INTEROPERABILITY ON THE LEVEL OF KNOWLEDGE UNITS*

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The term of interoperability is originally known from the area of ICT. In connection with knowledge it means mainly interoperability of knowledge bases or some knowledge; it is based on ontology as declarative forms of its representations. Objective of this paper is to suggest, specify and formalize interoperability on the level of knowledge units. For such purpose, systems´ approach based model of knowledge units is used. Formalization of interoperability based on knowledge unit model contributes to clarification of the less specified term "interoperability of knowledge", where the term of knowledge is not exactly defined. Plant production has been chosen as an application domain for the purpose of demonstration of suggested procedures and operations. Even though the selected application is very simple, it illustrates well how to transfer some procedures and knowledge into specific area of human activities (agriculture production). Formalization of interoperability on the level of knowledge units contributes to purposeful indication of the interoperability process for application of new knowledge in the target sector.

knowledge representation; knowledge unit; systems approach; plant production

INTRODUCTION

Nowadays, many works deal with a term of interoperability. Interoperability is usually understood especially in connections to different operation systems and basically describes an ability of two or more heterogeneous systems to communicate and to cooperate. In literature, there is possible to find a lot of definitions of such term as well as a lot of ways of its utilization in different application domains. The main attention is aimed at an area of ICT, at a way how some computer systems can share data and process it under different software environment.

In general, it is necessary to mention that interoperability is also one of the key factors of existence of both people and organizations in knowledge society. Now, the ability of people to acquire and to work with knowledge is a necessary condition. A man, who is also able to perceive usability of formerly acquired knowledge in more different contexts and/or different application domains, can save significant amount of resources. The saving can be expressed in units of resources that have not been spent for acquiring the same knowledge as a subject already has.

Interoperability becomes a part of human's cognition. Its description and understanding of its principles enlarges individual application areas with positive effects to their development in future. Interoperability is a key aspect of multidisciplinarity; it allows sharing findings, information, methods, and procedures across different disciplines. From the viewpoint of organizations, interoperability becomes a factor of competitive advantage.

Some references connect interoperability with interoperability of knowledge bases or with ontology as a base for some declarative forms of knowledge representation. Unfortunately, a technical viewpoint and a viewpoint of ICT dominate both application and user-oriented viewpoints. Thus, the objective of the paper is to suggest and specify an interoperability of procedural knowledge and choose a suitable way of its formalization. A model of knowledge unit based on systems analysis of characteristics of knowledge and its relevant attributes by systems approach will be used for such purpose.

MATERIAL AND METHODS

Interoperability definitions and characteristics

First, IEEE definition of interoperability (1990) is generally accepted. The definition is as follows:

"Interoperability is the ability of two or more systems or components to exchange information and to use the information that has been exchanged."

Interoperability means ability of cooperation and universality entities to exist and to work in different heterogeneous environments and/or exchange data and information with some other entities.

Above given definition and characterization of interoperability is quite general. More specific definition could be adopted from the area of software engineering. According to ISO/IEC 2382-01, Information Technology Vocabulary, Fundamental Terms, interoperability is defined as follows:

"Interoperability is the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units."

The main reason for mentioning of such definition is its user-oriented aim. Despite staying in the area of ICT,

* The paper is supported by the grant project of the Ministry of Education, Youth and Sports of the Czech Republic No. MSM6046070904.

the definition supposes that a user should not have any additional knowledge, when he wishes to work with various functional units of some artificial (computer) system.

Woodley (2005) characterizes interoperability by very similar way; as "the ability of different types of computers, networks, operating systems, and applications to work together effectively, without prior communication, in order to exchange information in a useful and meaningful manner". He also provides basic specification of the term of interoperability as follows:

1. Semantic interoperability

It is expression of metadata structure that allows combining semantically data elements from various schemes, dictionaries, thesauruses and some other tools and lets search information across heterogeneous distributed databases (especially in Internet environment) by single query. Semantic interoperability helps to solve cases when some individual entities use different terms for description of the same object or vice versa the same term for different objects. Semantic interoperability could be reached by using some standards for source content description like Dublin Core or XML (Hřebíček, 2001).

2. Syntactic interoperability

The same source describes syntactic interoperability as expression of metadata structure that allows combining syntactically data elements from various schemes, dictionaries, thesauruses and some other tools. Syntactical interoperability is based on marking the data by the same way or by creation of the same data structure, so it is sharable in various systems.

3. Structural interoperability

Müller et al. (2007) characterize such kind of interoperability as a structure of metadata. Structural interoperability could be reached by data model for semantic schemes specifications that could be thus applied together (e.g. RDF).

Knowledge and knowledge units

In the absence of its established definition, the term "knowledge" is at present difficult to apply. There is a prevailing opinion that knowledge defies any definition and only allows determining its qualities. For example, the following characteristics of knowledge can be found in literature (Dömeová et al., 2008):

"Knowledge is a variable mix of arranged experience, values, related information, expert opinion and substantiated intuition that constitutes the environment and framework for the evaluation and integration of new experience and information." (Gamble, Blackwell, 2001)

"Knowledge is information that has been checked through arrangement and analysis to make it intelligible and applicable for problem solution or decision-making." (Turban, 1992)

"Knowledge is information in motion." (Stuhlman, 2005)

"Knowledge is information applied in the right time at the right place in the right manner." (Folkes, 2004)

"Knowledge is the capability of a man (or an intelligent machine) to use information for problem-solving." (Havlíček et al., 2007)

The term "knowledge unit" is widely used. Similarly to the term "knowledge" it also has a lot of characteristics and more or less an exact definition. For example, Zach (1999) says that "a knowledge unit is an atomic packet of knowledge content that can be labelled, indexed, stored, retrieved and manipulated". There are many such clear definitions in specialised literature.

That is why in the following text the term of "elementary knowledge" will be used for expressing and representing knowledge units based on systems approach. As discussed in the previous chapter, the term "elementary" is more suitable for this purpose, because it includes and summarizes three important characteristics and approaches to knowledge unit – the knowledge unit is atomic, it is an element of some system, and it is the of knowledge of users.

Houška and Beránková (2006) suggested to define "elementary knowledge" (EK) as a special, well-structured type of knowledge unit, as contents of one production rule related to the successful solving of an elementary problem. Formally, elementary knowledge can be recorded as

$$EK = \{X, Y, Z, Q\},$$

where: X – stands for a problem situation,
Y – stands for the elementary problem being solved in the framework of the X problem situation (hypothesis),
Z – stands for the objective of solving the elementary problem,
Q – stands for a successful solution of the elementary problem (result).

The elementariness of knowledge is predetermined by the elementariness of the problem. The elementary problem is a problem or a part of a complex problem which is impractical to be further divided into more simple subproblems. Criteria for assessing the degree of elementariness are defined by the knowledge user, because they depend on his or her ability to understand and apply the rules included in elementary knowledge. This is in conformity with Zack's definition of knowledge units (Zach, 1999).

Ontology

Ontology is explicitly specified conceptualization. It describes specific area of aim (domain) formally; it defines classes of objects that appear there, and relationships that could exist among them. Ontology makes communication among people easier and it also improves software systems collaboration. In the area of systems engineering, ontology contributes to unifications, keeping consistency of ideas and terms and definiteness (Uschold, Gruninger, 1996).

Svátek (2002) notes that there is a difference in interpretation of the term of ontology in informatics and in philosophy. In philosophy, ontology is understood as a study of the nature of being, existence or reality in general, as well as of the basic categories of being and their relations. Ontology as a subject of ontological engineering describes what exists in reality and what could be represented in information or in knowledge systems.

For purposes of this paper, the term of ontology will be understood according to viewpoint of informatics; three main contexts are as follows:

- tool for helping people to understand interpersonal communication;
- tool for support of communication among computer systems (ICT interoperability);
- tool for development knowledge-oriented applications.

RESULTS

Knowledge transfer vs. knowledge interoperability

K v a s n i č k a (2009) suggested some basic ideas about general interoperability of knowledge. In general, the interoperability is understood as a specific kind of knowledge transfer, where three components could be differentiated (see Fig. 1):

- knowledge understood and expressed as a form of object;
- knowledge understood and expressed as a form of process;
- general (universal) terminology.

Despite supposing that all above mentioned environments are heterogeneous and the described process has really quality of interoperability, the scheme is not absolutely correct. The positions of scheme components "terminologies" are not placed well. Terminology is always a property of the environment; that is why it cannot play a role of transmitter of knowledge between two different environments.

Even though some definitions of interoperability were provided in the previous chapter, both terms interoperability and transfer of knowledge have been differentiated intuitively. For clear understanding of such two terms, a key aspect of their distinguishing has to be specified. Such aspect could be formulated as homogeneity of environments on supply side and demand side of knowledge transmission.

Knowledge transfer is realized in homogeneous environment or between homogeneous environments. That is why no terminological problems have to be solved. Both supply and demand side of knowledge transfer use the same terminology and fully understand the meaning of transferred knowledge (see Fig. 2).

Knowledge interoperability is always realized between two heterogeneous environments. Because of heterogeneity, it should be generally expected that terminology used in individual environment will be different against the others. The key question to solving is how to ensure understanding of transmitted knowledge by the same way in both environments. The solution is to identify a general topic scheme – ontology – that will be common for both supply and demand side environments. Of course, it is neither possible nor useful to try developing ontology for complete terminology of both environments; it is enough to have ontology for such small part of terminologies that allows understanding to transmitted knowledge. For corrected visualization of knowledge interoperability see Fig. 3.

Interoperability of knowledge units

Fig. 3 provides general way for knowledge interoperability. Nevertheless, it deals with aspect of content's understandability of knowledge in different environments; formal aspect of interoperability has not been mentioned. That is why it is useful to think about interoperability on elementary level – on the level of knowledge unit (as described in chapter 2). This is in concordance with systems approach to interoperability; exploring the interoperability process on elementary level allows its generalization for more complex knowledge objects.

From the viewpoint of interoperability, knowledge unit (KU) has two important advantages:

1) It has fixed structure KU = {X, Y, Z, Q}. Then it is possible define that interoperability of knowledge unit is finished if and only if all elements of it are received and accepted by demand side of interoperability.

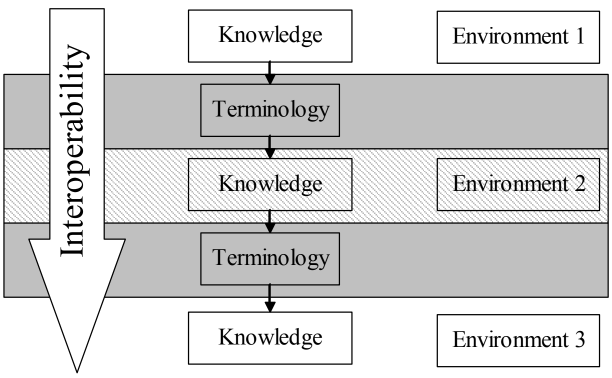

Fig. 1. General scheme of interoperability of knowledge

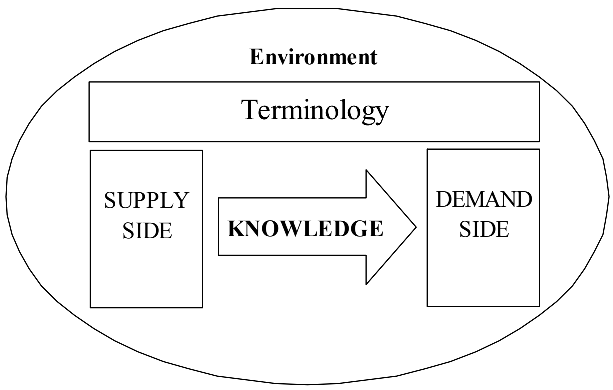

Fig. 2. Knowledge transfer in homogeneous environment

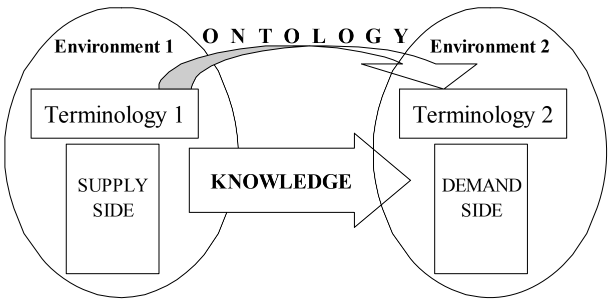

Fig. 3. Knowledge interoperability in heterogeneous environment

2) Structural element of knowledge unit X expresses explicitly a context (a frame) of knowledge unit application. It makes knowledge unit interoperability easier, because the operation can refer directly into the knowledge unit.

Formally, knowledge unit interoperability can be expressed as follows:

KU 1		KU 2
X1	→	X2
Y1	=	Y2
Z1	=	Z2
Q1	=	Q2

Fig. 4. Interoperability of knowledge units

In Fig. 4, two kinds of operators are used:

- "→" operator expresses formally a transmission of knowledge unit from the context X1 into the context X2 and
- "=" operator expresses equivalency between problems Y1 and Y2, objectives Z1 and Z2 and solutions Q1 and Q2.

There is not problem to interpret the operator "→", because change of knowledge unit context in the process of interoperability is natural. It is more difficult to interpret the operator "=", because the task is to decide about content equivalency of pair of text strings that include interpretable information.

It is only way to return to ontology, because it goes out from application of knowledge unit in supply side environment. If the demand side is able to construct the same terminological scheme as the ontology is, but in terms of its environment, then all pairs of expressions Y1 and Y2, Z1 and Z2 and Q1 and Q2 are comparable. So the formal equivalency is guaranteed; content equivalency must be judged by some human user.

Example: Interoperability of knowledge in agrobusiness

For demonstration purposes, an inverse procedure is selected. It means that two knowledge units in different (heterogeneous environments) will be formulated and then the whole process of interoperability will be described.

Story 1: Business lunch (business environment)

"In a small company dealing with agriculture production, a sales manager is going to arrange a business lunch with his partners. The meeting is very important because of range of estimated production sale contract to deal. Thus, manager's effort is to have the lunch smooth; especially, it is necessary to do a reservation call to the restaurant to reserve a private place in it."

Story 2: Sugar beet harvesting (production management environment)

"The same company particularly deals with sugar beet production. Sugar beet is being harvested in October. Subject to economical reasons, the company does not own the machinery for sugar beet harvesting, thus it must rent the harvester from agricultural service company. Because of competition it is better to prevent problems with availability of the harvester; production manager should send reservation order for the machine soon."

Based on previous stories, two knowledge units can be formulated. Before that, both stories should have specified their terminologies:
Terminology 1 (business environment)
Reservation, business lunch, restaurant, sales manager, partners, private place in the restaurant, reservation call.
Terminology 2 (production management environment)
Reservation, harvesting of sugar beet, reservation order, production manager, agriculture service company, sugar beet harvester.
Now, the two knowledge units could be expressed in both analytical and language forms as follows:
Knowledge unit 1 (KU1, business environment)
Analytical form:
X1 = "arrangement of lunch with business partners"
Y1 = "to reserve a private place in the restaurant"
Z1 = "to have private place for the lunch"
Q1 = "to make a reservation call to the restaurant"

Language form:

"If you want to reserve a table in the restaurant in the frame of arrangement of lunch with business partners to have private place for the lunch, make a reservation call to the restaurant."

Knowledge unit 2 (KU2, production management environment)

Analytical form:
X2 = "arrangement sugar beet harvesting"
Y2 = "to reserve a sugar beet harvester"
Z2 = "to have the machine available in specific time"
Q2 = "to send a reservation order to agriculture service company soon"

Language form:

"If you want reserve a sugar beet harvester in the frame of arrangement sugar beet harvesting to have the machine available in specific time, send a reservation order to agriculture service company soon."

Let business environment is supply side and production management environment is demand side of the knowledge interoperability. Then, the process of interoperability could be described as follows:

Step 1: Creation of the terminology for business environment

Only terms that are relevant for presented knowledge interoperability are included into supply side terminology:

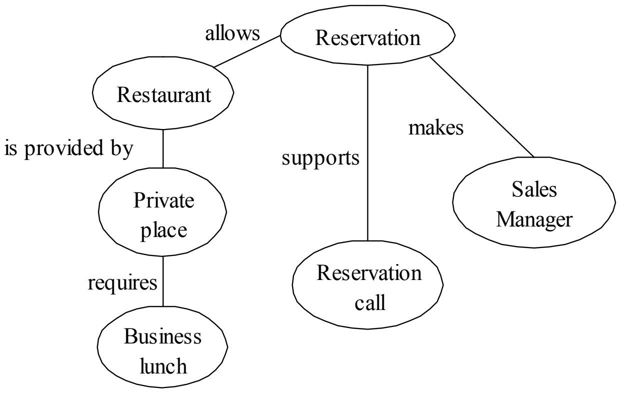

Fig. 5. Terminology of the supply side - business environment

Step 2: Development of the ontology to allow transmission of terms between environments

Based on terminological scheme provided in the Fig. 5, specific ontology for knowledge unit interoperability could be created as follows:

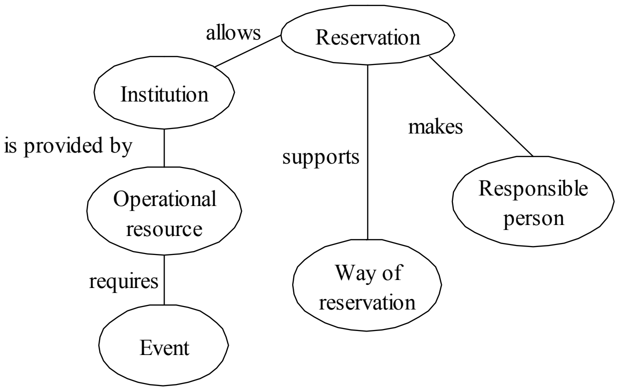

Fig. 6. Specific ontology for knowledge unit interoperability

Step 3: Creation of the terminology for production management environment

Finally, the terminology from supply side environment (Fig. 5) is converted by the specific ontology (Fig. 6) into demand side environment. Demand side terminology is described in Fig. 7.

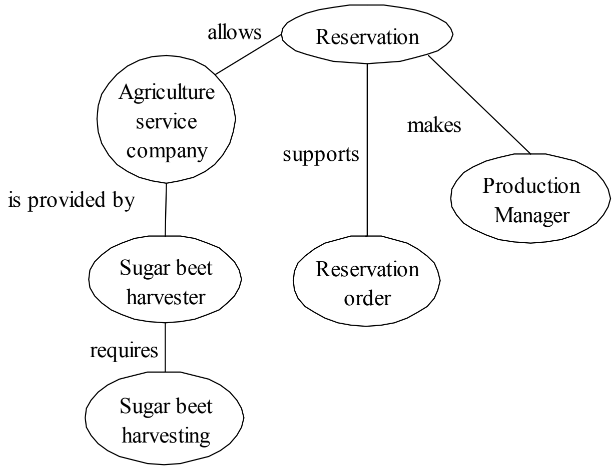

Fig. 7. Terminology of the demand side – production management environment

Now, the whole process of knowledge unit interoperability is finished and the knowledge unit is ready to be applied in new environment. Above given operability of knowledge unit could be formally expressed in analytical form as follows:

	KU 1			**KU 2**
X1	arrangement of lunch with business partners	→	**X2**	arrangement of sugar beet harvesting
Y1	to reserve a private place in the restaurant	=	**Y2**	to reserve a sugar beet harvester
Z1	to have private place for the lunch	=	**Z2**	to have the machine available in specific time
Q1	to make a reservation call to the restaurant	=	**Q2**	to send a reservation order to agriculture service company soon

Fig. 8. Analytical form of knowledge interoperability

Note: The way of understanding of operators "→" and "=" has been already explained. It is correct to talk about some kind of equivalency, because both terminologies are in concordance with the same ontology (Fig. 9).

Business	**Ontology**	**Production**
reservation	reservation	reservation
sales manager	responsible person	production manager
reservation call	way of reservation	reservation order
restaurant	institution	agricultural service company
private place	operational resource	sugar beet harvester
business lunch	reason	sugar beet harvesting

Fig. 9. Sameness of business and production terminologies through ontology

CONCLUSION

A problem of knowledge transfer between heterogeneous environments could be complicated, because there is not unique way how to understand and express the term of knowledge. Although some characterizations of knowledge that were given in the chapter 2 seem to be satisfying, it is sometimes better to understand and work with knowledge intuitively. This approach is typical for disciplines dealing with process view of knowledge, with knowledge sharing among people.

It is not enough to work with knowledge as an unspecific object, when its interoperability is studied. Systems approach to knowledge provides a definition of knowledge unit as an object with fixed and well specified structure. It seems to be possible to generally accept connection between knowledge unit and solution of some problem.

In this paper, the terms of knowledge transfer and knowledge interoperability were clearly differentiated. Homogeneity of environments, where the transferred knowledge unit is applied, is the key factor of it. In the first case, when the environments are homogeneous, the knowledge transfer is simple, because despite changing knowledge unit component "X" (a problem situation), the terminology of the new "X" is still the same. In the other case, under heterogeneous environments, it must be treated equivalency (better to use the term "sameness") of individual parts of knowledge units, because unique terminology could not be used. In this paper, construction of ontology as a topic scheme for specified part of environment terminologies is suggested for such purpose. Ontology allows expressing specific terminology generally, independently on application area. It mediates smooth identification of knowledge unit in the supply side environment as well as its adoption in the new (demand) environment, so it fulfils the objective and purpose of knowledge interoperability.

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Received for publication on April 1, 2010
Accepted for publication on June 16, 2010

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Interoperabilita na úrovni znalostních jednotek.

Scientia Agric. Bohem., *41*, 2010: 183–189.

Termín interoperabilita původně pochází z oblasti ICT. V souvislosti se znalostmi je obvykle spojen s interoperabilitou báze znalostí nebo znalostí, které jsou založeny na ontologii jako deklarativní formě jejich reprezentace.

Cílem článku je proto navrhnout a specifikovat interoperabilitu na úrovni znalostních jednotek a vhodným způsobem ji formalizovat. K tomuto účelu bude použit model znalostní jednotky, který je založen na analýze znalostí a jejich podstatných atributů pomocí systémového přístupu. Formalizace interoperability založená na modelu znalostní jednotky, která má svoji pevnou strukturu, přispěje k objasnění spíše vágního pojmu interoperabilita znalosti, kde pojem znalost není přesně specifikován.

Jako aplikační doména, na které jsou odvozené postupy a operace demonstrovány, byla zvolena oblast rostlinné produkce. Přestože je zvolená aplikace velmi jednoduchá, lze na ní velmi dobře ukázat, jak je možné do konkrétního oboru lidské činnosti (zemědělství) přenášet postupy úspěšné v jiných oblastech. Formalizace interoperability na úrovni znalostních jednotek přispěje k tomu, že bude možné tento proces úmyslně vyvolávat s cílem aplikovat v cílovém odvětví nové znalosti a postupy.

reprezentace znalostí; znalostní jednotka; systémový přístup; rostlinná produkce

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