasoning over argument structures. The arguments are represented in the Argument Interchange Format ontology, which is the current state-of-the-art standard for representing arguments in multi-agent systems. The authors focus on enhancing querying capabilities of the agents through automatic scheme classifications and inference on argument ontologies.

Our work is rather complementary, by focusing on the interaction between human and software arguments. The current vision of the World Wide Argument Web [11], as part of the Semantic Web wave, will be proved successful if enough numbers of arguments are annotated by the human agents. In this paper, we advocate that *FuzzyDL* is suitable when modelling real arguments.

Other approaches have investigated imprecise argumentation [5,14,15]. Fuzzy Argumentation Frameworks (FAF) were proposed as an extension of traditional Dung argumentation framework [17] to enrich the expressivity of the argumentation model [5]. An extension in FAF represents a set of arguments a rational agent can defend against attacks. Opposite to the classical argumentation model, the extensions may commit to a certain degree to the acceptance of a particular argument. The argument premises [14] are assigned weights and user defined functions describe propagation of these weights based on inference rules used in the construction of the argument. In [15] the weights are formalised under a possibilistic logic based on Godel fuzzy logic.

Our approach benefits from the supplementary expressive power provided by the description logic component, being committed to the idea of supporting large scale argumentation as envisaged by the World Wide Argument Web [18]. When modelling the interaction between humans and software agents arguments, an orthogonal issue to our work is represented by the ubiquity of enthymemes in human argumentation. The need to identify missing premises and common knowledge in arguments conveyed by humans is addressed in [4].

Regarding the type of argumentation schemes used in the running scenario, we must stress the fact that plausibility is different from probability [13]. While probability is computed by collecting data on statistical chances about possible events to occur, plausibility is about whether a claim appears to be true in normal and familiar situations, both for the arguers and the arbitrator. The mediator would find the argument plausible when it is able to put itself into the situation of the arguer, without considering statistical evidence. Therefore, the complematary approach of fuzzy reasoning is suitable to be used when dealing with such patterns of human argumentation.

Our fuzzy based approach to model argumentation is in the line of weighted argument systems of Dunne [2], aiming to provide a finer level of analysing argumentative systems. The authors in [2] introduce the notion of *inconsistency budget*, which characterises how much inconsistency one is prepared to tolerate within an argumentation base. In our fuzzy approach, the tolerated inconsistency requires that the sum between the confidence in a sentence *A* and the confidence in its negation *neg A*, should be less than 1. Fuzzy knowledge bases can naturally incorporate a certain level of inconsistency, therefore no additional technical instrumentation is needed to deal with the inconsistency in argument systems.

VI. CONCLUSIONS

The contributions of this paper are: Firstly, it proposes Fuzzy Description Logic as the adequate technical instrumentation for filling the gap between imprecise human arguments and software agents arguments.

Secondly, we advocate the link between fuzzy reasoning (Lukasiewicz and Godel semantics) and some issues in argumentation theory (such as the *weakest link principle* and *accrual of arguments*). Also, the property of fuzzy theories to deal with inconsistency, makes them suitable to model argument bases, which are characterised by different levels of incosistency.

Finnaly, the paper discusses a running scenario based on plausible argumentation schemes. Additional advantages of the FDL approach are the possibility to compute the relative strength of the attack and rebuttal relationships between arguments, and the possibility to signal situations in which the fuzzy knowledge is inconsistent with respect to the level of conflict tolerated.

An interesting line of future research regards the formalisation of fuzzy argumentation schemes in the Argument Interchange Format ontology [19]. Also, it would be interesting to see what advantages accrue from the argumentation based on the Description Logic restriction, rather than the full first order logic as described by Hunter and Besnard [16].

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