Towards the Integration of Ontologies and SA–Nets to Manage Design and Engineering Core Knowledge

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Abstract. This paper presents a conceptual framework for the development of Knowledge Management (KM) systems to support experts in complex design activities. Designing a complex object is not a simple task, since it is concerned not only with problem solving issues, but also with the growing needs for capturing and managing the core knowledge involved in it. A complex object is typically made of a huge number of parts that are put together according to a first set of constraints (i.e. the *procedural knowledge*), dependable on the functional properties it must satisfy, and a second set of rules, dependable on what the expert thinks abut the problem and how he/she would represent it (i.e. the *declarative knowledge*). The paper illustrates a way to unify both types of knowledge, exploiting the SA-Nets formalism to capture the procedural knowledge and a mereological approach to represent declarative knowledge.

1 Introduction

A growing number of studies, researches and information technology systems are focusing on the concept of *Community of Practice* (CoP), combining the organizational aspects with the Knowledge Management (KM) topics. A CoP may be characterized as *a group of professionals informally bound to one another through exposure to a common class of problems, common pursuit of solutions, and thereby themselves embodying a store of knowledge* [27] . Originally born in the situated learning theory, the concept of CoP [26] has been conceived to delineate the social and collective environment within companies where core knowledge is generated to create competitive products. Therefore, these Communities may be seen as a complementary organisational structure, made up of the personal networks created and used to solve problems arising from common practice. They are groups of people informally bound by their shared competence and mutual interest in a given practice, which makes it natural for them to share their individual experiences and knowledge in an informal and creative way, through which they are able to foster new perspectives and new ways of tending to arising problems. The importance of this notion with reference to KM re-engineering projects is well known and stressed [1,26], nonetheless the methodological systematization of the notion within Artificial Intelligence based Knowledge Management Systems is still an open issue. CoPs may deal with different kinds of problems, and some of them are focused on the Core Knowledge of a Company [16]. We define the people involved in these communities Core Knowledge Practitioners (CKP). The research area devoted to these topics develops itself upon experiences and theoretical reflections, which define new borders of competitive growth, giving value to internal knowledge for innovation. This is today a fundamental requirement to face more and more dynamic and competitive markets. Besides, only a part of all knowledge used by a company to innovate its range of products is stored into documents or recorded in other kinds of repositories. Most of it constitutes an implicit asset (or tacit knowledge, see e.g. [9,23]) guiding the decision making processes, nourished and preserved as a personal practical competence by the *area experts*. From this point of view software instruments should not only be able to manage and share knowledge but also to support the analysis of knowledge repository of companies and to exploit it [2]. This shift of perspective is changing the KM approach that cannot only rely on document management techniques but also on knowledge representation and management approaches developed in the Artificial Intelligence context (i.e. Knowledge Based Systems). In this framework we justify the adoption of the concept of CKP as the guideline to identification, acquisition and representation of Designers and Engineering Knowledge within companies deeply committed to product innovation as well as to the selection of the most suitable knowledge representation methods to manage Designers and Engineering Core Knowledge [2]. In the following, we'll refer to the specific Core Knowledge possessed by Mechanical Designers involved in configuration activity of complex objects as *Engineering Core Knowledge*. Section 2 will describe some related works about the management of Engineering Core Knowledge. In Section 3 our position about the need for a mereological approach to the representation of Engineering Core Knowledge is motivated. Section 4 briefly introduces the conceptual framework for the management of Engineering Core Knowledge, pointing out how the ontological representation of the considered domain and the adoption of SA–Nets could allow to overcome the difficulties in dealing with different knowledge subtypes Engineering Core Knowledge is made of. Finally, conclusions and future works are briefly exposed.

2 Related Works

From a theoretic and cognitive point of view, over the last decades, most engineering design researches have focused on developing prescriptive design methods such as the Systematic Approach [12]. Descriptive design theory was underestimated and sometimes ignored [13]. As a consequence, basic concepts and principles of designing are still not precisely formalized and understood. The elaboration of a theory of design, defined as *an iterative process which manip-*

ulates knowledge on existing known artifacts to specify new artefact satisfying a list of requirements [7], was recognized as a scientific topic at the beginning of 1960's with the development of CAD systems [14] and, from the seventies, design as an intelligent behavior has been the subject for researches in Artificial Intelligence, Cognitive Sciences and Computer Sciences [8]. This type of knowledge is bound to the subject of design and it contains the information relevant to the process of design. Information can be divided according to its structure and format into: geometric information (geometric representation of the model of the product in most cases the CAD model), information about the documents used during the design process (standards, manuals, and recommendations), information about inference rules and external program applications (calculations, simulations and so on) [14]. Starting from the end of the 1980's some tools have been marketed as *Knowledge-Based Engineering* (KBE)-Tools, for example ICAD (Knowledge Technologies International) or PACElab (PACE). These tools provide a software environment for automating repetitive engineering tasks [10]. Knowledge Based System applications have in fact a big potential to reduce cost and time for repetitive engineering tasks but require a big effort to collect and formalise the required knowledge in a knowledge representation scheme. In this field one of the most known examples of application to the industrial planning of complex objects in 3D environment have been proposed by Gero and Maher [11]. They defined a conceptual and computational approach starting from the definition of design as a *goal-oriented, constrained, decision-making, exploration and learning activity which operates within a context which depends on the designer's perception of the context* [18]. Their approach defines some knowledge representation schemes (the so–called *prototypes*) for the definition of the conceptualization and ideation process generally followed by a draftsman and he proposes the Case-based design paradigm to re-use previous design solutions to solve similar design problems [19]. From the Core Knowledge Management perspective, pointing out these representation schemes means to represent, store and manipulate in a formal way Engineering Core Knowledge adopted by Core Knowledge Practitioners so that it may be used by computer systems to accomplish a given task (see e.g. [3,17,20,21]). The nature of the design process and the complexity and variety of the Engineering Core Knowledge possessed by designers in a CKP and used during process of product creation is mainly performed on the basis of the designer's experiences integrating knowledge about process of planning and about the static structure of complex objects will be planned. For this reason representation schemes for managing Engineering Core Knowledge require a flexible and robust model for the representation and handling of both declarative and procedural knowledge daily involved in CKP's problem solving activities [1].

3 Our Position

Our idea is to develop a framework for managing knowledge in the field of planning and configuration of complex mechanical objects. Many of the knowledge representation schemes developed in the past have concentrated on declarative knowledge [24]. A lot of researchers have provided assertional mechanisms for deductive retrieval and some of them gave terminological mechanisms for classification and abstraction. However, none of them was developed with the same sophistication level from the *procedural knowledge* representation point of view [22]. Our research is currently devoted to elevate procedural knowledge at the same representational level as declarative knowledge, by integrating SA–nets, a subclass of Petri Nets and a diffused formalism for the modelling of concurrent systems (see e.g. [28], and ontological requirements: it will be proposed a conceptual and computational framework able to manage Core Engineering Knowledge involved in professional planning CKP activities, through the treatment and representation of ontological and procedural aspects involved in planning of complex mechanical objects. The extension of SA-Nets formalism will be proposed aims to synthesize the modelling of planning processes of these objects. This goal will be reached through the representation of the mutual influences among the constraints that the structure of complex objects impose on planning (i.e. *ontological constraints*) and the constraints that the planning steps (i.e. *procedural constraints*) impose on the single parts of the complex object. This approach to the treatment of Core Engineering Knowledge, where declarative knowledge on the structure of the object and procedural knowledge on the processes of planning of the object are reciprocally bound, will be proposed in hold correlation with some important and known philosophical paradigms. Problems like ontology and conceptual modelling need in fact to be studied under a highly interdisciplinary perspective: besides the basic tools of logic and computer science, *an open-minded aptitude towards the subtle distinctions of philosophy and the intricate issues of natural language and commonsense reality is in our opinion necessary* [32]. The unfolding of ontology (which is the theory of objects and their relations) provides in fact criteria for distinguishing various types of objects (concrete and abstract, existent and non-existent, real and ideal, independent and dependent) and their ties (relations, dependencies and predication) [4,5,25] For these reasons, instead of defining a cognitive theory on creativeness and design such as in Gero's knowledge base approach, the Ontologies and SA-Nets integration will be pursued with reference to philosophical and epistemological suggestions deeply related to the mereological theory of parthood relations [15,29,30]. In particular, the most important philosophical discipline which we will take into account is the phenomenology, which elaborates an ontological and mereological theory that will be presented as a good epistemological paradigm for the conceptualization of declarative and procedural knowledge into a unified representational framework [31].

4 Framework Model

Designing a complex object can be divided into two subproblems: how to represent procedural knowledge and how to represent declarative knowledge. This is a general issue of the design problem, but we'll talk about a specific case in which the complex object to be configured is a mechanical component. From the declarative knowledge standpoint, a mechanical component can be considered as made of different parts that can be grouped on the basis of different levels of abstraction, as shown in Figure 1.

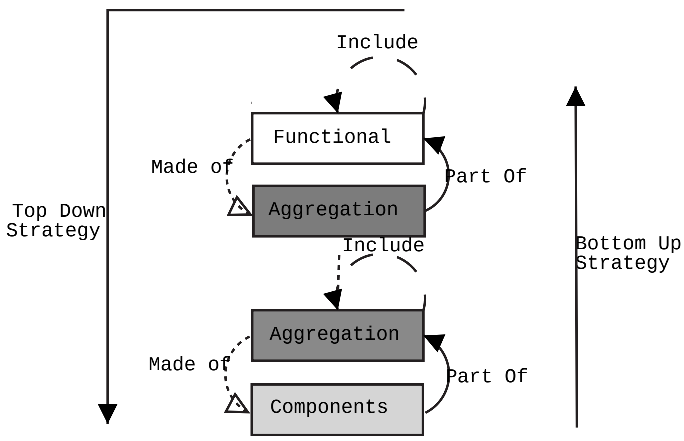

Fig. 1. *A mechanical object is made of three different kind of parts, bounded by three different types of relationships*

At the *Component Level* atomic components are placed, for which no design activity or knowledge are needed. Components are used to build more complex parts of the object, that are *aggregates*. An aggregate is a composition of one or more components and can include one or more other aggregates. Although aggregates have not specific meaning from the mechanical object point of view, they are useful to provide experts with a simpler way to deal with components. The last level of abstraction is constituted by *functional* units, that are built starting from aggregates and components, but different from them represent a functional property of the under construction object. The relationships among levels can be navigated according to a bottom–up or a top–down strategy: in the former case, it is necessary to start from the component level, in the latter the first level to consider is the functional one. While the bottom–up strategy is the most used when developing a KM system for supporting the design of complex objects (e.g. a case–based reasoning system calculates the similarity between two case according to the value associated to their attributes), the top–down strategy is closer to the real way of reasoning of an expert designer than the other one. The top–down strategy is implemented in our framework by the *include* and *made–of* relationships.

Procedural knowledge is related to how taking care of design constraints in building the object: such constraints can be due to geometrical aspects (e.g.

a component cannot be placed on an aggregate because of absence of space), customer requirements (e.g. don't use this type of component, use this one instead) or designer experience (e.g. the design of this functional unit influences the design of that one). This constraints can be captured by the adoption of a formalism like SA–Nets, that allows to manage the different steps by in a synchronous or asynchronous fashion.

5 Conclusions and Future Works

This paper has presented a conceptual framework for the representation of both procedural and declarative knowledge involved in the design of complex mechanical objects. Declarative knowledge is captured by a mereological model of the object, while procedural knowledge can be profitably managed through well known formal models, like e.g. SA–Nets.

The possibility to consider both knowledge types into a unique framework is very important step with respect to the development of KM systems in extremely dynamic domains, like ones in which CKP or Communities of Inquiry [33] operate. According to [34], the framework proposed can be considered as a initial step in the creation of a good design theory for the management of core and engineering knowledge involved in the building of complex mechanical objects.

This opinion has been partially confirmed by the participation to a research project in collaboration with Fontana–Pietro S.p.A, an Italian enterprise leader in dies manufacturing and in the construction of elite automobile bodies that works for some of the most important European car manufacturer (e.g. Mercedes–Benz, BMW, Ferrari, Renault, ...). A car die is a very complex mechanical product, that must be designed and manufactured in the shortest period of time and with the maximum level of accuracy to avoid loss of money and according to precise geometrical and customer constraints together with many rules inducted by designers on the basis of their own experience.

In that context, the mereological approach has allowed to build a die model shared by all the experts of the CKP community where it didn't exist before. Moreover, the developed KM system has been linked to sophisticated CAD tools used by Fontana–Pietro's experts, building an integrated environment able to completely support their creativity.

Anyway, a lot of work must be done in the future: in particular, the relationship between ontology and SA–Nets should be further investigated since it has been used superficially during the collaboration with Fontana–Pietro.

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