PHYSICIAN is a role played by an object, whereas SIGN is a role played by a concept

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Abstract

In this article we tackle controversial questions about the nature of method ontology and its relation to domain ontology. In order to consider a genuine "method ontology", and to explain the link between problem-solving concepts and domain concepts, we propose a new ontological framework consisting of attributing to concepts the status of extensional objects. Within this framework it becomes possible to consider concept states and to envisage different specializations of such states, in particular "roles". The problem-solving concepts can therefore be defined as roles played, not by objects modelling the external world, but by concepts. In the article we also envisage the consequences that this framework entails for the formalization of an ontology.

1 Introduction

The framework that we propose in this paper has been elaborated in reponse to problems encountered when designing an ontology for SATIN [Kas97a], an expert system in neonatalogy. This ontology will be named **OnS** (for: the **On**tology of **S**ATIN) in the paper.

OnS is an *application ontology*, as this term is understood by the PROTÉGÉ group [Tu95] and the KADS group [VHe97a], in that it contains the definition of all the concepts necessary for the application SATIN to perform its diagnostic task. It contains, in particular, descriptions of domain concepts such as HYPOCALCEMIA and ERYTHEMA, and of problem-solving concepts, specific to the task at hand, such as SIGN and SYNDROME[1]. These latter are usually assimilated to *roles* [MDe88] played by the former during problem-solving processes. However, as Reynaud *et al.* have recently recalled [Rey97], no consensus exists yet about the meaning of the notion of "role". When constructing OnS, we were therefore faced with the question of elucidating the nature of the link which exists between domain concepts and problem-solving concepts.

This question has recently formed the subject of a debate, in the journal IJHCS, opposing Guarino [Gua97] to van Heijst *et al.* [VHe97b]. In short, Guarino proposes applying to roles (or problem-solving concepts) the same treatment as applied to domain concepts, leading to the consideration of a *domain ontology* and a *method ontology* (a term borrowed from PROTÉGÉ-II).

> "... an explicit representation of the problem-solving vocabulary along the lines of Gennari *et al.*, (1994) and Falasconi and Stefanelli (1994) can help to systematically analyse the *knowledge roles* (McDermott, 1988) played by the domain knowledge within a particular problem solving strategy ..." [Gua97]

Opposed to this view, van Heijst and his colleagues refuse to consider that a method ontology is a real ontology, giving in particular as a pretext the example that current ontological frameworks such as Ontolingua are unable to render a correct account of the link which exists between domain concepts and roles. In their response to Guarino, they propose instead a different conception of the method ontology (a term they borrow for the sake of

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http://sunsite.informatik.rwth-aachen.de/Publications/CEUR-WS/Vol-18/

[1] Concepts names will be systematically noticed in capital letters and in the font Courier.

the debate) corresponding to the *ontological requirements* of the problem-solving methods in CommonKADS.

> "The problem is that dynamic knowledge roles are not classes and should not be treated as such. The relation between dynamic roles and ontological classes is not a simple specialization relation, and the vocabulary available in existing ontological frameworks such as Ontolingua is not sufficiently expressive to model this relation adequately. [...] In summary then, we believe that knowledge roles are integral components of PSMs. Although they often have the same names, they cannot be *replaced* by ontological concepts because they are of another epistemological type." [VHe97b]

Our aim in this article is to propose a conceptual framework allowing the reconciliation of these two points of view. We think, as Guarino, that the principles of formal ontology can apply to problem-solving concepts as they apply to domain concepts, and that the term "method ontology" can thus be heard in the same meaning as the term "domain ontology". However, we agree with van Heijst and his colleagues for considering that simple specialization relations cannot render an account of the link which exists between the two categories of concepts (as suggested by Guarino), and that a piece of the puzzle is missing which would enable us to speak of a real "method ontology".

The missing piece, or conceptual framework, that we propose relies on the following idea: It is worthwhile to attribute to concepts the status of object in their own right, enabling them to be referred in their turn by (meta)-concepts; it then takes sense to consider *states* of concepts and to envisage specializations of such states, among others *roles*; problem-solving concepts can then be defined as roles played, not by objects modelling the real world, but by concepts.

In order to outline this idea, we adopt the following plan. In a first part, we propose a "representation ontology" in which concepts are assimilated to individuals (section 2). Independently, we make precise our notion of "role": a role corresponds to an influence, either undergone or exercised, by an entity over another entity. As such, the concept `ROLE` is subsumed in OnS by the concept `STATE` (section 3). These two points are then considered simultaneously in order to clarify the nature of problem-solving concepts (section 4). We begin showing that objects, as a modelling primitive, are suitable for account to models of systems in the world (domain knowledge) whereas concepts are suitable for account to models of problem solving processes (solving methods). The main point here is that concepts, as opposed to objects, can exercise an influence over solving processes. According to this analysis, we conclude that the notion of a "role played by a concept" is a natural framework for accounting to the nature of problem-solving concepts.

2 Treating Concepts As Individuals

We postulate that a Problem-Solver (PS), or knowledgeable agent, has in particular at its disposal two categories of knowledge representation entities, or epistemological primitives, that can be distinguished according to their function (*cf.* figure 1):

- at a first level, *objects* function is to *model* a world, be it external or internal to the PS, while serving as substitutes for things which really exist in this world. These objects (of thought) are the means by which the PS can construct knowledge about this world.

- at a second level, *concepts* function is to *denote* representation entities, in particular - but not exclusively - objects at the first level. We shall also say that a concept corresponds to the *idea* a PS has about representation entities, which can be objects at the first level. Concepts are the means by which a PS can construct knowledge about its knowledge about a world.

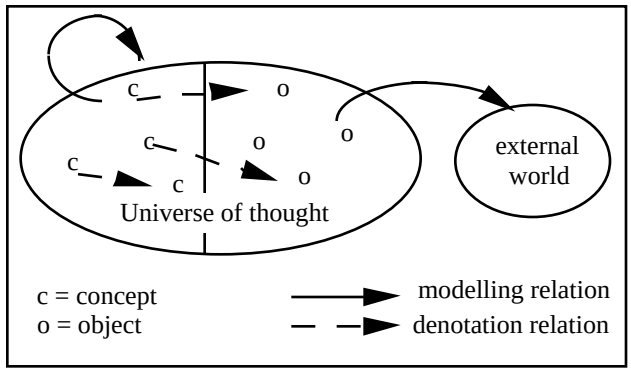

Figure 1: A Universe Of Thought Is Populated By Objects And Concepts

The notion of "concept" on which we rely comes back to consider, according to the classical framework of the semiotic triangle (*cf.* figure 2a), that a concept is made up of a term, a notion (its "meaning", or "intension") and an object (its "reference", or "extension"). With regard to this framework, we add two points (*cf.* figure 2b):

- On one hand, we attribute to concepts the status of object, which gives them the possibility of being, in their turn, referred by (meta)-concepts. From the point of view of the modelling relation, we admit that a concept models itself (*cf.* the loop of the modelling relation on the concepts in figure 1).

- On the other hand, we consider that the same relation of denotation, which exists between concepts and objects, also exists between meta-concepts and concepts. This point is illustrated in figure 1 by denotation links established between concepts.

Let us illustrate this "pivot" role that a concept can play - to denote or to be denoted - by taking the example of the concept `ONTOLOGY`. Its status of concept predicts that we can render an account of the meaning a sentence such as: *"An ontology is a specification of a conceptualization"*. This definition is usually put forward for trying to circumscribe the intension, that is the

meaning, of the concept ONTOLOGY. One expresses here that a certain property - being a specification of a conceptualization - is shared by all the objects-ontologies. The Universe of discourse is made up, in the present case, of ontologies developed by researchers or knowledge engineers. The object status of the concept predicts for its part that one can render an account of the following knowledge: *"The notion of 'ontology' is not completely defined and is still controversial"*. This last knowledge bears on the idea that the Knowledge Engineering community has about these object-ontologies. We could have stated a similar knowledge about the notion of "role". The Universe of discourse is this time composed of concepts. The concept ONTOLOGY is here referred by a meta-concept ILL DEFINED CONCEPT. One can interpret this knowledge as the fact that there does not yet exist a consensus in the Knowledge Engineering community about the meaning of this concept. This last knowledge bears the status of a meta-knowledge.

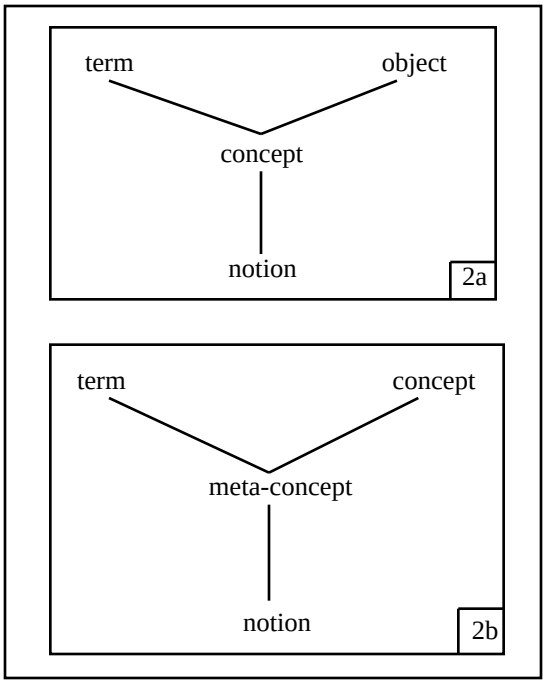

Figure 2: A Concept Denotes An Object (2a) And Can Be In Its Turn Denoted By A Meta-concept (2b)

The ontological framework, or *representation ontology*, that we have just sketched, is situated at the same level as the "Frame Ontology" of Gruber [Gru93]. Its contribution, in regard to the Frame Ontology and also to the (implicit) representation ontology of concepts languages [Hei94], is in treating concepts as a new level of extensional objects, following thus a proposition already stated by McCarty [MCa79][2]. In order to constitute an operational framework, and in particular to serve as a basis for the definition of a knowledge representation language, the framework should be completed. However for our purpose in this article we shall consider that this sketch is sufficient. We shall content ourselves in the following to introduce the distinction between *generic concept* and *individual concept*.

3 Modelling Roles As Temporal Objects

In this section, we make precise our notion of "role". To this end, we present and justify the place occupied by the concept ROLE in the top-level of OnS.

3.1 The Concept ROLE Belongs To The Sub-System TEMPORAL OBJECT

When designing OnS, we have reused and adapted the ontology developed within the AIM project MENELAS [Bou94], in particular its top-level. We therefore consider that objects are specialized into three categories: PHYSICAL OBJECT, ATTRIBUTE and TEMPORAL OBJECT.

The figure 3 shows the top-level of the sub-system TEMPORAL OBJECT (the part of OnS subsumed by the concept TEMPORALOBJECT). This concept denotes the set of the objects which are located in time, i.e. objects to whom information such as a duration or a date can be attached. These objects account for a snapshot of a world, fixed in time (concept STATE), or, on the contrary, for an evolution of the world (concept CHANGE).

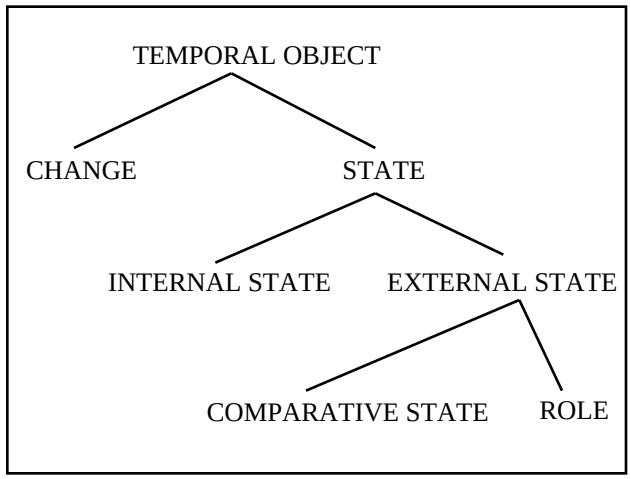

Figure 3: The Concept ROLE Is Subsumed By The Concept EXTERNAL STATE

Among the states a distinction is made between INTERNALSTATES, which consist in an internal manner of being (e.g., HYPOCALCEMIA, which we assimilate to an internal state of a human being), and EXTERNALSTATES, which consist in a way of being with regard to external objects. This latter concept is further specialized into two

[2] In this reference, Mc Carthy already proposed to consider individual concepts such as the concept MORNING STAR, refering to individuals, as new individuals. He noticed moreover that this proposition could very well be extended to generic concepts such as our concept ILL DEFINED CONCEPT, refering to sets of individuals.

distinct categories: states of objects considered as normal or abnormal with regard to objects of the same type (e.g., IMPORTANT CALCIUM RATE) and finally roles played by objects with regard to other objects. This last concept subsumes in OnS, for example, the status of PATIENT and of PHYSICIAN, as well as physiological functions fulfilled by organs with regard to the global physiological system.

The external states specialize therefore themselves according to whether the relation which exists between the entities does, or not, rely on the influence exercised by one of the entities over the other. For example, considering the physiological function of an organ is the same as considering the influence exercised by the organ within a physiological system. We consider that this relation is of the type ROLE. On the other hand, stating that an organ is abnormal requires comparison with another organ of the same type, considered as normal. We consider that we are here in presence of a COMPARATIVE STATE which situates two objects, one with regard to the other, without the possibility in this case of making a reference to some influence.

The definition that we have just given, in particular for the notion of ROLE, must be considered as an approximation for the meaning of this notion. It relies on distinctions which appeared both necessary and sufficient for constructing the domain ontology of SATIN. However, nothing assures us that for another application we shall not have to come back to these definitions, for example in refining them while detailing the distinction COMPARATIVE STATE *versus* ROLE. Therefore it is an operational definition - for the application SATIN - of the notion of ROLE, that we have given here.

3.2 Discussion About The Nature Of Roles

We have just seen that the concepts which we consider as roles are located in OnS within the sub-system TEMPORAL OBJECT. This is the case, for example, for the concept PHYSICIAN. However this choice may surprise at first sight. Indeed, considering that "every physician is a human being" it might seem more logical to define the concept PHYSICIAN as a specialization of the concept HUMAN BEING. Moreover, as is recalled by Guarino [Gua92], this last point of view corresponds also to the way Sowa conceives the notion of role:

> "Subtypes of ENTITY are of two kinds: *natural types*, which have no required set of linguistic associations, and *role types*, which are subtypes of natural types in some particular pattern of relationships. PERSON, for example, is a natural type, and TEACHER is a sub-type of PERSON in the role of teaching." [Sow88]

According to this conception, the role PHYSICIAN, just as the role TEACHER, must indeed be defined as a specialization of the concept HUMAN BEING. The *differentia* between the two concepts consists in the particular relation in which a person is engaged, and which defines the status of physician. This relation corresponds to an incidental property of a human being in that it is possible for him (or her) to lose the status of physician without (happily) ceasing of exist. We therefore notice that the concept PHYSICIAN, contrary to the concept HUMAN BEING, is not an essential concept, or, re-using a synonymous term introduced by Guarino, is not "semantically rigid" [Gua92].

Our conception is not far distant, however, where Sowa and Guarino see only one concept for accounting for a role, we distinguish two of them. We postulate that the particular relation characterizing the status of physician must be firstly defined as a concept in its own right, that is, that we must be able at first to account for the meaning of this relation. This latter being fixed in time, the concept which we name PHYSICIAN naturally belongs to the sub-system TEMPORAL OBJECT. We thus render the concept PHYSICIAN semantically rigid, denoting, not physical objects located in space as human beings, but temporal objects. Once this concept is defined, nothing prevents definition of a concept such as PHYSICIAN HUMAN BEING denoting persons having a physician status. This second concept, considered erroneously - we believe - by Sowa and Guarino as a role, will indeed be a non-semantically rigid concept. Furthermore it will be noticed that the term "role" designates for us a concept referring to objects, in this case particular temporal objects, and not a category of concepts, i.e. a meta-concept referring to particular concepts, as proposed by Sowa [Sow88] and Guarino [Gua94].

4 The Method Ontology Of OnS

In this section, we come to the method ontology of SATIN, that is the part of OnS corresponding to problem-solving concepts. The pre-requisites are established for explaining the meaning of these concepts. Relying on the object status of the concepts, presented in section 2, and on the notion of role that we have just seen in section 3, we are in a position to assimilate the problem-solving concepts into roles played by concepts.

To that end, we focus our analysis on the concept SIGN. We first underline the importance of distinguishing two models, the *model of a physiological system* and the *model of problem solving*, and clarify the respective role of the two primitives: object and concept, for taking these models into account (4.1). Thereafter we only have to specify the place occupied by problem-solving concepts in OnS (4.2).

4.1 Model Of A Physiological System *Versus* Model Of Problem-solving

In order to perform a diagnostic task, a Problem Solver must have knowledge about a specific case, a patient in the case of a medical diagnosis. But it must also have knowledge about its "domain", that is knowledge accounting for regularities observed in a class of patients analogous to the patient-specific case [Wie93]. We shall designate that knowledge by the term "model of a physiological system". Let us, for example, consider the

following specific case knowledge (KS) and domain knowledge (KD):

KS *the patient presents an hypercorticism*

KD *every hypercorticism provokes an hypocalcemia*[3]

It is easy to see that the level of the objects is well adapted, and also sufficient, for rendering an account of the meaning of this knowledge. One can for example propose, as a formalization of KS and KD, the following first order theory, in which the symbols of constants (in large letters) represent objects and the symbols of predicates (in small letters) sets of objects:

ϕKS1 *patient(A-PATIENT)*
ϕKS2 *hypercorticism(AN-HYPERCORTICISM)*
ϕKS3 *presents(A-PATIENT, AN-HYPERCORTICISM)*
ϕKD *x {hypercorticism(x) y [hypocalcemia(y) causes(x, y)]}*

The interest of domain knowledge relies in its predicative power. By relating the domain model to the model of the specific case, it becomes possible in the present case to predict that the patient presents an hypocalcemia. Again, one will note that the level of the objects is sufficient for *performing* such reasoning. From a clausal form equivalent to ϕKD and in using ϕKS2, a theorem prover will introduce a Skolem function in order to infer the existence of an hypocalcemia, and to infer that this hypocalcemia is provoked by the hypercorticism of the patient. In our description of the first inference, below, the symbol "⁄–" corresponds to the symbol for syntactical derivation of theorems.

¬ *hypercorticism(x) v hypocalcemia(f(x)) ; hypercorticism(AN-HYPERCORTICISM)*
ô ¾ *hypocalcemia(f(AN-HYPERCORTICISM))*

Let us now take the place of an external observer, and let us suppose that we have to describe these inferences, that is to state a "model of a problem-solving". One can therefore propose the formulation below. We have given it the status of knowledge and named it KSR - by analogy with KS - in order to indicate that this knowledge bears on a given reasoning process:

KSR *The idea according to which the patient presents an hypercorticism has led the PS to evoke the idea according to which the patient presents an hypocalcemia.*

We have used this time the level of the concepts. The expression "*the idea according to which ...*" may be seen as a means for making reference to a concept, by posing, in some sort, an equality, the phrases commencing by "*the patient presents an ...*" serving to designate concepts. The interest of resorting to concepts is to enable one to designate unambiguously objects, providing for that purpose necessary and sufficient conditions: the objects referred to in KSR are respectively the state of hypercorticism and the state of hypocalcemia shown by the patient. We are here in presence of *individual concepts*, making reference to individual objects.

We have just seen the usefulness of having recourse to concepts, however it is fitting to go further while noticing that the level of objects is inadequate for describing such an inferential process and that, in consequence, the level of concepts cannot be ignored. The argument that we put forward is that no direct causal relation exists between a physiological process occurring in the patient and an inferential process occurring in the PS. The inferential process relies on a model of the patient to whose development it contributes, by trying to reconstitute a causal history of the patient. By definition, this model does not necessarily reflect reality, and we thus cannot attribute the existence of the inferential process to that of a physiological process ... which perhaps has never existed. Only objects of knowledge exist for the PS, and these objects must moreover be endowed with properties in order to be able to give rise to inferential processes. In the case of KSR one can say that the inferential process exists due to the fact that there exists an object having the property of being an hypercorticism. Speaking about this state of knowledge refers back to an individual concept.

The knowledge KSR that we have considered concerns a given inferential process, in the same manner as knowledge KS was rendering an account of a given physiological process, concerning a given patient. Let us suppose now that - by analogy with knowledge KD - we wished to describe a class of inferential processes analogous to the process we have just seen, after having noticed, for example, that the inference "*hypercorticism ⁄– hypocalcemia*" is drawn for each considered patient. We are therefore seeking to express a model of a class of problem-solving. We shall state the regularity we have just mentioned in the following way:

KDR *the idea according to which patients present an hypercorticism has led the PS to evoke the idea according to which these patients present an hypocalcemia.*

In this description the concepts which are at the origin of (or which result from) the evocation, refer, no more to individual objects, but to sets of objects, respectively the set of hypercorticism and the set of hypocalcemia shown by the different patients. These are *generic concepts*, in contrast to individual concepts.

To sum up, we have taken care in this section to distinguish two types of descriptions, or models, depending on the nature of the modelled object: a physiological system, or a problem-solver. We have shown that the objects level is suitable to account for a

[3] In principle generalizations that can be drawn from a class of patients correspond rather to imprecise knowledge such as: ***generally*** *an hypercorticism provokes an hypocalcemia*. However, as ignoring the imprecision has no incidence on our analysis in this section, we will do so for the sake of simplicity.

model of a physiological system, whereas the concepts level is for itself suitable to account for a model of a problem-solver. As a consequence, one must expect that problem-solving concepts, or knowledge roles, will be defined as states of concepts. That is what we are going to discuss next in specifying the place of the concept SIGN in OnS.

4.2 The Sub-system CONCEPTUAL ROLE

A knowledge such as KDR equates to taking into account the influence exercised by a (generic) concept with regard to problem-solving processes. We thus rediscover here our notion of role, as defined in section 3. The only difference is that we have been interested up to now in roles played by objects, whereas in the present case we are confronted with roles played by concepts.

The notion of SIGN that we propose in OnS corresponds to a characterization of this conceptual influence for which knowledge KDR accounts. We state that a temporal object of the type SIGN exists as soon as a concept evokes another, enabling the PS to progress toward the establishment of the diagnosis. This meaning that we attribute to the term "sign" seems to us to correspond to currently accepted definitions of the term, even if these do not mention the distinction we have established between objects and concepts. The concept SIGN is subsumed in OnS by the concept DIAGNOSTIC ROLE, itself subsumed by the concept CONCEPTUALROLE (*cf.* figure 4).

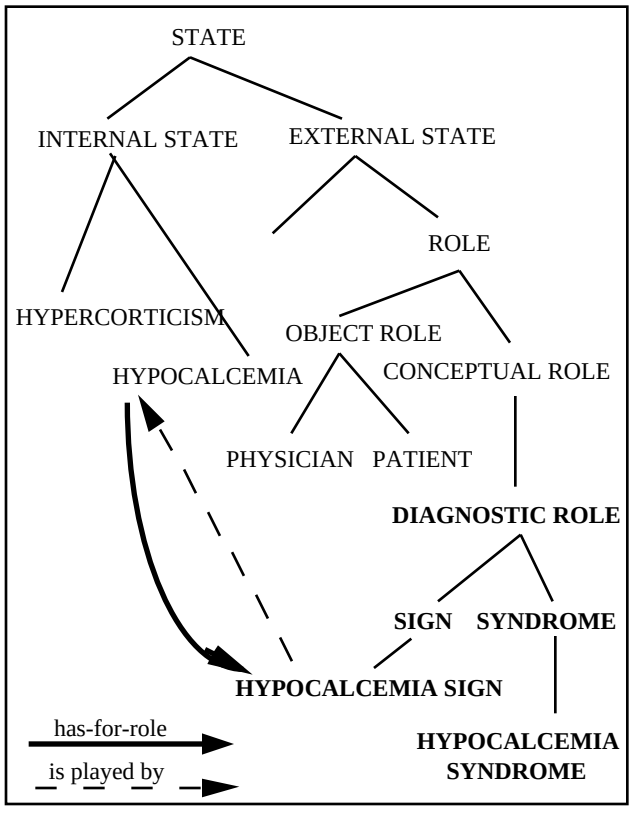

Figure 4: The Sub-System DIAGNOSTIC ROLE

As a consequence, a concept such as HYPOCALCEMIA (or HYPERCORTICISM, if we rely on knowledge KDR which describes the role played by this latter concept) and the different roles played by this concept, among others diagnostic roles, are as many distinct entities. Such an entity is the concept which we designate by the term "hypocalcemia sign". This concept is generic in that it refers to a class of situations (or evocation events), as described in KSR, in which a concept evokes another. The concepts HYPOCALCEMIA and HYPOCALCEMIA SIGN are linked by two relations, one being the converse of the other: a conceptual relation, named "has-for-role", enables to indicate what are the roles that a concept plays; conversely, the relation "is-played-by" indicates which concept plays a given role.

Another term: "hypocalcemia syndrome" (see figure 4), is also linked to the notion of hypocalcemia. The meaning of this term relies on the existence of a different conceptual role, which corresponds to the concept SYNDROME. The concept SYNDROME is opposed to the concept SIGN by attributing the evocation role to a set of concepts, and not to an isolated concept (as this set is not represented in figure 4, there is no arrow leading to the node HYPOCALCEMIA SYNDROME).

The definition of the term "syndrome" we have retained may seem incomplete for the reader. Indeed, a syndrome is usually defined as a *group of signs whose origin is not known*, yet our concept SYNDROME only retains the first part of this definition. The reason is that the second part - having an unknown origin - corresponds in OnS to another concept. This property amounts in reality to define a particular "state" of a pathological state. The concept in question, SYNDROMIC STATE, is thus located in OnS in a sub-system STATE OF TEMPORAL OBJECT, and it is there defined by opposition with the concept DISEASE, which denotes pathological states whose origin is known. The point of this model is that it enables syndromic states - as well as diseases - to be evoked by means of a group of signs. One can therefore speak about the "hypocalcemia syndrome" and the "meningitis syndrome", as suggested by an analysis of the domain knowledge, even if hypocalcemia and meningitis have a known origin. Of the two concepts: SYNDROMIC STATE and SYNDROME, only the second belongs to the method ontology of OnS.

5 Discussion

We have just seen on which basis the method ontology of SATIN has been developed. In the present discussion, we return to the positions expressed by Guarino [Gua97] and van Heijst and his colleagues [VHe97a][VHe97b], about the nature of these ontologies, in order to clarify our position. We organize the discussion around two controversial points: One, the question of the link existing between the two ontologies, this question referring in fact to specifying what a *method ontology* really is (5.1); and two, the question of the formalization of an application ontology, and of the limits of formal frameworks such as Ontolingua (5.2).

5.1 Nature Of A Method Ontology

As we have observed in the introduction, van Heijst and his colleagues deny for roles the status of "ontological concept", this denial reflecting in the title of their response to Guarino : "Roles are not classes". Their point of view is that an ontological approach, such as proposed by Guarino, does not provide an answer for the requirements which correspond to a method ontology, or more exactly that there exist two different conceptions for this ontology which are opposed:

> "We can imagine at least two interpretations of the term method ontology. Firstly, method ontologies can be *descriptions of the roles that domain concepts and relations can play in the reasoning process*. Guarino does not give a definition in his paper, but based on the examples that he gives [...] we assume that this interpretation corresponds to his view. [...] The second interpretation of the term method ontology that we can imagine is that a method ontology *describes the domain concepts and relations that are manipulated by a problem solving method in the reasoning process*. We believe that this is how method ontologies are understood in PROTEGE-II. Viewed in this way, method ontologies fulfill the same roles as the ontological requirements of PSMs in CommonKADS, the difference being that the relation between the method ontology and the domain ontology is implemented through ISA relations, whereas the relations between the requirements and the ontology concepts are "satisfies" relation. We prefer the requirements solution over the method ontology solution [...]." [VHe97b]

We think that the approach proposed in this paper is able to conciliate the two interpretations mentioned by van Heijst and his colleagues. We have seen in section 4.2 how we are able to specify, for each domain concept, the role(s) each one plays in the problem-solving process (by means of the relation "has-for-role"), and, for each role, which domain concepts play that role (by means of the relation "is-played-by". In our view, these two relations seem to correspond to the second interpretation quoted above. Inversely, specifying the description of the roles - which corresponds to the first interpretation - belongs to the exact definition of the role. So let us now look more closely at how the concepts of the conceptual sub-system `ROLE` are defined.

Let us first consider a role played by an object, for example, the parental role `MOTHER`. As a temporal object we define this role by assuming that this one exists as soon as a woman has a child. We equate a temporal object of the type `MOTHER` to this situation. In other words, we consider that the fact of a woman having a child defines, in a necessary and sufficient manner, the concept `MOTHER`. In the same way, the fact of a person undergoing a medical examination defines a role of the type `PATIENT`. One will note that these definitions give rules for recognizing the type of situation, but that they do not assume that there exists objects belonging in these situations. This last information belongs to a model of a world.

A knowledge role, or conceptual role, such as `SIGN` is defined in a manner analogous to that of a role played by an object. We have considered in section 4.2 that a role of type `SIGN` exists as soon as a concept evokes another concept. Therefore the intension of this problem-solving concept characterizes the domain concepts playing that role, without assuming that such concepts do exist. We find here exactly what van Heijst *et al.* expect of a method ontology, that is that it corresponds to the requirements of the problem solving methods of KADS, while applying to these concepts an ontological approach, as recommended by Guarino.

5.2 Formalization Of An Application Ontology

In order to complete our proposition, we still have to show how it is possible to formalize the kind of application ontology that we envisage. On that point, we agree with van Heijst *et al.* for noticing that a formal framework such as Ontolingua is inadequate:

> "The relation between dynamic roles and ontological classes is not a simple specialization relation, and the vocabulary available in existing ontological frameworks such as Ontolingua is not sufficiently expressive to model this relation adequately ." [VHe97b]

A candidate language has to extend the representation ontology presented in section 2, and in particular to give to the concepts the entire status of objects. This characteristic is essential, as we have seen, to account for the link between the domain concepts and the conceptual roles. Languages such as KIF within the project Ontolingua [Gru93] or languages of concepts descending from KL-ONE [Hei94] enable one to specify and manipulate intensions of concepts, however they do not allow for considering these intensions as real individual objects, by allowing one to attribute to them, in their turn, properties, that is by allowing them to be referred by meta-concepts. This limitation seems to us to correspond to the distinction proposed by Hirst [Hir89] between "weakly" and "strongly" intensional languages:

> "It is interesting to note that, generally speaking, KR formalisms that treat concepts as first-class objects do not formally distinguish them from individuals. [...] I don't know of any principled reason for this. Such systems are *weakly intensional* systems, countenancing intensions but not making anything special of them. In contrast, *strongly intensional* systems take intensions to be not just first-class objects but objects of a distinct kind. [...] I suspect that a strongly intensional system will be necessary for an ontologically adequate treatment of intensions." [Hir89]

The language Def-* that we have been developing for formalizing Knowledge Based Systems can be termed "strongly intensional" [Kas97b][Kas99]. From the point of view of the representation of the ontological knowledge, Def-* presents two main characteristics: it confers to concepts and propositions the entire status of objects, while offering an important propositional expressive power. In this paper, for reasons of space, we

must be content with illustrating these two characteristics by means of examples, without going into the details of the language. We comment below on the representation of the concepts HYPOCALCEMIA , SIGN and HYPOCALCEMIA SIGN (*cf.* figure 5).

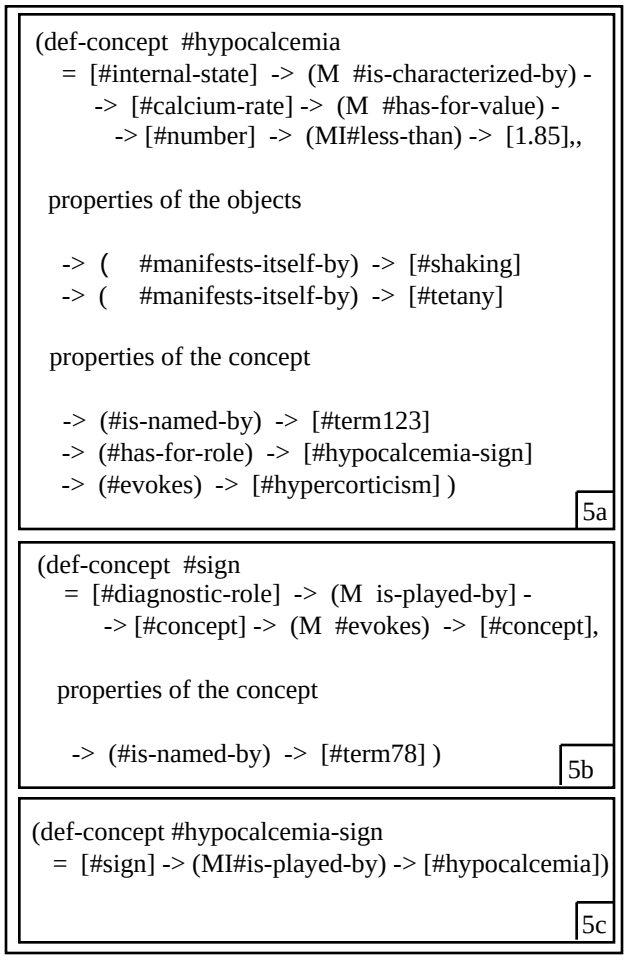

Figure 5: Representation In Def-* Of The Concepts HYPOCALCEMIA (5a), SIGN (5b) and HYPOCALCEMIA-SIGN (5c)

An entity introduced by the primitive "def-concept" represents both a class of extensional objects and the concept referring to that class, and even in some cases, several co-referential concepts having for extension the same set of objects. This explains that different parts are distinguished within such a construction (*cf.* figures 5a and 5b): The first part is dedicated to the definition of the properties of the class objects; the second part, which is delineated after the key-word "properties of the concept" allows to state the properties of the concept. The syntax used to formalize the properties corresponds to the linear syntax proposed by Woods for a semantic network [Woo91]: the links between concepts, or pairs of relations, have a quantificational import, moreover *assertional links* are distinguished from *structural links*. The assertional links comprise double quantifiers such as: " ", " ", " "[4], whereas the structural links comprise quantifiers such as: "M " or "M ", the quantifier "M" playing the role of a "modifier".

In figure 5a, the concept HYPOCALCEMIA is defined with regard to the genus INTERNAL STATE. The key-word "=" means that the *property "being an internal state characterized by a calcium rate less than 1.85"* corresponds to a necessary and sufficient condition. Other properties, corresponding to additional necessary conditions, follow behind the kew-word "properties of the objects", for example : "*every hypocalcemia manifests itself by a tetany*". These object properties are separated from the conceptual properties by the key-word "properties of the concept". The properties situated below the key-word then consider the concept as an object. Three propositions bearing on the concept are thus represented: "*the concept HYPOCALCEMIA is expressed in the language by some term*"; "*it plays the role hypocalcemia-sign during reasoning*"; "*it evokes the concept HYPERCORTICISM*".

The definitions for the concepts SIGN, in figure 5b, and HYPOCALCEMIA SIGN, in figure 5c, follow the same structure. As a temporal object, a SIGN is defined as a DIAGNOSTICROLE: this role is played by a concept which evokes another. Finally the role HYPOCALCEMIASIGN is defined as the sign played by the concept HYPOCALCEMIA.

We have seen with these two examples that the language Def-* allows us to represent both the domain concepts and the problem-solving concepts. The representation of a concept contains the representation of its intension, i.e. the representation of a set of properties verified by the objects referred to by the concept. This part of the representation corresponds schematically to the services offered by the languages of concepts, or terminological systems [Hei94]. But the representation also contains a representation of the properties satisfied by the concept itself, considered as an individual object. It is this second part of the representation which provides, in particular, an account of the link between the domain concepts and the problem-solving concepts.

6 Conclusion

The framework proposed in this paper mostly relies on the reification of the concepts as a new level of extensional objects. The precise meaning attributed to the notion of "role" is, as a matter of fact, secondary in our analysis.

In particular, the fact for a role of being a "class" or a "meta-class" does not matter. The same meaning of our concept ROLE is imbeded both in a concept such as PHYSICIAN and the concept SIGN. In return, what differentiates the two roles is that the former bears on an object, whereas the latter bears on a concept.

The knowledge according to which *a domain concept plays a particular role in reasoning* belongs to a model of problem-solving. We hope to have shown in this paper

[4] A link such as "[a] -> (Rel) -> []b]" is, for example, equivalent to the following first order logical formula: x [a(x) y (b(y) Rel(x, y))].

that languages such as KIF or similar languages of concepts are inadequate for formalizing such a model, but that it is necessary to resort to "strongly intensional" languages such as Def-* in order to attribute properties - not only to objects - but also to concepts.

This latter knowledge has indeed the status of meta-knowledge and its use in a reasoning must be assimilated to meta-resoning. We therefore think that our framework offers a new way for accounting to the reflective part of problem-solving processes. We are currently working on this perspective.

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