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Patterns for context-based knowledge fusion in decision support systems

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ABSTRACT

The here presented research focuses on the context-based knowledge fusion patterns. Patterns are discovered based on an analysis and investigation of knowledge fusion processes in a context aware decision support system at the operational stage of the system functioning. At this stage the context-based knowledge fusion processes are manifested around the context. The patterns are generalized in regard to the following three aspects: (1) the effects that the knowledge fusion processes produce in the system; (2) the preservation of internal structures for the context and multiple sources the information/knowledge is fused from; and (3) the preservation of multiple sources and the context autonomies. At that, seven knowledge fusion patterns have been discovered: simple fusion, extension, instantiated fusion, configured fusion, adaptation, flat fusion, and historical fusion.

1. Introduction

The present research continues the research on knowledge logistics [1]. Several *generic* knowledge fusion patterns were discovered within the knowledge logistics approach. These patterns generalize knowledge fusion processes occurring at different stages of building and application of a decision support system (DSS). The main objective of the present research is to identify *context-based* knowledge fusion patterns to generalize knowledge fusion processes occurring in the used DSS at the operational stage of its functioning, i.e., the stage where context aware functions of the DSS come into operation. At this stage the automatic knowledge fusion is supported. Such patterns are supposed to give an insight into the context-based knowledge fusion processes by virtue of the fusion schemes' typification.

The decision support systems heavily rely upon large volumes of data, information, and knowledge arriving from different sources. Whereas several years ago data fusion used to be the main technology integrating data and information from multiple sources within any DSS, today the focus of data fusion has changed to knowledge fusion. The objective of knowledge fusion is to integrate information and knowledge from multiple sources into some common knowledge that may be used for decision making and problem solving or may provide a better insight and understanding of the situation under consideration [2–5].

Semantics is the basis to ensure that several information and knowledge sources arrive at the same meaning regarding the situation and information/knowledge being communicated. This explains the fact that ontologies support most efforts in knowledge fusion (e.g., [6–10]). They provide for a shared and common understanding of some domain that can be communicated across the multiple information and knowledge sources as well as across the sources and DSS; facilitate knowledge sharing and reuse in open and dynamic distributed DSSs; provide means to come to certain conclusions about the contextual data and information; allow entities not designed to work together to interoperate [11].

The present research considers knowledge fusion within a framework of context aware decision support [12]. A central component of the framework is an application ontology. This ontology represents domain and problem solving knowledge fused from different knowledge sources. Thus, the application ontology turns into a knowledge source representing two different types of fused knowledge like domain knowledge and problem solving knowledge.

The context aware DSS built in accordance with the framework is intended to support decisions on involvement of autonomous entities in common activities and scheduling these activities. This DSS was tested by supporting decisions on configuration and planning tasks such as supply chain configuration [13], mobile hospital configuration [14], and planning emergency response actions [15]. In this work the applicability of the research is demonstrated by examples from the emergency management domain. A fire situation is considered as the situation where decisions about fire response plans are made. At that, the DSS solves the problem of organizing an emergency responders' community and scheduling the responders' activities.

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The main contributions of the present research are the typification of knowledge fusion processes occurring in the context-aware DSSs at the operational stage of their functioning and the generalization of these processes in the form of patterns. The patterns represent the knowledge fusion processes in terms of the effects these processes produce in the context aware DSS and map these effects into the ontology paradigm. Besides, the patterns specify how knowledge fusion impacts on the autonomy and structure of the sources the information/knowledge is fused from.

Discovery of the context-based knowledge fusion patterns starts with the determination where knowledge fusion processes occur in the context aware DSSs. Then processes of knowledge fusion and their effects are investigated. Search for such effects in the DSS that supports the present research is the aim of the following investigation. So, the conceptual framework underlying this DSS is introduced. The context-based knowledge fusion processes are manifested around the context. These processes are revealed and described. Some examples from a fire response scenario accompany these descriptions. At the end of each description an appropriate statement is formulated. The statements create awareness of the aspects to be generalized by the patterns and presents the knowledge fusion result as it appears in the DSS. Finally, the knowledge fusion patterns generalizing each of the statements are introduced for all the revealed knowledge fusion processes.

2. Knowledge fusion and context aware decision support

This research considers the context awareness as "up-to-date knowledge and run-time understanding of the surrounding environment" [16] [p. 163] (the current situation) by the DSS and the environmental sources. Context aware decision support aims at finding and putting together certain pertinent information allowing for making the informed decisions. The information continuously arrives from multiple diverse heterogeneous sources of data, information, and knowledge located in the environment. The information becomes interpretable in a context framework. The context model is the basis for situation understanding and for knowledge exchange between various entities involved in a decision situation (the settings in which decisions occur).

Although a number of context models exists [17,18], ontology-based models are most popular today. The major reasons for this are given in the Introduction. To be more specific, "ontologies provide a formal specification of terminology used to categorize objects and events. Without such ontologies, it is just impossible to automatically manipulate the terminologies defined for fusion tasks" [2, p. 18].

Context ontologies serve to model the context by ontologies' means. The context ontologies consist of the upper ontology for general concepts, and domain specific ontologies representing knowledge of different application domains [19–21]. The upper ontology is shared by these domains. As a rule, the upper ontology represents concepts that are common for all context-aware applications (*Context Entity*, *Time*, *Location*, *Person*, *Agent*, *Activity*, *Device*, etc.) and provide flexible extensibility to add specific concepts in different application domains (i.e., *Cell Phone* can be a subclass of *Device*) [22–24]. The context is an ontology-based model specified for actual settings.

Multiple sources of data/information/knowledge provide information about the actual settings. This information is integrated within the ontology-based model. The context is a result of the integration. Depending on the context objective the context can represent knowledge about surroundings [25], about sources of data/information/knowledge [26,27], about any entity involved in the decision situation [28,29], about the DSS itself [30], about the decision situation [31], etc.

The information integration results in information accumulated from multiple sources and represented in a uniform way within a knowledge-based structure (context). The knowledge fusion involves delivering the available information, analyzing this information, and drawing conclusions [32]. The knowledge fusion technology enables [33,34] to refine the information with respect to the contextual relevance, support a deeper information integration, improve the situation awareness, adapt the DSS to unexpected circumstances, enhance decisions based on the information and the knowledge describing it.

3. Knowledge fusion processes

The knowledge fusion problem refers to integration of information/knowledge from different sources to obtain new knowledge. The main feature of the knowledge fusion lies in creation of synergetic effect from the integration of information/knowledge. Basically, such effect can be achieved through integration of both tacit and explicit knowledge as well as through their combination. Tacit knowledge integration is embedded in societal activities and interactions. This kind of integration lies beyond the present research focused on the context-based fusion of explicit knowledge.

Based on the analysis of knowledge fusion studies, seven knowledge fusion processes eventuated in different results can be distinguished (Table 1). As a continuation of the previous research [1], such results are revealed in the context-aware DSS that supports the present research. As said in the Introduction, the focus of attention is the context aware stage of DSS functioning. The knowledge fusion is considered as an appearance of some new knowledge in consequence of the processes ongoing in the DSS.

4. Context aware decision support system

Before the examination of the context-aware DSS for knowledge fusion processes, the conceptual framework underlying this DSS is introduced [12]. The DSS is intended to function in open dynamic environments consisting of a large number of information/knowledge sources. In the framework the context is used to represent the knowledge about the decision situation. The framework relies upon a currently accepted definition of the context: "Context is any information that can be used to characterize the situation of an entity ..." [43] [p. 5]. In the proposed framework the context is defined as *an ontology-based model representing knowledge relevant to the decision situation*. Such model specifies, in the knowledge-based way, the information needed to describe the decision situation, makes this sharable and interpretable by the environmental sources, enables information/knowledge integration and fusion, and supports ontological reasoning over the fused information/knowledge. The DSS is considered context aware in a sense that it uses the context to provide the user with a set of decisions that can be made in some particular situation.

According to the proposed framework the context is extracted from the application ontology. This ontology is represented by constraints; for such representation the formalism of object-oriented constraint networks [1] providing for constraint-based reasoning is used (the application of constraint-based reasoning to knowledge fusion is described in a number of papers published within the project on Knowledge Reuse and Fusion/Transformation (KRAFT) [44,45]). The formalism supports some object-oriented knowledge specification. According to the formalism [1] an ontology (A) is described as: $A = (O, Q, D, C)$ where O – a set of classes ("*classes*"). Q – a set of class attributes ("*attributes*"); D – a set of attribute domains ("*domains*"), and C – a set of *constraints*. Six types of constraints are supported. They are: