An extension of frame-based knowledge representation schema

Ieva ZELTMATE
Department of Systems Theory and Design, Riga Technical University
1 Kalku Street, LV-1658, Riga, Latvia

and

Janis GRUNDSPENKIS
Department of Systems Theory and Design, Riga Technical University
1 Kalku Street, LV-1658, Riga, Latvia

ABSTRACT

This paper presents an overview of frame–based knowledge representation and Structural Modelling approach as well as a new extension of frame–based knowledge representation schema is described. The extension of schema is a result of analysis of student works and it can be used in Structural Modelling approach to improve knowledge acquisition and representation about systems. Three differently structured system models are given to show the possible knowledge representation forms that are found in student works. The created schema extension can be implemented in the already developed frame–based knowledge representation tool, which purpose is to support Structural Modelling approach.

Keywords: Knowledge representation, frame, Structural Modelling, structure

1. INTRODUCTION

Structural Modelling (SM) approach [3, 4] has been developed to support systematic, domain model based knowledge representation (KR) and automation of knowledge base construction for model–based diagnosis problem solving. The goal of SM is to develop a framework for knowledge acquisition, representation and processing based on a set of related structural models. When representing knowledge about complex systems using the SM approach there are several important aspects that must be taken into account to be able to create consistent system structure models: systems structure, functions, behaviour and deep cause consequence knowledge. Structural models capture declarative deep knowledge about systems morphology and operation in normal conditions and also under faults. The important advantage of structural models is their ability to capture both shallow (expert's experience) and deep (understanding of causal knowledge) knowledge. Morphological and functional models are used to support reasoning that provides diagnosis systems with additional facilities to explain the various processes in the system of interest [8]. To support intended reasoning and to fulfil the goals of SM suitable knowledge retrieval and representation schema is needed. Therefore in the SM a frame hierarchy that supports two kinds of relations, namely, "kind of" and "part of" is used [4].

Structural Modelling is being approbated in the "System and Process theory" practical works. One of the tasks in the students' practical works is to create the model of the system in which the student feels herself an expert. The main objective of the task is to represent the essential characteristics and the relationships for the selected system using SM approach. The SM can be used to create models for the complex technical systems with physically heterogeneous elements and is suitable in the situation of incomplete information. Students need to analyze and represent systems morphological and functional structure. Detailed analysis of the system leads to the system model design. Although using the SM approach system model can be designed also on the paper, all system representations are made in the specially designed tool called Frame System (FS) [12, 13, 14]. All designed systems within the Frame System were analyzed in order to assess student knowledge about the learned lecture material and to find drawbacks of the used tool. Despite the fact that in the FS a frame hierarchy is used and the frame–based representation [7] is well described, students` generated system representations are structurally different. Also it was concluded that even by following tool guidelines the student created system representations can vary even representing one and the same system. Accordingly similarities and differences found in the analysed systems' structure representations three different groups (KR forms) can be distinguished.

The analysis of students` works revealed that there exist gaps in the tool and the main problem is related to the KR schema and frame hierarchy implementation (this is evidenced by structural differences in the representations) in the FS. To find more suitable KR schema for the SM and to overcome gaps discovered in the tool it was decided to create a new extension for the existing frame–based KR schema [12, 14]. A new schema extension is well–grounded using the frame system theory [7], and examples of its application [2, 5, 6, 7, 9, 10] as well as using the rules and methods from the SM approach [3, 8]. Also approaches, which describe different structures of the frame, are overviewed [16, 17, 18, 20, 21].

The paper presents an extension of frame–based KR schema that is acquired examining the student created system models in the practical works. The paper is organized as follows. In section two a description of a frame–based KR and the Structural Modelling approach is given. The section three is devoted to the students created system representations and discovered structural differences. In the section four a new schema inspirer by analysis of student works is described and a case study using the schema is explored. At the end of the paper conclusions and also of a future work is given.

2. THEORY UNDERLYING NEW FRAME-BASED REPRESENTATION SCHEMA EXTENSION

A frame is a data structure that provides a structural representation of objects [3, 5, 24, 25, 30]. Object is a recognizable thing; reality that exists in space and time and can be real or abstract [1]. The original definition of a frame is given by Minsky. Most important features of frames are: specific representation form, inheritance, class (class–subclass) hierarchy [6, 7]. Using the frame in the KR all the information about the considered object is aggregated into one place. Therefore frame is used in the SM approach [3, 12, 13] to acquire and to represent knowledge about the chosen system.

Main components of the SM are system's objects, flows, behaviour and also cause–consequence knowledge. The object in the SM is used to describe the components of the system. The frame is a formalism that is used to provide the knowledge representation about the objects. Frame allows: using natural language; the organization in hierarchies and also has inheritance that support reasoning and therefore provide with some expectations. From the represented knowledge system structural models can be retrieved. All acquired knowledge is stored in the topological knowledge base. That must be stressed that in SM both the object (part-of relations) and class (kind-of relations) hierarchy [1, 28] play an important role. Therefore the knowledge base is structured as a frame hierarchy which maintains the knowledge about represented objects [3, 4, 12, 14]. The objective and usage of the represented knowledge are significant because these are conditions which determine the requirements of the KR form.

Frame is structure that can be described by frame name and slots [6, 7], like it is shown in Figure 1. This kind of representation is similar to Object–Attribute–Value triplet. Frame slots are used to represent the characteristics of the object. Each slot consists of the slot name and value [7] or list of values [9, 17, 25]. Usually one of the values in the list is a default value, but other values represent alternatives. Slot value can be: other frame name, descriptive variable or the procedure. The usage of other frame name as the value for the slot is most common in the KR and existing frame–based approaches [3, 5, 6, 7, 9, 10, 14, 16, 17, 20, 22, 23, 24, 26]. For example, lemon is a slot value for the slot name fruit; person is a slot value for the slot name IS-A (slot represents relation). Descriptive variables also are frequently used as slot values [3, 5, 6, 7, 9, 13, 16, 25]. Here the example is – red (for the slot name colour). The third case is procedure or the rule usage in the slots [5, 9, 18, 19, 21, 30]. The rules are represented in the If…Then… form and can be viewed also as separated slots [18, 21]. Sometimes procedures are called demons [6, 17, 19, 20, 22, 24] or conditions that are attached to slots. Example for this case is: Goto Next (slot name): when changed (slot value) [30, 31]. It should be noted that despite the already mentioned cases the value for the slot can be also unknown [5, 7, 23] and it helps to cope with situations of incomplete information.

Each frame has terminals added for attaching pointers to substructures. In the Minsky`s paper [7] the terminal is named also as a slot. The authors of this paper inspect the terminal as a pointer or a contact. Every slot can have link that represents the relation between two frames (see Figure 1). Collections of frames are linked together in one system. This kind of feature can be used to create a model of the system or a model of a group of interconnected systems [6, 7] and therefore it is relevant to SM approach.

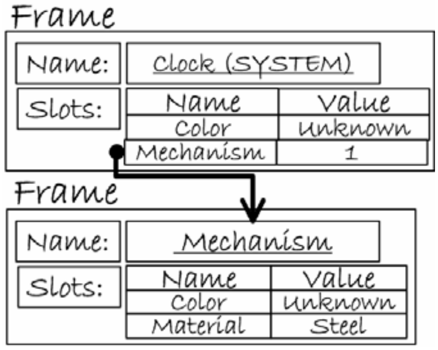

Figure 1. Frame–based representation

Sometimes in addition to described frame–based representation form data structure includes the superframe and/or subframe names. This feature helps to organize frames into taxonomy or inheritance hierarchies [7, 9, 16, 17, 23, 29]. Inheritance is a significant mechanism built in frames that allows the knowledge sharing between several frames. In most of the papers related to frame–based representation it is described how properties are inherited from superframes to subframes in the hierarchy [2, 6, 9, 29]. Class or type hierarchies known also as inheritance hierarchies are constructed using generalization – specialization relations IS-A or A-KIND-OF and provide mechanisms for inheritance [1, 5, 6, 23, 25, 27, 29]. When considering the case of inheritance slots are called properties/attributes and vice versa [5, 6, 7, 25]. Here an ambiguous interpretation of frame slots accordingly leads to the assumption that slots represent only properties of interested object. This misunderstanding is one of the reasons why students` represented knowledge even about one system is structured differently.

SM approach and also the frame idea are implemented in the frame–based knowledge representation tool Frame System [14]. Tool has built-in structure that allows representing the system objects, their properties, structure and relationships between objects [12, 13, 14]. Tool is used and tested in the "System and process theory" practical works. Concerning the FS authors has to acknowledge that: a) the functionality of the tool still can be improved; b) there are several problems that require a different solution. The analysis of student works helped to determine several solutions that can be used to improve existing frame–based KR and to provide a better application of SM.

3. KNOWLEDGE REPRESENTATION FORMS

When representing knowledge about the system student understanding about the tool application can vary. This is the reason why the KR schema must be well structured, explicit and also suitable for different insight levels. Although the frames are widely used and well described the analysis of the student works revealed that three KR forms can be found and all have significant drawbacks. This indicates that implemented frame–based KR schema is not sufficiently complete. Representing the knowledge about systems students used three KR forms. It should be noted that none of the representation forms is entirely right or wrong. The main drawback of the representation forms is that no clear boundary between the object and class hierarchy exists or even the KR form miss one of the hierarchies.

In the first KR form the decomposition of objects is not given. This means the structure of the represented object is not shown (see Figure 2). The first representation form was found in those students' works who: a) was not completely understood the task; b) was chosen systems in which alternative elements and the external environment represented.

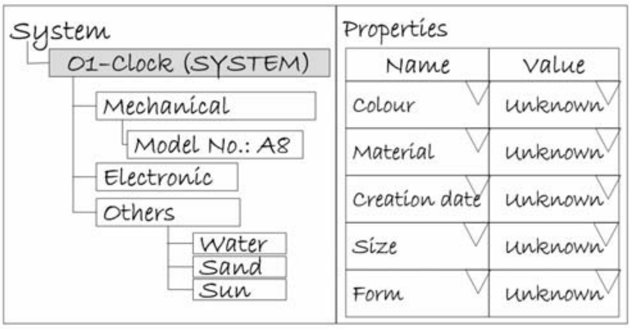

Figure 2. The first KR form

In this KR form only the class–subclass hierarchy, taxonomy and properties are considered. This representation is simple, but it is just because the decomposition level is very low. The KR form misses the object hierarchy and therefore the amount of knowledge that can be acquired is not suitable for the SM. In short this kind of representation lacks the system structure and allows seeing only the clock properties and classification, which is important to understand the context of represented domain.

Next KR form inspects the case where the object's structure is represented in the tree-view (see the left side of the Figures 3 and 4). The second KR form can be divided in two cases: case A – where only a system and/or object structure is represented (see Figure 3); case B – where the context and the object/system structure are represented (see Figure 4).

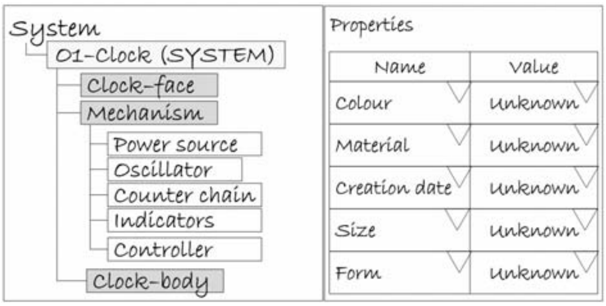

Figure 3. The second KR form – case A

The case A in some aspects is well suited for the SM approach – the system structure can be clearly represented and also the properties of objects can be acquired. The missing part in this representation form is the representation of alternatives for the objects and the system. To create several models of the system also several alternatives of the elements and functions must be represented. For example, mechanisms for the clock and also power sources for the mechanism can differ. This feature is significant in the modelling, because alternative models can't be created if there is no knowledge about alternative system elements. This KR form was found in those students' works who tried to represent structured system elements, but forgot that there can be the alternatives. This representation form is sufficient to create a system model in the case of proper functioning. However, here the KR form is assessed from the viewpoint of SM approach. Therefore it must be concluded that in this representation form it is possible to acquire some knowledge, design one system model, but it is hard to include the changes and dynamics.

In the case B the structure and the type of the clock are represented on one abstraction level. In Figure 4 only one level of the object's parts decomposition is shown, but it is possible to create a deeper representation for them. However, the representation in a given form is difficult to understand because both parts (a part of), and taxonomy (a kind of) are represented at the same place. This form was found in those students' works, which attempt to represent the system objects in a certain level, the object structure, and also several object types or alternative cases. It is evident that the same structure and the same frame names are represented over and over again in the hierarchy. This representation form has several negative aspects in relation to the invested time, obtained results and used memory: (a) the same structure representation must be repeated several times; (b) the frame name is unique and it is not allowed to use it more than once in the hierarchy; (c) the represented knowledge maintenance needs an extra memory (because of multiple copies); (d) although it would be necessary, the object structure can not be inherited. The simplicity which is essential for the KR here has been lost.

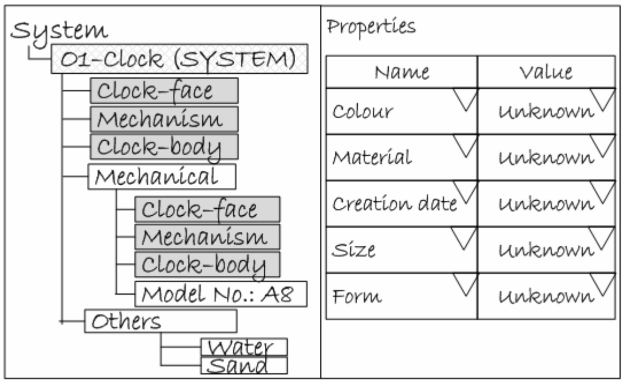

Figure 4. The second KR form –case B

In the last viewed KR form the object's structure is perceived as the attributes which are represented through object properties (see the right side of Figure 5). This KR form was found in those students' works, which were representing the knowledge about the system and: a) were experimented several times to get a realizable system structure; b) knew the system structure clearly even at the beginning of representation; c) had large systems which were thoroughly described.

Unlike the previous KR form, this has at least two advantages. One of them is a comprehensive inheritance usage. The represented object's structural can be assigned to other objects down in the hierarchy (inheritance). This also means that the same knowledge must be acquired and represented once, but can be used multiple times. Other advantage for the viewed representation form is that the object structure is viewed separately from the alternative object types and other things that are represented in the class hierarchy. The problem in this representation form is that the structural elements are examined as the object's properties. The two relation types that have a different meaning and that can be denoted with the titles "is–a–

property–of“ and “is–a–part–of” are represented together in one place. Although often structural elements are represented as the object properties [9, 10, 11, 17, 24] it must be stressed that the properties are not the same as structural elements. For example, the slot colour is the property, but slot mechanism is a structural element (see Figure 5). Although there are weaknesses in this KR form it provides a good representation result and therefore it is assumed as the best of all three KR forms. This KR form includes the class hierarchy as well as object hierarchy. Unfortunately, the object hierarchy unlike the class hierarchy can't be expanded more than it is shown on Figure 5. This means that the object detail level is low and can't be realized object decomposition even if it is needed.

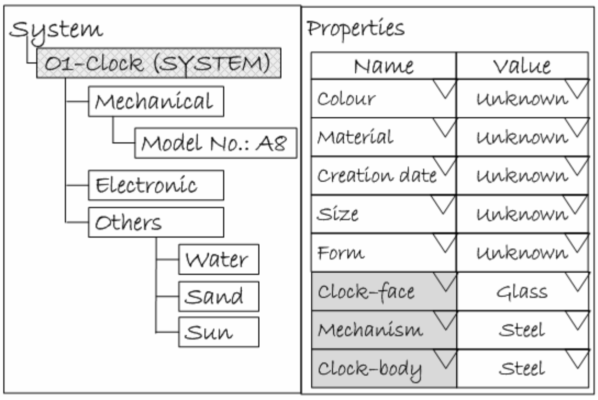

Figure 5. The third KR form

Even if a student is an expert in some field, the represented knowledge must be structured and well-considered. It is needed to understand can it be viewed in the appropriate context, how it meets other knowledge and whether the relation is understandable. After analysis it was found that there is a need for more structured schema that allows representing both: class and object hierarchies. Also no less important is to distinguish between the different relations in the system representations while maintaining all objects' characteristics in one frame. This requirement can be achieved using different slot types.

4. NEW SCHEMA EXTENSION AND CASE STUDIE

The idea about various slot types is not a new one and it was viewed already at the source of frame–based representation approach [7]. There can be different slots and each can be provided for a particular purpose or with a determined role [5, 6, 7, 16, 19, 20, 21]. In the papers that contain frame–based concepts usually different slot roles, slots having restrictions or types are inspected, although not stated that there is distinction between the slot types [11, 17, 24, 31].

To overcome drawbacks in the tool FS it was decided to create an extension for KR schema. It means that new knowledge representation form must be created and also KR structure in the FS must be changed. In a new schema extension several slot types are defined (see Figure 6 case b): property slots, structure slots, contact slots, procedure slots. In addition all slot types are divided in the local and inherited slots. Before in the tool was implemented a KR schema that was a set of several frames called a frame model (see Figure 6 case a). The frame model provides a similar, but not the same functionality as the usage of different slot types [12, 13, 14].

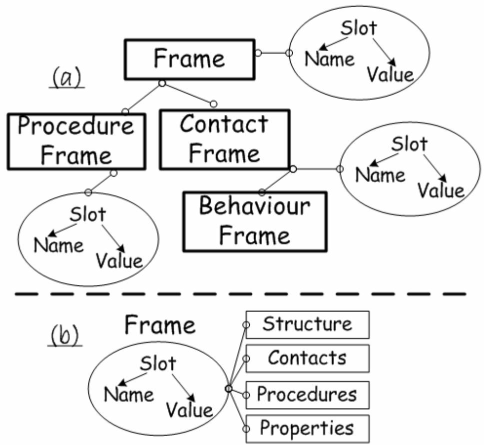

Figure 6. The knowledge representation schemas

The usage of various slots allows to determine and to distinguish between the relations in the structure. The Figure 7 represents an overview of the possible relations in a new representation schema extension.

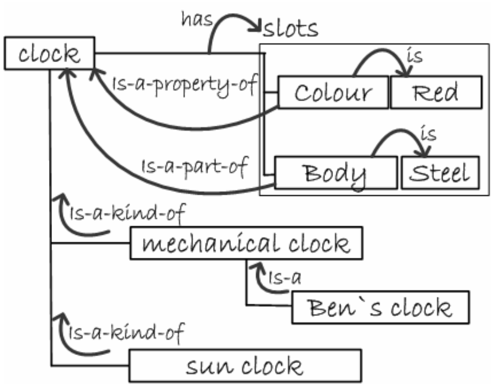

Figure 7. The relation types in the schema

It is not necessary to use the specific relation names in a slot, because the relation type can be determined by the slot location in the representation. Hence in the representation each slot has the name, value and relation. When the attributes are represented in the structure slot, between elements represented in the slot exists an aggregation relation [1]. Object can have multiple structure slots, which exist in relation to the object using part of link.

The authors described knowledge representation regarding the slots differs from the before mentioned (in the viewed publications). In the new representation schema extension two types of hierarchies (see Figure 8) can be created: class hierarchy and object hierarchy [1, 28]. Both hierarchies can exist simultaneously in the representation. The main differences between the hierarchies are the abstraction levels and relation types. In the class hierarchy abstraction levels can be class-subclass-instance or just class-subclass (see Figure 8 case a). The relation between class–subclass is is-a-kind-of, but between class-instance relation is is-a. In the object hierarchy the abstraction levels can be class-subclass and the relation is is-a-part-of (see Figure 8 case b). The class hierarchy was present in the frame–based KR schema even before [12, 15]. The typical examples can be found in the KR forms (see Figure 2 and 5).

Theoretically elements of system structural also must be represented in a hierarchy, but it will not be so called class hierarchy. The visual representation in the class and object hierarchies is the same but the context and the association type differs. In the case of class hierarchy exist "kind of" relation and it is possible to consider about the system structure alternative models. In the case of object hierarchy the relation is "part of" and it is possible to consider about the viewed object structure. The example for object hierarchy can be found in the Figure 3.

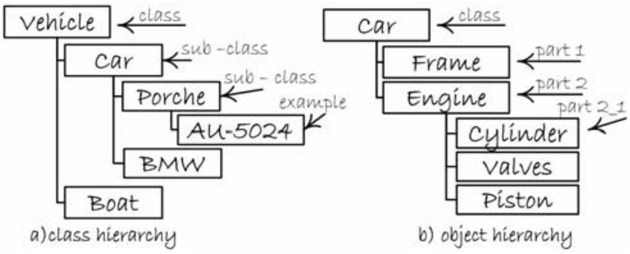

Figure 8. Class and object hierarchy

It is considered that the inheritance exist also in the object hierarchy. In a new KR schema extension two types of inheritance (see Figure 9) can be found: inheritance in a class hierarchy (that is most frequently used) and inheritance in the object hierarchy. In addition, in the KR forms must be distinguished simple and multiple inheritance cases.

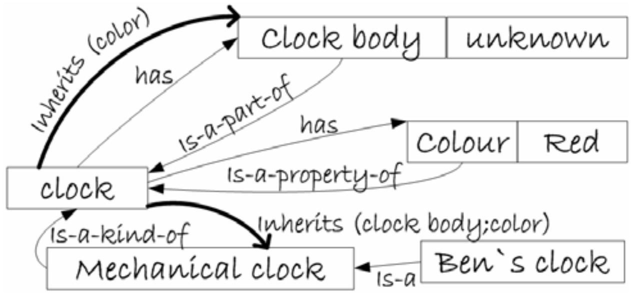

Figure 9. The types of inheritance

Regarding the class hierarchy it was found that if the structural elements are represented in the slots (called structure slots) they can be assigned to other frames in the class hierarchy. This means that the *mechanical clock* inherits the property slot (Color:Red) and the structure slot (Clock body:unknown) from the *clock* (see Figure 9). Concerning the object hierarchy the frame represented in the structure slot inherits slots which are represented in both object and class hierarchy (see Figure 9). Clock body can inherit the property slot (Color:Red) from the clock. In the new frame–based representation form inheritance can be used to provide with the characteristics, structure, behaviour, and procedures the related frames.

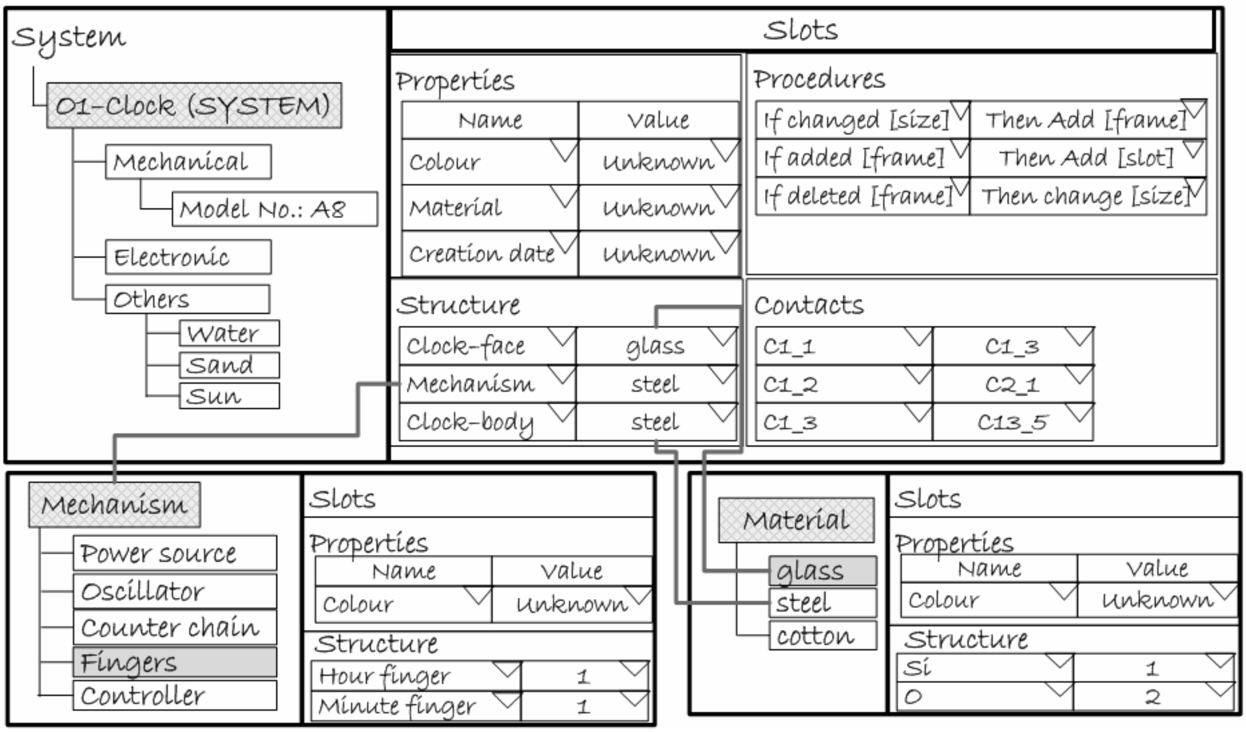

Figure 10. A new KR form and an example its usage

The acquired system structure representation form and also a new knowledge schema extension which example is shown in Figure 10 has several characteristics that are good for the KR and are meaningful in the SM approach: (a) although the representation form is simple, a rich knowledge representation can be provided (this is indicated by the potential decomposition level, alternatives and inheritance); KR form has new restrictions (slot types are used and extra links from slots must be provided), but it is flexible; (b) all slots can be inherited and exists 2 type inheritance; (c) There can be represented two type hierarchies. The extension better supports the goals of SM, since it is possible to create an alternative system models and this is provided by class hierarchy. Also it is possible to represent a deeper level of object detail and this feature is provided by object hierarchy. The usage of different slot types allows formalizing and structure the knowledge representation. Therefore it is easier not only represent, but also understand and interpret the represented knowledge and structured representation is more accurate.

5. CONCLUSIONS

This paper has presented a new frame–based knowledge representation schema extension that can be used to improve knowledge acquisition and representation about systems. Using an extension and already existing theory the system structure representation form known before and implemented in the Frame System is slightly changed. The introduced hierarchies, inheritance and slot types can be used to provide a better application of SM approach. The future work will be focused on development of the Intelligent System (using the existing tool) that can be used for the Complex System Structural modelling. The acquired frame–based schema extension must be implemented in the tool Frame System to cope with the found drawbacks.

ACKNOWLEDGEMENT

This work has been supported by the European Social Fund within the project „Support for the implementation of doctoral studies at Riga Technical University".

REFERENCES

[1] Booch. G., Object-Oriented Analysis and Design with Applications. 2nd ed. Addison-Westley, ISBN 0805353402, 1998, 543 lpp.

[2] Evertsz R., Motta E., 1991, The abstract interpretation of hybrid rule/frame-based systems, Lecture Notes in Computer Science, AI/IA, In Ardizzone, E. Gaglio, S. & Sorbello F. (eds.) Palermo, Italy, October, pp. 147 – 156, published by Springer-Verlag.

[3] Grundspenkis J., 1997. Structural Modelling of Complex Technical Systems in Conditions of Incomplete Information: A Review. In: Modern Aspects of Management Science, No 1. Riga, Latvia, pp. 111-135.

[4] Grundspenkis, J., 1999, Reasoning Supported by Structural Modelling. Intelligent Design, Intelligent Manufacturing and Intelligent Management. K.Wang and H.Pranevicius (Eds.), Kaunas University of Technology Press, Techmologija, pp.57-100.

[5] Fikes R., Tom Kehler, 1985, The Role Of Frame-Based Representation In Reasoning, pp. 904- 920

[6] Karp P.D., 1993. The Design Space of Frame Knowledge Representation Systems, Artificial Intelligence Center, SRI International, SRI AI Center Technical Note Nr. 520

[7] Minsky, M. 1975, A Framework for representing knowledge, P.Winston, (Ed.) The Psychology of Computer Vision. New York: McGraw-Hill, pp. 211–277.

[8] Grundspenkis, J., 2002, Reasoning in Structural Model-Based Diagnosis, In: Proceedings of the 4th International Conference on Quality, Reliability and Maintenance, QRM 2002, Oxford, G. J. McNulty (Eds.), Professional Engineering Publishing, London, UK, pp.295-298.

[9] Roberts, R. B. and Goldstein, I. P. 1977 The FRL Primer. Technical Report. UMI Order Number: AIM-408. Massachusetts Institute of Technology.

[10] Steels L., 1978, Frame-Based Knowledge Representation, MIT Artificial Intelligence Laboratory Working Papers, WP-170, MIT Artificial Intelligence Laboratory

[11] Czogala E., Cholewa W., 1991, Management of Statements in Frame Interpreter of CC_SHELL, p. 10

[12] Valkovska I., Grundspenkis J., 2005. Representation of Complex Agents by Frames for Simulation of Internal Relationships in Structural Modelling. In Proceedings of the 19th European Conference on Modelling and Simulation (ECMS 2005), pp. 151-157.

[13] Valkovska I., Graudina V., Grundspenkis J., 2005, Usage of Frame System for Modelling of Intelligent Tutoring System Architecture. In Annual Proceedings of Vidzeme University College. ICTE in Regional Development. Valmiera, pp. 105-109.

[14] Zeltmate, I., 2007. Frame system development for structural modelling knowledge representation purpose, Master thesis, RTU, Riga, Latvia, p. 214

[15] Zeltmate, I. J.Grundspenkis, M.Kirikova, 2008, The Challanges in Knowledge Representation for Analysis of Inter - Institutional Knowledge Flows. In Proceedings of the IADIS International Conference on Cognition and Exploratory Learning in Digital Age (CELDA 2008), Freiburg, Germany, pp. 145-152

[16] Wheeler, L. A., Shapiro, A. E., 1993, Method and apparatus for storing information about and associating slot behaviors of a slot in a frame-based semantic network, United States Patent US5208899 , (Pittsburgh, PA), p. 13

[17] Greiner R., 1980, RLL-1: A Representation Language Language, Proceedings of the First National Conference of the American Associationi of Artificial Intelligence, p.46

[18] Merritt D., 2003, AI Expert Newsletter, Architecture & Design (11), Dr. Dobb's Journal, p. 6

[19] Cook S. C., Kasser J.E., Asenstorfer J., "A Frame-Based Approach to Requirements Engineering", 11th International Symposium of the INCOSE, Melbourne, Australia, 2001, p. 9

[20] Martins J. P., 2006, Foundations of knowledge representation and reasoning, Chapter 7: Frames, Technical University of Lisbon (Portugal), pp. 270 – 299

[21] Lee, F., and Heyworth, R., 1999, Error Due to Misperception and the Default- Value Model. Advanced Research in Computers and Communications in education. In Cummin, G., Okamoto, T., & Gomez, L. (Eds), IOS Press, p. 6

[22] Adeli H., 1988, Expert systems in construction and structural engineering., Chapman and Hall, 29 West 35th Street, New. York, NY 10001, USA,. pp. 330 (p.16, p.229)

[23] Spenser C., Flex Tutorial, 2002, Logic Programming Associates Ltd, p. 68

[24] Kusiak A., 1997, Knowledge – based systems, Lecturer notes of the Nordic-Baltic Summer School on Applications of AI to Production Engineering, K. Wang, H.Pranevicius (Ed.), Kaunas, Lithuania, pp. 45-79.

[25] Sharma A.K., Kumar C., Mustafa K., & Kumar A., 2003, A Fuzzy Frame Based Expert Shell, In Proceedings of the National workshop on Information Technology Services and Applications (WITSA-2003), New Delhi, p. 6

[26] Stefik M., 1979, An examination of a frame-structured representation system. Proceedings of the International Joint Conference on Artificial Intelligence, Tokyo, Japan (IJCAI-79), pp. 845-852

[27] Robinson, G.P., Colchester, A.C.F., Griffin, L.D., 1994, Model-Based Recognition of Anatomical Objects from Medical Images, Image and Vision Computing 12 (8), pp. 499-507

[28] Kak A.C., Programming with Objects: A Comparative Presentation of Object-Oriented Programming with C++ and Java., John Wiley & Sons, 2003, p. 1115 (pp. 29-36)

[29] Gan H., 1993, Script and Frame: Mixed Natural Language Understanding System with Default Theory, Methodologies for Intelligent Systems, In proceedings of 7th International Symposium (ISMIS '93), Trondheim, Norway, pp. 466-475

[30] Negnevitsky M., 2004, Artificial intelligence: a guide to intelligent systems, Chapter 5: Frame-based expert systems, Addison Wesley; 2 edition p. 440 (pp. 131-162)

[31] Okafor E.C., Osuagwu C. C, 2007, Issues in Structuring the Knowledge-base of Expert Systems Electronic Journal of Knowledge Management, Volume 5 Issue 3, pp. 313-323