Supporting decision making in organ transplanting using argumentation theory

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Abstract

In this paper, we describe an application of argumentation theory in order to support decision making in a real world problem. In particular, we present an application of argumentation theory in order to support the decision of whether an organ is viable or not for transplanting. Our research is divided in two directions: the first one is related to manage the conflicts between arguments and the second one is related to the encoding of medical knowledge and the building of arguments from the medical knowledge.

1. Introduction

Human organ transplantation constitutes the only effective therapy for many life-threatening diseases. While becoming a commonplace medical event there is a growing disparity between the demand for and the supply of organs for transplantation. Despite this disparity, a great percentage of human organs available for transplantation, are discarded as being considered non-viable for that purpose. Given the importance of this issue, much effort is devoted in finding ways to reduce this gap between demand and supply.

In [25], we describe an alternative procedure for reducing the number of organs which are discarded for transplanting[1]. The main idea in this procedure, is that most specialists in transplantations (Transplant Coordinators) take part on the decision if an organ is viable or not for transplanting. This idea is based on the premises that organs are rarely non-viable or ideal *per se* and in areas as the medical domain, the qualified professional often disagree. This means that what may be a sufficient reason for discarding an organ for some qualified professional may not be the same for others. Our proposal is embedded in the context of a multi-agent platform, called CARREL [26]. Essentially, we can identify two agents supporting the decision if an organ is viable or not. The first one is the Transplant Coordinator Agent ($TCAx$), which makes the decisions, if an organ is viable or not, in each Transplant Unit (Hospital). The second one is the Mediator Agent (ME) which evaluates TCA_j's arguments by considering TCA_j's reputation and TCA_j's considerations.

Example 1 *Let us assume that we have two transplant coordinators, one which is against the viability of the organ (TCA_D) and one which is in favour of the viability of the organ (TCA_R). TCA_D argues that the organ is not viable, since the donor had endocarditis due to* streptococcus viridans*, then the recipient could be infected by the same microorganism. In contrast, TCA_R argues that the organ is viable, because the organ presents correct function and correct structure and the infection could be prevented with post-treatment with penicillin, even if the recipient is allergic to penicillin, there is the option of post-treatment with teicoplanin. From these disagreements, we can identify the following arguments:* nv = *organ is non viable,* v = *organ is viable,* cfs = *organ has correct function and correct structure,* risv = *recipient could be infected with streptococcus viridans,* pp = *post-treatment with administer penicillin,* pt = *post-treatment with administer teicoplanin,* ap = *recipient is allergic to penicillin.*

The relationship between the arguments could be represented by a direct graph, as it is shown in Figure 1. Where the arrows represent disagreements between them. For instance, the argument nv disagrees with v. Now, the mediator Agent (ME) needs to evaluate TCA_D's arguments

1 We freely admit that our experience of practice is limited (to this date) to the Spanish and Catalan organizations, however they are among the leaders in organ transplantation in the world.

and TCA_R 's arguments in order to give an answer to the following question: is the organ viable for transplanting?

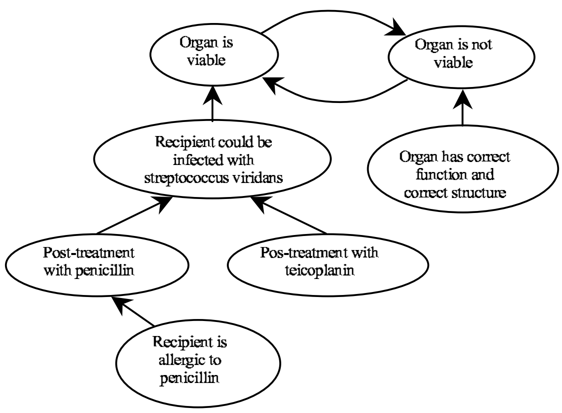

Figure 1. A simple scenario.

Nowadays, several approaches have been proposed in order to support/make a decision in situations like Example 1. The decision, if and organ is viable or not, can be regarded as an *argumentation-based inference.*

The first part of an argumentation-based inference is to build arguments from a knowledge base *e.g.,* TCAx's knowledge base and donor information. After that, the conflicts between arguments are identified *e.g.,* why an organ is viable for transplanting and why is not viable for transplanting. In this part of the argumentation-based inference, one can define preferences over the arguments *e.g.,* a transplant coordinator could prefer transplanting organs only if the donor does not have any infections. After the definition of preferences, it is selected the set of arguments which are considered as acceptable and then, from this set of arguments conclusions are built.

Thus, in order to TCAx and MA act plausibly under a process of argumentation based inference, we need to provide them certain basic components: 1.- a rationality criterion for choosing one decision over another; 2.- an enough versatile specification language for encoding the available knowledge and the uncertainties involved; and 3.- effective computational algorithms for implementing the choices dictated by 1) and 2).

In this paper, we present our positions and our research issues in order to design and build argumentative agents which could support the decisions that a specialistic, in organ transplanting, makes in order to decide if an organ is viable or not for transplanting.

The rest of the paper is structured as following: In §2, we describe one of the most successful abstract argumentation approach for managing conflicts between arguments. In §3, we describe some of the issues that must be considered in order to support medical decisions and encode medical knowledge. In §4, we present our results in order to pursue our objectives. Finally, in the last section we present our conclusions.

2. Abstract Argumentation

Although, several approaches have been proposed for argument theory, Dung's approach, presented in [8], is a unifying framework which has played an influential role on argumentation research and AI. Besides, Dung's approach is mainly relevant in fields where conflict management plays a central role. For instance, Dung showed that his theory naturally captures the solutions of the theory of n-person game and the well-known stable marriage problem.

Dung's approach is regarded as an abstract argumentation approach because it does not define a structure for the arguments. It only looks for the arguments which could be considered acceptable. Dung's approach is captured by four argumentation semantics: *stable semantics*, *preferred semantics*, *grounded semantics*, and *complete semantics.* The central notion of these semantics is the *acceptability of the arguments.* An argument is called *acceptable* if and only if it belongs to a set of arguments which is called *extension.*

The basic structure of the Dung's approach is called argumentation framework. Essentially, it is a pair of sets $\langle AR, attacks\rangle$, where AR is a finite set of arguments and *attacks* is a binary relation on AR, *i.e.* $attacks \subseteq AR \times AR$. For instance, the argumentation framework that represents the problem of Example 1 is $\langle AR, attacks\rangle$, where $AR := \{nv, v, cfs, risv, pp, pt, ap\}$ and $attacks := \{(v, nv), (nv, v), (risv, v), (cfs, nv), (pp, risv), (pt, risv), (ap, pp)\}$.

Although Dung's framework is captured by four argumentation semantics, the main semantics for collective acceptability are the grounded semantics and the preferred semantics [22]. The first one adheres to the so-called unique-status approach, since for a given argumentation framework it always identifies a single extension, called grounded extension. Instead, the preferred semantics follows a multiple-status approach by identifying a set of preferred extensions. Since the preferred semantics overcomes the limitations of the stable semantics and the grounded semantics, it is regarded as the most satisfactory approach.

Nowadays, it has been pointed out that the preferred semantics has some problems. It seems that one of its problems is that the preferred semantics is affected by the length of the cycles of attacks [20, 5]. Authors in [20] underline: "In fact, this seems one of the main unsolved problems in argumentation-based semantics." Also, Caminada has identified that the preferred semantics does not satisfy a postulate what he calls *non-contamination* [7]. Baroni *et al.* [4] have also identified that the preferred semantics does not satisfy a property that they call *skepticism adequacy.*

Although, the preferred semantics' problems happen in some particular cases, it is not difficult to build examples in our medical domain where preferred semantics' problems protrude. Let us consider the following example.

Example 2 *Let us suppose that there is a kidney from a donor which had endocarditis and then the kidney was labeled as not viable for transplanting. On the other hand, there are three transplant coordinators which agree that the endocarditis is not a contraindication for discarding the kidney. However, they disagree w.r.t. the treatment which must be applied to the recipient and the donor (in this case the donor is already brain-dead).*

Let e be the argument that suggests that the kidney is viable for transplanting, d be the argument that suggest that the kidney is not viable for transplanting because the donor had endocarditis, and a, b, c be the arguments of the transplant coordinators. The relationship between these arguments defines the following argumentation framework: $AF = \langle AR, attacks \rangle$, where $AR := \{a, b, c, d, e\}$ and $attacks := \{(a, c), (c, b), (b, a), (a, d), (c, d), (b, d), (d, e)\}$.

Now, let us consider the preferred semantics of AF. The only preferred extension of AF is the empty set $\{\}$. This means that the preferred semantics could not say anything about the viability of the kidney. Intuitively, we can expect to get at least the argument e as acceptable which suggest that the kidney is viable for transplanting since there are three transplant coordinators which agree w.r.t. the viability of the kidney.

It is clear that we need to find some new abstract argumentation semantics, however it seems that the new argumentation semantics must follow preferred semantics' philosophy, since preferred semantics has been shown its utility.

3. Argumentation-based decision making systems

To support/justify a decision in the medical domain is not an easy task. This is because, in many medical situations a medical decision is needed before the decision options, or the relevant information source, are fully known [9].

Example 3 *For instance, suppose that a donor suffering from certain symptoms takes a blood test, and that the results show the presence of a bacteria of a certain category in his blood. There two types of bacteria in this category, and the blood test* does not pinpoint *whether the bacteria present in the blood is either streptococcus viridans or X. The problem is that if the bacteria is streptococcus viridans the recipient have to be treated by antibiotics of large spectrum because streptococcus viridans suggests endocarditis. However, the doctor tries not to prescribe antibiotics of large spectrum, because they are harmful to the immune system. The doctor in this case must evaluate a potentia choice, where each potential choice has* pros *and* cons *of various strengths and incomplete information*[2].

This example suggests that usually medical decision making is taken under *uncertainty.* This means that the environment in which the decision takes place is *incomplete*, *imprecise* or *uncertain.* Thus, we need to identify a suitable argumentation approach which considers decision making under uncertainty in order to build arguments that support the medical decisions.

As, in many medical situations a medical decision is needed before the decision options, or the relevant information source, are fully known. Modeling assumptions (*absence of evidence*) in our knowledge base takes special relevance. For instance, let us consider again Example 3. One doctor's belief could be: *Use antibiotics of large spectrum if there is not alternative treatment.* It may be expressed using *negation as failure* as:

$$antibiotics\_large\_spectrum \leftarrow not\ alternative\_treatment$$

However, this is a dangerous way to state it: assume that there is no available knowledge about any other alternative treatment. Instead, it would be appropriate to demand for all available explicit knowledge about whether or not there exists an alternative treatment, as could be expressed using explicit negation (classic negation):

$$antibiotics\_large\_spectrum \leftarrow \neg\ alternative\_treatment$$

The combination of negation as failure and explicit negation allows for a more cautious statement as positive facts, while the rule:

2 This example is an adaptation of Example 6 from [11].

$$\neg antibiotics\_large\_spectrum \leftarrow alternative\_treatment$$

states that the doctor should not use antibiotics of large spectrum if there is an alternative treatment, the rule

$$\neg antibiotics\_large\_spectrum \leftarrow not\ \neg alternative\_treatment$$

states more cautiously that the doctor should not use antibiotics of large spectrum if it has not been establish that there is not another alternative treatment.

As far as we know, there are few attempts to formalize argument-based decision making under uncertainty. According to [21], the most representative approaches are Bonet and Geffner [6], works based on Logic of Argumentation [12] and more recently works based on the Possibilistic Logic [1]. The first approach is not really an argumentation approach. Also the *expressive power* of that approach is limited. The second approach is a more interesting approach than the first one. One of its best qualities is the use of a *dictionary* for quantifying the knowledge base and the arguments. However, there is not room for the notion of defeasibility between arguments as in Dung's approach. The third approach is one of the richer approaches that there exists. It defines a clear structure for building arguments from a knowledge base. In fact, in the case of inconsistent knowledge bases, the acceptability of arguments is essentially determined by the grounded semantics. However, its expressiveness is limited to classic negation, therefore modeling assumptions is not quite natural.

Modeling uncertainty by numbers in the possibilistic argumentation approach is a natural process, however since medical decision-making is susceptible to the evidence of the information, it is not always natural to quantify the medical knowledge in a numerical way. For instance, in [24] it is pointed out that the chief disadvantages of the decision theory approach are the difficulties of obtaining reasonable estimates of probabilities and utilities for a particular analysis. Although techniques such as sensitivity analysis help greatly to indicate which potential inaccuracies are unimportant, the lack of adequate data often forces artificial simplifications of the problem and lowers confidence in the outcome of the analysis. Hence, to quantify uncertainty, as it is required in the possibilistic argumentation approach is not natural in the medical domain.

We can say that the languages of the existing argumentation-based decision making systems are quite limited for our application domain. Thus, we require to look for a new approach which allows to use both negations (*negation as failure* and *explicit negation*), and to define the *notion of logical consequence* for defining the notion of argument in favor of a decision/belief. Also we require that the new argumentation approach must emphasize in the evidence, that there is in the medical knowledge, in order to model the uncertainty involved.

4. Research issues

In this section, we present our result in order to design and build argumentative agents which could support the decisions. We start with our result *w.r.t.* abstract argumentation and then we present our result *w.r.t.* our approach for modeling medical knowledge and building arguments.

4.1. Abstract argumentation

It is well-known that in many cases a proper representation of a given problem, is a major step in finding robust solutions to it. For instance, in [2] it was introduced a simple and practically efficient method for repairing inconsistent databases. The method is based on a logic representation. Thus, our first step in order to get a good understanding of Dung's semantics in terms logic programming semantics was to get a proper representation of Dung's semantics in terms of Answer-Set Syntax [3].

Answer Set Programming (ASP) is a rich knowledge representation approach which permits to make specifications of knowledge in a high-level [3]. The efficiency Answer Set Solvers has made possible to use this approach in real problems.

In [18], we present a characterization of the admissible sets, stable semantics and preferred semantics in terms of *Answer-Set Models*. In fact in that paper, we present two approaches for inferring the preferred semantics. The first one is based on the *enumerate* and *eliminate* approach, this approach is based on the high-level expressiveness of ASP's language. And the second one is based on a procedural algorithm.

The results of [18] have been extended in [16]. In this paper, we explore new ways of *how* to characterize the complete Dung's approach using *Answer-Set Models*, *Minimal Models* and *Well-Founded Models (WFS)* ([10]). In particular in that paper, we present three approaches in order to infer Dung's approach: 1.- By using the *enumerate* and *eliminate* approach, 2.- UNSAT algorithms, and 3.- mappings from an argumentation framework to logic programs.

With respect to the first point, we characterize the admissible sets, which are the basic concepts of the Dung's semantics, and the preferred semantics.

With respect to UNSAT algorithms, first we characterize the preferred semantics by using minimal models and therefore we make a direct relationship between preferred semantics and unsatisfiability.

And finally, with respect to the use of mappings from an argumentation framework to logic programs, first we characterize the stable semantics by using normal programs. Second, we characterize the preferred semantics by using positive disjunctive logic programs. Third, we characterize the grounded semantics by using logic programs and WFS. Thanks to our mappings, we identify a syntactics equivalence between normal programs *w.r.t.* WFS. Fourth, following the WFS's approach of 3-valued semantics, we introduce the concept of 3-valued extension, and then we define three possible extensions of the grounded semantics based on extensions of WFS and 3-valued extensions. Fifth, we define three possible extensions of the grounded semantics which take in consideration *acyclic arguments* in order to treat cycles of attacks between arguments. Also, we present a extension of the preferred semantics based on *acyclic arguments* in order to treat cycles of attacks between arguments. Finally, we characterize the complete semantics by using nested programs.

In order to illustrate one of the results of [16], let us consider the definition of *3-valued extension.*

Definition 1 (3-valued extension) *Given an argumentation framework* $AF := \langle AR, attacks \rangle$*, and* $S, D \subseteq AR$*. A 3-valued extension is a tuple* $\langle S, D \rangle$*, where* $S \cap D = \emptyset$ *and* S *is an admissible set. We call an argument* a *acceptable if* $a \in S$*, an argument* b *defeated if* $b \in D$*, and an argument* c *undefeated if* $c \in AR \setminus \{S \cup D\}$*.*

Now, one of the grounded semantics' extensions that was introduced in [16] is the $WFS^{WK+LLC'}$-ϕ-semantics. If we apply the $WFS^{WK+LLC'}$-ϕ-semantics to the argumentation framework of Example 2, we get that e is an acceptable argument, d is a defeated argument, and $\{a, b, c\}$ are undefeated arguments. This means that $WFS^{WK+LLC'}$-ϕ-semantics suggests that the kidney is viable for transplanting (see [16] for details).

Nowadays, based on a proper representation of the Dung's argumentation framework introduced in [16], we introduce an extensions of the preferred semantics in [17]. From the point of view of abstract argumentation semantics, this new argumentation semantics has suitable features *e.g.,* it follows preferred semantics's philosophy and it is characterized by minimal models. In fact, the flexibility of the representations of the Dung's argumentation framework introduced in [16] permit to consider generalizations of the Answer Set Semantics for defining new abstract argumentation semantics. For instance, by considering G'3-Stable semantics [19] is possible to characterize and/or extend the preferred semantic.

4.2. Argumentation-based decision making

In [14], we present our first approach in order to define an argumentation approach which combine ASP's inference, ASP's syntax, complete lattices, and aggregate operators. In this paper, we present an interesting approach where our specification language is quantified by levels of *certainty* (in that paper the level of certainty is called *modality*).

Following Logic Argumentation's argument structure, our arguments are of the form:

$$Arg = \langle Claim, Support, Qualifier \rangle$$

where $Claim$ is a literal, $Support$ a set of clauses similar to ASP's clauses plus a quantifier, and $Qualifier$ is an element of a complete lattice. In our case, the inference of $Claim$ from $Support$ is not given by classic inference rather by an answer set of $Support$. In that paper, we define two attitudes *w.r.t.* the $Qualifier$ of an argument. These attitudes are given by the *Greatest Lower Bound*(GLB) and the *Least Upper Bound* (LUB) of the qualifiers which are in $Support$ of Arg.

The levels of certainty, used in [14], are quantifiers for the *knowledge base* and the *arguments.* Examples of quantifiers in [14] are: *Certain, Confirmed, Plausible, Probable, Supported, and Open.* In fact, these quantifiers were inspired from the Logic Argumentation's approach.

One weak point of the approach in [14] is that the quantifiers of the arguments are inferred in a separated process. In fact, this weak point also happens in the approach based on possibilictic logic.

In [15], we present a variation of the approach of [14]. In this case, the inference of an argument is based on Possibilistic Stable Models [13]. In [15]'s approach, the inference of the *Claim* and the *Qualifier* are close related by Possibilistic Stable Models. Until now, we only have explored the definition of *arguments in favor of believes.* The next step will be to define the decision process where the interaction between arguments will define the preferences between goals.

5. Conclusions

Argumentation theory is a young field of research which main purpose is to study the fundamental mechanism, humans use in argumentation, and to explore ways to implement this mechanism on computers. In fact, argumentation theory has a wider range of application, for instance, argumentation is gaining increasing importance as a fundamental approach in multiagent interaction, mainly because it enables rational dialogue and because it enables richer forms of negotiation that have hitherto been possible in game theory or heuristic based models [23].

In this paper, we describe an application of argumentation theory in order to support decision making in the medical domain. Although, there are some problems which must be overcome in order to use this approach in our medical domain. As shown argumentation theory is a robust approach for building a flexible and solid tool for supporting the decision if an organ is viable or not for transplanting.

References

[1] L. Amgoud and H. Prade. Using arguments for making decisions: A possibilistic logic approach. In UAI-04, pages 10–17, Arlington, Virginia, 2004. AUAI Press.

[2] O. Arieli, M. Denecker, B. V. Nuffelen, and M. Bruynooghe. Database repair by signed formulae. In *FoIKS*, volume 2942 of *LNCS*, pages 14–30. Springer, 2004.

[3] C. Baral. *Knowledge Representation, Reasoning and Declarative Problem Solving.* Cambridge University Press, Cambridge, 2003.

[4] P. Baroni and M. Giacomin. Evaluating argumentation semantics with respect to skepticism adequacy. In *ECSQARU 2005, Barcelona, Spain, July 6-8, 2005, Proceedings*, volume 3571 of *LNCS*, pages 329–340. Springer, 2005.

[5] P. Baroni, M. Giacomin, and G. Guida. SCC-recursiveness: a general schema for argumentation semantics. *Artificial Intelligence*, 168:162–210, October 2005.

[6] B. Bonet and H. Geffner. Arguing for decisions: A qualitative model of decision making. In UAI-96, pages 98–105, San Francisco, CA, 1996. Morgan Kaufmann Publishers.

[7] M. Caminada. Contamination in formal argumentation systems. In *BNAIC 2005, Brussels, Belgium, October 17-18*, pages 59–65, 2005.

[8] P. M. Dung. On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games. *Artificial Intelligence*, 77(2):321–358, 1995.

[9] J. Fox and S. Das. *Safe and Sound: Artificial Intelligence in Hazardous Applications.* AAAI Press/ The MIT Press, 2000.

[10] A. V. Gelder, K. A. Ross, and J. S. Schlipf. The well-founded semantics for general logic programs. *Journal of the ACM*, 38(3):620–650, 1991.

[11] H. Jakobovits and D. Vermeir. Robust semantics for argumentation frameworks. *Journal of logic and computation*, 9(2):215–261, 1999.

[12] P. Krause, S. Ambler, M. Elvang-Gøransson, and J. Fox. A logic of argumentation for reasoning under uncertainty. *Computational Intelligence*, 11:113–131, 1995.

[13] P. Nicolas, L. Garcia, and I. Stéphan. Possibilistic stable models. In IJCAI, pages 248–253, 2005.

[14] J. C. Nieves and U. Cortés. Modality argumentation programming. In MDAI-06, volume 3885 of LNCS, pages 295–306. Springer, 2006.

[15] J. C. Nieves, M. Osorio, and U. Cortés. Modality-based argumentation using possibilistic stable models. unpublished.

[16] J. C. Nieves, M. Osorio, and U. Cortés. Modeling argumentation based semantics using non-monotonic reasoning. Research report LSI-05-59-R, U.P.C., Software Department, Barcelona, Spain, December 2005.

[17] J. C. Nieves, M. Osorio, U. Cortés, I. Olmos, and J. A. Gonzalez. Defining new argumentation-based semanitcs by minimal models. In *To appear ENC-06*, 2006.

[18] J. C. Nieves, M. Osorio, C. Zepeda, and U. Cortés. Inferring acceptable arguments with answer set programming. In ENC-05, pages 198–205. IEEE Computer Science Press, September 2005.

[19] M. Osorio, J. A. N. Pérez, J. R. A. Ramírez, and V. B. Macías. Logics where logical weak completions agree. *Journal of Logic and Computation*, to appear.

[20] H. Prakken and G. A. W. Vreeswijk. Logics for defeasible argumentation. In D. Gabbay and F. Günthner, editors, *Handbook of Philosophical Logic*, volume 4, pages 219–318. Kluwer Academic Publishers, Dordrecht/Boston/London, second edition, 2002.

[21] Project-ASPIC. *Deliverable D2.1: Theoretical framework for argumentation.* Argumentation Service Plarform with Integrated Components, 2004.

[22] Project-ASPIC. *Deliverable D2.2:Formal semantics for inference and decision-making.* Argumentation Service Plarform with Integrated Components, 2005.

[23] I. Rahwad, S. D. Ramchurn, N. R. Jennings, P. Mcburney, S. Parsons, and L. Sonenberg. Argumentation-based negotiation. *The Knowledge Engineering Review*, 18(4):343–375, 2004.

[24] P. Szolovits. *Artificial Intelligence and Medicine.* Westview Press, Boulder, Colorado, 1982.

[25] P. Tolchinsky, U. Cortés, J. C. Nieves, A. López-Navidad, and F. Caballero. Using arguing agents to increase the human organ pool for transplantation. In *Proc. of the Third Workshop on Agents Applied in Health Care (IJCAI 2005)*, 2005.

[26] J. Vázquez-Salceda, U. Cortés, J. Padget, A. López-Navidad, and F. Caballero. The organ allocation process: a natural extension of the carrel agent-mediated electronic institution. AiCommunications. 3(16):153–165, 2003.