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CONSENSUS METHODS IN MULTIAGENT DECISION SUPPORT SYSTEM IN SMALL AND MEDIUM ENTERPRISES

Summary: The methods of setting consensus in a multiagent decision support systems in small and middle enterprises are presented in this article. the article presents the problem of supporting the decision taking and characterizes multiagent system of decision support. In the next part it shows methods of setting a consensus that is the definition of distance function which is an element of setting a consensus, a definition and characteristic of consensus function and then the postulates of consensus function.

Key words: consensus methods, conflict of knowledge, multiagent systems, decision support systems, small and medium enterprises.

1. Introduction

Taking a decision is a hard and complicated problem. In order to support taking a decision more and more often information systems are used. The development of computer networks and the methods of artificial intelligence made it possible to create program tools supporting taking a decision. These systems have updated data needed to make a decision and they let to solve a given problem. There are more and more often used multiagent systems of decision support consisting of several or between ten and twenty agents programs which aim is to present a user a decision concerning a given problem. An agent is an autonomous object which has a definite purpose, is able to communicate with other agents, takes agents and reacts to changes of environment in which it works.

However, it often happens that multiagent decision support system generates different versions of solutions, in other words there is conflict of agents knowledge. Conflict of knowledge concerns a situation when for the same objects of the world and the same attributes participants of conflict assign different values. Of course we assume that knowledge of participants of conflict is described with the help of a certain set of attributes that is with the help of a certain structure. If structures presented by participants of conflict are different, or when values of attributes are different in structures, we have conflict of knowledge. However, a user expects one version from a system, in other words one decision. Therefore, on base of several solutions one solution should be determined which will meet the requirements of a user that is it will solve the conflict of knowledge. We can do it for example choosing one out of existing solutions using certain criteria of estimation, we can also randomly choose one solution. We can also employ consensus methods (called also in different works "methods of consensus setting"), which also allow to set one solution (in this case a decision) among a lot of alternatives. A decision set with the help of consensus methods does not have to one of decisions generated by a system. It can be very similar to them.

If we use consensus methods for setting consensus to solve a conflict, then consensus is such a solution, which gives participants of conflicts the following benefits [HENG04]:

1) every participant is taken into account in consensus,
2) every participant loses as least as it is possible,
3) every participant contributes his share to consensus,
4) every participant accepts consensus,
5) consensus is a representation of all participants of conflict.

Consensus methods have not yet found the application in multiagent decision support systems (the applications are in multiagent systems, however, they mainly concern systems, which task is only the penetration of Internet network to find required information). However, the attention should be paid that the benefits from the application of consensus methods which are mentioned earlier allow their application employment in exactly such systems. Let us notice that in the process of taking a decision we deal with choosing one of many solutions. If we act in conditions of uncertainty or risk (we are not able to define the consequences of a decision which has been taken), we can often take an incorrect decision. The use of consensus methods causes that we do not have to choose from existing solutions, we can create a new solution which will be the most similar to the existing ones, in other words all solutions will be to a certain degree taken into consideration what will decrease the risk of a taken decision. Therefore, the conflict of knowledge of agents will be solved.

This article presents multiagents decision support system and characterized consensus methods used in this system to solve the conflict of knowledge.

2. Multiagent decision support system

Multiagent system is defined in different ways. Summing up the definitions from different literature items [DYLE06; FERB99; KOLI08; NGUY02] we can say that the multiagent system is defined as a system which is characterized by:

- *environment* E, which has definite borders,
- *objects* creating set O, which belong to environment E, having in it their own position, objects can be researched, created, modified and destroyed by agents,

- *agents* creating set A which are active objects of system (A ⊆ O),
- *relations* creating set R, which connect objects one with another attributing semantic to this connection,
- *operations* creating set Op, which enable agents from set A to research, create, use and transform object from set O,
- *operators* of representation of usage of these operations, and the reaction of environment to these attempts which are called *the rights of ruling the environment.*

A multiagent system must always have a purpose of operation (for example the purpose can be to look for information of competition, steering of a power station).

The main purpose of multiagent decision support system is to help a user in taking a correct decision.

However, a decision is a notion defined in several ways. And so in the work [KULS98] a decision is defined as conscious choice from among alternative possibilities. In other item of literature a decision is a notion from the range of decision theory range. The theory of decision is a common area of interest of many domains of science which includes the analysis and supporting the process of taking a decision. It is used among others by mathematics, statistics, psychology, sociology, economy, management, philosophy, informatics and medicine. They also provide the methods.

A decision in sense of theory of decision is one of possible variants of operation in the decision problem. In order a decision process has a sense, we need at least two different decisions. A set of all decisions is called a decision area [NGUY02].

From the point of view of possessed information, we can divide decision problems into three groups:

- a decision taken in the conditions of certitude – every decision results in definite, known consequences,
- a decision taken in the conditions of risk – every decision results in more than one consequence, we know a set package of possible consequences and the probability of their occurring,
- a decision taken in conditions of uncertainty – we do not know the probability of occurring a given decision consequence.

If a decision is taken in conditions of certainty, we say about deterministic methods of decision theory, however, uncertainty and risk are dealt by undeterministic methods.

The majority of methods assume that a decision-maker acts in the environment where there are not competitors who could affect the result of a decision or the states of nature. In a situation when we know all possible consequences of decision variants, the choice of optimal variant comes down to the choice of a decision bringing the biggest benefit. The choice of variant is trivial in simple cases. If a decision problem takes on more complicated form, a section of mathematics called operational research is used. The section of decision theory called multicriterial decision analysis deals with the case of more than one criterion of estimation of a decision.

In conditions of risk consequences of every decision are defined schedules of probablity, so for cases undeterministic we mainly use the methods of theories of credibility and statistics.

Classic statistic methods fail in cases of uncertainty, because we are not able to define the schedules of credibility of decision consequences. Bayes statistics deals with taking a decision in such conditions. Generally statistic decision analysis deals with undeterministic cases (risk and uncertainty). Taking a decision in conditions of risk and uncertainty requires the need of executing complicated analysis and calculations. Thus, they are time-consuming and they generate high costs. Therefore, information decision support systems (DSS) started to be used. They do not substitute a person, but they help to solve complicated decision problems.

The notion of decision support system (DSS) has quite an extensive meaning. DSS are identified with many kinds of orders, instruments and technology. Some

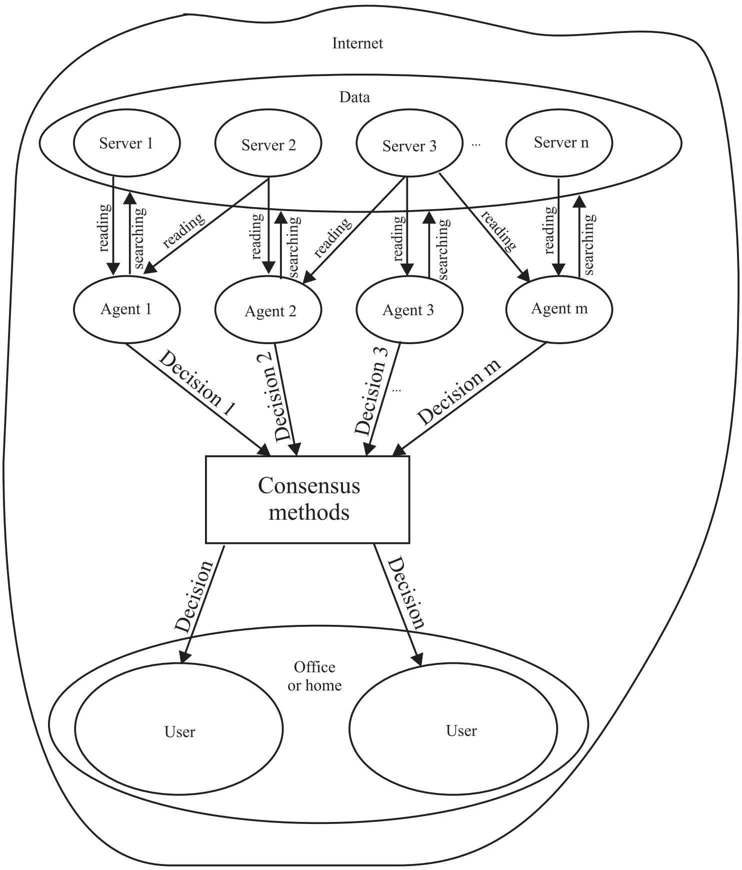

Fig. 1. Diagram of multiagent decision support system

Source: self study.

specialists find this notion obsolete and they substitute it with a term OLAP (on-line analytical processing) and they call it "new type systems". OLAP is a software allowing analytics and leading management to perceive business data through a wide choice of perspective. It takes place with fast utilization of compact, interactive access to information. The information emerge in the process of source data processing and it presents an intelligible reflection of real effect of undertaking for a user. Others recognize so called – knowledge based DSS as the highest degree of development in this class of systems. However, from the point of view of operational research simulation and optimalizing models used in decision support systems are interesting. It seems that for DSS it is possible to recognize a software which can directly help a manager in taking a decision.

A multiagent decision support system is presented in this article.

This system consists of several agents programs, which are able to communicate one with another with the help of computer network. Every agent looks for and reads data from the Internet. Then the process of concluding follows which results in a decision. There can be a situation in which every agent presents a different decision. Therefore, consensus methods are used in the next stage (characterized in the next part of the article) to set one common decision for all agents which is presented to the user of the system.

A diagram of multiagent decision support system is shown in Fig. 1.

The system consists of following elements.

Data – they are placed in Internet network on different servers. Every agent searches on Internet servers data which are required to take decisions and reads them.

Agent – an intelligent program which not only concludes on the base of received data but it also takes definite operations which serve to achieve a set purpose, in this case to take a decision. Every agent uses other method of taking a decision. Agent can be implemented to any computer connected to Internet.

Consensus methods – allow to set one decision which has to be presented to a user on the base of different decisions of individual agents. Consensus methods are implemented on one server connected to Internet. This server reads these decisions of agents which it has an access to.

Users – persons who with the help of computers connected to Internet read decisions set through the use of consensus methods. They can be people responsible for taking a decision in enterprises, stock market investors, etc.

In the presented system it is assumed that every agent has implemented a different method of taking a decision. Of course every agent can propose a different solution (different decision). However, a user of a system needs one specific decision and, therefore, the system has been extended to the methods of consensus which allow to set one solution (decision) among the decisions of all agents that is in other words to solve a knowledge conflict among agents.

The aim of multiagent decision support system is to help people who manage firms and institutions, and investors to take correct decisions. Except supporting a decision through suggesting exact decisions (the system suggests the best – according to it – solutions, but it is a human who takes a final decision) which is the main aim of the system. He system can also realize auxiliary aims:

– independent decision taking (if we decide that a decision of system is ultimate, it can make a decision without the participation of human),
– finding the best solution from among different alternatives in particular cases we can exclude the functioning of agents programs and employ only the consensus methods for decisions provided by human),
– reporting a user about changes in the environment.

Presented multiagent system has the following functions:

– searching needed data in Internet and local network,
– reading data from servers working in Internet and local network,
– data revision,
– possibility of handwritten data introduction,
– data processing and concluding with the use of methods of artificial intelligence (mainly expert systems),
– presenting the results of processing and concluding of individual agents,
– calculating one solution and presenting it to a user.

3. Consensus methods

The theory of consensus has roots in the theory of choice, which deals with the following problem: there is set Z (e.g. set of objects) which is a subset of set X. Saying about choice, we make a selection according to certain criteria of certain subset of set Z. However, in the theory of consensus the choice does not have to be a subset of set Z, does not also have to have the same structure as the elements of set Z. Theory of consensus initially concerned simple structures such as linear order or partial order. Next more complicated structures began to be dealt with, such as partitions, hierarchies, *n*-trees. Therefore, theory of consensus concerns problems related to the analysis of data to get useful information (as well as data exploration). However, when the aims of exploration methods concern searches of cause and effect relationships which are hidden in data, the consensus methods purposes concern certain determining such as a certain version for data which represents the given versions the best or is a compromise which is accepted by parties being the authors of these versions. With help of theory of consensus we can solve different conflicts which appear at the level of data. In work [NGUY02] problems solved by consensus theory belong to the following groups:

1. Problems related to discovering the hidden structure of an object. For example, a set of elements is given and the discovering structure is the function of distance among these elements.

2. Problems related to agreeing incoherent or contradictory data concerning the same object. For example, experts present different versions of data one version should be found which will be presented to a user of the system.

Setting consensus consists of several stages. First the structure of set Z should be thoroughly examined. Next one should know how to calculate the distances among subsets of set Z. Consensus setting relies on choosing such a set that a distance among this set (consensus) and the subsets of set Z is minimal (according to different criteria).

Results obtained by the employment of consensus methods are a good representation of a given set, because in practice they take into consideration all subsets of the examined set, while the methods of choices to a large extent take into consideration one of the subsets of a given set and to a small extent the remaining subsets of the examined set.

Theory of consensus is used to solve conflicts of different data structures in different systems, for example conflicts of experts knowledge, conflicts in temporary databases, conflicts in multiagent systems, restoring the cohesion of replicated data. The article presents, however, the possibility of using the consensus methods in multiagent systems of supporting decision taking.

Generally we can divide consensus methods into constructive methods, operational methods and methods using bool concluding.

Constructive methods rely on solving consensus problems on two levels: microstructure and macrostructure of universum U. The microstructure of set U is a structure of its elements. The macrostructure of U is its structure.

Operational methods rely on defining the function of consensus using operational rules. In this methods quasi-mediane functions are used very often owing to which consensus is more similar to all solutions from which it is set. At the same time distances of consensus for individual solutions are even.

Methods using bool concluding rely on encoding the problem of consensus in the form of bool formula in such a way that every first implicant of this formula sets a solution of a problem. Bool concluding is useful if a number of variables and their domains are not big.

Individual kinds of consensus methods are used depending what structure of data consensus is set. In the multiagent system of decisions support mainly constructive and operational methods are used.

If we will assume, that decisions are represented by certain structures of data, then a process of taking a decision relies on the choice of a subset from a set of possible solutions. Therefore, we can define a distance function.

We assume that the macrostructure of universum U is a certain function:

$$o : U \times U \to [0,1]$$

which meets the conditions [NGUY02]:

a) $(\forall x,y \in U)(o(x,y) \geq 0)$,
b) $(\forall x,y \in U)[o(x,y) = 0 \Leftrightarrow x = y)$,
c) $(\forall x,y \in U)[o(x,y) = \mathrm{o}(y,x))$.

Thus function *o* meets all conditions of distance function. However, let us notice that here we do not assume the condition of inequality of triangle, that is the function of distance does not have to be metrics. In work [NGUY02] it is found that metric conditions are often imposed on functions of distances, but in some cases they are far too strong. The pair (*U,o*) is certain space called the space with distance.

In the multiagent system of decision support distance functions of class MK (cost minimizing) and OU (participation defining) characterized in detail in works [HERN04; HENG07; NGUY02; SOHE06] are the most useful. The function of distance of class MK between two sets of elements relies on the determination of minimal cost of transformation of one set into another. As it has been assumed that decisions are certain sets of elements, so the employment of function of distance of this type in multiagent decisions support system is appropriate. However, it often happens that except the set of certain elements (solutions) a decision includes also a time bracket which defines the frames of relevance of decisions. In such a case we should employ the function of distance of class OU between two sets of elementary values of a given attribute which relies on the determination of participation of each elementary value in this difference [NGUY02].

Axiomatic approach is often used to set the function of consensus. The purpose of introduction of an axiom is to determine on their basis the class of function of consensus that is in other words different methods of consensus setting. Apart from that because axioms provide intuitive conditions that consensus function should meet, owing to them we gain the grounds of applying these functions in practice.

In the next part of the article we will use the following symbols:

$\Gamma(U)$ set of all not empty subsets of universum U,

$\Gamma'(U)$ set of all not empty subsets with repetitions of universum U,

$\cup'$ – sum of sets with repetitions.

Let $X, X_1, X_2 \in \Gamma'(U)$, $x \in U$. We will

$o(x,X) = \sum_{y\in X} o(x,y)$,

$o^n(x,X) = \sum_{y\in X} [\, o(x,y)]^n$ for $n \in \mathrm{N}$.

Let us notice that the parameter $o(x,X)$ represents the sum of distance from element x of universum U for elements of profiles X and the size $o^n(x,X)$ represents the sum of n-powers of these distances. This value can be interpreted as a measure of evenness of distance from element x to elements of profile X. The greater value n the more even the distances.

In work [NGUY02] consensus function is defined as follows:

The consensus choice function (or consensus function) in space (U,o) we call an optional function in the form of:

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

For profile $X \in \Gamma'(U)$ each element of set $c(X)$ we will call its *consensus* while the whole set $c(X)$ we will call the *representation of profile X.* Let C is the set of all consensus functions in space (U, o).

The following definition presents axioms for consensus function [NGUY02]:

Let X be optional profile; we say that consensus function $c \in C$ *meets a postulate:*

1. *Reliability (Re), if*
   $C(X) \neq \emptyset$.
2. *Cohesion (Co), if*
   $(x \in C(x)) \Rightarrow (x \in c(X \cup' \{x\}))$.
3. *Quasi-unanimity (Qu), if*
   $(x \notin C(x)) \Rightarrow ((\exists n \in \mathrm{N}) x \in c(X \cup' \{n*x\}))$.
4. *Proportion (Pr), if*
   $(X_1 \subseteq X_2 \wedge x \in c(X_1) \wedge y \in c(X_2)) \Rightarrow (o(x,X_1) \leq o(y,X_2)$.
5. 1-*Optimum* (O_1), *if*
   $(x \in C(x)) \Rightarrow (o(x,X) = \min_{y \in U} o(y,X))$.
6. 2-*Optimum* (O_2), *if*
   $(x \in C(x)) \Rightarrow (o^2(x,X) = \min_{y \in U} o^2(y,X))$.

These postulates express primary conditions for consensus function so they define different method of consensus.

The first postulate (of *reliability*) assumes that for every profile it is always possible to set consensus. It answers optimistic attitude: *it is possible to solve every conflict*. Reliability is a known criterion in the theory of choice [DYLE06].

Postulate of *cohesion* requires the implementation of condition that if some element x is consensus for profile X , then after the expansion of this profile with $x(X \cup, \{x\})$, this element should be consensus for a new profile. Cohesion is an important property of consensus, because it allows users to predict the maintenance of rules of consensus setting, when premises of independent choices are joined one with another.

According to the postulate of *quasi-unanimity,* if certain element x is not consensus for profile X then it should be consensus for profile X_1 including X and n of element x occurrence for certain n. In other words every element of universum U should be chosen as consensus for such a profile, if the number of its occurrences is sufficiently high.

The postulate of *proportion* is quite a natural property, because the larger the profile the larger the difference between its elements and the consensus which has been chosen for it.

The last two postulates are very special. First of them, the postulate of 1-*optimum* requires that consensus is the nearest (the most similar) to the elements of profile. This postulate, very well known in literature, defines an exact class function, called *medians*. However, the postulate of 2-*optimum*, on the other hand, requires that the sum of square of distance from consensus for elements of profiles was the smallest. This postulate has been introduced because of the following condition (which is also very natural) concerning the determination of consensus function: consensus should be as "fair" as possible. It means its distance to the elements of profile should be the most even. Let us notice that number $o^n(x,X)$, which is defined above, can be treated as the measure of evenness of distance between a certain object

x and the elements of profiles X. Therefore, the above-mentioned condition requires to value o^n (consensus, X) to be minimal. In work [NGUY02] it is showed that the functions meeting the postulate of 2-*optimum* are better then the functions meeting the postulate of 1-*optimum* because of greater evenness. They differ from other functions of consensus in greater similarity to the elements of profiles. It results from that the postulate of 2-*optimum* is a good criterion of consensus setting.

Let us notice that the first three postulates *Re, Co* and *Qu* are independent of the structure of universum U which is the function of distance o, while the last three postulates Pr, O_1 and O_2 are formulated on the base of function o. Therefore, the postulates *Re, Co* i *Qu* are suitable in situations when it is impossible to define the function of distance (or generally macrostructures) for universum U.

In the process of taking a decision, especially in the conditions of uncertainty, a good solution the most even consensus, that is such which to the same extent takes into account all possible solutions. If the postulate of 2-*optimum* allows to get greater evenness than the postulate of 1-*optimum* the postulate of *n-optimum* should be also defined. It will allow for $n > 2$ to get even greater evenness of consensus than the postulate of 2-*optimum*. Therefore, the definition of this postulate is as follows:

We say, that consensus function $c \in C$ meets the postulate of n-optimum (O_n) if

$$(x \in C(x) \Rightarrow (o^n(x,X) = \min_{y \in U} o^n(y,X)).$$

This postulate is generalization of the postulates of 1-*optimum* and 2-*optimum*.

In work [NGUY02] it is proved that it is not possible that the function of consensus met at the same time all postulates. Therefore, the detailed functions of consensus defined for different structures will differ depending on postulates which they have to meet. The postulates of the functions of consensus define individual kinds of consensus methods.

We can use all postulates in constructive methods. Of course as it is mentioned above the concrete function of consensus (setting consensus for the concrete structure of data) cannot meet all postulates at the same time, however, we can define different functions of consensuses in constructive methods so generally these methods use all postulates.

Operational methods use postulates *Pr,* $O_{1,}$ $O_{2,}$ O_n. They allow to define quasi-median functions.

Methods using bool concluding are mainly used in case of postulates *Re, Co, Qu.*

Other postulates of functions of consensuses can be also found in many works, however, this article presents the postulates which can be used in multiagent decision support system.

4. Conclusions

The characteristic of consensus methods with reference to multiagent decision support system is presented in the article. Conflicts of knowledge concerning decisions of individual agents which should be solved effectively can be found in this system.

Using the consensus methods in this scope allows to achieve a result which does not have to be one of considered solutions, but it is very similar to them. It of course causes the reduction of risk of taking a wrong decision and the solution of knowledge conflict. The result of applying the consensus method is one decision which is presented to a system user.

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METODY CONSENSUSU W WIELOAGENTOWYM SYSTEMIE WSPOMAGANIA DECYZJI W MAŁYCH I ŚREDNICH PRZEDSIĘBIORSTWACH

Streszczenie: W niniejszym artykule przedstawiono metody wyznaczania consensusu w odniesieniu do systemów wieloagentowego systemu wspomagania decyzji w małych i średnich przedsiębiorstwach. W artykule omówiono problem wspomagania podejmowania decyzji, a następnie scharakteryzowano wieloagentowy system wspomagania decyzji. W dalszej części artykułu przedstawiono metody wyznaczania consensusu, a więc definicję funkcji odległości, która jest elementem wyznaczania consensusu, definicję i charakterystykę funkcji consensusu, a następnie postulaty funkcji consensusu.