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Andrzej Bytniewski, Marcin Hernes, Kamal Matouk
Wroclaw University of Economics
e-mail: {andrzej.bytniewski; marcin.hernes; kamal.matouk}@ue.wroc.pl

A UNIVERSAL MODEL OF KNOWLEDGE CONFLICT RESOLVING USING CONSENSUS METHODS IN MULTI-AGENT DECISION SUPPORT SYSTEMS

Summary: The article presents a proposition of a universal model of knowledge conflict resolving using consensus methods, which can be used in a multi-agent decision support system. Knowledge conflicts often appear, when individual agents generate different solutions of the same problem. It is very difficult for the user – decision-maker to make a good decision because the analysis of solutions generated by agents is very time-consuming and the decision must be made quickly. Moreover, selecting one of the decisions on the basis of the experience of the decision-maker is very risky, because he/she could choose the worst solution. Consensus methods, however, allow to agree, on the basis of the solutions generated by agents, one solution, which is a compromise. As a consequence, reducing the time and decreasing the risk level of the decision taking process, to enable the functioning of the enterprise in more flexible.

Keywords: decision support systems, knowledge conflicts, multi-agent systems, consensus methods.

1. Introduction

The social and economic environment makes quick and accurate decision-making crucial for the competitiveness of a company. The economy forces company managers to make complex operational, tactical, yet most of all, strategic decisions that influence the future of the organization [Kisielnicki 2008]. Decision- makers are usually exposed to risk and doubt because they cannot foresee the consequences of their decisions, or their predictions have very low probability [Kubiak 2009; Matouk 2006].

The process of decision-making employs decision-making support computer systems [Bytniewski (ed.) 2005] as well as multi-agent systems [Badica et al. 2006; Ferber 1999]. Multi-agent systems significantly shorten the time necessary to make a decision because they relieve the decision-maker of the task of information processing and they are able to draw decision-based conclusions and react properly, following the conclusions, thus they can suggest various new solutions to the decision-maker [Korczak, Hernes, Bac 2013]. However, the final decision is made by the decision-maker who also takes responsibility for the results of the decision.

However, it often occurs that a multi-agent decision-making support system generates conflicts of different kinds among the agents, especially conflicts of knowledge [Sobieska-Karpińska, Hernes 2013]. Conflicts of knowledge result from the fact that agents may offer different decisions or solutions to the user, which in turn may result from different methods of supporting the process of decision-making employed by the agents. If a conflict of knowledge occurs in the system, the system is unable to generate a correct decision and, consequently the decision-maker will then have to make a decision without help from the system, which is time-consuming, requires a lot of work and can lead to a decision that is inaccurate and made with incomplete information.

The key element to make multi-agent systems work properly is to detect and identify conflicts of knowledge and to resolve them automatically. Professional literature does provide many examples of methods on how to resolve such a conflict, for instance through negotiation, arbitration or choice, yet they often require complex computations or the selected solution is not always accurate. Consensus methods are also in use allowing a single decision, among all decisions generated by all agents, to be presented to the user. In other words, all decisions from all agents are taken into consideration. This approach minimizes the risk of making a decision and also shortens the time necessary to run the process. Existing publications say that consensus-making algorithms strictly depend on the structure of knowledge representation in an agent, which differs with different kinds of decisions to be made. For instance, definitions of structures for financial decisions, supply chain management or environment monitoring are all different from one another. Such an approach makes it increasingly difficult to use consensus-making algorithms in practice, because each type of decision requires a different type of consensus-making software module to be created, which is a time-consuming and expensive process. The solution where consensus is made regardless of the nature of decision (in other words, regardless of the knowledge structure in the agents), may prove to be far more useful.

The aim of this article is to present a concept of a universal model for resolving conflicts of knowledge in a multi-agent decision-making support system, using the consensus method. The model will enable the system to resolve conflicts of knowledge connected with various types of economic decisions and, in turn, indicate a decision which will be satisfactory for the decision-maker.

2. Related works

Resolving conflicts of knowledge has become the subject of many scientific works and papers. The work by [Katarzyniak, Nguyen 2000] states that conflicts of knowledge result from incoherence or contradiction of knowledge among agents. Incoherence occurs when one agent claims that a given feature of domain occurs or does not occur in a given period of time, while another agent does not have the information or is not willing to address the feature in a given time period. Contradiction occurs when one agent claims that a given feature of domain occurs in a given period of time, while another agent claims that the same feature does not occur in the same period of time. The work by [Nguyen 2006] contains definitions of incoherence and contradiction broadened with different data values of features.

On the other hand, the article by [Yager 2000] deals with employing the techniques of approximation inference for the purpose of resolving conflicts of knowledge.

The work by [Subba Reddy, Nagabhushan 1997], instead describes a system which identifies hand-written symbols and resolves conflicts of knowledge which occur during the process of identification.

Often consensus methods are used for knowledge conflicts resolving [Hernes, Nguyen 2007; Nguyen 2006]. These methods consist of the opinion of parts of conflicts but they do not consist of the degrees of certainty. However to match fully the needs of decision-makers, a decision structure must consist of the degrees of certainty because most economic decision are taken in terms of risk or uncertainty. Nowadays such structures [Sobieska-Karpińska, Hernes 2010] and consensus algorithms as regards these decisions, are [Sobieska-Karpińska, Hernes 2013]. Work consisting of functional dependencies between attributes of structure of agent's knowledge, was also carried out [Zgrzywa 2007].

What follows from the conducted relevant literature review is that there are currently no effective ways of resolving conflicts of knowledge in multi-agent decision support systems, and therefore a consensus model is developed in a further part of this paper to enable resolution to such conflicts. As a consequence, this will lead to a situation where the system determines – on a real time basis – one scenario bringing satisfying benefits to the user in terms of quantity, timeliness and cost intensity of decisions as well as reducing the risk involved in the process of decision-making. Such behavior will enable a more effective and more flexible decision-making process, which will have a positive impact on the economic effectiveness of enterprises.

3. The universal model of knowledge conflicts resolving

Multi-agent systems are capable of finding information of adequate value and draw conclusions based on the findings [Sobieska-Karpińska, Hernes 2012]. The systems use up-to-date data necessary to take decisions, and they enable arriving at a quick solution to a given problem. Individual agents can act and make decisions on their own, without the interference of users or external factors. Agent programs used in electronic auction systems may serve as an example. However, if agents generate different versions of solutions, a conflict of knowledge among agents occurs in the system. The user expects a single version (a single decision) though. Therefore it is necessary to determine, from a group of solutions, a single solution that meets the user's requirements. This can be performed, for instance, through selecting one of the existing solutions, using some criteria of assessment, or randomly picking one of the solutions. One may also employ the consensus methods (professional literature also uses the term 'consensus setting methods') which allow to find a single solution (or a decision in this case) from a number of alternatives. A decision chosen by using the consensus methods does not have to be one of the decisions generated by the system, it can be very similar.

Subject literature lacks an approach that would make it possible to devise a model of resolving conflicts of knowledge which will be universal on account of the definition of the agent's knowledge structure. Note that the process of decision-making includes selecting one solution from a number of solutions. If one operates under uncertainty or risk (one is unable to determine the consequences of a decision made), one may often make an incorrect decision. Using the consensus method means that one does not have to make their choice from the existing solutions, one can create a new solution which approximates the existing ones. In other words, all the solutions are taken into consideration to some extent, which will lessen the risk of making a wrong decision. Another essential aspect is shortening the time necessary to make a decision on account of the fact that the system presents a single decision to the user, so the user does not have to give so much thought to making their selection from all the decisions generated by all agents.

Despite the fact that decision trees and negotiation methods are most often used to resolve conflicts, it is worth mentioning that the consensus methods may turn out to be a much better solution because they lessen the risk of making a wrong decision to a minimum, taking into consideration all opinions from all sides of the conflict, meaning all decisions indicated by all agents. For instance, having a number of solutions to a single problem and using the selection method does not yield the certainty that the selected solution will be satisfactory for the decision-maker. On the other hand, the consensus methods guarantee that all solutions will be considered, thus it is more probable that the result will be satisfactory. A satisfactory solution is understood as a decision that brings the expected investment rate. In terms of economic decisions, it is difficult to speak of an optimum decision as one that brings the highest profit, it is more appropriate to regard an optimum decision as one that brings satisfactory benefit (investment rate). Operating under uncertainty and risk, it is much more difficult to make an optimum decision that brings the largest benefit. However, if one assumes the rule of satisfactory benefit, known in professional literature as the rule of subjective expected utility [Katarzyniak, Nguyen 2000], then the entire decision-making process becomes less complicated. According to the rule, each alternative needs to have a specified level of expected utility attributed to it and one should select the alternative with the highest level of utility. Such an approach allows to 'raise the bar' so that the utility level becomes higher and higher, and the final decision is optimal. Consequently, it can lead to achieving much greater benefit by the organization, for example higher profits or higher effectiveness in competing markets.

The universality of a model for resolving conflicts of knowledge results from the ability to configure knowledge structures of agents through determining the quantity and types of structure attributes. So far, applying the consensus methods to resolve conflicts has not been satisfactorily employed in multi-agent decision-making support systems. Attempts have been made to use the consensus methods in multi-agent search systems and weather forecasting systems, but the solutions were applied to consolidate information for agents' inference, not knowledge generated through inference. Several works have suggested using the consensus methods to support the process of making economic decisions, however there was always a need to define different algorithms for setting consensus depending on the kind of decisions to be supported by the system (in other words, depending on the knowledge structure of an agent). Such an approach constitutes a certain hindrance while designing and implementing the consensus module because it requires from a few, to more than a dozen, different algorithms to be taken into consideration. Additionally, professional literature lacks a definition of algorithms for setting consensus with regard to some types of economic decisions, which is a problem. Such decisions include, for example, production process decisions and controlling decisions.

The universal model will constitute an extension to the consensus theory with the ability to resolve conflicts of knowledge in multi-agent economic decision-making support systems. Thanks to the model being configurable, the consensus can be determined regardless of the type of knowledge structure in an agent, which will allow to implement the consensus module in multi-agent systems that support making various kinds of economic decisions.

Created by employing a universal model, a multi-agent decision-making support system that uses the consensus methods to resolve conflicts of knowledge will improve the process of decision-making support by shortening the time necessary to make a decision and lessening its risk. Shortening the time to make a decision obviously allows to obtain higher flexibility of an organization. It is important to note that the contemporary social and economic environment makes lessening the risk connected with making economic decisions an essential aspect, that not only influences the competitiveness of an organization, but also determines the ability of an organization to operate in a turbulent economic environment.

In this article it is assumed that multi-agent decision support system functions in the following way (Figure 1):

– agents programs may implement different of decision support methods in each generic group (for example a group may be agents determining financial decisions, or agents determining supply chain management decisions or agents determining manufacturing decisions– each of the groups may consist of several agents),

– each of the agents searches and reads data from servers in Internet or/and systems which function in the enterprise,
– on the basis of these data, with user determined frequency, or reacting to environment events (for example raw material missing, change of price of product by competitors), agents generates the decisions,

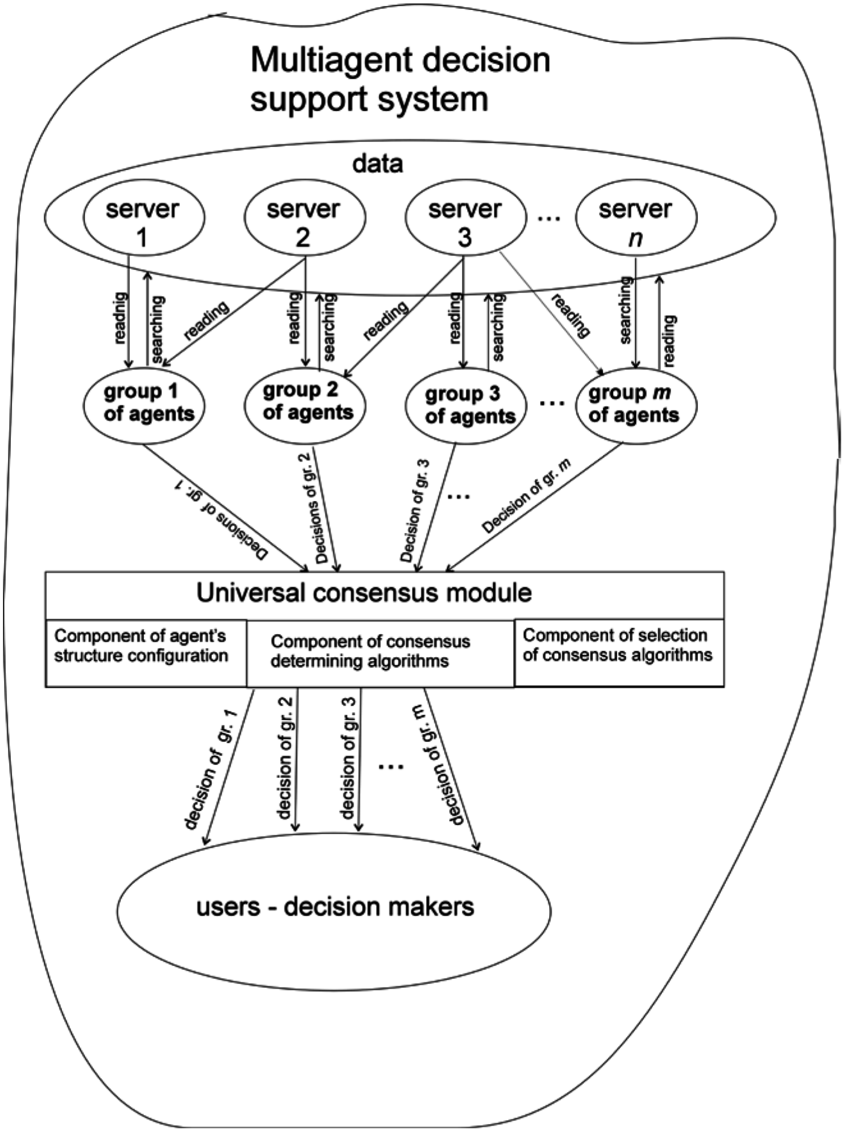

Figure 1. Diagram of multi-agent decision support system including consensus module

Source: own preparation.

– on the basis of a decision generated by agents with each group, a consensus is determined, and one decision made in each group (this decision is the result of consensus determining algorithms).

Configure the agent's structure (component of agent's structure configuration) will rely on setting the number and type of attributes of its structure.

Let:

$S = \{s_1, s_2, \cdots s_n\}$ – denote set of structures of *n* agents,

k_y – denote number of attributes of agents *y* structure , where *y* = 1 ... *n*,

$\{t_1, t_2, \cdots, t_m\}$ – denote set of *m* types of attributes,

The agent structure is set as the following variation with repetition:

$$s_x = \overline{V}_m^{k_x}, \text{ where } x = 1 \ldots n.$$

For example: the structure consists of two attributes: tree-classes ordered partition and date of decision (the types of attributes will be determined earlier).

Because consensus algorithms will be determined not due to the kind of decision, but due to types of structure attributes, the component selection of consensus algorithms is defined as follows:

Let:

$A = \{a_1, a_2, \cdots a_m\}$ denote set of *m* algorithms of consensus determining (there is the one consensus algorithm for each type of attributes).

The selection of consensus algorithm is defined as as the following function:

$$csel(t_x) = t_x \to a_x .$$

For example, a different algorithm will be used in the case of an ordered partition, and a different algorithm in the case of a date.

The component of consensus determining algorithms is responsible for running consensus algorithms for each attribute of profile structures. A profile is a set of conflicting structures (each group of agents creates a profile, so the number of profiles equals the number of the group of agents, in other words profiles are subsets of set *S*) and for this profile consensus is determined, not due to the kind of decision, but due to the types of structure attributes.

A formal definition of consensus function is the following:

Let:

$\Gamma(S)$ – denote set of all not empty subsets of set *S*,

$\Gamma'(S)$ – denote set of all not empty subsets with repetitions of set *S*,

The consensus function we call optional functions of forms:

$$c : \Gamma'(S) \to \Gamma(S).$$

For profile $X \in \Gamma'(S)$, each of elements of set $c(X)$ we call consensus, however all set $c(X)$ we call a representation of profile *X*.

4. Conclusions

The process of making a decision is very complex, especially when conducted under uncertainty and risk. The decision-maker may then be certain of the consequences that the decision will bring. Supporting the decision-making process by using multi-agent systems is effective only when the decision-maker receives a credible solution from the system. However, if a conflict of knowledge occurs among the agents, it considerably lowers the credibility of the decision generated by the system. The conflict needs to be resolved, then, so that the decision-maker receives the best suggestion from the system and, consequently, makes the right decision which will improve the operation of the organization. Employing in this case a universal model for resolving conflicts of knowledge that uses the consensus methods will lead to a result that brings satisfactory benefit to the investor. Another advantage is shortening the time necessary to make a decision and decreasing the risk associated with the decision-making process.

Consensus methods do not guarantee the best decision, but they guarantee a certain level of satisfaction. It might turn out that one of the decisions generated by the agent is better than a decision determined by the consensus methods, however, one can never be positive that the decision-maker will choose the best decision. The decision-maker may sometimes pick the worst one. Obviously, the level may be increased with time, which may result in achieving the optimum level, in other words, the decisions made will be optimal. The work on elaborating, on the basis of the model, a prototype of a software module, which can be used by companies to make up the multi-agent systems, are in progress.

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UNIWERSALNY MODEL ROZWIĄZYWANIA KONFLIKTÓW WIEDZY Z WYKORZYSTANIEM METOD CONSENSUSU W WIELOAGENTOWYCH SYSTEMACH WSPOMAGANIA DECYZJI

Streszczenie: W artykule podjęto próbę opracowania uniwersalnego modelu rozwiązywania konfliktów wiedzy z użyciem metod consensusu, który może być wykorzystany w wieloagentowym systemie wspomagania decyzji. Konflikty wiedzy występują wtedy, gdy agenty generują różne decyzje dotyczące tego samego problemu. Podjęcie przez użytkownika (decydenta) prawidłowej decyzji jest trudne, ponieważ analiza rozwiązań wygenerowanych przez agenty programowe jest bardzo czasochłonna, a ostateczna decyzja musi przecież zapaść bardzo szybko, w czasie zbliżonym do rzeczywistego. Dodatkowo wybór przez decydenta jednej z decyzji wygenerowanych przez agenty jest obciążony dużym ryzykiem, ponieważ może on wybrać rozwiązanie najgorsze. Metody consensusu umożliwiają automatyczne uzgodnienie, na podstawie decyzji wygenerowanych przez agenty, ostatecznej decyzji będącej kompromisem. W konsekwencji umożliwia to skrócenie czasu potrzebnego na podjęcie decyzji oraz obniżenie poziomu ryzyka związanego z tym procesem, co może skutkować funkcjonowaniem przedsiębiorstwa w sposób bardziej elastyczny.

Słowa kluczowe: systemy wspomagania decyzji, konflikty wiedzy, systemy wieloagentowe, metody consensusu.