Achieving Competence by Argumentation on Rules for Roles

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Abstract. We consider the deep venous thrombosis (DVT) as case study for the specification and implementation of a multi-agent system. The DVT is an application with low clinical accuracy, needing objective tests, some of them satisfactorily accurate in experienced hands and others more definite but invasive. Whether one or more decision makers are involved in this activity is a matter of context, but the main events are decided by a process that has in itself some forms of argumentation. Our approach is an argumentative multi-agent system specified by rules capturing various roles in the diagnosis activity. Although the DVT scenario is a real one, more aspects of health care than the ones presented in this paper can conveniently be accommodated in this framework by extending the set of roles and refining the set of rules.

1 Introduction

There are many situations in the medical setting when conflicts of opinion may appear between different care providers, each judging the situation based on its own knowledge and duty. Consider the case of a patient that has just been diagnosed; there are several possible treatments given the diagnostic and a choice must be made among those treatments. Different care providers may have different opinions about the optimal treatment based on their role and expertise. Still, a decision has to be made based on their possible contrary opinions. Another point of divergence between medical professionals may be the investigations that are more appropriate to perform for establishing a diagnostic. Some investigations are cheaper, while others may be less harmful to the patient.

Although sometimes it is possible to make decisions in diagnosis taking into account just the information available [1], in the cases considered above several roles are involved in the medical decision process, a choice having to be made between the possible conflicting opinions of each role. Additional information may be needed for making that choice, due to the multiple options available.

Automated monitoring of medical protocols has been already tackled with a multi-agent system [2], using a negotiation process to mediate between multiple medical protocols, where role refers to a particular service that can be played by a staff person. A multi-agent environment to support training of diagnostic reasoning and modeling of domains with complex and uncertain knowledge [3] uses Bayesian networks to offer physicians probabilistic reasoning.

The framework described in this paper aims to help automate/model the decision making between different roles that are involved in the medical care process by making use of the knowledge base of each role and also by additional knowledge needed to solve conflicts of opinion between roles. Recent work [4, 5] is used to develop a more flexible methodology required by realistic applications in the health providing activity.

2 Argumentation with Rules for Roles

Different care providers have different roles within the system. For each role there is a specific ontology which defines rules, axioms and facts. The care provider ontology is composed of the role specific ontology together with additional facts and axioms specific to the user. An agent is attached to each care provider, with access to the care provider ontology and other ontologies (figure 1). The agent notifies the user on the actions possible and the final decision that has been arrived at.

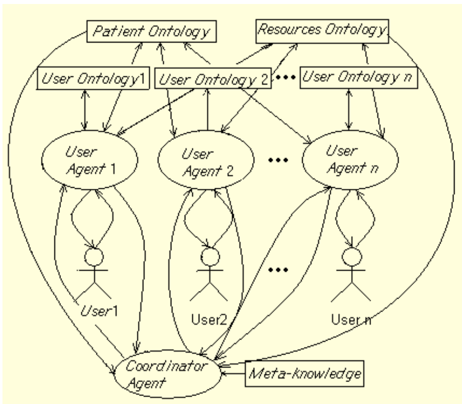

Fig. 1. System architecture

The coordinator agent has the main role in the process of decision making, having access to a special ontology, named meta-knowledge. Priority relations between rules for different roles show the preference toward one rule or another, when conflicts among roles appear.

2.1 Basic Argumentation Framework

The system selects an action for execution or derives new information by reasoning in an argumentative manner using Gorgias[3][4, 5]. Gorgias was conceived as a tool for agent self-deliberation where the agent must be endowed with a **non-monotonic argumentation theory**, viewed as a pair of sentences (T, P) written in the usual extended logic programming language $(L, \vdash)$ with explicit negation, but without the Negation as Failure (NAF) operator. Rules in P with the consequent $h\_p(rule1, rule2)$ express preference relations between other rules. An **argument** for a literal L in a theory (T, P) is any subset T of this theory that derives L, $T \vdash L$, under the background logic. The subset $T_0 \subset T$ from which any argument rule can draw information is called the **background theory**, the non-defeasible part of the theory.

According to the framework a ground literal L is a credulous (respectively skeptical) consequence of the theory iff L holds in a (respectively every) maximal admissible subset of T. Admissibility of an argument (T, P) is defined in terms of an **attacking** relation, where (T', P') attacks (T, P) if it derives a contrary conclusion and makes the rules of its counter proof at least as strong as the rules for the proof by the argument that is under attack. Thus (T, P) is admissible iff $T \cup P$ is consistent and for any (T', P') if (T', P') attacks (T, P) then (T, P) attacks (T', P').

Argumentation rules from the first part T of an argumentation theory (those that are not in the background theory) are called Object - level Decision Rules. Preference rules from P are divided in two categories: Role Priorities (P_R), with head $h\_p(r_1, r_2)$ s.t. $r_1, r_2 \in T$, and Context Priorities (P_C), with the head $h\_p(R_1, R_2)$ s.t. $R_1, R_2 \in P_R \bigcup P_C$, specifying the policy under which the agent uses its Object-level decision rules according to roles and context. Specification of conflict between rules is also allowed.

2.2 Rule Types

In our approach Gorgias is used for inter-agent deliberation,the knowledge of all the agents in the system being viewed as a non-monotonic argumentation theory. There are rules that specify actions possible to be executed when several preconditions are met or the impossibility to execute certain actions in a given situation, called here Action Rules. Another type of rules which together with the Action Rules form a partition of the Object-level Decision Rules are argumentation rules about literals that can hold or not in certain situations, called Fluent Rules.

Priority Rules may appear in a role specific ontology or in the meta-knowledge. While role specific ontologies may contain rules from all categories, the meta-knowledge contains only Priority Rules that express preferences between Action Rules or Fluent Rules from role specific ontologies or between other Priority Rules from the meta-knowledge.

[3] http://www.cs.ac.cy/˜nkd/gorgias

2.3 Reasoning with Rules

Reasoning is performed in steps, with three different stages for each step (figure 2). In each step each user agent tries to prove literals that appear as the head of some Object-level Rule from its role specific ontology. Each user is presented the set of derived literals and is offered the possibility to reject some of those literals. Finally, a set of literals with associated proofs is obtained as the union of the sets of literals that were derived from each user ontology and were not rejected by the corresponding user.

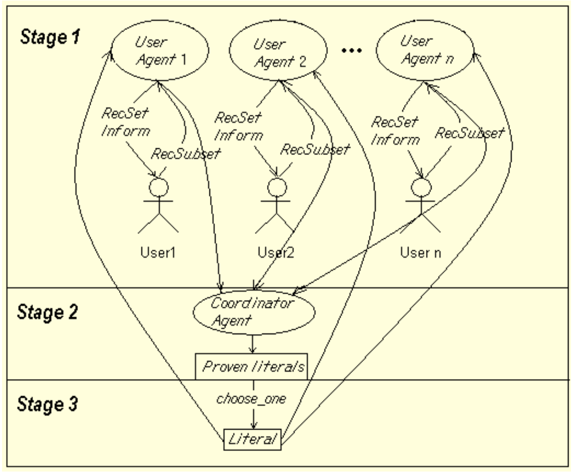

Fig. 2. Stages within a reasoning step

The coordinator agent tries to prove skeptically all the literals from the computed set using the knowledge it has access to (meta-knowledge, patient ontology, resource ontology). Since the coordinator agent does not have access to specific role ontologies, some proxy rules are introduced for the Object-level Rules from those ontologies.

A proxy for an Object-level Rule is a rule with the same label as the rule it replaces. Also the head of the rule (literal) is preserved but the body of the new rule contains only one literal $isPresent(X)$ where X is the rule label. At each reasoning step, after the set of proved literals not rejected by users is computed, a set of facts $\{isPresent(X) | X : Object\text{–}Level\text{–}Rule\ based\ on\ which\ literal\ was\ derived\}$ is added to the meta-knowledge. Together, these facts and the proxy rules stand for the proofs of the literals from the set (proofs the coordinator agent cannot (re)construct because it does not have access to the supporting information). If the resulting set has more than one element, one literal is chosen randomly or by applying some negotiation protocol. If the chosen literal is an action, then the action is recommended for execution.

2.4 Reasoning about Change

As at each step rules are triggered, deriving all possible literals, two problems appear: (i) how the current situation changes after a decision has been taken and (ii) how procedural knowledge like a pre-imposed order between some actions executions can be expressed through rules? After a decision is made, the decision should be implemented in the real world. If the decision was about choosing between alternative actions the chosen one is executed; otherwise, if the decision was about a debatable issue, the solution found by the system is asserted to some ontology.

There are many situations in the medical care process when predetermined sequences of actions should be executed. For example, a test should be performed only after patient anamnesis has been done or a treatment is recommended only after a diagnostic has been set. Formally this is equivalent with successor actions that have as preconditions effects of executions of predecessor actions and predecessor actions that do not have as preconditions effects of successor actions. Rules are triggered after some information becomes available as the result of a decision implementation or while some information is still unavailable. Two predicates $known(X)$, respective $unknown(X)$ are used for evaluating information availability.

3 Deep Venous Thrombosis Scenario

Deep venous thrombosis (DVT) could be defined as the presence of an occlusive thrombus (clot) within a deep vein, impairing the normal blood flow. Deep venous thromboses occur commonly in the lower extremities, and half of them cause pulmonary emboli (the most severe complication of DVT) in the absence of treatment.

The *major predisposing risk factors* are a familial or a personal history of prior DVT and the hyper-coagulation states: antithrombin III deficiency, antiphospholipidic syndrome, polycytaemia vera, thrombocytemia etc.

Predisposing clinical conditions. Patients particularly prone to the development of DVT (see figure 3) are those who are seriously ill and have been at bed rest for prolonged periods. Some of the patients who are at highest risk are those who have congestive heart failure, stroke, recent myocardial infarction, or a shock syndrome. Other clinical conditions favoring DVT are malignancy and its treatment, pelvic /abdominal surgery, especially orthopedic procedures, trauma - particularly with prolonged immobilization.

Additional risk factors. Persons more than 60 years old have an increased incidence of DVT, as do obese persons, patients with varicose veins, users of contraceptives or high-dose estrogen therapy. Pregnancy and the period following childbirth favor DVT. Long journeys, prolonged venous compression, venous catheter insertion or injections increase the thrombosis risk mainly in the association with other risk factors.

History and physical examination are neither sensitive nor specific for diagnosis. The presence of symptoms or signs as pain or edema is not sufficient

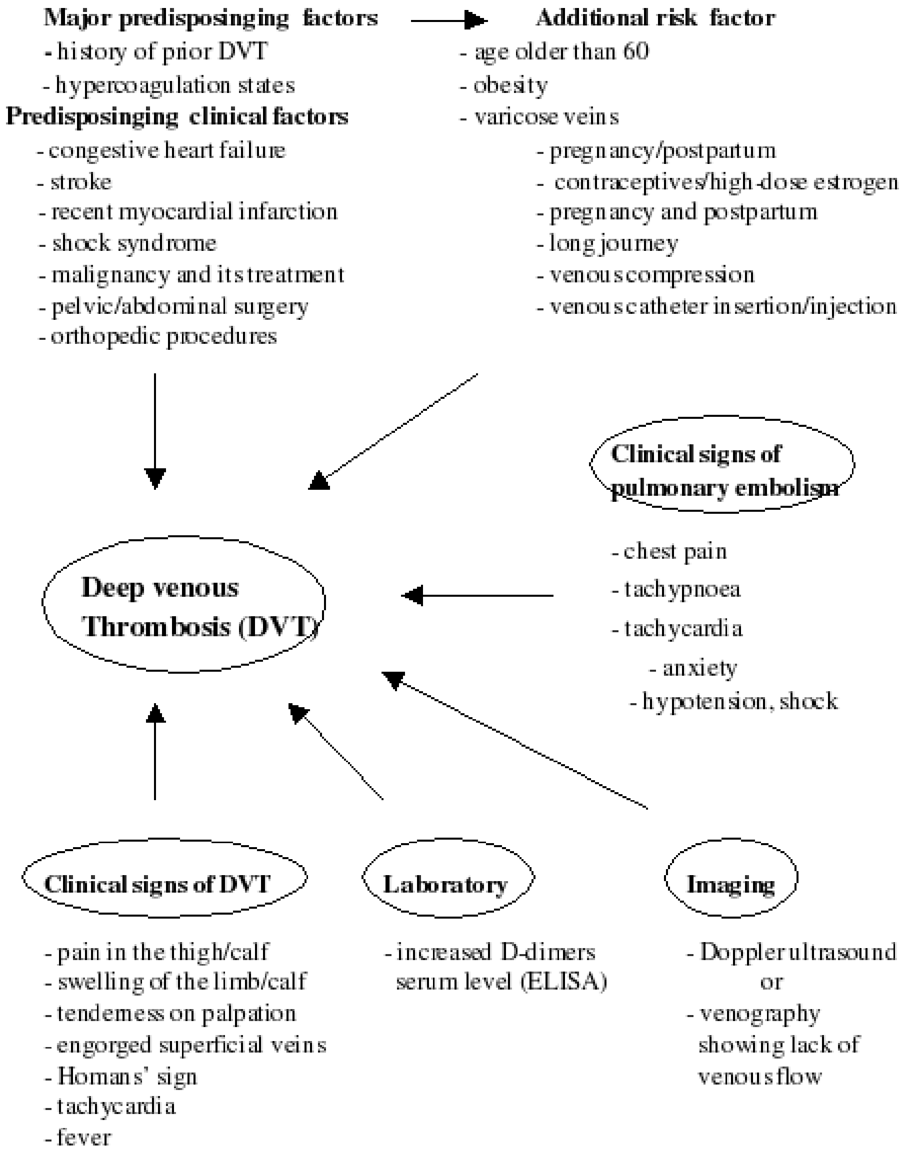

Fig. 3. Deep venous thrombosis. The major *predisposing factors* and clinical conditions favor development of DVT. The *additional risk factors* contribute to the increased risk of DVT, mainly in the presence of predisposing factors. The diagnostic clues are encircled.

for diagnosis and implies the need for objective diagnostic testing. Among the objective tests, the increased serum level of D-dimers (established by ELISA) has a high sensitivity (>95%), but lower specificity: a positive test makes DVT probable, and a negative test excludes DVT. Venous ultrasonography, combined with Doppler, is satisfactorily accurate in experienced hands, readily available, noninvasive and repeatable. Contrast venography is the reference standard for the diagnosis of DVT, being the most definitive diagnostic test, but it is an invasive examination. A result of lack of venous flow of the imaging tests usually indicates DVT.

3.1 Ontology for Deep Venous Thrombosis

The rules related to the diagnosis and treatment of DVT are part of the same ontology, the role specific ontology associated to the DVT specialist. For a better exemplification of the argumentative reasoning through which a diagnostic is established, a virtual Another disease is considered, patients suffering of it, like those suffering of DVT, being supposed to have increased serum level of D-dimers. An excerpt from another ontology with rules related to the diagnosis of the Another is also presented. The meta-knowledge contains Priority-Rules that establish preference relations between rules from these two ontologies.

As depicted in the figure 3, clinical signs are not enough for the diagnostic setting, and laboratory and/or imaging tests have to be performed. The question is what makes a patient being suspect of DVT so that a test should be performed? A patient is considered suspect of DVT if after the clinical examination he presents either at least one clinical sign and one predisposing factor of DVT or asymptomatic behavior specific to DVT.

Argumentation can be employed for making decisions regarding the test that should be performed for a patient with clinical signs of DVT and also for discriminating, when it is needed, between DVT and Another disease.

3.2 Representing Knowledge

For promoting automatic rule interchange between institutions and for making use of extant medical terminologies (e.g, Galen[4]) knowledge is represented using Semantic Web technologies. Two choices must be made: first, the language for representing taxonomic information about the domain, and second, the language for representing rules. This is a situation where the 'equation' **ontology=taxonomy+axioms** of the W3C proves its validity. Taxonomic information is represented using OWL (Web Ontology Language)[5] and rules are represented in RuleML[6] (Rule Markup Language).

There is an ontology for every role, e.g. the administrator ontology, the DVT specialist ontology, etc., that specifies the vocabulary of that role and the associated rules. Role specific ontologies have two components, e.g., the 'DVT

[4] http://www.galen.org
[5] http://www.w3.org/TR/2004/REC-owl-ref-20040210/
[6] http://www.ruleml.org

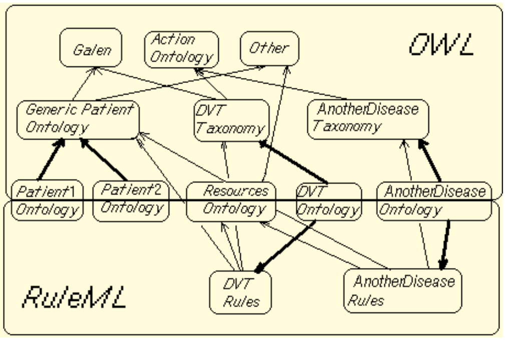

Fig. 4. Ontologies used for reasoning in the current system and relationships between these and external ontologies. Simple arrows point from one ontology to another one which contains concepts used for defining the concepts from the first one. Thick arrows point from one ontology to another ontology that it is included in the first one.

ontology' is composed of the 'DVT Taxonomy' specified in OWL and of the 'DVT Rules' specified in RuleML. Every actor has its own ontology which can extend his role specific ontology with additional axioms and facts.

OWL taxonomies for describing actions, patient data, information about resources are also defined. Though defeasible rules appear only in role specific ontologies and in the meta-knowledge, axioms may describe those types of information; this explains the extent of the Patient Ontology and Resources Ontology, which include rule repositories (figure 4). Definitions of concepts from these ontologies may reference concepts defined in external ontologies, e.g. the OWL version of Galen[7].

4 Argumentation on DVT Diagnosis

Some non-defeasible rules are shown in the figure 5. Three possible investigations: $measureSerumLevel(P)$, $dopplerUltrasound(P)$ and $contrastVenography(P)$ have been identified. The first action corresponds to the laboratory test and its effect is $known(pathological(P, incrSerumLevel))$, which means that the execution of this action consists in acquiring the information whether or not $pathological(P, incrSerumLevel)$ holds, in which case $dopplerUltrasound(P)$, $contrastVenography(P)$ are the actions corresponding to the imaging tests, with the same effect: $known(pathological(P, lackOfVenousFlow))$. Returning to investigations, one Action Rule corresponds to each one as shown in figure 6. The preconditions for the first action are the presence of clinical signs of deep vein thrombosis and the uncertainty of the patient suffering from DVT. These are preconditions for all three actions. Apart from those, the preconditions for the other two actions $dopplerUltrasound(P)$, respective $contrastVenography(P)$ refer to

[7] http://www.daml.org/ontologies/400

$$\begin{array}{l}
clinicalSign(P, dvt) \leftarrow hasPain(P, calfPain)\\
clinicalSign(P, dvt) \leftarrow swelling(P, calf)\\
clinicalSign(P, dvt) \leftarrow hasPain(P, limbTenderness)\\
clinicalSign(P, dvt) \leftarrow hasFever(P, true)\\
predisposingFactor(P, dvt) \leftarrow history(P, dvt)\\
predisposingFactor(P, dvt) \leftarrow history(P, hypercoagulation)\\
predisposingFactor(P, dvt) \leftarrow pathological(P, stroke)\\
asymptomatic(P, dvt) \leftarrow hasDisease(P, pulmonaryEmbolism)\\
suspect(P, dvt) \leftarrow predisposingFactor(P, dvt), clinicalSign(P, dvt)\\
suspect(P, dvt) \leftarrow asymptomatic(P, dvt)
\end{array}$$

Fig. 5. Rules for clinicalSign, predisposingFactor, asymptomatic and suspect.

$$\begin{array}{l}
dvtM(P) : measureSerumLevel(P) \leftarrow suspect(P, dvt),\ unknown(hasDisease(P, dvt))\\
dvtD(P) : dopplerUltrasound(P) \leftarrow suspect(P, dvt), doctor(D),\\
\qquad\qquad hasExperience(D, doppler), unknown(hasDisease(P, dvt))\\
dvtC(P) : contrastVenography(P) \leftarrow suspect(P, dvt),\\
\qquad\qquad available(contrastSubstance), unknown(hasDisease(P, dvt))
\end{array}$$

Fig. 6. Action rules for investigations.

the existence of an experienced doctor to interpret the test, as the medical specification suggests that is required for the test to give satisfactorily accurate results, respective to the existence of contrast substance, a needed resource for performing contrast venography. At a given moment only one of the three investigations should be performed, which is expressed by conflict rules, like conflict(dvtM(P), dvtD(P)).

4.1 Enactment of Preference Rules

If more than one action precondition is fulfilled then preference rules come into the stage to complete the argumentation policy for this case. We derived a policy from the piece of domain information given above. Thus, if all the investigations have met their prerequisites the choice among them should be made based on the preference rules (figure 7). As indicated by the rules $dvtMD$ and

$$\begin{array}{l}
dvtDM : h_p(dvtD(P), dvtM(P)) \leftarrow known(pathological(P, incrSerumLevel))\\
dvtCM : h_p(dvtC(P), dvtM(P)) \leftarrow known(pathological(P, incrSerumLevel))\\
dvtMD : h_p(dvtM(P), dvtD(P)) \leftarrow unknown(pathological(P, incrSerumLevel))\\
dvtMC : h_p(dvtM(P), dvtC(P)) \leftarrow unknown(pathological(P, incrSerumLevel))\\
dvtDC : h_p(dvtD(P), dvtC(P)) \leftarrow criterion(investigation, invasiveness)\\
dvtCD : h_p(dvtC(P), dvtD(P)) \leftarrow criterion(investigation, standard)
\end{array}$$

Fig. 7. Preference rules.

$dvtMC$, the laboratory test is preferred to imaging tests when the value of the fluent $pathological(P, incrSerumLevel)$ is not known. Since initially the value of that fluent is not known for a given patient the precondition says that $measureSerumLevel(P)$ is preferred to imaging tests if it has not been executed before. Otherwise, according to the rules $dvtCM$ and $dvtDM$ one of the imaging tests would be executed.

The last two rules, $dvtDC$ and $dvtCD$ specify which test should be performed if it is to choose between the two imaging tests. Since some criterion about the nature of preferred investigation must be specified, the predicate *criterion* is defined as an abducible predicate. If the criterion is *invasiveness*, the noninvasive test is chosen, namely venous ultrasonography, combined with Doppler; if its value is *standard* the contrast venography should be performed which is the reference standard for the diagnosis of DVT.

Finally, two Action Rules specify when it should be accepted or rejected that a patient has DVT, based on the results of the laboratory test (figure 8). The actions $acc(X)$ and $rej(X)$ have as effects X, respectively $neg(X)$.

$$\begin{array}{l} dvt1(P) : acc(hasDisease(P, dvt)) \leftarrow pathological(P, incrSerumLevel), \\ \qquad\qquad unknown(hasDisease(P, dvt)) \\ dvt2(P) : rej(hasDisease(P, dvt)) \leftarrow neg(pathological(P, incrSerumLevel)), \\ \qquad\qquad unknown(hasDisease(P, dvt)) \end{array}$$

Fig. 8. Action rules for diagnosis.

4.2 Argumentation Sample on DVT Diagnosis

Assuming the case of the patient p characterized by the following set of facts after his anamnesis has been performed {hasPain(p,calfPain), history(p,stroke)}, the Object-level Rules whose consequents are all among the literals from the patient case must be found. Suppose that rules from two ontologies satisfy this requirement. The first one is related to the treatment of DVT, while the second one is related to the treatment of ANOTHER disease.

A relevant rule from the second ontology for this case would be:

$$\begin{array}{l} unk1(P) : acc(hasDisease(P, another)) \leftarrow pathological(P, incrSerumLevel), \\ \qquad\qquad unknown(hasDisease(P, D)) \end{array}$$

i.e. a condition seen as an alternative explanation for $pathological(P, incrSerumLevel)$. It cannot occur simultaneously with DVT, fact expressed in the meta-knowledge by conflicts between corresponding Object-level Rules conflict(unk1(P), dvt1(P)).

Priority Rules in the meta-knowledge (figure 9) specify the discrimination among the two diseases through the fluent $pathological(P, lackOfVenousFlow)$, which is known after the execution of one of the imaging tests.

$$prdu(P) : h\_p(dvt1(P), unk1(P)) \leftarrow pathological(P, lackOfVenousFlow)$$
$$prud(P) : h\_p(unk1(P), dvt1(P)) \leftarrow neg(pathological(P, lackOfVenousFlow))$$

Fig. 9. Priority rules.

Also, as in the case described in the previous section, meta-knowledge includes proxy rules for defeasible rules from the DVT specialist ontology and from ANOTHER specialist ontology.

5 Implementation

The first implementation of the agents has been done in SWI-Prolog with inter-agent communication through temporary files. This prototype is currently extended in OAA (Open Agent Architecture)[8]. For each user agent a solvable is defined which is called by the coordinator agent whenever a new reasoning step is performed. As a result of the call a variable is instantiated with the derived proofs of the user agent. When in possession of that knowledge the coordinator creates and attaches temporarily to its knowledge base the facts of the form $isPresent(X)$ and makes its own derivations. User agents are defined via other solvables through which the coordinator agent can announce them of the opportunity to perform an action or of a decision that has been taken that concerns them.

6 Conclusions

Our prototype implementation of argumentation has shown the convenience to extend the scenario of DVT with symptoms caused by different diseases. Thus, given a patient which presents a set of symptoms different specialists with different areas of expertise may draw different conclusions about the disease the patient is suffering of. Controversies may also appear in the medical setting between the medical staff and the administrative personnel. While the main concern of a physician is the healthy state of the patient, the administrative personnel is more concerned with available resources.

OO RuleML was designed with the objective of allowing the representation of rules built on top of RDF(OWL). In [6] it is shown how RDF triples can be mapped to RuleML, but that does not work for the kind of rules present in this application. A new way for representing rules on top of OWL ontologies has been devised, not shown in the paper for lack of space.

Although work on argumentation in negotiation [7] seems to be quite advanced, the roles imposed in some activities in the applications that we envisaged require more cooperation, even if argumentation is a significant instrument

[8] http://www.ai.sri.com/~oaa/

in such contexts. Since our main goal is in advising human agents in their decisions on acting in the real world our next step in this line of research will be on how argumentation on the acts could be further refined to better capture their effects on agents' objectives [8]. Ideas of the domino agent model and the PROforma language will be considered for representation in a future development of our argumentation scheme [9]. We are also interested in finding out how electronic institutions [10] can contribute to better model/automate argumentation processes in more realistic applications.

7 Acknowledgements

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