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PERFECTING THE SYNERGIC EFFECT IN HYBRID MULTI-AGENT SYSTEMS

Abstract: The validity of applying hybrid multi-agent system for the purposes of solving a given problem, when compared with other technologies, should stem from their unique features, and should also allow for an additional effect, which may be a result of agents cooperating and connected to distributed processing. The effect obtained by the agents can be called the synergic effect. To achieve and perfect this effect, in the paper a normative knowledge metamodel was proposed as an element of hybrid multi-agent system, designed in OWL ontology language. The first part of the study outlines the concept of hybrid multi-agent systems, as presented in literature, followed by the elaboration upon the term synergic effect. Based on this groundwork, the application of the hybrid multi-agent system was illustrated, a system designed by the author and applied for the purpose of achieving the synergic effect based on the normative knowledge metamodel, employed to support the process of filling out electronic documents. The final part of the study contains conclusions pertaining to the discussed issues.

Keywords: hybrid agent, multi-agent system, synergic effect, knowledge metamodel.

1. Introduction

In recent years, the author has participated in research focused on the concept of applying an interface agent to assist in decision-making processes, finalized by the implementation of the ASISSO system. This led to research on the concept of constructing multi-agent solutions, particularly hybrid multi-agent systems. Such systems, whose purpose is to manage the interface agent's functions and which are linked with recent postulates concerning communities of software agents and the development of ontology, should facilitate decision-making processes by providing novel knowledge processing mechanisms.

Semantic web development and issues related with users interacting, observable currently in various types of social portals, create an opportunity to research the application of both these concepts in the e-administration development process. Applying internet users' knowledge and new software agent technology, which aids users' interactions and is based on domain knowledge models, allows us to indicate the manner in which these two research trends could contribute to the development of intelligent decision support systems, especially knowledge-based decision support systems.

Such solutions, in order to show the effectiveness of their application, should generate a positive effect, as a consequence of their use in a particular field. That effect, a result of the cooperation of agents aided by the employment of various domain knowledge representation mechanisms, could be described as the synergic effect.

The first part of the study outlines concept of hybrid multi-agent systems, as presented in literature, followed by an elaboration upon the term synergic effect. Based on this groundwork, the application of the hybrid multi-agent system will be illustrated, a system designed by the author and applied for the purpose of achieving the synergic effect based on the normative knowledge metamodel, employed to support the process of filling out electronic documents. The final part of the study contains conclusions pertaining to the discussed issues.

2. Hybrid multi-agent systems

The aim of research oriented on the application of artificial intelligence methods is to construct solutions that would mimic human features, such as autonomy, adaptability, self-organization, mobility, personification and cooperation. The agents cannot be defined solely in these terms, but there is a clear tendency to view them as more than algorithms or programs. This is the result of a higher abstraction level, which we bestow upon these artifacts, in relation to expert systems and solutions based on object languages. Software agent can be defined as follows: “An agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives” [Weiss 1999] and “autonomous agent is a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to affect what it senses in the future” [Luck, Ashri, D’Inverno 2004]. As the definitions show, viewing agents as reactive units, as in the first definition, is being displaced by the proactive approach which defines the agent as a unit capable of analyzing its environment and responding to changes in it, particularly to operations performed by other units in a given system.

Solutions in which particular agents interact, based on cooperation or competition [Symeonidis, Mitkas 2005], are called multi-agent systems, which classically [Zambonelli, Jennings, Wooldridge 2003] “can be conceived in terms of an organized society of individuals in which each agent plays specific roles and interacts with other agents according to protocols determined by the roles of the involved agents”. Authors also agree that agent organization is more than simply a collection of roles and “to effectively build a MAS in organizational terms, further organization-oriented abstractions need to be devised and placed in the context of a methodology”

[Zambonelli, Jennings, Wooldridge 2003]. From the agent technology perspective and their domain orientation, it is necessary to elucidate the concept of hybridity. Assuming that the feature-orientation of the agents is justified, we can point to the study [Nwana 1996], whose author shows the hybridity of agents in the context of their features. On the other hand the study [Bellifemine, Caire, Greenwood 2007] also assumes that the hybrid architecture combines both proactive and reactive behavior. Finally, within the framework of the construction of artificial intelligence concept, hybridity is perceived as the combination of different solutions, including different solutions of artificial intelligence [Stanek 2007].

Regardless of the approach, the hybridity of a multi-agent system, equivalent with greater complexity, should cause an increase in a system's functionality, which in turn provides better results.

3. The synergic effect

The validity of applying hybrid multi-agent systems for the purposes of solving a given problem, when compared with other technologies, should stem from their unique features, and should also allow for an additional effect, which may be a result of agents cooperating and connected to distributed processing.

The application of a multi-agent structure results mainly from the desire to construct units with low functionality, which makes their design and construction processes easier. However, the interactions among the agents in a particular system should also generate results that are better qualitatively or quantitatively than they would be if no such cooperation were taking place.

Interactions among the agents could be based on the mechanisms of cooperation or competition. While in the case of cooperation the observable task of the agents is to carry out common goals, and the result of their tasks can be viewed the sum of those actions, in the case of competition the effect of an agent's task is examined individually, an example being auction systems.

The effect obtained by the agents can be called the synergic effect. The word "synergic" is derived from the Greek words: *syn* – with, together; *ergon* – work, action. It was Aristotle who said that "the whole is more than the sum its parts", which expresses the need to view the functioning of a program holistically, in the context of the results it generates.

According to Piekarz [1991] within the framework of management science, it can be assumed that the synergic effect is "the phenomenon of joining particular factors, which create a complex effect, while fulfilling [...] formal conditions. The achieved complex effect differs, both quantitatively and qualitatively, from the base effect, and is valued higher. The definition can be expressed by an inequality (Es – complex effect, calculated as the synergic effect) > (B – base effect)". Given such a definition of the synergic effect, the base effect is the "result of isolated operations carried out within autonomic units, not united in cooperative relations by formalized, organizational relations" [Piekarz 1991].

In his work [Krzyżanowski 1992], the author points to a more formal definition of the effect, as "the difference between the joint *EF* effect, of operations carried out by a set of objects $\{P\}$, among which there is an cooperation (V), and the sum of individual *EF* effects, attainable by the objects acting individually (not cooperating)". This definition of the synergic effect is exemplified by the equation (1).

$$EF_{syn} = \mu[EF(\{P\},V) - \mu \left[\sum_{i=1}^{n} ef(P_i)\right]. \tag{1}$$

As indicated by the cited definitions, the interaction/cooperation of a system's elements should generate better effects than achievable by these elements working individually.

Within the framework of the hybrid multi-agent system concept and the knowledge-driven decision support system, the aim of constructing such solutions is to aid the actions of decision-makers. The interactions of separate agents in the hybrid multi-agent system should, therefore, provide a new and observable effect, which aids the decision-maker. From the point of view of the aforementioned decision support system concepts, the application of multi-agent structures should not be oriented at replacing the decision-maker in the decision-making process – it should generate results which support the process.

From the agent technology perspective it seems that synergy comes into existence due to interaction, or cooperation, within organized systems. The state of being organized, from the functional perspective, resulting from the organization of agents for the purpose of jointly realizing a given operation, or from an attributive perspective, where the roles of agents clearly determine their tasks, is a result of an attempt to aid decision-makers' actions. It can be assumed that the synergic effect is a phenomenon occurring in a particular dynamic system, organized in a specified structure whose elements display cooperation features. Such features are noticeable in hybrid multi-agent systems and may be the result of the agents' interaction/cooperation in the multi-agent system, the agents' monitoring their common actions, and their ability to shape other units [Kamilka, Tambe 1998].

Norms, principles or rules of interaction among agents may be the elements supporting these actions, defining the agents' desirable behavior and regulating the *modus operandi* of particular tasks. These norms, according to the accepted postulates concerning the application of standards in hybrid multi-agent systems [Żytniewski 2009], based on the defined mechanisms of their representation and interpretation, may influence the actions of the agents by indicating successive goals, and at the same time enable monitoring the agents and indicating which actions are desirable from the established agents' reputation mechanism perspective.

4. Agents' knowledge, an element serving to perfect the synergic effect

The application of the hybrid multi-agent system in a particular field should be preceded by determining how its knowledge is to be represented. Presently, approaches to semantic internet construction are oriented on the application of ontology as a building block in the construction of hybrid multi-agent systems' knowledge models. Ontologies, to be understood as the language used to describe ontology and which provide knowledge model construction mechanisms due to their clearly defined metamodel, enable the creation of hybrid multi-agent systems' knowledge databases. The agents carry out tasks provided for them by the decision-maker and are supported by a specific knowledge model, which in turn supports the construction of artificial intelligence elements. The agents can thus utilize stored knowledge and support the decision-maker. The previously mentioned synergic effect can be a result of their actions.

Research conducted by the author of this study, concerning the construction of hybrid multi-agent systems which would aid decision-makers, allowed the creation of a normative knowledge metamodel, based on OWL language. Normative knowledge metamodel is defined as the combination of a chosen ontology-describing language, which defines the representation means of the system's knowledge model, a domain knowledge model utilized in the agents' task realization process, and a knowledge model concerning norms and determining the agents' cooperation methods within the hybrid multi-agent system. The use of the term metamodel in the portrayed solution resulted from the assumed interaction hierarchy in the models being defined. To define the knowledge models, the approach of Noy and McGuinness, as appears in their study [Sobczak 2006] was assumed. The metamodel suggests a series of concepts, based on which a reasoning mechanism of the agent could be built. The agents can have the following beliefs:

- **Norms** – prohibitions, obligations, permission for an agent to carry out an operation within the system.
- **Effect** – defines the effects of insubordination or subordination to rules defined in the system's domain data base. The effect can be either a reward or a sanction. The differentiation allows the agent to interpret whether an outcome of an operation determined by norms is positive or negative.
- **Agent** – an agent's entity. In the model being presented, an agent can be a unit defined by a norm or a unit responsible for following norms. The goals, plans and beliefs of agents can stem from their role in the systems, or can be directly attributed to a given unit.
- **Role** – defines an agent's roles in the system and constitutes the Addressee subclass.
- **Addressee** – defines which units are to be the addressees of which norms. It was assumed for the purposes of the project that only a Role can be the addressee of a norm. Addressee is defined due to the possibility of expanding the model.

- **Location** – the agents' possible mobility requires a definition of the location where the agent is obliged to act within its role.
- **Limits** – determines the limits set by norms. In the model being discussed, limits pertain to an agent's beliefs. This is a consequence of the assumption that an agent's actions stem from the knowledge it possesses.
- **Beliefs** – are the knowledge than an agent possesses. Nomenclature is in accordance with the assumptions of BDI architecture.
- **Goals and plans** – the components of a BDI agent, as for BDI agents within the JADEX platform.
- **Address**, address information.
- **Working hours**, the days and hours in which an individual is at work.
- **Document**, information about documents which can be used in a given service.
- **Employee**, basic employee information, employees' tasks, functions, and possible forms of contact.
- **Citizen**, allows basic information concerning a resident to be defined.
- **Service**, defines which services are available to customers.
- **Coordinates**, stores information about the geographical coordinates of an address or area.
- **Contact information**, stores information concerning a given person's contact information.
- **Fee**, stores information concerning the costs of a given service.
- **Legal basis**, stores information concerning a service's legal basis.
- **Deadline**, stores information concerning the date that a service is to be finalized.
- **Category**, a class of objects, will enable the integration of knowledge concerning services with the SEKAP system, where services are categorized by subject.

Thus defined normative knowledge metamodel, based on OWL language, will allow research on obtaining and perfecting the synergic effect in hybrid multi-agent systems, in the context of citizen support.

5. The application of the synergic effect for the purposes of citizen support

In order to fill in forms or e-files, a decision-maker must enter various data, frequently repeatedly inputting the same data. Often problems appear as to the meaning of particular items. The problem is significant especially now, due to the development of e-administration, which enables contact with various government offices, as well as filling in forms, over the internet. Direct contact with office personnel and direct assistance will thus be more difficult. In the defined domain knowledge model, the Document concept may be the element which defines such files. It may be assigned to a specific service in a specific government office or institution. The Document concept could also be used to represent any e-form, whilst the "Service" concept could be designed to determine the way the form is used, e.g. to input data concerning shipping in an online store (Figure 1).

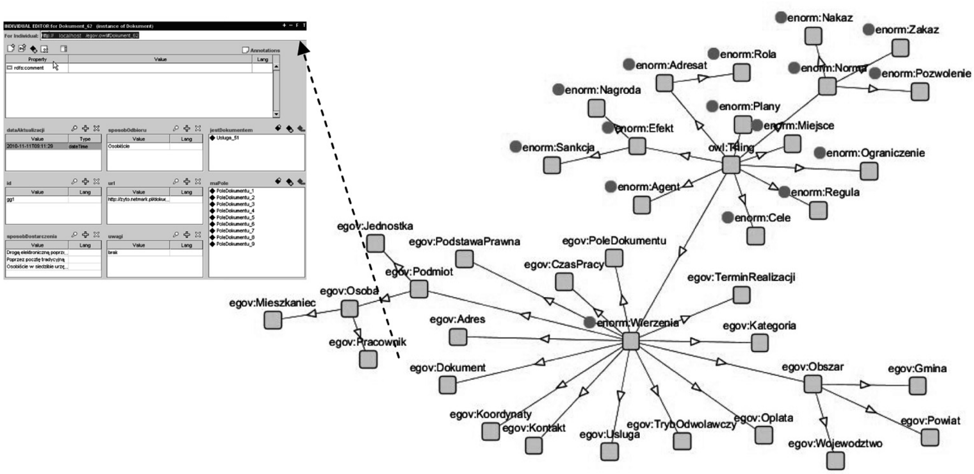

Figure 1. Normative knowledge metamodel and its concept Document

The popularization of the semantic internet and interface agents, which would support users' actions, should in the short time enable the creation of solutions capable of interpreting a user's actions and adding them to their knowledge databases.

An agent reading data from a form filled int by the user can store the data in a database. URI/URL addresses and date of the last update can be used as user IDs. Stored data entries, saved in the agent's database, can be reused to construct the same document. Current web browsers already have these options, but the saved data is represented in the browser's internal format.

The development of the concept of knowledge discovery processes is linked with discovering dependencies in vast data bases. In case of electronic file application, discovering dependencies can involve – based on the client-server structure – sending many files from different users to a knowledge discovery system, discovering relations between them and generating conclusions in the form of dependency rates.

In the case of electronic files in the possession of different users and containing different content, such a solution is not acceptable, as it would require sharing personal data.

The structure of the hybrid multi-agent system might be the solution to that type of problem. The system, due to its knowledge representation mechanisms, could generate hints concerning the file without sharing its content.

For experimental purposes, the hybrid multi-agent system's architecture was designed, elements of which are shown on Figure 2.

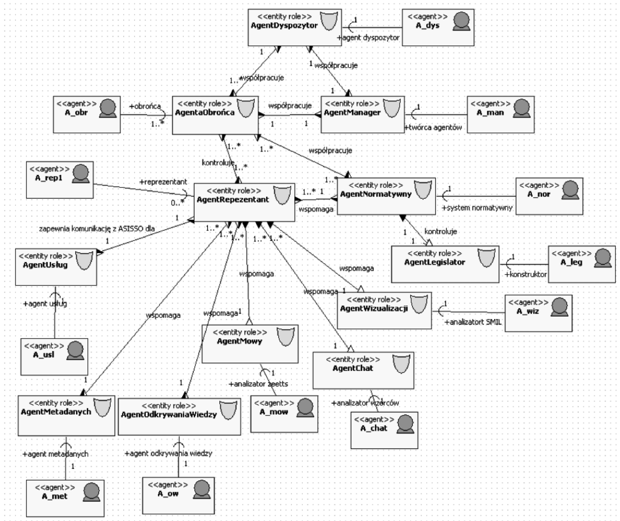

Figure 2. Hybrid multi-agent system architecture

The main element of that architecture was the role of a representative agent, which indicated the unit acting on behalf of a citizen within the hybrid multi-agent system. An integrative element of the ASISSO system was the role of a service agent, which communicated with the ASISSO agent with the help of a defined remote invoke procedure mechanism.

The communication between the representative agent and the service agent was based on FIPA communication standards for multi-agent platforms. The currently available technology and web-design methods cannot be used to obtain real documents, which is why files prepared by the experimenters were used during the experiment.

Multiple ASISSO agents were defined as part of the experiment, each possessed over one hundred electronic files. The tests were done on the JADE platform. Each ASISSO agent had access to files (up to twenty files), which contained personal details of the person that agent was representing. It was assumed that a person assisted by the ASISSO agent would try generating a completely new file.

Unfortunately, the original assumptions of the ASISSO system did not allow such a process to be supported by the agent, as the extent of the agent's knowledge was not great enough. It could only utilize the hints defined for it by office personnel, for a given file (Figure 3).

The hybrid multi-agent prototype system operated as follows. First, a user chooses the file he or she wanted to generate. The ASISSO agent informs (with the help of an agent acting as the AU service agent) the agent acting as the representative agent (AR) which file requires a hint and which files are in the user's possession. Only the metadata of those files was transferred, defined in the domain knowledge model (strictly speaking in the "Document" concept) (Figure 4).

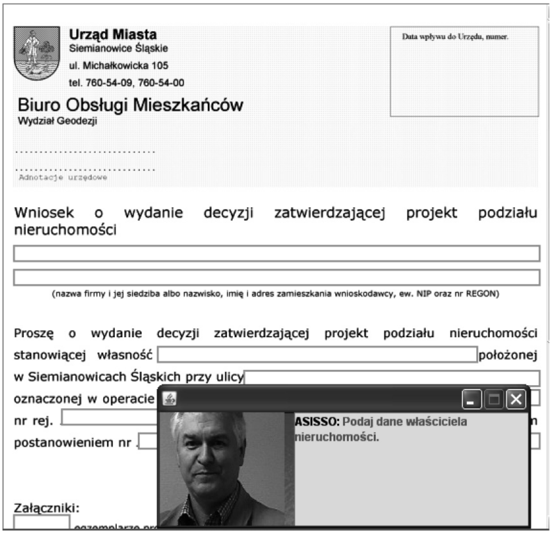

Figure 3. Sample interface agent hint

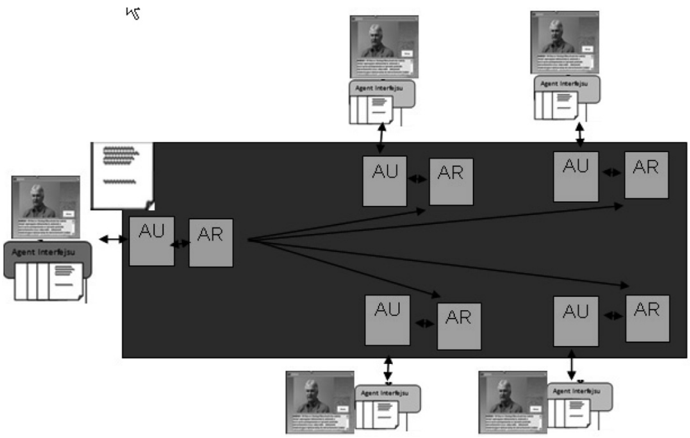

Figure 4. Agent AR ask for documents

The AR agent, created when the ASISSO system merged with the multi-agent platform, checked for the presence of other representatives in the system. It passed on information concerning the files being created and files in the user's possession. Each ASISSO agent received the message, and in turn checked if it was in possession of the destination file or any of the files already in the possession of the agent initiating the process. If so, the agents generated a matrix of relations, and determined whether there were any similarities in the entered data, on the basis of a defined certification function. The results were sent to the representative agent, the initiator of the process.

On the basis of answers collected from individual agents, the initiating agent generated a collective matrix of relations, integrating – with the help of an algorithm – the partial matrices. As a result, new knowledge was acquired by the agents, concerning possible relations between document fields, in files owned by the user (Figure 5).

The normative agent was to indicate whether the goal of an AR agent's actions is causing results, such as the need for secondary goals (Figure 6).

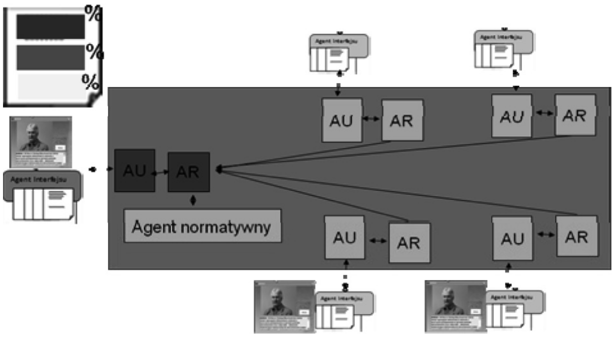

Figure 5. Agents return results

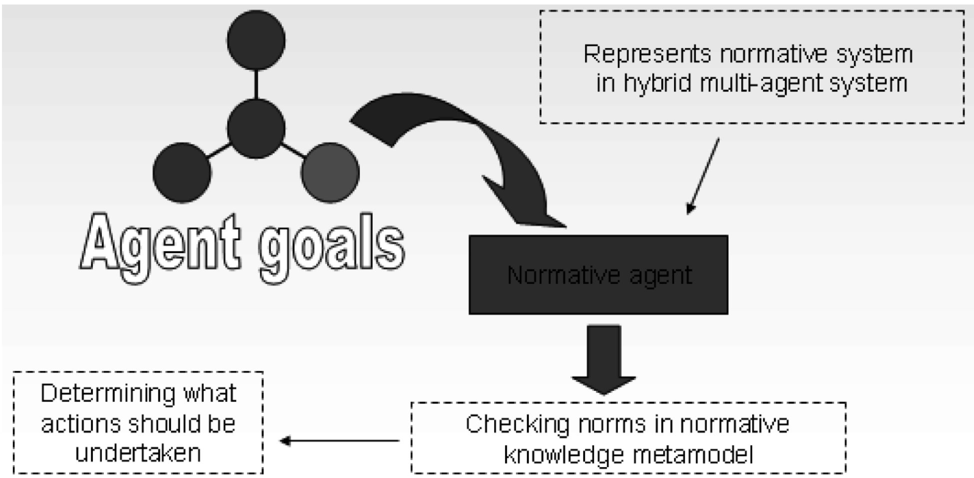

Figure 6. Generating an answer

In the presented example, in the phase of generating a collective matrix of relations, the normative agent's goal was to indicate – in the form of an order – what additional action plans should be undertaken by the representative agent in order to reduce the set of agents taken into consideration in the calculations. The action plan can be defined in the course of its creation or during the connection with the multi-agent platform. The agents not authorized by the hybrid multi-agent system to initiate such a process are rejected. The regulating norm protected the hybrid multi-agent system from the actions of undesired units, yet a representative agent could disobey the norm if the units generated new hints, not indicated by other agents.

The knowledge newly generated could now be used by the ASISSO agent to generate a system hint, specifying for the user which values can be inputted and indicating the agent's compatibility percentage. The hint generating process is portrayed on Figure 7.

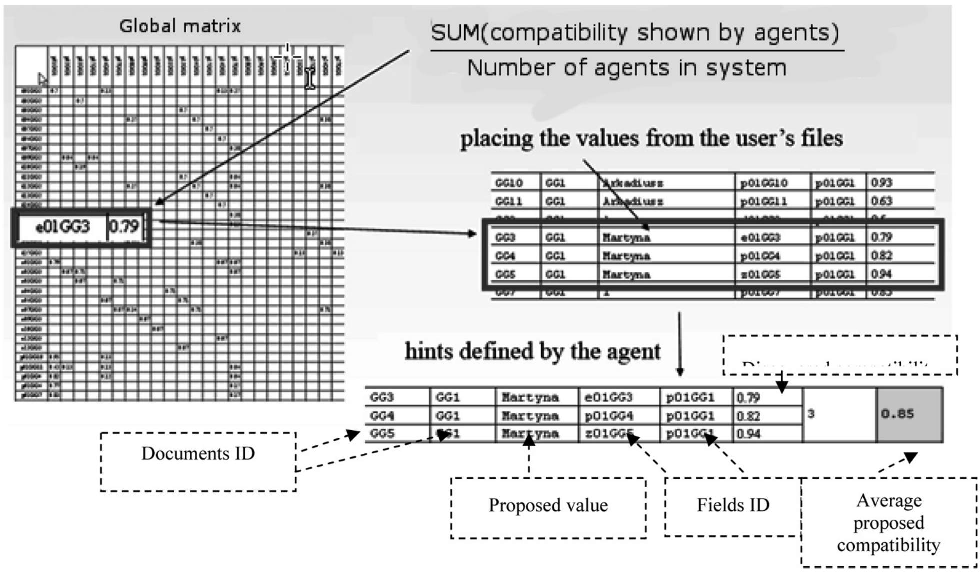

Figure 7. The hint generating process

The example proves that the application of the proposed hybrid structure facilitates the synergic effect, as new knowledge concerning the files is thus discovered.

The application of the proposed structure enabled new knowledge to be obtained, a result of the agents' cooperation, and support the hint generating process – as a result of hints generated by users and those stemming from distributed processing. The result confirmed that the cooperation of representative agents can generate a positive synergic effect.

The application of the mechanism of interpreting norms indicated the possibility of separating norms, principles and task realization rules to the agent's code, and further perfect the effect by limiting the number of agents taking part in the process.

Table 1 shows results generated by the system for the file "Application for the issuance of an identification card", defined on the basis on the SEKAP portal document.

Table 1. Document fragment: “Application for the issuance of an identification card”. An example of the system’s results

Field name	Value assumed as correct (according to the defined user’s profile)	Hint | System’s suggestion | (the representative agent’s compatibility with that score, on a scale of 0-1)
Name 1	Martyna	1. Martyna (0.85)
Name 2	Katarzyna	1. Katarzyna (0.82)
Surname 1	Wilska	1. Wilska (0.8)
Father’s name	Mateusz	none (not available in the possessed files)
Date of birth	1978-12-12	1. 1978-12-12 (0,76)
Place of birth	Chorzow	1. Chorzów (0.58)
Eyes	Blue	none (not available in the possessed files)
Height	165	none (not available in the possessed files)
Gender	F	1. F (0.71)
Postal code	41-902	1. 41-902 (0.86)
Residence (P/T)	P	none (not available in the possessed files)
City	Bytom	1. Bytom (0.71)
Street	Powszechna	1. Powszechna (0.86)
House number	132	1. 132 (0.84)
Apartment number	11	1. 11 (0.67)

The study revealed that adding a second user’s profile to the file set caused the system to generate additional hints concerning the new files. The system generated two hints, indicating alternative values, based on both document sets.

The experiment reveals that the application of the chosen agent domain model concept facilitated/perfected the process, enabling the separation of data stored in a file from their description (the metadata), and allowing conclusions to be drawn based on the same concept range. This ensured that users remain anonymous and facilitated the agents’ communication process by allowing for the semantic interpretation of sent messages, an outcome of the application of the domain knowledge model. As only fragments of metadata were sent, the data’s size was reduced. The user was provided with additional hints, which could facilitate the electronic file generation process.

The proposed norm mechanisms allowed the regulating norms to be separate from the representative agent’s code. The multi-system agent, and particularly its normative agent role, indicates which actions are to be undertaken by the entire community of agents within the system. This normative subsystem can perfect agent cooperation and possible effect of this cooperation, synergic effect.

6. Summary

The application of ontologies, viewed as the descriptive language of ontology, in the context of agent-based solutions, enables the creation of elements which support distributed processing, where individual heterogeneous units cooperate within same interpreted knowledge model.

The example illustrated that the synergic effect is possible to achieve with the use of agent technologies, which may be a relevant element of intelligent decision support systems. In these systems the agents may support the decision process by generating new knowledge.

This is especially significant from the e-administration perspective, as the eGovRTO2020 [Dawes 2008] report indicates that data and identity protection, trust, information quality, e-participation, the citizens' commitment, democratization processes, ontologies, intelligent technology and knowledge management will prove crucial in its development.

The structure applied, which facilitates the knowledge discovery process of agents within a given hybrid multi-agent system, provides complete information protection due to the fact that information is not shared with other agents. The system's architecture is linked with the concept of e-participation, as participation in the system may provide support for other users, as new knowledge is automatically generated in the hybrid multi-agent system.

The application of the normative knowledge metamodel has furthermore lead to an additional effect – new goals can be indicated for the agents, with respect to the goal an agent is currently dealing with. The result of an agent's actions, defined as a reward or a sanction, enables further research on agent reputation within the multi-agent system, where compliance with norms or their rejection will cause an increase (or decrease) in the agent's reputation. The author's future research will focus on these aspects.

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DOSKONALENIE EFEKTU SYNERGICZNEGO W HYBRYDOWYCH SYSTEMACH WIELOAGENTOWYCH

Streszczenie: zastosowanie hybrydowego systemu wieloagentowego w celu rozwiązania postawionego problemu powinno zapewnić uzyskanie dodatkowego efektu wynikającego z procesu kooperacji agentów oraz przetwarzania rozproszonego. Efekt takiej współpracy określany może być mianem efektu synergicznego. W celu doskonalenia tego efektu w niniejszej pracy zaproponowano elementy normatywnego metamodelu wiedzy, opracowanego na podstawie języka opisu ontologii OWL. W pierwszej części wskazane zostaną różne prezentowane w literaturze podejścia do hybrydowości systemów wieloagentowych oraz wyjaśnione zostanie pojęcie efektu synergicznego. Na tej podstawie wskazany zostanie przykład zastosowania opracowanego przez autora hybrydowego systemu wieloagentowego do uzyskania efektu synergicznego. Całość pracy zakończą wnioski dotyczące omawianej problematyki.