UDC 005.53:004.8
Original Scientific Paper

Multi-Agent System for Decision Support in Enterprises

Dejan Lavbič *Dejan.Lavbic@fri.uni-lj.si*
University of Ljubljana
Faculty of Computer and Information Systems

Rok Rupnik *Rok.Rupnik@fri.uni-lj.si*
University of Ljubljana
Faculty of Computer and Information Systems

Abstract

Business decisions must rely not only on organisation's internal data but also on external data from competitors or relevant events. This information can be obtained from the Web but must be integrated with the data in an organisation's Data Warehouse (DW). In this paper we discuss the agent-based integration approach using ontologies. To enable common understanding of a domain between people and application systems we introduce business rules approach towards ontology management. Because knowledge in organisation's ontologies is acquired from business users without technical knowledge simple user interface based on ontology restrictions and predefined templates are used. After data from internal DW, Web and business rules are acquired; agent can deduce new knowledge and therefore facilitate decision making process. Tasks like information retrieval from competitors, creating and reviewing OLAP reports are autonomously performed by agents, while business users have control over their execution through knowledge base in ontology. The approach presented in the paper was verified on the case study from the domain of mobile communications with the emphasis on supply and demand of mobile phones and its accessories.
Keywords: Intelligent agent, ontology, business rules, data warehouse, information retrieval.

1. Introduction

There is a growing recognition in the business community about the importance of knowledge as a critical resource for organisations. The purpose of knowledge management is to help organisations create, derive, share and use knowledge more effectively to achieve better decisions, less reinventing of wheels, increase of competitiveness and fewer errors. In order to run business effectively an organisation needs intelligence about competitors, partners, customers, and also employees as well as intelligence about market conditions, future trends, government policies and much more. There are several products and technologies available on the market that support advanced Business Process Management, Data Mining and Web Mining applications in Business Intelligence, Customer Relationship Management (CRM) etc. Organisations expect these applications to support wide range of functionalities – analyses of customer profiles, building and analysing business strategies, developing customer-specific products, carrying out targeted marketing and predicting sales trends.

Since the mid 1980's Data Warehouses have been developed and deployed as central integral part of a decision support environment. A Data Warehouse (DW) provides an infrastructure that enables businesses to extract and store vast amounts of corporate data from operational systems for efficient responses to user queries. DW empowers knowledge workers with information that allows them to make decisions. For an effective DW to prove useful, different types of data and different forms (e.g. text streams, binary large objects, rules, what-if cases) of data need to be captured, codified and catalogued. In addition, these data must contain metadata and must be analysed to create new knowledge. Practitioners and academia have both noted the significant benefits that information systems integration within enterprise can bring about for business in terms of reduced costs, improved product line in tune with market needs, and responsive and improved customer service [8, 15, 16, 27].

One of the prominent approaches for information system integration is the use of ontologies. In Computer Science this paradigm was first used in Artificial Intelligence for knowledge representation and facilitating knowledge sharing and reuse. The reason ontologies are becoming popular is largely due to what they promise: "a shared and common understanding of a domain that can be communicated between people and application systems" [1]. As such, the use of ontologies and supporting tools offers an opportunity to significantly improve knowledge management in large organisations.

The purpose of this article is to present integration of several information resources for Decision Support in Enterprises using agent-oriented approach based on ontologies. During the past few years a lot of research [3, 17, 20, 23-25, 31, 38, 43] has been conducted involving Multi-Agent Systems (MAS) and ontologies as further discussed in section 2. These studies have been focused on using ontologies in MAS in limited scope and not fully employing the main idea of creating a common understanding of problem domain for both people and application systems. The goal of our research was to minimize the gap between human users and intelligent agents (application systems) that perform tasks in their behalf. The intention was to apply business rules approach for ontology manipulation in MAS. Ontology used in our Multi-Agent System for Decision Support in Enterprises (DSS-MAS) was divided into different task and domain ontologies while business users were enabled to manipulate with them directly in a user friendly environment without requirement of detailed technical knowledge. Business users with a role of decision makers have to be notified proactively, based on the context and profile, while usually they had to manually request the information (i.e. OLAP reports, list of Key Performance Indicators (KPI) etc.). One of the main requirements of DSS-MAS was the need for aggregated information from various sources – internal (i.e. DW, relational databases) and external (i.e. World Wide Web).

The remainder of this paper is structured as follows. First, in section 2, we will give some background information about Multi-Agent Systems and ontologies in general. This will be followed by an introduction to our case study of integrated Multi-Agent environment from the domain of mobile communications. The case study is focused in one of the mobile operators and furthermore oriented to supply and demand of mobile phones and its accessories. After presentation of architecture and decomposition of ontology every agent (OLAP & Data Mining Agent, Information Retrieval Agent, Knowledge Discovery Agent, Notifying Agent and Mobile Agent) from DSS-MAS will be presented in detail. An overview of our approach to implementation of prototype will be given in section 4. Finally the last section presents conclusions and plans for future work.

2. Background

2.1. Multi-Agent Systems

Multi-Agent Systems (MAS) offer a new dimension for cooperation and coordination in an enterprise. The MAS paradigm provides a very suitable architecture for a design and implementation of integrative business information systems. With agent-based technology a support for complex information systems development is introduced by natural decomposition, abstraction and flexibility of management for organisational structure changes [15]. The MAS consists of a collection of autonomous agents that can define their own goals and actions and can interact and collaborate among each other through communication. In a MAS environment, agents work collectively to solve specific problems. It provides an effective platform for coordination and cooperation among multiple functional units in an organisation.

While there is no universally agreed definition of an agent, the following one is the most widely accepted: "an agent is a computer system that is situated in some environment, and that is capable of autonomous actions in this environment in order to meet its design objectives" [41]. Furthermore, it has been proposed that an intelligent agent is autonomous, reactive, proactive, and social. Nevertheless what characteristics are used to describe agent, it is clear that an agent is different from traditional object. First of all, agents are commonly modelled using mentalistic notions, such as knowledge, belief, intention, obligation, while objects are modelled as simply encapsulating their internal structure as methods and attributes. The degree to which agents and objects are autonomous is quite different. Objects do not have control over their behaviours, because they are invoked by others. On the contrary, agents are able to decide whether or not to execute an action after receiving request. Ontologies are frequently used for internal knowledge representation in agents that furthermore enables knowledge sharing, inference etc.

The research on intelligent agents and MAS has been on the rise over the last two decades. The stream of research on business information systems and enterprise integration [14, 18, 35] makes the MAS paradigm a very appropriate platform for integrative decision support within business information systems. Similarities between the agent in the MAS paradigm and the human actor in business organisations in terms of their characteristics and coordination lead us to a conceptualisation where intelligent agents in MAS are used to represent actors in human organizations.

Whereas the popularity and applications of the agent technology in the business domain have grown over the recent years, the field currently deals with innovative approaches and architectures for solving business and information systems integration problem. There is a lack of unifying framework that would be used for business information systems (ERP, workflow, etc.) and the MAS paradigm integration. This framework would also have to provide a foundation for conceptual analysis and modelling of integrative business information systems based on the MAS paradigm. Because the agent-based approach provides the proactivity and adaptivity necessary for decision support processes that take place in enterprises we find it very appropriate for implementation of DSS-MAS that is furthermore presented in section 4.

2.2. Ontology

Today, semantic technologies based on ontologies and inferencing are considered as a promising means towards the development of the Semantic Web. The original meaning of ontology is the study of being as a branch of philosophy. In information science, ontology is a knowledge model that describes a domain of interest using semantic aspects and structure. The most prominent definition is an explicit formal specification of a shared conceptualization [11], meaning that the ontology is completely defined using a formal notation automatically interpretable by machines, and that the conceptualization should be shared by a group.

Although the most difficult part of ontology design is the conceptual structure, the ontology by itself is of minor value if there are no methods defined on it. Inference is an important mechanism on ontologies. Ontology represents abstracted domain concepts and relation expressed in terms of a standard knowledge representation language that can be reused and shared by others over the internet. The standard knowledge representation languages have been defined as RDF (Resource Description Framework) and OWL (Web Ontology Language) by the World Wide Web Consortiums (W3C). The recent standard OWL that is used in our prototype implementation currently has no defined rule language; therefore SWRL proposal was used for knowledge acquisition at the business level and furthermore executed in KAON2 inference engine at the information system level.

The approach presented in this article is targeted towards using ontologies for several tasks, where emphasis is on using business rules approach for interoperability between business user and information system. In [7, 38] research considered ontologies for information management and addressed the issue of ontology-based information systems. Authors also identified roles of ontology related actors. First of all the most important task that has to be achieved is domain knowledge representation. In DSS-MAS this will include mobile communications domain with definition of several tasks needed in decision support –

OLAP analyses, Data Mining, Information Retrieval, context and profile definition, organization structuring and notification.

In MAS several autonomous agents exist, therefore agent-to-agent communication is very important. There have been several contributions on using ontologies in **agent communication**. Williams in [39] argues that the development of the Semantic Web will require agents to use common domain ontologies to facilitate communication of conceptual knowledge. He shows Multi-Agent knowledge sharing and how that will assist groups of people in locating, translating and sharing knowledge. In [40] authors present the use of ontology in MAS for distributed software development with the emphasis on team management.

For **domain knowledge representation** ontology has been widely used for knowledge synthesis in a form of data, application and information integration [26]. Jovanović in [13] concludes that the need for knowledge sharing and interoperable knowledge bases exists and the key element for achieving that are domain ontologies. In that approach XSLT transformation is used to enable knowledge interoperability. Furthermore some attempts have also been made towards ontology programming in dedicated languages such as Go! [9] that is distinguished from OWL-like languages where stress is on logic and object oriented programming.

Regarding the domain of **Data Warehouses** and **OLAP analyses** research has dealt with Document Warehousing [37] where extensive semantic information about the documents is available but still not fully employed as in traditional Data Warehouse. The use of ontologies showed useful as a common interpretation basis for data and metadata. Furthermore research has extended to Web Data Warehouses [22] with the emphasis on managing the volatile and dynamic nature of Web sources. Information Retrieval is also very appropriate for introduction of ontologies and its integration. This approach has been used for fuzzy tagging of data from the Web [4, 21], query construction tool in semi-automatic ontology mapping [34] and semantic based retrieval of information from the World Wide Web [10, 29]. In **Data Mining** integration with ontologies has also been considered in [2, 6, 30, 42] where ontology was used for representation of context awareness, handling semantics inconsistencies and as a communication bridge.

The use of ontologies in MAS environment enables agents to share a common set of concepts about contexts, user profiles, products and other domain elements while interacting with each other. With Semantic Web ontological and logical layer supports, agents can exploit the existing reasoning mechanisms to deduce high-level unknown contexts from known contexts, and to make decisions to adapt to the environment, current status, and personal setting of the user. This approach will be further explained in the following section with the architecture of DSS-MAS prototype and ontology decomposition.

3. Integrated Multi-Agent environment

3.1. Architecture

Multi-Agent System for Decision Support in Enterprises (DSS-MAS) that we propose in this paper is introduced in Figure 1. The running case study is from the domain of mobile communications and is based on business environment and information resources from one of the mobile operators in Slovenia. DSS-MAS is situated in the environment with several existing systems, from Data Mining Decision Support System (DMDSS), to Data Warehouse (DW) and various resources outside the organisation available on the World Wide Web.

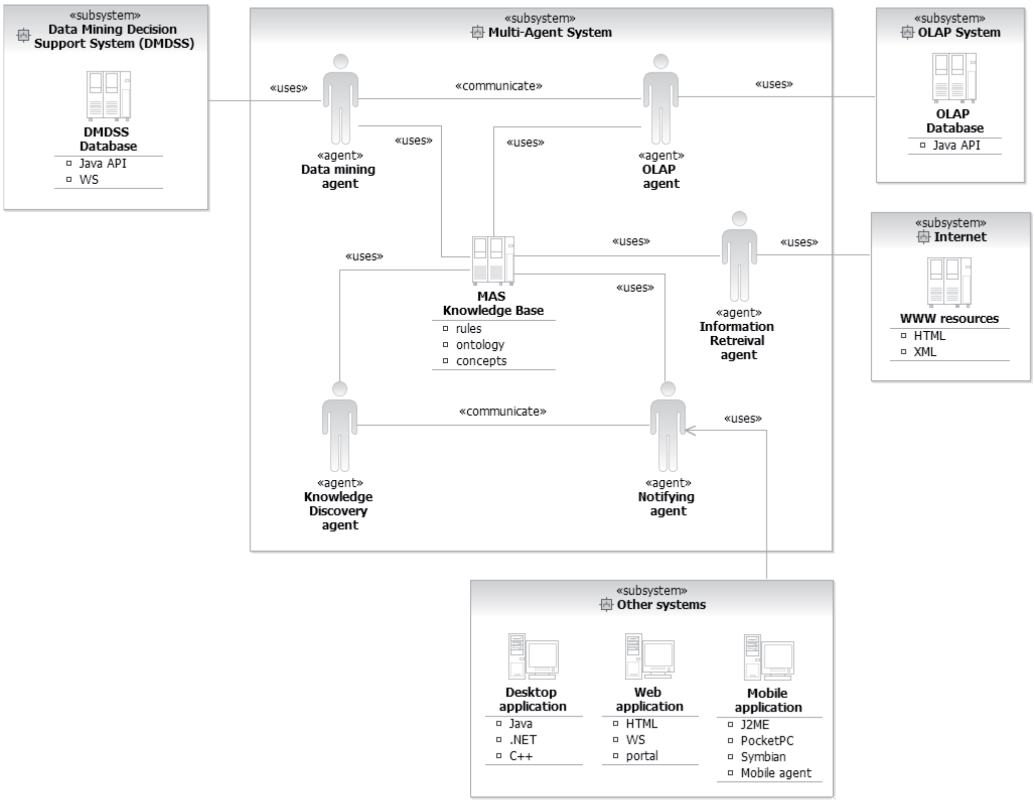

Figure 1: Architecture of MAS for Decision Support in Enterprises

Global goal that agents in DSS-MAS strive to is supporting decision making process while using existing systems for business analysis that already exist in organisation and employing information from environment where organisation resides. To support this goal DSS-MAS includes several agent roles as following: Data Mining Agent (DMA), OLAP Agent (OLAPA), Information Retrieval Agent (IRA), Knowledge Discovery Agent (KDA), Notifying Agent (NA) and Mobile Agent (MA). Ontologies are used as a main interconnection element for domain knowledge representation, agent-to-agent communication and most important for agent-to-business user communication. A very important element of an environment is the World Wide Web, where agents play information retrieval role for the purpose of decision making. The retrieved information is included in central knowledge base and available for further inclusion in Data Mining and Data Warehouse analyses. After all information from internal and external resources is gathered it is then furthermore considered by KDA, with the emphasis on inference over several task ontologies. Moreover the sub goal of DSS-MAS is delivering the right information at the right time to the right users. The system needs to be context aware and consider the relevant features of the business, i.e. context information such as time, location, and user preferences [19]. Business user in DSS-MAS is able to employ an agent to perform tasks on his behalf. For example managers in organisations have to request reports from their systems – OLAP or transactional, and they have to review them every period (day, week, month etc.). This task of information acquisition is predecessor for decision making and is more or less straightforward – business user sends a request for analyses and reviews the content according to some Key Performance Indicators (KPI). In DSS-MAS tasks like this are automated and user intervention reduced as much as possible. An initial analysis has to be captured in the ontology by business users, while execution and optimisation is left to agents. When some action is required from business user, he is notified and has the ability to act or change the rules of agent's execution.

DW analysis could show that the price from the provider of the specific product have risen last month, whereas IRA discovered that market prices of competitors dropped down last week. That could be a matter of importance for decision makers when negotiating with vendor and that is why business users should be alerted as soon as DSS-MAS discovers this fact and not only when they request the report.

To enable these functionalities we introduce ontologies as a mediation mechanism for knowledge exchange between actors (agents and business users) that cooperate in DSS-MAS. The following section will present the structure and organization of ontologies we have used for the case study.

3.2. Ontology decomposition

According to Guarino in [12] ontology can be structured into different sub-ontologies – upper ontology, domain ontology, task ontology and the application ontology. Following similar guidelines we have defined upper ontology named **Common ontology** and combined domain and task ontologies in **Notifying ontology**, **Information retrieval ontology**, **Data Mining and Warehousing ontology** (see Figure 2). Common ontology is limited to abstract concepts and it covers reusable dimensions. It is primarily used by KDA, furthermore described in section 3.5. Task ontologies specify concepts of notification, Information Retrieval and Data Mining and Warehousing. Mobile communications is the domain of all task ontologies and the emphasis is on supply and demand of mobile phones.

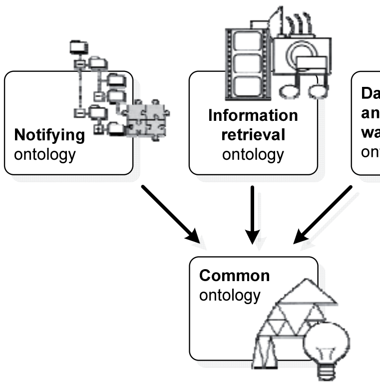

Figure 2: Architecture of ontologies

Each of the agents has its own representation of knowledge that we define as internal memory. Agent employs a portion of specified ontology as follows: DMA and OLAPA work with Data Mining and Warehousing ontology, IRA works with Information retrieval ontology, NA and MA work with Notifying ontology and KDA works with Common ontology. There are several possibilities with knowledge management in DSS-MAS:

- Every agent has knowledge about its problem domain and directly communicates with another agent whenever it needs information about certain subject other agents might have.
- An agent only sends an inform message to all the agents which might be interested (or subscribed) that some new information on certain subject exists.
- **Every agent has knowledge about its problem domain, but whenever something new arises about the common knowledge which might be of interest for other agents, it updates the common ontology.**

In this research we adopted the last option with every agent having knowledge about its problem domain and updating the common knowledge when needed. The common ontology in this case comprises an intersection of all domain and task ontologies. This is a possible solution to avoid unnecessary message passing. When an agent finds some information that might be of interest to other agents it simply notifies other agents about the change and writes the change to the common ontology. All the agents that are concerned about this piece of information can thereafter acquire it in the common ontology.

3.3. OLAP & Data Mining agent

As aforementioned in the domain of mobile communications our research has emphasized on sales of mobile phones and its accessories. The results from execution of internal business processes is available in aggregated form for two purposes – Data Mining and OLAP analyses, as depicted in Figure 1. The existing Data Mining Decision Support System (DMDSS) and Data Warehouse both share the same dimensional model which is, in simplified form, introduced in Figure 3.

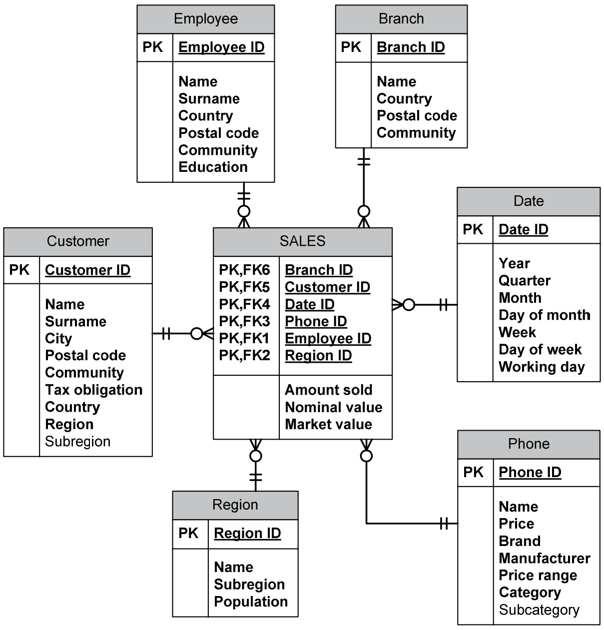

Figure 3: Simplified form of Data Warehouse in DSS-MAS

Manipulation with internal data storage is handled by two types of agents – OLAP Agent (OLAPA) and Data Mining Agent (DMA). They both have distinct tasks but still share common goal – periodically or on demand autonomously executing analyses models. The information about the execution is stored in the ontology (based on business user preferences) or is requested by another agent in the system. OLAPA has on first hand very straightforward task of performing OLAP analyses on behalf of business user and reporting its findings back to the requesting user. Nevertheless OLAPA does much more – after each execution it prepares the report for business user based on detected findings – movements and Key Performance Indicators (KPI) (see Figure 4). If certain finding is substantially different from previous running further analysis is performed to discover the reason of change by drilling down or up the hierarchies and levels. The knowledge about dimensional schema and relation to domain knowledge is available in Data Mining and Warehousing ontology as depicted in Figure 4.

Figure 4: Excerpt from Data Mining and Warehousing ontology

By capturing the knowledge in ontology we enable business users to change the behaviour of agents by simply altering the ontology using simple graphical user interface. This interface incorporates all logical restrictions defined in ontology and does not allow users to enter false inputs and most important does not require technically educated users. Previous experiences have shown that business users have great difficulties especially with setting the parameters required to run Data Mining and Warehousing analyses models so user interface has to really be simple and intuitive. In approach this was accomplished by introducing the architecture depicted in Figure 8 and using templates as further discussed in section 4.

3.4. Information Retrieval agent

Nowadays Web retrieval systems are widely extended and deeply analyzed from different points of view. The main objective of all of them is to help users to retrieve what they really need (obviously as quickly as possible) [10]. While the techniques regarding DW, multi-dimensional models, on-line analytical processing (OLAP), or even ad hoc reports have served enterprises well; they do not completely address the full scope of business intelligence. It is believed that, for the business intelligence of an enterprise, only about 20% of information can be extracted from formatted data stored in relational databases [37]. The remaining 80% of information is hidden in unstructured or semi-structured documents. This is because the most prevalent medium for expressing information and knowledge is text. For instance, market survey reports, project status reports, meeting records, customer complaints, e-mails, patent application sheets, and advertisements of competitors are all recorded in documents.

In DSS-MAS we introduce Information Retrieval Agent (IRA) for information retrieval of data mainly from the World Wide Web. The tasks that IRA performs can be grouped into three categories:

- Identification of new online shops,
- analysis of mobile phones supply worldwide and
- extending Data Warehouse with information found online.

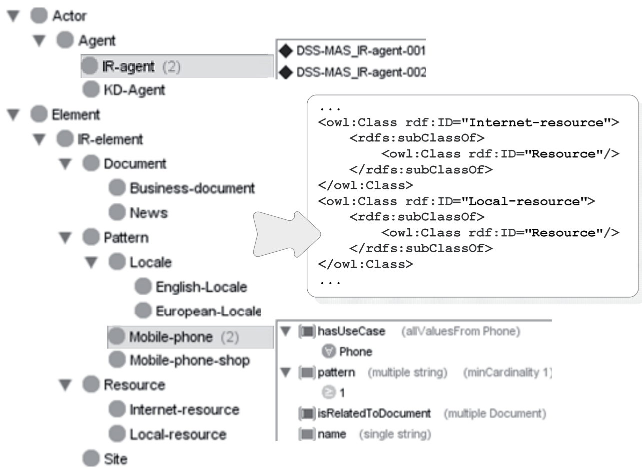

Figure 5: Excerpt from Information retrieval ontology

First two tasks are concerned about the supply of mobile phones and its accessories at various online shops worldwide. Identification of new online shops is conducted with web crawling and the use of several existing services on the Internet, such as Google[1], Froogle[2] and Microsoft Live Search[3]. Not only that these internet resources are managed through ontology (see Figure 5), but also rules for text extraction are defined as rules which makes all domain knowledge available in Information retrieval ontology and not codified in agent itself. More details about implementation can be found in section 4. Furthermore every shop found online is analysed to identify unique patterns for searching phones and accessories. Using these search patterns IRA traverses through online shops and determines phones with their market prices and stores this information into Information retrieval ontology to be available for further knowledge derivation by Knowledge Discovery Agent (KDA). Found phones are used to determine new market trends, enable price comparison between competitors, facilitate possible inclusion in organisation's sales program etc.

One of the tasks that IRA also performs is extending Data Warehouse analyses with information found online. While business user performs OLAP analyses, he deals with only internal information about the business, but before decision making other resources also have to be examined, e.g. news about the suppliers and competitors, opinions about certain products and organisations, change of stock prices of business collaborators etc. IRA therefore scans the dimension data (through hierarchies and levels) from Data Warehouse dimensional schema and uses this information to search several internet resources (news archives, forums, stock changes, Google trends etc.). When users review OLAP reports these data from the Internet is also displayed according to their restrictions in dimensions. For example when business user tries to make decision whether to increase support to Nokia or Sony Ericsson phones it only has reports about sales of selected brands from their market program. In our approach the user is provided with additional data that is found online and what will make decision easier.

3.5. Knowledge Discovery agent

Knowledge Discovery Agent (KDA) is very important element of DSS-MAS since it consolidates all findings from Information Retrieval, Data Mining and Warehousing and furthermore mediates derived findings to Notification. To fully employ inference capabilities over several ontologies (see Figure 2) business rules from the organisation are essential. While business concepts are captured in ontology, these concepts further have to be yet linked

[1] http://www.google.com
[2] http://froogle.google.com
[3] http://search.live.com

together. Generally business rules are prepared by business users and not by technical users and also business rules in enterprises tend to change frequently; therefore we introduced architecture (see Figure 8) for business rules management (further discussion in section 4).

Findings of KDA are presented as instances of **Domain-specific-element** and **Findings** classes (see ontology in Figure 6). Example of such a finding can be:

[Phone], [Nokia N80], [include], [sales program], [discount price]

This statement is from the case study further presented in section 4 and it means that phone Nokia N80 should be included in the sales program at discount price for the reason of attracting new customers.

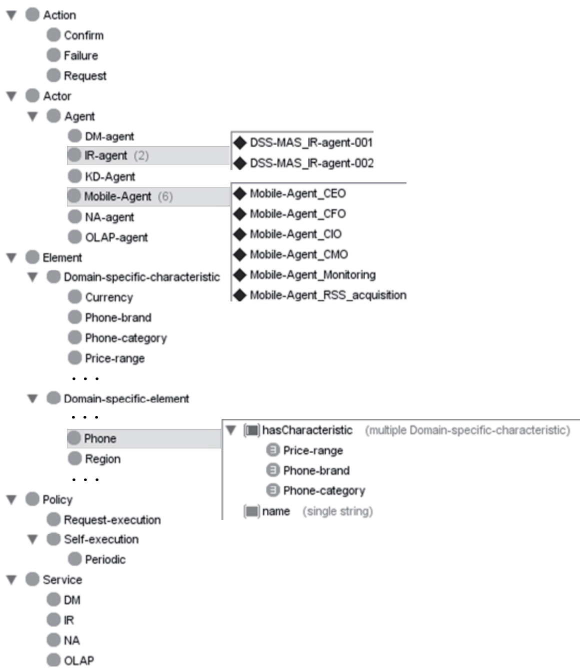

Figure 6: Excerpt from Common ontology

The portion of Common ontology that is used by KDA is depicted in Figure 6. Besides already mentioned elements it also defines policy for execution of agents that is constantly monitored by KDA. If for example initial setting for OLAPA is to run Sales OLAP analysis every day and the results hardly change after 5 executions, the execution period is to be altered. The ontology also contains information about available service that agents offer and security for service invocation.

3.6. Notifying agent

As depicted in Figure 1 Notifying Agent (NA) represents an entry point to DSS-MAS for all external applications and business users. The main role of NA is the information dissemination by simply delivering the right information at the right time to the right users. While in vast majority of today's applications users have to request the information using so called "pull model" in our approach we implemented the "push model", where information is proactively delivered by agents to the user without a specific request. This is achieved by making system context aware and considering the relevant features of the business, i.e. context information such as time, location, position in the organisational hierarchy etc.

All knowledge about notification is captured in Notifying ontology (see Figure 7), where every user has his own context defined and the position within organisation across two dimensions – organisational unit (e.g. Marketing, Sales, Human resources etc.) and decision making level (e.g. CEO, CIO, CFO etc.). According to that position rules for delivery of several message types are defined. These message types range from Notification to Warning and Critical alert. Each message also addresses the domain of specific organisational unit, e.g. when a new mobile phone is found online at competitor's website, Chief Marketing Officer (CMO) and Chief Analytics Officer (CAO) have to be notified. Organisational structure also defines that both CMO and CAO are inferior to Chief Executive Officer (CEO) therefore he is also notified, but only in a case of a Critical alert.

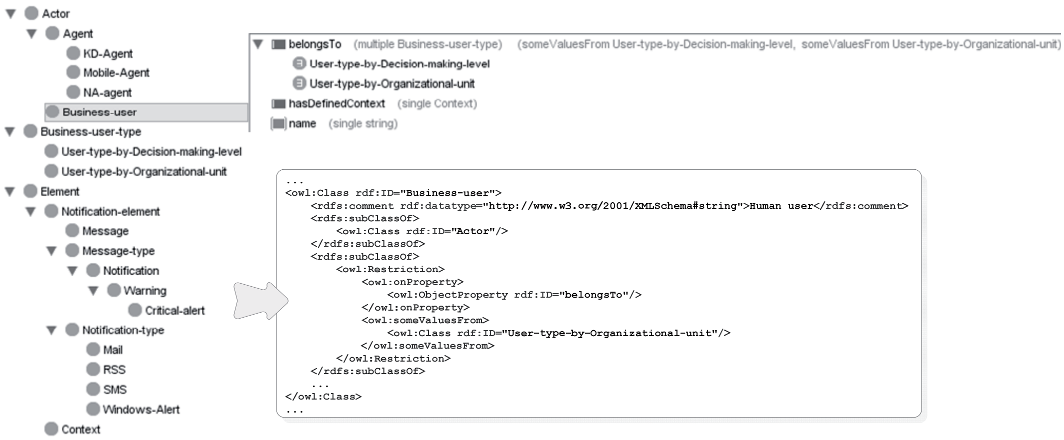

Figure 7: Excerpt from Notifying ontology

According to the business user profile, notification can be sent using several technologies from Windows Alert, e-mail, RSS, SMS etc. These notification types are also ordered by priority for each business user and according to this type the content is also adapted.

3.7. Mobile agent

Mobile agent is an example of an application that can reside on a mobile device (e.g. PDA, mobile phone etc.) and uses resources of DSS-MAS through Notifying Agent (NA). The typical use case includes sending mobile agent across network to DSS-MAS, where all needed information according to owner context is collected and then the mobile agent is returned back to originating location on a mobile device and presents the collected data to business user. When the process of acquiring data is in progress, business user does not have to be connected to the network, he can just wait offline until mobile agent is ready to return with the findings.

4. Prototype implementation and discussion

The selected language for ontology presentation was OWL DL [28], since it offers the highest level of semantic expressiveness for our needs and is one of the most widely used ontology language nowadays that has extensive support in different ontology manipulation tools. Besides OWL logical restrictions, SWRL rules were also used due to its human readable syntax and therefore supporting our business rules oriented approach to knowledge management. SWRL rules are stored as OWL individuals and are described by OWL classes contained in the SWRL ontology. This approach enables us storing schema, individuals and rules in a single component, which makes management much easier. SWRL rule form in a combination with templates that we introduce is very suitable for knowledge acquisition by business users that do not have extensive technical knowledge. An example of a rule from DSS-MAS defines that the message of type Critical-alert-Level-3 has to be sent to Chief Executive Officer (CEO) and takes the following form in SWRL syntax

$$Message(?m) \land hasMessageType(?m, ?t) \land sameAs(?t, Critical\text{-}alert\text{-}Level\text{-}3) \rightarrow hasRecipient(?m, CEO)$$

while user enters it using a template in a following syntax

IF *[Message] [has type] [Critical-alert-Level-3]*
THEN *[Message] [has recipient] [CEO]*

The user interface for ontology manipulation for business users is based on Protégé editor [32] and SWRL Tab for Protégé [33]. It enables entering OWL individuals and SWRL rules where a step further is made towards using templates for entering information (see Figure 8). With the use of templates with ontology, business logic is excluded from the actual programming code whereas the majority of data for templates is acquired from restrictions and natural language descriptions in ontology, while others are prepared by users with technical knowledge.

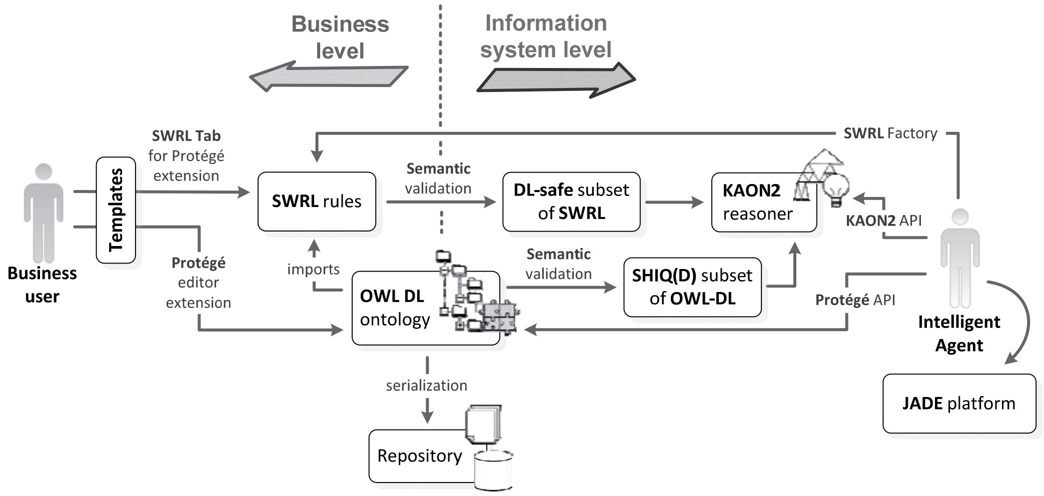

Figure 8: Prototype implementation architecture

At the execution level KAON2 reasoner is used to enable inference capabilities. Due to limitation of SHIQ(D) subset of OWL-DL and DL-safe subset of SWRL language, before inference is conducted, semantic validation takes place to ensure that all preconditions are met. The rules and entities from ontologies are employed as knowledge representation mechanism in agents.

Agents use OWL ontologies with the combination of SWRL rules for their internal memory representation. The agent memory is initialized upon start up from belonging ontology (see Figure 2) as described in section 3. Manipulation with ontology classes, individuals and rules is implemented using Protégé API, while write back of rules in SWRL syntax is conducted with SWRL Factory API [33]. The access to derived knowledge within the KAON2 reasoner is performed by using KAON2 API.

We selected FIPA compliant Multi-Agent System platform JADE [36] in DSS-MAS as it offers broad range of functionality and is most widely used platform. This is due very good support and availability of agent framework, where a lot of common tasks are already implemented (i.e. agent communication at the syntax level, agent management, migration of agents etc.). For Mobile Agent implementation an add-on JADE-LEAP [5] was used to support the mobility of agents.

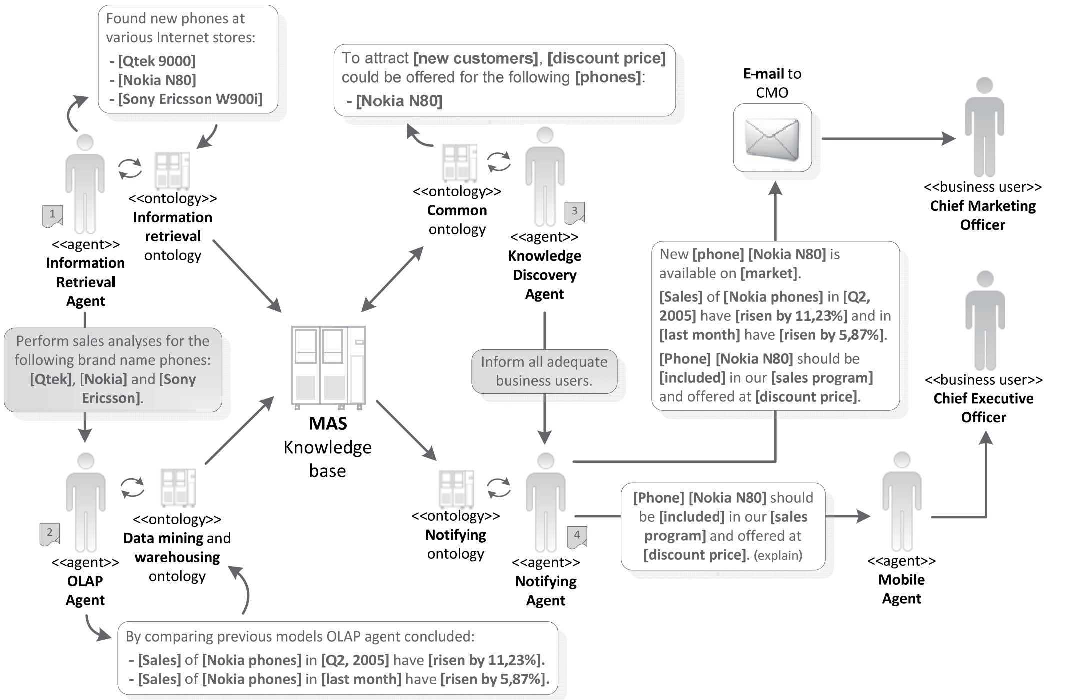

Figure 9: Use case from DSS-MAS

One of the use cases from DSS-MAS is depicted in Figure 9. This example is triggered by a result of Information Retrieval Agent (IRA) where three new mobile phones: Qtek 9000, Nokia N80 and Sony Ericsson W900i are found at online mobile shops. According to the execution policy from Common ontology, OLAP Agent (OLAPA) is notified with a request to re-run all Data Warehouse analyses where brands of identified phones can be found in dimension elements. After running OLAP analysis of Sales schema from Figure 3 with restrictions of Nokia brand in Phone dimension and last year in Date dimension OLAPA creates a report as following:

[Sales], [Nokia phones], [Q2, 2009], [risen by 11,23%]
[Sales], [Nokia phones], [Last month], [risen by 5,87%]

The fields that appear in the report are all instances of **Domain-specific-element** from Common ontology (see Figure 6). After these findings have been updated into ontology, Knowledge Discovery Agent (KDA) will be executed to derive new knowledge. One of the business rules defined in the organisation and also captured in ontology states that if there has been consecutively rise of sales of certain phone brands and a new phone has appeared on the market, then organisation should offer this product at discount price to attract new customers. Therefore the result of KDA is the following finding:

[New customer], [Discount price], [Phone], [Nokia N80]

After consolidation of all new findings KDA informs Notifying Agent (NA) to forward notifications to appropriate users. The result of inference of NA is the list of business users that have to be notified about this event. It shows that in this case Chief Marketing Officer (CMO) and Chief Executive Officer (CEO) have to be notified whereas their context has to be considered. According to CMO's preferences an e-mail is sent with the following content:

New [Phone] [Nokia N80] is available on [market].
[Sales] of [Nokia phones] in [Q2, 2009] have [risen by 11,23%] and
in [last month] have [risen by 5,87%].

[Phone] [Nokia N80] should be [include] in our [sales program] and offered at [discount price].

The CEO uses a Mobile Agent on his mobile device and is also notified by a truncated message of new finding, while explanation is available upon request.

5. Conclusion and future work

A Data Warehouse (DW) system is constructed over several heterogeneous data sources. Some of these sources are internal to the organisation, while others are external and originate from an independent business organisation. As DW systems have improved, external data has become increasingly important to improve OLAP analyses and decision making process. The specific data (i.e. competitors' offers) may only exist on the Web. Since the Web is the platform for information publishing, it can also be viewed as the biggest resource of information of any type. There is a lot of valuable specific business data like the newest product announcement and other generic business data.

Documents in the Web, enterprise repositories, and public document management systems are all growing. This vast majority of data is managed to some level but knowledge workers, managers, and executives still have to spend much of their working time reading dozens of various types of electronic documents spread over several sources. There is just too much information to digest in a daily life. The fast growing and tremendous amount of documents has far exceeded the human ability for comprehension without powerful tools.

In this paper we discussed Multi-Agent System for Decision Support in Enterprises (DSS-MAS) where internal and external data was integrated using agent-oriented approach and ontologies as a common interpretation basis for data and metadata. Agents were used due to their mentalistic notions for modelling, similarities between the agent in the MAS paradigm and the human actor in business organisations and also great possibilities for the use of ontologies as their knowledge base. The external information from the Web was integrated with the data in organisation's DW and after applying business rules new knowledge was derived by employing agents' inference capabilities. Tasks like information retrieval from competitors, creating and reviewing OLAP reports are autonomously performed by agents, while business users have control over their execution through knowledge base in ontology. The research also emphasized agent-to-business user communication and trying to minimize that gap. This was accomplished by introducing different views on ontologies for business user and agent. While agents dealt with formal description of business concepts, logical restrictions and rules, business user had simplified view on formal description of knowledge. User was able to manipulate with ontology through templates, where very little technical knowledge was required. The role of the mediation mechanism was then to translate these business level concepts into formal descriptions at information system level.

This approach was verified and implemented using a case study from the domain of mobile communications, where the aim was to provide the knowledge worker an intelligent analysis platform that enhances decision making process. The domain was limited to supply and demand of mobile phones and its accessories in one of the mobile operators in Slovenia. The system framework described in this paper has been implemented in Java and using mainly open source technologies.

This article has only been able to touch on the most general features of business rule approach for ontology management. Further work will be focused on integration with Business Rules Management Systems (BRMS). In BRMS's abstraction hierarchies from business level to information system level are more precisely defined and therefore facilitating business users to enter business rules in a form very similar to natural language. This enables business users really to focus on the content and not on the specification language syntax, but further work has to be devoted to building the mediation mechanism that is in the domain of technical users. With this approach the knowledge will be codified in an ontology language and available for employment in other systems. This all leads to the

Semantic Web vision with the availability of semantically annotated data where agents or other software will be able to deduce new knowledge by inferring from several ontologies.

6. References

[1] Abou-Zeid, E.S., What can ontologists learn from knowledge management? *Journal of Computer Information Systems*, 2003. 43(3): str. 109-117.

[2] Bernaras, A., I. Laresgoiti, in J. Corera. Building and resusing ontologies for electrical network applications. v zborniku '*European Conference on Artificial Intelligence (ECAI '96)'*. 1996.

[3] Boloni, L., et al., Software engineering challenges for mutable agent systems. *Software Engineering for Multi-Agent Systems Ii*, 2004. 2940: str. 149-166.

[4] Buche, P., et al., Fuzzy semantic tagging and flexible querying of XML documents extracted from the Web. *Journal of Intelligent Information Systems*, 2006. 26(1): str. 25-40.

[5] Caire, G. in F. Pieri. LEAP User guide. Posodobljeno 20.1.2006; dostopno na: http://jade.tilab.com/doc/LEAPUserGuide.pdf.

[6] Cao, L.B., et al., Ontology services-based information integration in mining telecom business intelligence. *Pricai 2004: Trends in Artificial Intelligence, Proceedings*, 2004. 3157: str. 85-94.

[7] Caplinskas, A., A. Lupeikiene, in O. Vasilecas, The role of ontologies in reusing domain and enterprise engineering assets. *Informatica*, 2003. 14(4): str. 455-470.

[8] Chen, M., Q.M. Zhu, in Z.X. Chen, An integrated interactive environment for knowledge discovery from heterogeneous data resources. *Information and Software Technology*, 2001. 43(8): str. 487-496.

[9] Clark, K.L. in F.G. McCabe, Ontology oriented programming in Go! *Applied Intelligence*, 2006. 24(3): str. 189-204.

[10] Garces, P.J., J.A. Olivas, in F.P. Romero, Concept-matching IR systems versus word-matching information retrieval systems: Considering fuzzy interrelations for indexing Web pages. *Journal of the American Society for Information Science and Technology*, 2006. 57(4): str. 564-576.

[11] Gruber, T.R., A Translation Approach to Portable Ontology Specifications. *Knowledge Acquisition*, 1993. 5(2): str. 199-220.

[12] Guarino, N. Formal Ontology and Information Systems. v zborniku '*FOIS'98'*. 1998. Trento, Italy: IOS Press.

[13] Jovanović, J. in D. Gašević, Achieving knowledge interoperability: An XML/XSLT approach. *Expert Systems with Applications*, 2005. 29(3): str. 535-553.

[14] Kang, N. in S. Han, Agent-based e-marketplace system for more fair and efficient transaction. *Decision Support Systems*, 2003. 34(2): str. 157-165.

[15] Kishore, R., H. Zhang, in R. Ramesh, Enterprise integration using the agent paradigm: foundations of multi-agent-based integrative business information systems. *Decision Support Systems*, 2006. 42(1): str. 48-78.

[16] Lee, W.P., Applying domain knowledge and social information to product analysis and recommendations: an agent-based decision support system. *Expert Systems*, 2004. 21(3): str. 138-148.

[17] Lee, Y. in Q. Chong, Multi-agent systems support for Community-Based Learning. *Interacting with Computers*, 2003. 15(1): str. 33-55.

[18] Lei, Y., E. Motta, in J. Dominque. IIPS: An Intelligent information presentation system. v zborniku '*7^{th} International Conference on Intelligent User Interfaces'*. 2002. San Francisco, USA.

[19] Liao, L.J., K.Q. Xu, in S.S.Y. Liao, Constructing intelligent and open mobile commerce using a semantic web approach. *Journal of Information Science*, 2005. 31(5): str. 407-419.

[20] Liao, S.H., Expert system methodologies and applications - a decade review from 1995 to 2004. *Expert Systems with Applications*, 2005. 28(1): str. 93-103.

[21] Macias, J.A. in P. Castells, Providing end-user facilities to simplify ontology-driven web application authoring. *Interacting with Computers*, 2007. 19(4): str. 563-585.
[22] Marotta, A., R. Motz, in R. Ruggia, Managing source schema evolution in Web Warehouses. *journal of the Brazilian Computer Society*, 2002. 8(2): str. 20-31.
[23] Naumenko, A., S. Nikitin, in V. Terziyan, Service matching in agent systems. *Applied Intelligence*, 2006. 25(2): str. 223-237.
[24] Orgun, B. in J. Vu, HL7 ontology and mobile agents for interoperability in heterogeneous medical information systems. *Computers in Biology and Medicine*, 2006. 36(7-8): str. 817-836.
[25] Paraiso, E.C. in J.P.A. Barthes, An intelligent speech interface for personal assistants in R&D projects. *Expert Systems with Applications*, 2006. 31(4): str. 673-683.
[26] Qiu, R.G., Towards ontology-driven knowledge synthesis for heterogeneous information systems. *Journal of Intelligent Manufacturing*, 2006. 17(1): str. 99-109.
[27] Rivest, S., et al., SOLAP technology: Merging business intelligence with geospatial technology for interactive spatio-temporal exploration and analysis of data. *Isprs Journal of Photogrammetry and Remote Sensing*, 2005. 60(1): str. 17-33.
[28] Russomanno, D.J. in C.R. Kothari, Expressing inter-link constraints in OWL knowledge bases. *Expert Systems*, 2004. 21(4): str. 217-228.
[29] Shan, F., et al., A programmable agent for knowledge discovery on the web. *Expert Systems*, 2003. 20(2): str. 79-85.
[30] Singh, S., P. Vajirkar, in Y. Lee, Context-based data mining using ontologies. *Conceptual Modeling - Er 2003, Proceedings*, 2003. 2813: str. 405-418.
[31] Soo, V.W., et al., A cooperative multi-agent platform for invention based on patent document analysis and ontology. *Expert Systems with Applications*, 2006. 31(4): str. 766-775.
[32] Stanford Medical Informatics. Protégé. dostopno na: http://protege.stanford.edu.
[33] Stanford Medical Informatics. SWRLTab. dostopno na: http://protege.cim3.net/cgi-bin/wiki.pl?SWRLTab.
[34] Suomela, S. in J. Kekalainen, User evaluation of ontology as query construction tool. *Information Retrieval*, 2006. 9(4): str. 455-475.
[35] Tewari, G., J. Youll, in P. Maes, Personalized location-based brokering using an agent-based intermediary architecture. *Decision Support Systems*, 2003. 34(2): str. 127-137.
[36] TILAB. Java Agent DEvelopment Framework. dostopno na: http://jade.tilab.com.
[37] Tseng, F.S.C. in A.Y.H. Chou, The concept of document warehousing for multi-dimensional modeling of textual-based business intelligence. *Decision Support Systems*, 2006. 42(2): str. 727-744.
[38] van Elst, L. in A. Abecker, Ontologies for information management: balancing formality, stability, and sharing scope. *Expert Systems with Applications*, 2002. 23(4): str. 357-366.
[39] Williams, A.B., Learning to share meaning in a multi-agent system. *Autonomous Agents and Multi-Agent Systems*, 2004. 8(2): str. 165-193.
[40] Wongthongtham, P., et al., Ontology-based multi-site software development methodology and tools. *Journal of Systems Architecture*, 2006. 52(11): str. 640-653.
[41] Wooldridge, M., An Introduction to MultiAgent Systems. 2002, Chichester, England: John Wiley & Sons.
[42] Zhou, L., Q.E. Booker, in D. Zhang. ROD - Toward Rapid Ontology Development for Underdeveloped Domains. v zborniku '*35^{th} Hawaii International Conference on System Sciences*'. 2002.
[43] Zhu, Y., et al., Materializing Web data for OLAP and DSS. *Web-Age Information Management, Proceedings*, 2000. 1846: str. 201-214.