OntoKADS: a core ontology for developing expertise models for the CommonKADS methodology

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Abstract. The project that we are carrying out aims at defining an ontological approach to elaborating expertise models for the CommonKADS methodology. The approach relies on a core ontology (OntoKADS) which distinguishes two levels of conceptualization. At an "object level", OntoKADS offers a set of concepts enabling definition of classes of problem-solving situations. At a "meta level", OntoKADS offers a set of meta-concepts coding CommonKADS' modelling primitives and enabling definition of expertise models in conformity with this methodology. In this article, we describe how we have elaborated the OntoKADS core ontology by extending the DOLCE foundational ontology.

1 Introduction

From the end of the 1990s on, the building of explicit ontologies has been considered a promising way of improving the knowledge engineering process: the elaboration of domain, task and method ontologies early on in the construction of problem-solving models was recommended [18]. At the same time, however, certain components of these problem-solving models - in particular *roles* - seemed to have to be excluded from ontological treatment [19]. This component (called a *Knowledge role* in the CommonKADS methodology [16]) is a modelling primitive which fulfils an important function: it must allow specification of problem-solving methods in terms which are independent of particular application domains, thus supporting the re-use of these *generic* methods.

Since that time, and indeed up until very recently, work seeking to clarify the concept of *role* in particular has been carried out in a variety of fields - notably knowledge engineering [15], conceptual modelling [17] and ontological engineering [7][11][13]. In our own work [9], we suggested distinguishing two categories of roles: roles played by *objects* (e.g. *Physician*, *Student*) and roles played by *concepts* (e.g. *Sign*, *Hypothesis*). Having assimilated the latter to the *Knowledge roles* of the CommonKADS methodology, we ascribed them the status of *meta-concept*, rejoining the proposition of Nicola Guarino (i.e. making the concept of *role* appear in an ontology of universals [7]). In 1999, however, we were unable to propose a coherent ontological framework to account for expertise models of the CommonKADS methodology in their entirety.

Today, we are starting to get to grips with this task, notably by taking advantage of i) recent efforts in defining (by means of rigorous logical axiomatization) a top-level ontology like DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering) [12] and ii) the integration of reified entities like Descriptions/Propositions into such an ontology and their expression by means of a language [6][4]. We therefore now possess a necessary and sufficient ontological device to make such a proposition.

In this article, we present the general principles of this proposition by focusing on modelling of the knowledge roles: for reasons of space, the modelling of the other primitives (*inferences*, *tasks* and *solving methods)* is only partially addressed here. Section 2 introduces the role and contents of the OntoKADS core ontology - an ontology dedicated to the construction of problem-solving models in conformity with the CommonKADS methodology. Section 3 presents three OntoKADS sub-ontologies which make it possible to define: i) the nature of the entities participating in the reasonings corresponding to inferences and tasks; ii) their modes of participation in these reasonings and iii) various types of knowledge roles which report on various modes of participation. Before concluding, Section 4 compares OntoKADS to other recent ontological efforts.

2 Our approach

2.1 The OntoKADS methodology

Our proposition consists of a methodology - named OntoKADS – for the construction of expertise models in conformity[1] with the CommonKADS methodology, based on the building of ontologies. This methodology is in two main parts (see Fig.1).

In a first step, the knowledge engineer works out a problem-solving-driven application ontology. This ontology is specified in a semi-informal way using the OntoSpec language [10]. For this purpose, the knowledge engineer uses a core ontology dedicated to problem solving (named after the methodology: OntoKADS) as his/her main resource.

In a second step, a software module automatically translates this ontology into three sub-components of a CommonKADS expertise model specified in CML [16]: the domain model, the inference model and the task model. In addition, the knowledge engineer specifies (directly in CML) the problem-solving methods associated with the tasks he/she has identified.

[1] We will see in section 3.3 that these are actually expertise models close to the CommonKADS methodology but not completely in conformity.

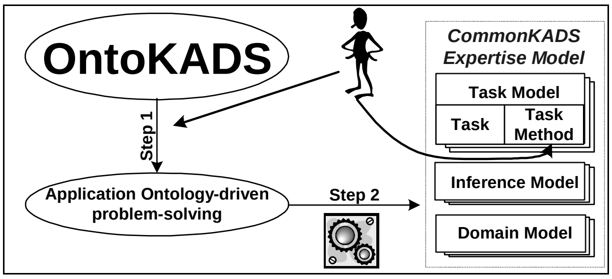

Fig. 1. Main steps in the OntoKADS methodology

2.2 The OntoKADS ontology

The OntoKADS ontology is made up of two main sub-ontologies: a problem-solving ontology (independent of CommonKADS) and an ontology of CommonKADS' modelling primitives.

The OntoKADS concepts and relations are defined by specialization of the concepts and the relationships present in DOLCE. DOLCE's domain, i.e. the set of entities classified by the concepts in this ontology (called the set of *particulars* (PT[2])), is partitioned into four sub-domains. For the needs of this paper, we consider only two of these, the sets of *endurants* and *perdurants*, putting the *qualities* and *abstracts* aside:

- The *endurants* (ED). These are entities which are wholly present whenever they are present (objects and substances), within which one can distinguish *physical objects* (POB), in particular *physical objects capable of intentionality* (APO) and *non-physical objects* (NPOB), including *social objects capable of intentionality* (ASO) and *mental objects dependent on an intentional agent* (MOB).
- The *perdurants* (PD). These are entities which are only partially present (events and processes), within which one can notably distinguish *states* (ST) and *actions* carried out by agents (AC[3]). The main relationship between perdurants and endurants is that of *participation*, represented by the relation PC(x,y,t) holding for "*x (necessarily an endurant) participates in y (necessarily a perdurant) at a time t*". For instance, the *author* of an article - an endurant (ED), more precisely a physical object capable of intentionality (APO) - participates in the *writing* of the article - a perdurant, more precisely an action (AC).

The domain of OntoKADS' problem-solving sub-ontology is that of entities which intervene in problem-solving situations, e.g.: *diagnosing a breakdown occurring in a*

[2] In the rest of the article, we employ the predicates used for logical axiomatization of DOLCE, presented in [12]. The names of these predicates correspond to abbreviations or acronyms. To distinguish DOLCE's concepts from those of OntoKADS, we represent the latter by predicates named with words or complete syntagms, using a JAVA-like notation.

[3] This category is defined in an extension of DOLCE, DOLCE-Lite+, also presented in [12].

car or *calibrating a simulation code*[4]. The entities in question are *Reasonings* (considered as types of *Actions*, e.g. *Diagnosing, Calibrating*) on one hand and the entities intervening in these *Reasonings* on the other. The latter (which are *endurants*) "participate" in *Reasonings* according to the relation PC(x,y,t). They are defined in OntoKADS according to two complementary points of view. On one hand, their *identity* is characterized by means of *rigid*[5] concepts (e.g. *Person, Computer*, *KnowledgeExpression*[6]). In addition, the *way in which they participate in the Reasoning* is also characterized by means, this time, of *anti-rigid*[4] concepts called "thematic roles" in the literature (e.g. *Agent, Data, Result*).

The second OntoKADS sub-ontology codes the CommonKADS methodology's modelling primitives: *Task, Inference, KnowledgeRole* and *DomainConcept*. Technically, we consider that this ontology is at a "meta" level compared to the previous one, corresponding to an ontology of *meta-concepts*. Such meta-concepts enable one to classify the concepts of the problem-solving ontology, according to the CF(x,y,t) relation standing for "*x is classified by y at time t*"[7]. It thus becomes possible to assert (at the time when an expertise model is built) that the *Calibrating* and *Diagnosing* concepts are classified as *Tasks* and the *Data* and *Result* concepts as *Roles* respectively. In Figure 2, we indicate which meta-concepts (noted in bold) can classify concepts in OntoKADS' problem-solving sub-ontology.

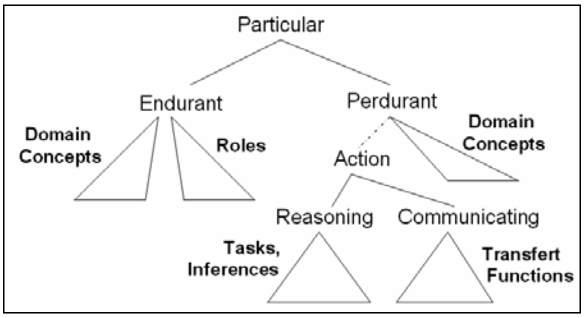

Fig. 2. Structure of the OntoKADS ontology

The reader will note a similarity between this concept classification and the practice of concept labelling recommended by the OntoClean methodology [8]. This labelling consists in classifying the concepts and relationships of an ontology by means of meta-properties, in order to contribute to the specification of their meaning. Thus, the designer of an ontology can decide to classify the *Person* concept with the *Rigid* meta-

4 We will follow these two instances throughout the article. The first corresponds to a teaching instance treated in the reference book on CommonKADS [16]. The second corresponds to an application that we are using currently to evaluate OntoKADS [2].

5 A rigid concept or property is a concept which is essential for all its instances. On the contrary, an anti-rigid concept is a concept which is non-essential for all its instances [7].

6 We give another name to this concept in section 3.2.

7 This relationship was introduced in [13] to describe the temporal classification of an instance by a concept. We extend it here by considering that the instance can be a concept classified by a meta-concept.

property and the *Student* concept by the *AntiRigid* meta-property, which amounts to claiming that any instance of the concept *Person* remains classified by this concept in every possible world, while for any instance of the *Student* concept there are worlds in which these instances are not classified by this concept. This similarity of practice is due to the fact that we give the same status to the modelling primitives of CommonKADS as the meta-properties used in OntoClean (e.g. *Rigid, Sortal, Role* or *BearsAUnityCriteria*) and defined by Guarino and Welty in their formal ontology of properties [7].

3 OntoKADS's kernel

For reasons of space, we only present OntoKADS's kernel here by showing how the ontology enables one to answer three important questions: what is the identity of the entities taking part in *Reasonings*? How do they participate in the *Reasonings*? How can we code this knowledge by means of the CommonKADS primitives?

3.1 Nature of the participating entities

OntoKADS' response to the first question is as follows: setting aside the entities carrying out the *Reasonings* as *Agents/Reasoners* (e.g. *Persons* or *Computers*), the entities which the *Reasonings* "cover", or rather which are "used" for the *Reasonings* as *Data* or *Results* are *expressions of knowledge*.

Let us take the example of checking a car for faults: it is neither the car nor even a state of the car (e.g. the fact that its gasoline tank is empty) which take part in the diagnosis but rather knowledge, or a piece of information, that the reasoner has about the car, for example about its state. This knowledge or piece of information is expressed by means of a language (an expression code) and inscribed on a support. And it is the existence of such (digital) inscriptions which allows *Reasonings* to be automated by computers! Thus, the car diagnosis data can be *EmptyFuelTankHypothesis* or *LowBatteryLevelComplaint*. In the case of code calibration, the data (a simulation code) is a formal expression (constituted by equations) of a model - for instance, the description of the behaviour of a system such as a car.

The previous examples show that both the means of expression and the expressed contents can be very diverse. To account for this diversity, OntoKADS contains a sub-ontology - I&DA (for Information and Discourse Acts) - whose domain is that of Signs and Acts enabling one to elaborate and interpret these Signs[8].

At a first level (see Fig.3), I&DA introduces *ContentBearingObjects* which are expressions (signifiers) of a *Content* (signified). *ContentBearingObjects* and *Contents* are non-physical objects (NPOB), more precisely mental objects (MOB), which acquire a physical location only when they are fixed on a support as *Inscriptions*, these latter being physical objects (POB). The *ContentBearingObjects* become specialized according to the expression code (e.g. *LinguisticObject*) or their role in the transmis-

[8] For a detailed presentation of I&DA, the reader is invited to refer to [4].

sion of a piece of *Information* or "message" (*Discourse*). Among the *Contents*, I&DA distinguishes the *Concepts* or "properties" (which are a means for an *Agent* to grasp or "classify" an entity according to a certain point of view) and *Propositions* (which are a means for the *Agent* to grasp situations that it regards as occurring in the world).

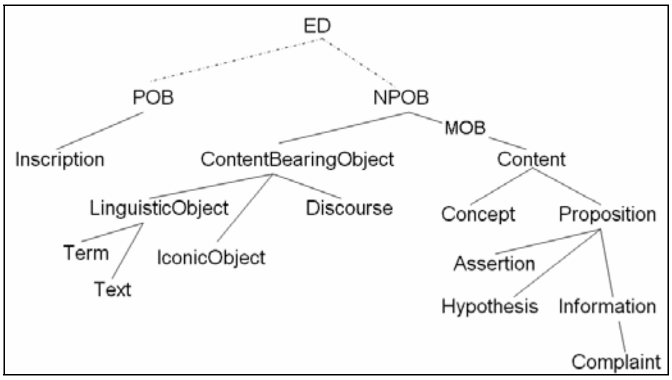

Fig. 3 Top level of the I&DA ontology

The contribution of I&DA to OntoKADS is to enable the modelling of various contents. Thus, I&DA leads us to model the entities *EmptyFuelTankHypothesis, BenzineLeakComplaint* and *LowBatteryLevelComplaint* as *Propositions* - the subjects of which are *Concepts* in the domain of the car, *EmptyFuelTank, BenzineLeak* and *LowBatteryLevel*. The latter are assimilated to states of the car (or its components) and are, as such, subsumed by the perdurant *State* (ST)[9]or *Process* (PRO).

The different kinds of *Propositions* which we have just considered show that propositional attitudes (e.g. to believe that) as well as communication intentions (e.g. to complain about) can be attached to these entities. A *hypothesis* can thus be considered as a *Proposition* being the object of a particular propositional attitude (or mental state) *BelievingThat*, whereas a *Complaint* can be considered as a *Proposition* being the result of a particular discourse act *ComplaintAbout*.

3.2 Modes of participation

This sub-ontology takes up a central place in OntoKADS, establishing a link between the entities taking part in *Reasonings* and the *Reasonings* themselves. It comprises a generic part (presented here) which describes general participations of endurants in perdurants, or their “participative role”. Two dimensions are distinguished in this description.

On one hand, there is a temporal dimension. For instance, an endurant can participate at the beginning and/or at the end of a perdurant. The relation *ParticipatesFrom-*

[9] This explains why the *DomainConcept* primitive can label endurants as well as perdurants, as presented in Figure 2.

Beginning (D1) allows us to define the participative role *ParticipantFromBeginning* (D2), which is an endurant (T1).

(D1) ParticipatesFromBeginning(x,y) $\equiv_{df}$
$\exists t(PC(x,y,t) \wedge \forall t'((PRE(y,t') \wedge t' \leq t) \rightarrow PC(x,y,t')))$
(D2) ParticipantFromBeginning(x) $\equiv_{df}$ $\exists y$(ParticipatesFromBeginning(x,y))
(T1) ParticipantFromBeginning(x) $\rightarrow$ ED(x)

In addition, there is a manner of participating. For instance, an endurant can control, be handled and/or created by a perdurant. To define these participations, relations specializing the PC(x,y,t) relation are introduced, like the *controls* (A1)(T2), *actsIntentionallyIn* (A2)(T4) and *isAgentOf* (D4)(T5)(T6) relations. These relations are used to define thematic roles like *Determinant* (D3) and *Agent* (D5)(T7), the latter being constrained to be played only by an entity capable of intentionality (A3). The temporal dimension can also complete the definition of roles, as in the case of *Data* and *Result* participations (see Fig.4).

(A1) controls(x,y) $\rightarrow \exists t(PC(x,y,t))$
(T2) controls(x,y) $\rightarrow$ ED(x) $\wedge$ PD(y)
(D3) Determinant(x) $\equiv_{df}$ $\exists y$(controls(x,y))
(T3) Determinant(x) $\rightarrow$ ED(x)
(A2) actsIntentionallyIn(x,y) $\rightarrow \exists t(PC(x,y,t))$
(T4) actsIntentionallyIn(x,y) $\rightarrow$ ED(x) $\wedge$ PD(y)
(D4) isAgentOf(x,y) $\equiv_{df}$ controls(x,y) $\wedge$ actsIntentionallyIn(x,y)
(T5) isAgentOf(x,y) $\rightarrow \exists t(PC(x,y,t))$
(T6) isAgentOf(x,y) $\rightarrow$ ED(x) $\wedge$ PD(y)
(D5) Agent(x) $\equiv_{df}$ $\exists y$(isAgentOf(x,y))
(T7) Agent(x) $\rightarrow$ Determinant(x)
(A3) Agent(x) $\rightarrow$ (APO(x) $\vee$ ASO(x))

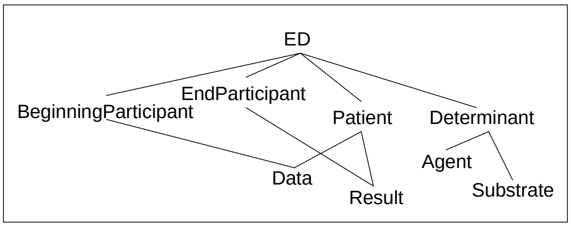

Fig. 4. Excerpt of the Participant ontology

It should be noted that the participative roles defined in this section are antirigid. We consider, for instance, that an entity may participate in the beginning of a perdurant in one world but may not necessarily have this property in another world.

Basically, these participative roles show "dynamic" behaviour in time, analogous to that described by Masolo *et col.* [13] for their *social roles*. Besides been able to cease participation in a perdurant, an entity can simultaneously participate in many perdurants in various fashions, by being the *Agent* of one perdurant and the *Patient* of another, for instance. It can also participate in the same manner in several perdurants simultaneously or at different times, by being the *Agent* of different perdurants, for instance.

3.3 Ontology of modelling primitives: the case of *Knowledge roles*

The two sub-ontologies that we have just seen - the expressions of knowledge (3.1) and the participative roles (3.2) - enable us to report on more specific concepts encountered in applications [2], for instance: *DiagnosisHypothesis*, *ModelToCalibrate*, *CalibratedModel*, etc. To characterize these concepts and compare them to CommonKADS's "knowledge role" primitive, we refer to the formal ontology of meta-properties defined by Guarino and Welty [7], and in particular to three meta-concepts: (*role, formal role* and *material role)* defined as follows:

- A *role* is an anti-rigid concept *dependent*[10] on an external identity. The classification of an entity by a role involves the existence of another entity, external to the other.
- A *formal role* is a role lacking an *identity criterion*[10]. Intuitively, a formal role defines a mode of dependence with respect to the external entity without constraining the identity of the entity which it classifies.
- A *material role* is a role carrying an identity criterion. A material role is usually subsumed, on one hand, by a formal role from which it inherits anti-rigidity and the dependence property and, on the other, by a type from which it inherits the identity criterion.

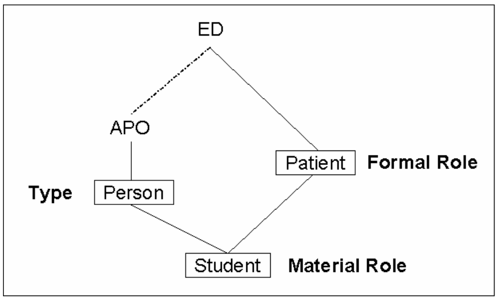

Fig. 5. Labelling of the student concept.

By analogy with this reference framework and by particularizing it with the entities which interest OntoKADS, i.e. the entities intervening in the description of classes of problem-solving situations, we define three notions of "knowledge role" (Figure 6 illustrates the labelling of concepts with these primitives):

[10] For reasons of space, we are not able to give the full definition of these concepts here. The reader is thus kindly requested to refer to [7].

- A *KnowledgeRole* is a role dependent on a particular *Reasoning*. Thus, it is a matter of a participative role depending on a *Reasoning* and not just on any kind of perdurant.
- A *FormalKnowledgeRole* is a *KnowledgeRole* lacking an identity criterion, for instance *CalibrationData, DiagnosisResult.* Such roles don't constrain the identity of the entities they classify.
- A *MaterialKnowledgeRole* is a *KnowledgeRole* bearing an identity criterion whose *Type*[10] it inherits, for instance: *DiagnosisHypothesis, ModelToCalibrate*. It is subsumed by a *FormalKnowledgeRole* (e.g. *DiagnosisResult, CalibrationData*) and a *Type* (e.g. *Hypothesis, Model*). The latter is constrained to be a *Proposition.*

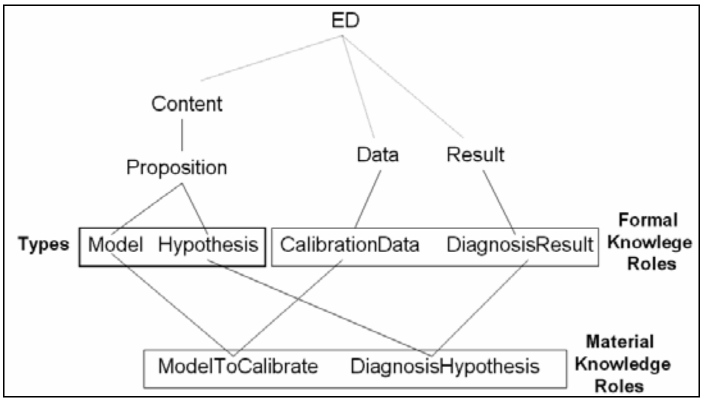

Fig. 6. Labelling of participants by *Knowledge roles*

Finally, the proposition that we formulate to report on the ontological nature of the CommonKADS' "knowledge role" primitive can be summarized as follows:

- The *KnowledgeRole* primitive is a meta-concept (just like other primitives), i.e. a concept classifying other concepts or having them as instances.
- This meta-concept classifies participative roles in *Reasonings*. The *Inputs* (a primitive specializing the *KnowledgeRole* primitive) classify reasoning data and the *Outputs* classify reasoning results.
- These reasoning data and results are played by *Propositions* which have *DomainConcepts* as subjects.
- The *DomainConcepts* classify the objects of the domain, their qualities (attributes) and the states and processes in which these objects participate.

An important feature of this proposition is related to the introduction of a theory of signs with concepts like *ContentBearingObject* and *Content*. This introduction indeed sheds new light on the nature of knowledge roles: the point of view of OntoKADS is that particpants in *Reasonings* are not *DomainConcepts* but *Propositions* having *DomainConcepts* as subjects. OntoKADS' *KnowledgeRole* (meta)-concept thus differs from the meaning given to the "knowledge role" modelling primitive in CommonKADS. In this respect, the reader will note that the *Hypothesis* concept - regarded as a knowledge role in CommonKADS - is not regarded as a *KnowledgeRole* in Onto-

KADS. We can thus anticipate that the expertise models elaborated according to the OntoKADS methodology will differ from those elaborated with CommonKADS.

4 Related ontological work

Other recent work, such as that by Crubézy and Musen [3], pursues a goal which is similar to ours, in continuity with the work of Van Heijst and al. [18] mentioned in the Introduction: the definition of an ontology-centred approach for the development of problem-solving models. However, their approach (which furthermore is also that of CommonKADS [16]) is different. On one hand, the ontologies considered are different: they are modelled within an object-attribute-value framework and do not resort to a top-level ontology (which would constrain the meaning of the domain concepts): thus, the taxinomic relations used do not have the semantic rigour of DOLCE's subsumption relation. In addition, and most importantly, the relations between knowledge roles and domain concepts are considered mainly from a syntaxical angle, with recourse to renaming rules. In contrast, our approach - with the introduction of the I&DA sub-ontology - can be described as semantic[11].

Recently, various research work has sought to introduce the basis of a semiotics into top-level ontologies, following the example of the OntoKADS' I&DA sub-ontology. The IEEE SUMO (Suggested Upper Most Ontology) ontology, for instance, has been endowed with a "practical semiotics" [14]. Furthermore, Fox and Huang [5] elaborated an ontology of *propositions* to represent and reason on the origin and validity of information contained in web pages. More recently, a theory of "information-objects" has been proposed in DOLCE-Lite+ [12, chap.15] - it borrows and completes the Descriptions and Situations (D&S) ontology suggested by Gangemi and Mika [6]. Lastly, an ontology of *social concepts* was proposed by Masolo and al. [13] in an analysis of *social roles*.

Overall, these propositions appear coherent: however, alignment work of these ontologies, for instance in the DOLCE framework, is still to be performed. This supposes more comprehensive specification of the ontological commitments on which the introduced concepts are based (at least in I&DA). This work constitutes one of our short-term objectives. We can already note that a common characteristic of *Descriptions* of D&S [6], *social concepts* in [13] and our *Contents* in I&DA is being defined as reified entities and being assimilated with endurants. This characterization as endurants enables *Contents* to participate in perdurants in general and in reasonings in particular. This is a critical property of our proposition.

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[11] In [4], we treat the syntaxical part of our proposition. We show that the operationalisation of the I&DA ontology (and therefore of OntoKADS) requires one to resort to a language allowing the representation of meta-knowledge by assigning properties to concepts and propositions whose content is represented in the language.

5 Conclusion

Our in-depth ontological analysis (prompted by our use of the foundational ontology DOLCE) has led us to revisit CommonKADS' modelling primitives. In this article, we have focused on the *KnowledgeRole* modelling primitive and we have proposed an ontological framework which sheds new light on this topic.

According to this framework: i) on one hand, *DomainConcepts* like *Car*, *Car-Breakdown*, etc., only participate indirectly in the *Reasonings*, i.e. they participate only insofar as they are mobilized in *Contents* handled by these *Reasonings*; ii) on the other hand, we distinguish two categories of *KnowledgeRoles*: *FormalKnowledgeRoles* (referring only to particular *Reasonings)* and *MaterialKnowledgeRoles* (referring, in a complementary way, to particular *Contents*).

At present, our work is progressing in several directions. Scale-up to the whole of the CommonKADS methodology (by taking account of known tasks and problem-solving methods) is being studied in order to evaluate and complete OntoKADS. In particular, we are examining the impact of OntoKADS on the modelling of problem-solving methods, in particular for the choice of roles as inputs and outputs of the methods. In addition, we estimate that OntoKADS ontology has reached a state which now allows us to begin the development of software to support the method. This software will be defined as an extension of the TERMINAE ontology construction platform [1].

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