Context-Based Knowledge Fusion Patterns in Decision Support System for Emergency Response

Alexander Smirnov
St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (SPIIRAS), St. Petersburg, Russia
smir@iias.spb.su

Tatiana Levashova
SPIIRAS, St. Petersburg, Russia
tatiana.levashova@iias.spb.su

Nikolay Shilov
SPIIRAS, St. Petersburg, Russia
nick@iias.spb.su

ABSTRACT

The purpose of this paper is discovery of context-based knowledge fusion patterns. Knowledge fusion is considered as an appearance of new knowledge in consequence of processes ongoing in decision support systems. The knowledge fusion processes are considered within a system intended to support decisions on planning emergency response actions. The knowledge fusion patterns are generalized with regard to preservation of internal structures and autonomies of information and knowledge sources involved in the knowledge fusion and to knowledge fusion results. The found patterns give a general idea of knowledge fusion processes taking place at the operational stage of decision support system functioning, i.e. the stage where context-aware functions of the system come into operation. As a practical application, such patterns can support engineers with making choice of knowledge sources to be used in the systems they design.

Keywords

Context aware decision support, knowledge fusion, context-based knowledge fusion patterns, emergency response.

INTRODUCTION

Decision support systems (DSSs) heavily rely upon large volumes of data, information, and knowledge available in multiple sources. Whereas several years ago the main technology used to integrate data and information within DSS was data fusion, today the focus of data fusion has naturally changed to knowledge fusion. Knowledge fusion problem refers to integration of information/knowledge from different sources to obtain new knowledge. The main feature of knowledge fusion is synergetic effect from the integration.

A shared conceptualization is the key to enable knowledge fusion. Ontologies are a way to ensure the shared conceptualization. They provide a shared and common understanding of a 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 mechanisms to reason about contextual data and information; allow entities not designed to work together to interoperate (Hong, Suh and Kim, 2009). All these explain the fact that ontologies support most efforts on knowledge fusion (e.g., (Bossé, Valin, Boury-Brisset and Grenier, 2006; Gu, Xu and Chen, 2008; Dapoigny and Barlatier, 2013; Little and Rogova, 2009; Yao, Raghavan and Wu, 2008)).

In the present research the ontology is a conceptual model of the application domain. This model serves as an intermediary between heterogeneous sources involved in knowledge fusion and decision support as well as a means of context modeling. *Context* is defined as *an ontology-based model, which represents knowledge relevant to the current situation*. Such a model specifies, in knowledge-based way, information needed to describe the situation, makes this information sharable and interpretable by the environmental sources, enables integration and fusion of information and knowledge, and supports ontological reasoning over the fused information/knowledge.

The objective of this paper is discovery of context-based knowledge fusion patterns. This issue is treated within the context-aware DSS intended to support decisions on planning emergency response actions. DSS is context

aware in the sense that it uses context to provide the user with a set of decisions that can be made in the current situation. Throughout the paper, the task of planning fire response actions is considered to illustrate main ideas.

The rest of the paper is organized as follows. In the next Section, some previous research results related to the issues discussed in this paper and a brief description of related research are presented. Then, a conceptual framework for the decision support is introduced. Knowledge fusion processes and their manifestations in the context-aware DSS are the focuses of the next two Sections. At last, context-based knowledge fusion patterns are presented and systematized. Main research findings and a brief discussion conclude the paper.

BACKGROUND AND RELATED RESEARCH

The present research is a continuation of the research on knowledge logistics. The knowledge fusion technology was an important constituent of the knowledge logistics approach. As main results of that approach, a conceptual framework for context-aware operational decision support (Smirnov, Pashkin, Chilov and Levashova, 2005) was developed and *generic* knowledge fusion patterns were discovered (Smirnov, Pashkin, Chilov, Levashova and Haritatos, 2003). The *generic* patterns generalized knowledge fusion processes not focusing on context aware functions of the DSS. The present research is a follow-up of the previous one. The center of attention of this research is the operational stage of the DSS functioning, i.e. the stage where the *context aware* functions of the system come into operation.

Discovery of knowledge fusion patterns has not been a hot research topic. Up to now, some general patterns like unstructured fusion (Chen and McQueen, 2010), convergence (Lee, 2007), fractal fusion (Lee, 2007), knowledge recombination (includes two patterns: knowledge fusion and knowledge reconfiguration) (Lin and Lo, 2010) were mentioned in a few studies. These patterns were discovered as a generalization of processes of knowledge interchange and combination (integration) in different distributed organizations and as a specialization of technology fusion patterns.

CONTEXT AWARE DECISION SUPPORT SYSTEM: CONCEPTUAL FRAMEWORK

The conceptual framework adopts the idea of ontology-based context representation. The central constituent of the framework is the application ontology (AO). This ontology represents non-instantiated knowledge to describe situations happening in the application domain along with problems to be solved. Domain & problem solving knowledge fused from different knowledge sources make up AO. In this regard, AO can be considered as a knowledge source representing two different knowledge types. AO is supported by an object-oriented representation – it is specified by sets of classes, class attributes, attribute domains (ranges), and relationships.

Ontological knowledge is instantiated in the context by environmental resources. The set of resources comprises sources of data/information/knowledge, problem solving resources and various actors (acting resources). Context represents a decision situation (the setting in which the decision occurs). A situation is represented at two levels. At the *first level* it is represented by *abstract context* that specifies non-instantiated ontology knowledge relevant to the current situation. Such knowledge is extracted from the application ontology. As two components make up the application ontology, the abstract context specifies domain knowledge describing the decision situation and problems to be solved in this situation. At the *second level* the situation is represented by *operational context* that is an instantiation of the abstract context with the actual information.

A subset of all the environmental resources is organized to instantiate the abstract context. This subset is referred to as contextual resources. The set of contextual resources comprises data/information/knowledge sources that can provide data values to create instances of the classes represented in the abstract context or solve problems specified in it. The set of contextual resources with the specified sequence of their execution organizes a resource network. Nodes of this network are resources providing data values and/or solving problems; network arcs signify an ordering on the resource execution.

As soon as the operational context is produced, the problem of search for feasible plans for emergency response actions is solved as a constraint satisfaction problem. The result of problem solving is a set of alternative solutions that can be made in the current situation. These alternatives are plans for the common activities of available acting resources. The plans are generated with regard to user preferences, which are taken from the profiles of the acting resources and decision makers and included in the specification of the constraint satisfaction problem. The decision maker chooses one plan from the set of alternative ones and delivers it to acting resources that are in this plan. The chosen plan is considered to be the decision.

The made decision (plan), the abstract context, and the operational context along with the resource network are saved in a context archive. The operational context and the resource network are saved in their states at the instant of alternatives generation.

KNOWLEDGE FUSION

The main feature of knowledge fusion is synergetic effect from integration of a wide variety of information and knowledge sources. Based on the carried out analysis of publications on knowledge fusion, several types of knowledge fusion can be distinguished:

- Intelligent fusion of massive amounts of heterogeneous data / information from a wide range of distributed sources into a form which may be used by systems and humans as the foundation for problem solving and decision making (Alun, Hui, Gray, Marti, Bench-Capon, Cui and Jones, 2001; Scherl and Ulery, 2004).
- Integration of knowledge from various knowledge sources resulting in a completely different type of knowledge or new idea how to solve the problem (Grebla, Cenan and Stanca, 2010; Lee, 2007). Integration of different types of knowledge (domain, procedural, derived, presentation, etc.) resulting in a new knowledge type (Holsapple and Whinston, 1986) and integration of multiple knowledge sources into a new knowledge object (Gou, Yang and Chen, 2005; Kuo, Tsen, and Lin, 2003) belong to this type of knowledge fusion.
- Combining knowledge from different autonomous knowledge sources in different ways in different scenarios, which results in discovery of new relations between the knowledge from different sources or/and between the entities this knowledge represents (Jonquet, LePendu, Falconer, Coulet, Noy, Musen and Shah, 2011; Laskey, Costa and Janssen, 2008).
- Re-configuration of knowledge sources to achieve a new configuration with new capabilities or competencies (Lin and Lo, 2010).
- Knowledge exchange to improve capabilities or competencies through learning, interactions, discussions, and practices (Lin and Lo, 2010).
- Involving knowledge from various sources in problem solving, which results in a new knowledge product (Smirnov, Pashkin, Chilov, Levashova and Haritatos, 2003).

The analysis above enabled to reveal the possible results of knowledge fusion: new knowledge object created from data/information; new knowledge type or knowledge product (service, process, technology, etc.); new relations between knowledge objects; new capabilities / competencies of a knowledge object; new problem solving method; solution for a problem.

The listed results allow one to conclude that any kind of new knowledge (new knowledge object, new relation between knowledge, new property of a knowledge object) obtained as a result of information/knowledge integration can be thought of as a knowledge fusion result. In the next Section, the context-aware DSS is investigated for the knowledge fusion results; knowledge fusion patterns behind the knowledge fusion processes producing the found results are discovered.

CONTEXT-BASED KNOWLEDGE FUSION IN DSS

Processes of knowledge fusion are considered with references to abstract and operational contexts. At first, processes in DSS resulting in knowledge fusion outcomes outlined in the precedent section are described. Demonstrations with examples from the fire response scenario accompany these descriptions. At the end of each description, a statement is formulated. The statement creates awareness of preservation of internal structures and autonomies of knowledge sources involved in the knowledge fusion and presents the knowledge fusion result as it appears in the DSS.

Any sources of data, information, or knowledge are considered as knowledge sources. Particularly, AO, abstract contexts, operational contexts, and resources of the DSS are thought of as knowledge sources in this Section. By internal knowledge source structure, the structure used in the representation of this source is meant. Knowledge source autonomy depends on how this source is related to other sources. Autonomous knowledge source is an independent source, which does not have any relationships with other sources. Such a source may change at any time not affecting other sources. On the contrary, non-autonomous knowledge source has relationships with other (non-autonomous) sources. Changes in a non-autonomous knowledge source are passed to the related sources and reflected in them.

The statements and patterns describe the knowledge fusion process in relation to initial and target knowledge sources. The sources, fusion (or integration) of knowledge from which produces a knowledge fusion result are referred to as initial knowledge sources. The sources organized as a result of knowledge fusion or enclose such a result are referred to as target knowledge sources.

Knowledge Fusion: Abstract Context

Referring to abstract context, knowledge fusion results appear in the DSS at the stages of abstract context creation and its future use.

Abstract context creation

Abstract context is created from the single knowledge resource – AO. The procedure of the abstract context creation consists in selection knowledge relevant to the decision situation within AO, its extraction, and integration into a new knowledge object. This object corresponds to the abstract context, which can be considered as a new knowledge object fusing two types of knowledge related to domain and problem solving.

Referring to the illustrative scenario, the abstract context is created for a fire situation. Figure 1 shows pieces of AO's knowledge and abstract context knowledge. The abstract context significantly reduces the amount of knowledge represented in AO. The created context, among other things, specifies that in a fire situation the services provided by emergency teams and fire brigades are required. These teams and brigades can use ambulances, fire engines and special-purpose helicopters for transportation. In the figure, the problem-solving knowledge specified in the abstract context is collapsed in the class "Emergency response". Partly, this class is shown expanded in Figure 1 on the right.

Statement 1. The procedure of the abstract context creation neither affects the internal structure of AO nor its autonomy. The abstract context becomes an autonomous object with a proper structure. The knowledge fusion result is a new knowledge source of the same type as the initial knowledge source.

Abstract context refinement

The knowledge integration may result in discovery of new relationships between the knowledge unrelated in AO. Figure 2 illustrates the case when AO specifies that a value for the attribute representing the current location of a transportation device serves as an input parameter of the routing method (1). In this ontology the class "mobile" representing a mobile acting resource and the class "transportation device" are related by a functional relationship (2) assigning that the location of a mobile acting resource is the same as the location of the transportation device this resource goes by. In the abstract context a new functional relationship (3) has been inferred. This relationship means that a value for the attribute representing the current location of a mobile acting resource serves as an input parameter of the routing method. In other words, values for the both attributes representing the current location of a transportation device or the current location of a mobile resource can be used by the routing method as one of its input parameter.

Statement 2. AO preserves its structure and autonomy when the abstract context is refined. This context preserves its autonomy, but its structure is changed. The knowledge fusion result is that the existing knowledge source is extended with new knowledge.

Abstract context reuse

Reconfiguration of the resource network appears useful if an abstract context is reused in settings when not all available information and knowledge sources are intended to instantiate it. Sometimes, an analysis of inputs and

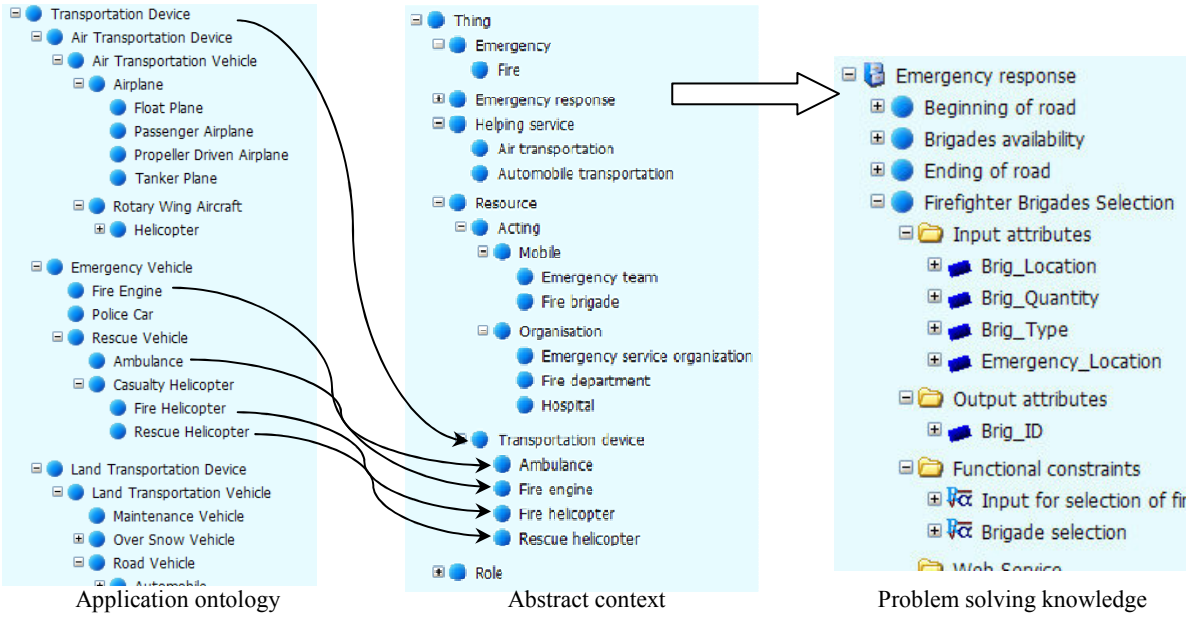
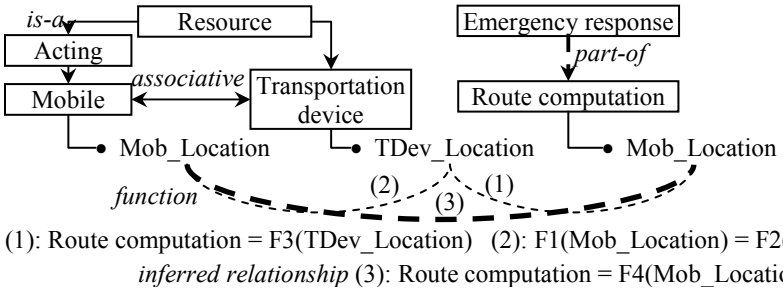


Figure 1. Fire situation: abstract context (a fragment)



(1): Route computation = F3(TDev_Location) (2): F1(Mob_Location) = F2(TDev_Location)
inferred relationship (3): Route computation = F4(Mob_Location)

Figure 2. Inferred relationship

outputs of the available sources may result in a new configuration of sources, which suites to the context intentions. As a result of the reconfiguration alternative sources can be discovered. Particularly, it is the case when alternative problem-solving methods can be found. When alternative sources are found they are explicitly specified in the abstract context. The changes in the abstract context do not affect the internal structure and autonomy of AO. Knowledge fusion results appear in DSS as a new configuration of the resource network implying introducing new knowledge into the abstract context.

Figure 3 illustrates the case when the abstract context specifies the routing problem as a hierarchy of methods, one of which (*GetLocation*) returns the current locations of objects in the format of coordinates of a point on the map. In the example under consideration it is required to determine the locations of hospitals. The method *GetLocation* uses data from sensors. The set of contextual resources comprises no sensors dealing with static objects like hospitals. But this set comprises some other resources. One of them (*A*) implements the method (*MedicalCareSuggestions*) intended to make recommendations on which medical care organizations can be used to access a specific medical service. This resource contains a private database with information about hospitals. The other resource (*B*) implements the method (*Conversions*) that converts the address format into the format of coordinates. The execution of the methods *MedicalCareSuggestions* and *Conversions* one after another is an alternative way to calculate the hospital locations in the format of coordinates.

Statement 3. AO preserves its structure and autonomy when alternative sources are introduced in the abstract context. The internal structure of the abstract context is changed. The autonomies of the abstract context and the alternative sources are preserved. The knowledge fusion result is a new configuration of the resource network implying extension of the existing knowledge source with new knowledge.

Knowledge Fusion: Operational Context

Mainly, operational context entails knowledge fusion processes relating to fusion of information and knowledge within the existing structure of the abstract context. Besides this, multiple operational contexts enable knowledge fusion from different contexts, which result in discovering new relations between the instances involved in these contexts.

Operational context producing

An operational context is produced through the semantic fusion of data/information from multiple data/information resources within the ontology structure of the abstract context. As soon as the resources start instantiating the abstract context, they lose their autonomies. The result of this kind of fusion is a new

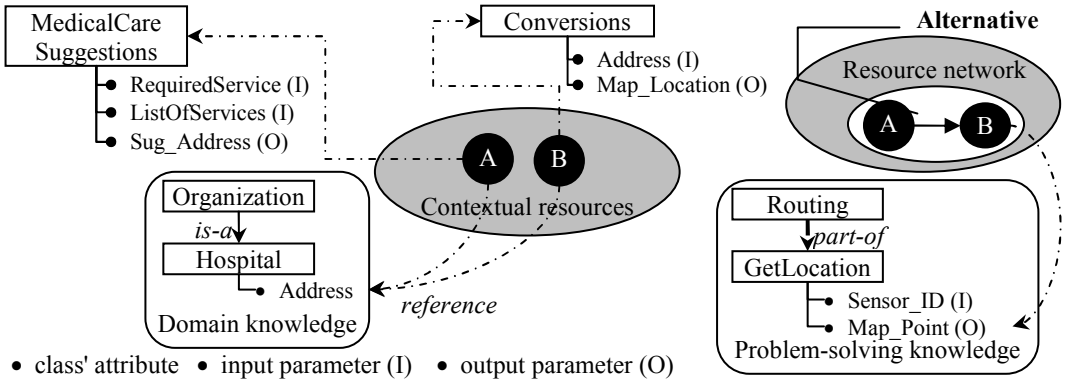


Figure 3. Discovery of alternative problem-solving methods

knowledge object (operational context) created from data/information.

In case of fire, the operational context includes a GIS-based representation of the fire situation. This representation is supplemented with characteristics of the fire situation specified in the abstract context. Examples of such characteristics are the location and intensity of the fire, the number of victims, etc. These characteristics are represented by attributes of the class "Fire". As well, the operational context represents information about the traffic situation, available routes, weather conditions, and found acting resources (their locations, availabilities, capacities, transportation devices being used, etc.). According to the abstract context, the main acting resources are emergency teams, fire brigades, and hospitals.

Statement 4. The abstract context preserves its structure and autonomy when the operational context is produced. The contextual knowledge sources lose their autonomies but preserve their internal structures. The operational context is a new non-autonomous knowledge source of a new type. The knowledge fusion result is a new knowledge source of a new type, which reflects the actual information.

Problem solving

When the operation context is produced, values for the input arguments of the specified problems are being assigned. As assigning the values, contextual resources solve these problems. Referring to the main purpose of decision support, the problem of planning fire response actions is solved for the fire situation. For the emergency teams, fire brigades, and hospitals a plan for their joint actions is produced. An example of such a plan is shown in Figure 4. The dotted lines indicate the routes to be used for the transportations. This result relates earlier independent instances. The result of problem solving is a new knowledge product (plan for actions) of a new type.

Statement 5. As a result of problem solving, the operational context dissolves within the new knowledge source and do not preserve its internal structure and autonomy. The new knowledge source and the contextual resources become autonomous objects. The knowledge fusion result is a set of alternative solutions fused with the operational context, i.e. a new knowledge source of a new type.

Decision implementation

The decision is a solution that the decision maker has chosen from the set of alternative ones. This decision is made at a certain time instant. The situation may change from the moment the decision was made to the moment of its implementation. The actors whom the decision is delivered may be unable to implement it in the changed circumstances. In some cases, the activities assigned to actors who become unable to operate can be delegated to or redistributed between other actors participating in the decision implementation. As a result of this, the actors that are ready to take the assignments gain new capabilities / competencies.

For instance, an emergency team trained to rescue operations has failed in the course of actions because of road destruction, ambulance blockage, etc. In some cases these operations can be delegated to available teams. Then the profiles of teams agreed to take part in the rescue operations are extended with this new capability.

Statement 6. At time of the decision implementation, the instances representing the actors are not autonomous. If the actors participating in the decision implementation are engaged in an activity that the actors' profiles do not provide for, the structure of the profiles is changed. The changed decision structure results in changing the internal structure of the knowledge source containing the set of solutions. This knowledge source is not autonomous until the decision is implemented. The knowledge fusion result is that the actors gain new capabilities / competencies.

Knowledge Fusion: Archival knowledge management

Archival context management deals with management of knowledge contained in the archived components. The main intention of such management is inference of new knowledge based on the accumulated knowledge. For instance, new relations between the knowledge represented in the operational contexts can be discovered based on a comparative analysis of these contexts accumulated in the context archive. Finding the same instance in different operational contexts may lead to revealing new relations for this instance.

For example, the emergency team encircled in Figure 4 participated in different emergency response actions. Some operational contexts in which this team appeared and then participated in corresponding actions do not represent any instances of the class *Emergency response organization* specified in the abstract context (Figure 5). This suggests that the emergency team is a part of one of the hospitals represented in the operational contexts together with this team. Based on the operational context (Figure 5) it can be judged that most probably the team

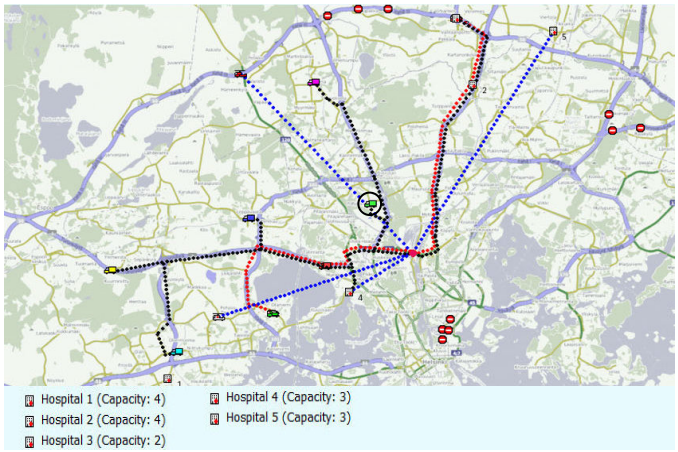


Figure 4. Problem solving: plan for actions

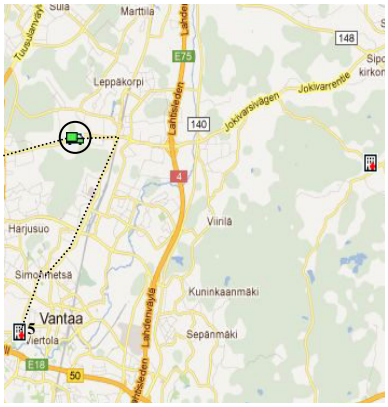


Figure 5. History for an emergency team

is a part of hospital 5 represented in this context since the context does not represent any other hospitals from Figure 4 except this one. *Part-of* relation between the hospital 5 and the encircled emergency team is the new revealed relation.

Statement 7. The operational contexts are non-autonomous objects in the context archive. As a result of archival context management, new relations for the knowledge stored in the context archive can be inferred. These relations are not introduced in the operational contexts, but they are specified in the application ontology. The new relations change the structure of the application ontology, but do not affect its autonomy. The result of knowledge fusion is a new property, which was not specified in the application knowledge.

Context-based Knowledge Fusion Patterns

The discussion above enables to distinguish patterns of the context-based knowledge fusion (Figure 6). The patterns map the result appearing in the DSS into the ontology paradigm. Classes, properties, and instances are considered as fundamental ontology representation items (it is supposed, that the relationships between classes or instances are modeled as properties). The list of patterns is as follows:

- *Simple fusion*: selection of pieces of knowledge from a knowledge source and their integration into a new knowledge source. The initial knowledge source preserves its internal structure and autonomy; the target knowledge source becomes an autonomous object with a proper structure. The knowledge fusion result is a new ontology extracted from another ontology.
- *Extension*: introducing a new knowledge into a target knowledge source created from an initial knowledge source. The initial knowledge source preserves its structure and autonomy. The target knowledge source preserves its autonomy, but its structure is changed. The knowledge fusion result is a new class / property.
- *Instantiated fusion*: semantic fusion of data/information from multiple sources within the existing ontology structure. The initial knowledge source preserves its structure and autonomy. The target knowledge source is a new non-autonomous knowledge source of a new type. The knowledge fusion result is a new ontology of a new (dynamic) type.
- *Flat fusion*: producing a new knowledge source which contains the initial knowledge source. The initial knowledge source dissolves within the target knowledge source and do not preserve its internal structure and autonomy. The target knowledge source becomes an autonomous object. The knowledge fusion result is a new knowledge product representing the dynamic ontology fused with a set of alternative decisions.
- *Adaptation*: adaptation of the made decision to the context that results in gaining new capabilities / competencies by the executive actors. The initial knowledge source is non-autonomous object; its structure is changed. The target knowledge sources remain non-autonomous and do not preserve their structures. The knowledge fusion result is that the classes representing the instances gain a new property.
- *Historical fusion*: revealing new knowledge as a result of inference based on the knowledge from one or more unrelated knowledge sources. The initial knowledge sources are non-autonomous objects. The target knowledge source remains an autonomous object, but its structure is changed The initial knowledge sources preserve their structure. The result of knowledge fusion is a new property.

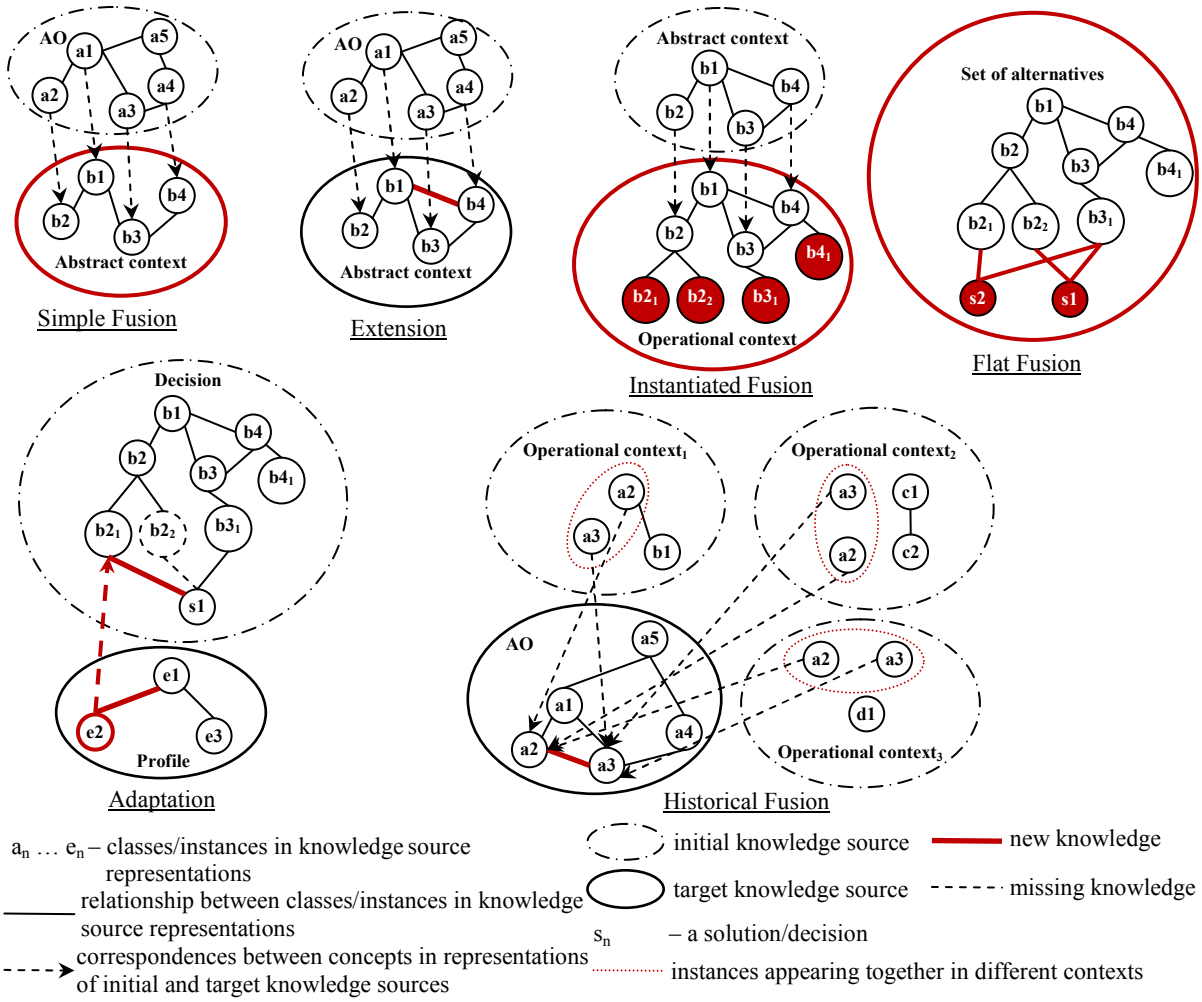


Figure 6. Context-based knowledge fusion patterns in DSS

The correspondences between the formulated statements and the patterns are presented in Table 1.

Stmt #	Phase of DSS functioning	Meaning	Knowledge fusion pattern
1	Abstract context creation	Integration of multiple knowledge pieces from a single knowledge source into a new piece of knowledge	Simple fusion
2	Abstract context refinement	Revision of initial knowledge in a new context	Extension
3	Abstract context reuse	Reconfiguration of the resource network when the abstract context is reused in new settings	Extension
4	Operational context producing	Instantiation of the abstract context with values from multiple data/information /knowledge sources	Instantiated fusion
5	Problem solving	Generation of a set of alternative decisions	Flat fusion
6	Decision implementation	Redistribution of planned actions between the executive actors resulting in gaining new capabilities / competencies by the actors	Adaptation
7	Archival knowledge management	Revealing new knowledge as a result of inference based on the knowledge represented in several operational contexts	Historical fusion

Table 1. Correspondences between the statements and knowledge fusion patterns

The patterns are proposed to be specified using the following elements (with examples for the Simple Fusion indicated by italic):

Name (a name to refer to the pattern): *simple fusion*;
Problem (a problem the knowledge fusion process solves): *creation of a new ontology from existing one*;
Solution (a meaningful description of the knowledge fusion process): *integration of multiple knowledge pieces from a single knowledge source into a new knowledge source*;
Initial knowledge sources (knowledge sources integration or fusion of knowledge from which produces the knowledge fusion result): *application ontology*;
Target knowledge sources (knowledge sources that are organized as a result of knowledge fusion or that enclose such a result): *abstract context*;
Related pattern (may be omitted): an alternative pattern that can be used instead of the described one or in parallel or after termination of the described;
Exception (may be omitted)**:** a description of conditions / cases when the pattern is not applicable;
Autonomy pre-states (the degree of autonomy of knowledge sources before the knowledge fusion process):

initial knowledge source	target knowledge source
autonomous	*n/a*

/*Three degrees are provided for: autonomous, non-autonomous, and n/a (for a non-existing knowledge source)*/;
Result in DSS (the result the knowledge fusion process produces in the decision support system): *new knowledge source created from a single knowledge source*;
Result in ontology paradigm (ontology-based generalization of the knowledge fusion result): *new ontology extracted from another ontology*;
Post-states: degrees of preservation of the knowledge source autonomies and internal structures after the knowledge fusion process completes:

initial knowledge source	target knowledge source
preserved	*new*
autonomous	*autonomous*

/*For the knowledge source autonomies the degrees introduced in pre-state descriptions are kept on. Three degrees of knowledge object structure preservations are provided for: preserved, changed, and new (for a new knowledge source)*/;
Schematic representation (the knowledge fusion process represented schematically): *Figure 6 – simple fusion*;
Phase of DSS functioning (the phase of DSS functioning where the knowledge fusion process takes place): *abstract context creation*.

CONCLUSION

In the paper, the knowledge fusion processes in the context-aware DSS for the emergency response domain were investigated. Knowledge fusion was considered as an appearance of some new knowledge in consequence of processes ongoing in the system. The results of knowledge fusion were identified at the context-aware phase of DSS operation. Six context-based knowledge fusion patterns behind the processes producing the found results were revealed. These patterns proposed a generalization of the knowledge fusion processes with regard to preservation of internal structures and autonomies of knowledge sources involved in the knowledge fusion and to results produced by these processes. The patterns give a basic idea of the mechanisms supporting knowledge fusion processes. In practice, the patterns allow the system engineers to specify requirements to sources from which information and knowledge they plan to use in the system.

The patterns presented in this paper leave out configurations of the resource network. Nevertheless, a new configuration of the network can be considered as a new knowledge. In future, the presented patterns are planned to be enriched with elements enabling to specify not only changes in structures of knowledge sources and existence of relations between them, but to be more specific about these relations.

Currently, the generalization of the found knowledge fusion results at the ontological level brought to light four results: new ontology, new class/property (new ontology representation item), new ontology type, and new type of knowledge source (knowledge source with a structure different from the ontological one). These four results can pretend to form a full set of knowledge fusion results from the ontology perspective. But the situations around decision support resulting in the listed results can be different. Different situations can produce the same result and different results can appear in the same situation. At the current stage of research, unique correspondences between the situations resulting in knowledge fusion results and these results have not been found. Quite probably that at the current stage of research not all the possible situations around decision support were considered. One of the future research goals will consist in search for situations resulting in the listed results and their generalization. This will serve as the first step to finding correspondences between the knowledge fusion results and the situations giving rise to these results.

ACKNOWLEDGMENTS

The present research was supported partly by projects funded by grants 10-07-00368, 11-07-00045, 11-07-00058, 12-07-00298 of the Russian Foundation for Basic Research, the project 213 of the research program "Information, control, and intelligent technologies & systems" of the Russian Academy of Sciences (RAS), and the project 2.2 of the Nano- & Information Technologies Branch of RAS.

REFERENCES

1. Alun, P., Hui, K., Gray, A., Marti, P., Bench-Capon T., Cui, Z. and Jones, D. (2001) Kraft: an agent architecture for knowledge fusion, *International Journal of Cooperative Information Systems*, 10, 1–2, 171–195.
2. Bossé, É., Valin, P., Boury-Brisset, A.-C. and Grenier, D. (2006) Exploitation of a priori knowledge for information fusion, *Information Fusion*, 7, 2, 161–175.
3. Chen, J. and McQueen, R. J. (2010) Knowledge transfer processes for different experience levels of knowledge recipients at an offshore technical support center, *Information Technology and People*, 23, 1, 54–79.
4. Dapoigny, R. and Barlatier, P. (2013) Formal foundations for situation awareness based on dependent type theory, *Information Fusion*, 14, 1, 87–107.
5. Gou, J. Yang, J. and Chen, Q. (2005) Evolution and evaluation in knowledge fusion system. In: J. Mira and J.R. Alvarez (Eds.), *IWINAC 2005*, LNCS, 3562, 192–201.
6. Grebla, H.A., Cenan, C.O. and Stanca, L. (2010) Knowledge fusion in academic networks, *BRAIN: Broad Research in Artificial Intelligence and Neuroscience*, 1, 2. Retrieved November 30, 2012, from http://www.edusoft.ro/brain/index.php/ brain/article/download/60/145.
7. Gu, J., Xu, B. and Chen, X. (2008) An XML query rewriting mechanism with multiple ontologies integration based on complex semantic mapping, *Information Fusion*, 9, 4, 512–522.
8. Holsapple, C.W. and Whinston, A.B. (1986) Building blocks for decision support systems. In: G. Ariav and J. Clifford (Eds.), *New directions for database systems* (pp. 66–86). Norwood: Ablex Publishing Corp.
9. Hong, J., Suh, E., Kim, S. (2009) Context-aware systems: a literature review and classification, *Expert Systems with Applications*, 36, 8509–8522.
10. Jonquet, C., LePendu, P., Falconer, S., Coulet, A., Noy, N.F., Musen, M.A. and Shah, N.H. (2011) NCBO Resource Index: ontology-based search and mining of biomedical resources, *Journal of Web Semantics*, 9, 3, 316–324.
11. Kuo, T.-T., Tseng, S.-S. and Lin, Y.-T. (2003) Ontology-based knowledge fusion framework using graph partitioning, In P.W.H. Chung, C.J. Hinde and M. Ali (Eds.), *IEA/AIE 2003*, LNAI, 2718, 11–20.
12. Laskey, K.B., Costa, P. and Janssen, T. (2008) Probabilistic ontologies for knowledge fusion, *Proceedings of the 2008 11th International Conference on Information Fusion*, IEEE, Retrieved November 30, 2012, from http://ieeexplore.ieee.org/xpl/freeabs_all.jsp? arnumber=4632375.
13. Lee, K.-R. (2007) Patterns and processes of contemporary technology fusion: the case of intelligent robots, *Asian Journal of Technology Innovation*, 15, 2, 45–65.
14. Lin, L.Y. and Lo, Y.J. (2010) Knowledge creation and cooperation between cross-nation R&D institutes. *International Journal of Electronic Business Management*, 8, 1, 9–19.
15. Little, E. G. and Rogova, G. L. (2009) Designing ontologies for higher level fusion, *Information Fusion*, 10, 1, 70–82.
16. Scherl, R. and Ulery, D.L. (2004) *Technologies for army knowledge fusion* (Final report no. ARL-TR-3279). Monmouth: Monmouth University, Computer Science Department, West Long Branch.
17. Smirnov, A., Pashkin, M., Chilov, N. and Levashova, T. (2004) Knowledge logistics in information grid environment, *Future Generation Computer Systems*, 20, 1, 61–79.
18. Smirnov, A., Pashkin, M., Chilov, N. and Levashova, T. (2005) Constraint-driven methodology for context-based decision support, *Journal of Decision Systems*, 14, 3, 279–301.
19. Smirnov, A., Pashkin, M., Chilov, N., Levashova, T. and Haritatos, F. (2003) Knowledge source network configuration approach to knowledge logistics. *International Journal of General Systems*, 32, 3, 251–269.
20. Yao, J., Raghavan, V. V. and Wu, Z. (2008) Web information fusion: a review of the state of the art, *Information Fusion*, 9, 4, 446–449.