From Concepts to Design Ontologies

Pertti Saariluoma and Kalevi Nevala
Cognitive Science, University of Jyväskylä, Finland

Abstract. The research on engineering knowledge systems is continually evolving. Knowledge is conveyed through the thought processes of engineers. In order to provide adequate support for engineering design the thought processes must be understood. The aim of this paper is to discuss how to transform conceptual knowledge to design ontologies. We suggest a procedure termed Cartesian reasoning to explicate some intuitive steps in engineering thinking and to put them under scrutiny.

Keywords: Conceptual contents, Cartesian reasoning, content-based analysis, design engineering thinking, engineering ontologies.

1 Introduction

Engineering ontologies are knowledge systems referring to objects, actions and events relevant in engineering. There are many other ways of defining these knowledge systems, but the above seems to capture the essence of the ways in which the problem has been defined elsewhere [1], [2]. The main property of ontologies is that they give a description about the contents of their references [3].

Ontologies are vital because they provide both means for systematizing and transferring organizational information [4] and tools for collaborative design and the use of everyday knowledge in organizations [5], [6], [7]. Moreover, they improve knowledge reuse and enable us, to some degree, apply algorithmic problem solving in design processes [8]. Finally, they can be seen as theories of contents [3]. This means that research on ontologies shall have vital role in future engineering design thinking.

So far, the research into ontologies has mainly concentrated on the form of actual knowledge systems, and much less attention has been paid to the dynamics of the thought processes creating them. Content-based design analysis is specifically targeted when investigating thought processes in design [9], [10], [11]. Consequently, it is natural in its context to ask about the nature of thought processes relevant in building new ontologies. Content-based design analysis assumes that thought processes are based on transforming the information contents of mental representations. Consequently, understanding design as thinking, we have to be able to explicate the way information contents behave when designers think. Succeeding in this would make us better capable in controlling engineering design. We would be able to answer questions such as how to organize design knowledge, how to organize design groups, what happens in creative thinking and how organizations could be evaluated according to their knowledge management processes. This means that we would be able to manage the information and data, as well as human processes.

For a content-based ontology research a natural stating point is to investigate the thought processes emerging from ontology design. Concepts form perhaps the most fundamental knowledge element in ontologies. Here we analyse the tacit aspects of concept processing in designing ontologies as well as in engineering design in general. Our focus is on how to use knowledge packed in our concepts when building ontologies. We apply and essentially extend the earlier discussions to a form of conceptual inference, which can also be called Cartesian reasoning [12], [13], [14].

2 On Knowledge in Concepts

It is not possible to present infinitely long chains of arguments. For this reason scientific knowledge is eventually intuitive [15], [16], [12]. The idea of axiomatic system represents perhaps the best-known recognition of the ultimate intuitive character of scientific knowledge. Even conceptual systems in science have their intuitive foundations, the contents of which are no longer analyzed but assumed. These basic theoretical notions could be called conceptual postulates [12]. Typical examples of such postulates might be ‘system’, ‘function’ or ‘process’. These concepts are constantly used in building scientific knowledge, but they are seldom defined or individuated in any detail [12]. Of course, one could easily present numerous other examples.

In this paper, the notion of ‘concept’ itself is put under scrutiny. The concept of *concept* is also a conceptual postulate. It is commonly seen as a classifier in so-called classic theories of concepts. In these theories the definition and the defining characteristics are aimed to provide us with a criterion of determining which objects, events or ideas can be subsumed under a particular concept (cf. [17]). However, in so-called prototypical theories and even in theory-theory of concepts, the main function of a concept is also seen to be that of a classifying entity [17], [18]. Finally, the whole tradition of mathematical theories of concepts from logic to neural networks and learning machines mainly concentrates on classification. This means that classification or categorisation provides the dominant intuition in the way we see concepts [13].

However, we could view concepts from a very different intuitive standpoint, where they serve functions other than classification. Concepts are used to construct propositions and representations and could thus be seen as constructors [13]. The constructor view is not contradictory with the classificatory view, and it opens us new possibilities in considering the nature of conceptual knowledge.

A crucial difference between the two intuitions, i.e., concepts as classifiers and concepts as constructors, is in the way we think about their contents. In the classificatory view, the content of a concept is a set of objects which belong to its scope. In the constructor view, on the other hand, the contents of a concept are what they add to the information contents of representations. Thus, the content of ‘possible’, for example, is what it adds to the propositions within which it is incorporated. 'Possible' considerably modifies the propositions it is inserted into. The constructor role is made evident in the modification of the sentence ‘the belt cannot tolerate so high temperatures’ to ‘possibly the belt cannot tolerate so high temperatures’. 'Possible' adds some content element to the second proposition. The constructor perspective is important, because it opens us new possibilities when using conceptual knowledge in investigating representations and inferences.

3 How Concepts are used in Designing Ontologies?

If we put the work with ontologies under a careful scrutiny, it is possible to find in it a tacit thought operation, which people regularly make, but which they never explicate. This process somehow connects concepts with their attributes. Chandrasaekaran, Josephson and Benjamins [3] discuss four very common ontologies. They all use the same root concept, i.e., *thing*. CYC gives it three major attributes: individual object, intangible and represented [6]. Wordnet presents a twofold division into living and non-living, Sowa [20] differentiates between concrete, process, object and abstract.

Borst and Akkermans [1] present an analysis of a mechanism which firstly allocates three major attributes: connectivity, effort and domain. After that the major attributes are given different values. These values are very clearly attributes of the major attributes. Two-port, for example, is an attribute of connectivity. This way of creating attributes is obviously the same as the one in the previous example.

Let us look finally into a third example. Spyns, Meersman and Jarrar’s analyse the structure of book [21]. They give their ontology attributes such as author, title, price, and product type. If necessary, one could add some other attributes such as size and weight. Perhaps the last one would be problematic with e-books, though we might be willing to think that they have weight. Anyone familiar with ontology literature can see that there is nothing strange in this construction of the attribute system. One could easily find more examples.

Designing ontologies is a thought process, which enables us to generate the attributes. How do we come to the conclusion that the concept of thing has an attribute such as living? How can we deal with the problem of having numerous different types of attribute systems related to a thing? How can we verify that e-books have weight? How do we know that the attributes are correct, as the systems of attributes can be very different even within the same concept? Are these systems of attributes actually arbitrary? At least they are incommensurable. These questions have one important implication. When working with ontologies we have to consider the process of deriving attributes of concepts. Today, this process is conceived all too intuitively, and therefore we have to explicate it in order to be able to investigate it.

4 Conceptual Inferences

Concepts can operate in some of the human inferential processes, but it is not always clear what are the main inferential functions that concepts have. On hearing the words "New York", it is quite possible without any accurate knowledge to generate quite a lot of information about a place of that name. You may be able to infer that it is on the coast of the Atlantic Ocean. What precisely is this kind of inference requires some consideration.

Firstly, we must ask what makes it possible to infer something from a single concept. Animates, objects, artefacts and events have properties. This means that the concepts, which represent them or stand for them, must represent these properties. Otherwise, the concepts could not make distinctions between objects. The representations of properties of objects are called here the attributes of concepts [12], [13]. Consequently, one can see concepts as integrated systems of attributes [12].

The attributes of concepts are important, because it provides us with a form of conceptual reasoning, which can be termed Cartesian or conceptual inference to honour the famous French philosopher, Rene Descartes, who produced perhaps the most famous example of this kind of inferential process in his "Cogito" argument. His claim "I think, therefore I exist" means that he inferred the notion of existence from the notion of thinking. This inference is possible only if a thinking thing has the attribute of existence. Without taking any position with respect to the correctness of the Descartes' inference, one can accept his schema as a general mode of inference for inferring conceptual attributes from a concept.

Cartesian inference can be explicated by the following abstract schema:

$$(1) \qquad C(A_1, \ldots, A_n) \rightarrow A_1 \,|, \ldots, |\, A_n$$

In this formula C is a concept and $A_1 \ldots A_n$ represent its attributes and the sign ‘|’ corresponds to ‘or’. Hence, the schema (1) should be read: if the concept C has attributes $A_1, \ldots, A_n$ then any or all of the attributes $A_1, \ldots, A_n$ can be inferred from it.

One can also use another schema:

$$(2) \qquad C \rightarrow A_n$$

This schema naturally contains the same information as that in (1), which is that from a concept one can infer any of its attributes.

Cartesian inference has been relatively little discussed apart from historical contexts, however, it is surprisingly common in ordinary thinking. If I say that Joan is a grandmother, you know immediately that she is a female most probably in her late middle age or older. Joan cannot be a baby or a teenager, for example. From the notion of a paper machine, one can infer its motors or from the notion of a roll its radius etc. These kinds of inferential examples are easy to generate. Cartesian inference is thus an important inferential tool when the contents of concepts are considered.

There are several forms of inferences, which are close to the Cartesian inference. Typical examples are entailment or lexical inferences, psychological, case-based reasoning and meaning postulates [17]. Here our individuating of Cartesian reasoning is quite logical, because the differences between it and other forms are clear. We do not infer only a priori properties with Cartesian inference as we do when using meaning postulates. Meaning postulates follow necessarily from a concept without any empirical analysis, but this is not true with all attributes of concepts. Some of the attributes of concepts are logically contingent, and therefore, they are not meaning postulates. The same criterion differentiates Cartesian inference also from inferential schemes of a psychological type [17]. The explication of necessary attributes is thus only a special case of the general Cartesian analysis of conceptual contents. In

Cartesian inference all types of attributes can be inferred from a concept. No difference is made between a priori and empirical attributes. Any attribute of a concept can be inferred when defined as above. Cartesian reasoning is also different from case-based reasoning, because instead of relying on previous cases, it relies on conceptual contents (cf. [22]).

The next problem in developing Cartesian inference is its validity. One must determine under which conditions it is valid and what is the criterion for its correctness. Its validity is difficult to determine, because attributes, which are inferred, can be empirical.

1) A paper machine has dryers of paper web.
2) A paper machine has brains.

The two examples make the point clear. An attribute can validly be inferred from a concept if and only if it really is an attribute of a concept. This means that it is empirically true that the referenced object has the respective property. Inferential processes are thus objective in the empirical sense and there is no room for subjectivity. The first proposition is true and the second one is false. Paper machines have brains only in a metaphorical sense, and therefore it is incorrect to infer that they have them. Empirical validation guarantees thus the objectivity of Cartesian inferences.

Empirical validation and the content-based structure of Cartesian inference make it different from formal ontologies. Content-based analysis of ontologies has different goals from formal investigations. Instead of producing formal grammars for ontologies (cf [23]). Cartesian reasoning is relevant in content-level analysis and in the justification of ontological structures.

5 Analyzing Concepts

One important application of Cartesian reasoning is the analysis of the contents of concepts. By means of Cartesian inference, we generate the attributes of a concept and can subsequently investigate their content. In this way, the attributes may be explicated and their properties investigated. The goal of conceptual analysis is to determine the correct use and interpretations, conceptual relations, and structures of concepts.

The analysis of concepts is vital, because the information contents in human mental representations are dependent on their conceptual contents. Concepts are the basic construction elements of any mental representation. These representations can entail only what is expressed by the means of the concepts. For several reasons, we need to be able to analyze the contents of concepts to understand the information contents of the representations.

In analyzing concepts in representations such as design discourses or plans, it is important that we firstly differentiate between three analytical aspects of concepts, because we need them in clarifying the conceptual analysis. These aspects are total contents, definition, and use of a concept. If we generate all the attributes of a concept, i.e., all the known properties of its reference, we speak about total contents. Of course, this is in practice a kind of a theoretical value, which does have practical significance only in very few cases, since references have an unlimited number of properties. For example, it would be rather futile to explicate all the spatio-temporal locations of all the electrons in an object. However, having an unlimited number of attributes does not mean that objects could have any kinds of attributes. Paper machines, for example, are not living beings.

The second aspect is the definition of a concept. Very often we need to get clarity to concepts we use, and then we generate some characteristic attributes of a concept arguing that it defines the concept. For example, one definition of a human being is ‘homo sapiens’ ("intelligent/wise human"). However, we should not rely too blindly on definitions, because they are seldom absolute but relative to some use contexts [23]. In geometry, we can say that circle is round, but in practical engineering, the notion of round is much less clear.

The elusive nature of definitions makes it necessary to consider also the uses of concepts, in an attempt to find out what are the actually relevant attributes of a concept in a particular representation. The ‘use of concepts’ is an important notion, because it sheds light on the fact that apparently similar content elements in various representations may have very different actual contents. The meaning of words, for example, varies from one context to another [23]. The notion of use expresses how we abstract different aspects of concepts in different contexts. The speed of a car may play an important role in many occasions, but it has no relevance when we need to ship the vehicle in question. Then such attributes as weight or size are more relevant [12], [13], [14].

The analysis of concepts is important, when we need to get clarity to the ways we think. Only a precise understanding of the contents of thoughts can make our thinking explicit to us [23]. This is why conceptual analysis is needed in many practical situations, for example in design processes and design thinking.

6 Cartesian Reasoning and Design Engineering Ontologies

A way towards accurate thinking is to explicate our thoughts in an ontological form. This method enables us to socially analyze the structures and assumptions of our thoughts. In its most basic sense, ontology means a theory of *being qua being*, as Aristotle in his Metaphysics formulated this field of research. In a narrower sense, it has become to mean an aspect of data modeling in information systems development.

In investigating design processes, this ontological stance is important both in the general sense of investigating the function and structure of being as well as in the sense of developing data analysis for information systems [25], [3]. From our point of view, the ontological stance is important because it allows a clarification of the design thinking processes. When we explicitly know the structure of our conceptual system, the foundational assumptions which we make about reality and about the appropriate ways to present it, make it much easier to guide and control innovative design processes.

The connection between ontological research and Cartesian reasoning is very natural. Our concepts reflect the way we are able to represent a being and its aspects and subparts. This is why conceptual analysis based on Cartesian reasoning offers us the means to investigate conceptual knowledge for the development of design ontologies [14].

The idea is to define the core ontological concepts and to generate their attribute structures. It is possible to explicate conceptual structures by iteration; the analytical process proceeds from the core concept to their attributes and from the generated attributes to their attributes until terminal attributes have been explicated. These structures are naturally expressions of ontologies for a particular domain of design. An example of the procedure can be found in Saariluoma and Maarttola, 2005 [14]. In it, the design process of a family house is described by iteratively applying Cartesian reasoning. In this paper, we have chosen the machine engineering domain to further develop this way of building ontologies and to demonstrate the function of Cartesian reasoning when working with design ontologies.

7 Extended Nip Press: a Test Example

Although the basic framework of Cartesian reasoning is quite clear, it cannot be applied in generating engineering ontologies automatically. It is necessary to test how it works and how it should be used in analysing engineering design. Therefore, we decided to take a reasonably advanced product of design engineering in order to investigate how we can apply the principles of Cartesian reasoning in generating a conceptual ontology for the object. This object is the extended nip press (ENP), which is one of the crucial breakthrough innovations in paper technology during the last two decades.

ENP provides a wider contact zone than the earlier conventional press nip between two rolls and consequently a longer press impulse on the fast running paper. The lower roll has a flexible mantle, which is pressed by the upper roll against a contoured “press shoe” inside the lower roll.

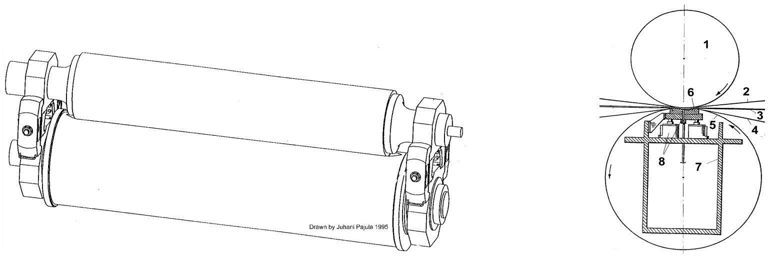

Figure 1 Schematic illustration of an extended nip press, ENP (Valmet SymBelt Press, 1995). (1) Hard counter roll, (2), (4) dewatering felts, (3) paper web (5) flexible mantle, (6) press shoe, (7) supporting beam inside the flexible roll, (8) loading cylinders and lubrication hydraulics. Reprinted by the permission of Metso Paper Inc. and the inventors; edited by Kalevi Nevala.

One practical realization of ENP is SymPress B (Figure 2).

1984: SymPress II

2004: SymPress B

Figure 2 An example of twenty years development of the press section; a renovation of press section for better efficiency by utilizing ENP (SymBelt Press). Source Metso Paper Inc., edited by Kalevi Nevala.

The idea of an extended press zone in the dewatering presses of board and paper making machines is old, and actually a very natural proposal in order to increase the press impulse for a better water removal.

However, there have been many obstacles in the way of utilizing the idea. The problems have been mainly due to facts and beliefs of techno-economical kind. First of all, up until the end of the 1970s the technology was lacking for reliable means for flexible support of the wet paper web through the extended nip zone. Secondly, an exhaustive “patent jungle” was believed to prevent the industrial use of the general idea of extending the press zone. The culmination point in the history of ENP was the delivery of the first production scale open belt “shoe press” for a board making machine in Springfield, USA 1981 by Beloit Corporation (USA). This breakthrough alerted other paper and board machine producers. This is also the starting point of our inquiry, which concerns the development of press section at Valmet/ Metso Paper Inc. 1983 – 2003. The following chapter describes one outcome of this extensive research project.

8 Conceptual Ontology of a Machine

An extended nip press is a part of a paper machine. However, as is the case with all sophisticated machines, also ENP is an assembly of assemblies. Therefore, we decided to develop the basic ontology for the extended nip press beginning from the concept of machine and not from the concept of a machine part or element.

Cartesian reasoning is useful in developing conceptual ontologies. It is a tool for explicating conceptual structures in our minds and making our thoughts more explicit to ourselves. The first step in the procedure is to find the major attributes of the basic concept. Here, this means the basic attributes of a machine.

An attribute must correspond with some property of the entity, i.e., event, person, object or artefact. This attribute must be true, which means that the reference really has the property. Thus, an “oven” has a colour but an “idea” does not. In searching for a good ontology for machines, we have to find such general attributes of machines that are true with most of them, if not with all.

An attribute is a basic or a first level attribute if it cannot be reduced, i.e., inferred from, the other basic level attributes. Here, we have generated four basic level attributes for any machine: need, function, structure and operation. By *need*, we refer to the human dimension of the requirement for a machine. All machines are made for serving some human need. Of course, human need itself can be further analysed into attributes. Here we generated, for example, *intention,* i.e., corporate goals, *demands*, i.e. the expectations of the markets, and *usability*, which entails, among other things, *process efficiency* and *operational efficiency.*

Table 1. Ontology with concrete attributes

Machine ontology	Examples from ENP in paper machines
1. Need	
1.1 Intention	Higher production rate for paper machines
1.2 Demand	Reduction of cost per produced paper ton
1.3 Usability	Easy and efficient utilization of the process
1.3.1 Process efficiency	Running time of ENP must be maximized
1.3.2 Operational efficiency	User-friendly control and driving systems
2. Function	
2.1 Use	Applies adjustable press load on paper web
2.2 Role	Second stage of water removal from paper web
3. Structure	
3.1 Materials	Steel, aluminium, reinforced polyurethane, fabrics
3.2 Forms	Supporting enclosed beam or I-beam inside the roll, functionally contoured "press shoe"-beam against the flexible mantle
3.3 Energy	
3.3.1 Source	Electric drives, pumps, compressors
3.3.2 Transmission	Gears, hydraulic tubes, pneumatic hoses, friction between flexible mantle and a hard roll
3.4 Information	
3.4.1 Control	Human controller
3.4.2 Steering	Automation
4. Operation	
4.1 Machine processes	
4.1.1 Load conditions	
- Static	Ten million N pressing force
- Dynamics	Vibrations of massive fast rolling machine elements
- Kinematics	Dragging flexible roll-mantle driven by a hard roll
4.1.2 Strength	Support beam of steel, reinforced flexible mantle
4.1.3 Loss of energy	Friction and deformations between the press shoe, the press fabrics and the dragging flexible roll mantle
4.1.4 Wear	Life-cycle of the flexible mantle
4.2 Product process	Dewatering the paper web by pressing

By *function*, we refer to the traditional functional analysis of a machine. This main attribute refers to why a machine has been designed and built, what it produces, and what is its goal. This knowledge is expressed in the concept of *use*. A machine has always a role in its contextual environment. The extended nip press, for example, is designed to improve water removal in a paper machine. This is its *role*.

The third main attribute is *structure*. This attribute refers to numerous structural properties of a machine, including its *materials, forms, energy, and information* aspects. *Materials* entail what the machine is built of, and *forms* how the whole and the components are designed. *Energy* is the attribute of all power supplying aspects of the machine. Finally, information explicates the *steering* and *control* attributes.

The last of the four main attributes is *operation*. This refers to those aspects of a machine which emerge when it is used. This means, on the one hand, *machine processes* and, on the other, *product processes.* Machine processes refer here to various *load conditions, i.e., static, dynamics* and *kinematics* in use. *Strength* attributes tell us how the machine stands the load conditions. *Product process* explicates everything that happens in the actual use of the product. In the extended nip press, the question is about removing water from the paper web.

Ontology for a machine is presented in Table 1. Examples of the concrete properties of the extended nip press are also incorporated to the ontology.

The presented ontology is not meant to be complete and exhaustive, because that would be outside the scope of this paper, which deals with the role of Cartesian reasoning in generating conceptual ontologies for engineering purposes. However, the ontology should give some insight about the way Cartesian reasoning can be used in making ontologies.

9 Criteria for Attributes

Ontologies are systems of concepts. For the sake of conceptual clarity it is important that the generated attributes are independent. This means that we cannot infer the attributes of the same conceptual level from each other. They offer thus different points of view to the reference. In our example, human need naturally cannot be reduced to the machine attributes nor can function or structure be reduced to that need. All the attributes are mutually independent.

However, this does not mean that they would not refer to the same reference. They are all attributes of machines and for this reason they can describe or represent many exemplars. Our ontology is not valid only for the extended nip press but it can be applied to a bicycle or a car as well. The power of ontological work is in the content-based abstract generality, which enables people to transfer general level knowledge from one exemplar to another and from one person to another.

Because attributes are themselves concepts, Cartesian reasoning can be used iteratively. In this way, it is possible to build consistent conceptual systems for various purposes. One may model, for example, design processes, design products or organizations [14]. This helps in getting clarity for conceptual systems used in engineering.

Although the attributes in ontologies are independent, they provide, as a whole, a holistic representation of the reference. The attributes may be contradictory but complementary. Each of them provides us with one perspective to the reference and the system as a whole entails all its important properties. Each of them opens a perspective to the reference, but they operate as a whole.

A couple of concrete examples may clarify how ontologies serve holistic thinking. Intention calls our attention to the interest of the industry, its owners, and corporations and demand reminds us that markets have their own interest. Need may have an important role to play in structural solutions. Markets may want to reduce costs, and consequently, engineers must look for new technical solutions. They may have to reduce the power consumption. However, having interconnections between the various aspects of a reference expressed in different attributes does not mean that the attributes are dependent on each other.

10 Conclusions

The significance of knowledge management and ontologies is rising in the world of engineering. There are many obvious reasons for this development. It is necessary to decrease the design time, because in current competitive situations there is the need to make the investments pay back swiftly. The complexity of designs is often also increasing, because it is one of the very few ways to improve performance and satisfy the needs of the markets.

In the current situation, it is obligatory for the designers to get a better understanding of the design process. Ultimately, this means that they have to have a better understanding of their own thinking, human thinking still being the main enigma in all design. Building ontologies is one way of explicating the structure of designers' thinking. In this way they can get a clearer view to their own work.

Ontology is like a grammar. We unavoidably follow some principles in our design, but we do not necessarily understand them any better than a non-linguist understands the regularities of grammar in our speech. A grammar explicates the underlying regularities of speech and makes it possible to consider them in socially shared thinking. Similarly, design ontologies aim to open up what happens in designers' minds to enable them to improve their practices.

A problem in generating ontologies is that the methodologies so far have been very intuitive. Only few aspects of this highly important form of thinking have been explicated so far. The Cartesian model opens us a way of analysing conceptual structures involved in designers' thinking. Developing methodology for generating conceptual ontologies or for conceptual engineering is vital.

The importance of knowledge management is constantly increasing. Progress in artificial intelligence, knowledge management, information systems development, design analysis and Semantic Web make it necessary for us to be able to effectively analyse knowledge in concepts [22], [3]. One problem in this work is the lack of systematic methods. Ontological work is still very intuitive [23]. The need is recognized among specialists of ontologies.

In this situation, Cartesian reasoning might give some rigour to the way conceptual knowledge is analyzed and explicated. It enables us to see the most important conceptual points in the view which guides our thinking. It enables us to look for conceptual clarity, which is often an important presupposition for accurate thinking and communication. If we do not understand how other people represent key concepts, we can hardly follow their thinking either. Most importantly, Cartesian reasoning as empirically validated process offers a possibility to get rid of the inherent subjectivity in developing ontologies. Thus, Cartesian reasoning is important in the search for more efficient design processes.

References

1. Borst, P., Akkermans, H., Top, J.: Engineering Ontologies. Int. J. Human-Computer Studies, 46, 365-406 (1997)

2. Gomez-Perez, A: Ontological Engineering: A state of art. Cited 19.8.2007, http://66.102.1.104/scholar?hl=fi&lr=&q=cache:8wey-l1jwHoJ:www.ift.ulaval.ca /~kone/Cours/WS/Onto-Gomez-StateArt.ps+engineering+ontologies+Gomez

3. Chandrasekaran, B., Josephson, J., Bejamins, V. R.: What are ontologies, and why do we need them? IEEE Interlligent systems, Jan-Feb. 20-26 (1999)

4. Grueninger, M., Atefi, K., Fox, M. S.: Ontologies to Support Process Integration in Enterprise Engineering. Computational & Mathematical Organization Theory 6, 381-394 (2000)

5. Holzapple, C. W., Joshi, K. D.: A Collaborative Approach to Ontology Design. Communications of the ACM 45, 42-47 (2002)

6. Strassner, J., O'Sullivan, D. Lewwis, D.: Ontologies in the Engineering of Management and Autonomic Systems: A Reality Check, Journal of network and systems management, 15, 5-11, (2007)

7. Eddington, T., Choi, B., Henson, K., Raghu, T. S., Vinze, A.: Adopting ontology to facilitate knowledge sharing, Communications of the ACM, 47, 85-90, (2004).

8. Lenat, D. B.; Guha, R.V.: Building Large Knowledge-Based Systems. Representation and Inference in the CYC Project. Reading, M.A: Addison-Wesley (1990)

9. Saariluoma, P., Nevala, K.: The focus of content-based approach to design engineering, In: S. Hosnedl (Ed.) Proceedings, AEDS 2006 Workshop, Pilsen, Czech Republic, 27 – 28 October (2006)

10. Saariluoma, P., Nevala, K., Karvinen, M.: Content-based Design Analysis, In: J. S. Gero & Bonnardel (Eds.) Studying designers '05, Key Center of Design Computing and Cognition (2005)

11. Saariluoma, P.: Apperception, Content-based Psychology and Design, In: Udo Lindeman (Ed.) Human Behavior in Design. Individuals, Teams, Tools, Springer, Berlin (2003)

12. Saariluoma, P.: Foundational Analysis. Presuppositions in Experimental Psychology, Routledge, London (1997)

13. Saariluoma, P.: Does Classification Explicate the Contents of Concepts, In: I. Pyysiäinen and V. Anttonen (Eds.) Current Approaches to Cognitive Science of Religion (2002)

14. Saariluoma, P. and Maarttola, I.: Applied Conceptual Inference in Design, In: S. Hosnedl (Ed.) Proceedings, AEDS 2005 Workshop, Pilsen, Czech Republic, 3 – 4 November (2005)

15. Bunge, M.: Intuition and Science, Greewood, Westport Conn. (1962)

16. Nagel, E.: The Structure of Science, Harcourt, New York. (1961)

17. Smedslund, J.: Psycho-logic, Springer, Berlin. (1988).

18. Laurence, E., Margolis, E.: Concepts in Cognitive Science, In Margolis, E, Laurens, E, Concepts: Core Readings (1999)

19. Rosch, E.: Principles of Categorization, In: E. Rosh, B. Lloyd (ed.), Cognition and Categorization, Erlbaum, Hillsdale NJ (1978)

20. Sowa, J.: Conceptual Structures, Addison-Wesley, Boston (1984)

21. Spyns, P. Meersman, R., Jarrar, M.: Data Modelling versus Ontology Engineering, Sigmoid record, 31, 12-17, (2002).

22. Kolodner, J. Case-based reasoning, Morgan-Kaufman, San Francisco (1993)

23. Andreasen, T., Nilsson, J.: Grammatical specification of domain ontologies, Data & Knoweldge Engineering, 48, 221-230, (2004)

24. Wittgenstein, L. Philosophical Investigations, Basil Blackwell, Oxford (1958)

25. Chandrasekaran, B. Design Problem Solving: Strands of My Research. In: Lindemann, U. (ed.), Springer, Berlin (2003)

26. Kim, H.: Predicting how Ontologies for the Semantic WEB will Evolve. Communications of the ACM, 45, 48-54 (2002)