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Jadwiga Sobieska-Karpińska, Marcin Hernes
Uniwersytet Ekonomiczny we Wrocławiu

DETERMINING CONSENSUS IN DISTRIBUTED COMPUTER DECISION SUPPORT SYSTEM

Abstract: The problem of using consensus methods in solving knowledge conflict in distributed decision support system is presented in this article. The manner of decision representation behind assistance of multiattrib and multivalue structure, profile of decisions and the problem of knowledge conflicts are characterized. Next, the heuristics algorithm determining consensus for profile consisting of a set of decision structures was elaborated.

Key words: distributed systems, decision support systems, knowledge conflicts, consensus methods.

1. Introduction

Distributed decision support systems act nowadays as a very important role in different type of organization functionalizing. These systems consist of a certain number of computers joined by network. It has to have to such properties as [Hernes, Nguyen 2004; Nguyen 2002]: resource partition, openness, scaleness, fault tolerance, transparency. Thanks to these properties, it is possible to support a group decision. Generally multiagent systems or expert systems are used in this goal.

It is necessary to stress that taking decisions is a very important element of organization functioning at the market and it is connected with many problems [Drucker 1994]. Markets are very turbulent. The decision-makers have to take fast and relevant decisions. So it is necessary to use computer systems. They can find information which has to have proper value [Sobieska-Karpińska, Hernes 2009] and make conclusions based on this information. These systems read suitable data needed to take decisions and allow to quickly solve a problem.

However the distributed decision support system generates different kinds of conflicts. Conflict is defined as incompatibility of part of conflict knowledge [Nguyen 2002]. Often it happens that nodes of systems (e.g. agents, experts) generate different versions of results. The user (decision-maker) expects one version of results, in other words, one of decisions. It is necessary to select one result, which meets user requirements, based on several different results. This can be done by choosing one of the results based on different criterions or by choosing random results. However such ways take into consideration an opinion on one of part of the conflict and other parts of the conflict are not taken into consideration. In this situation the system can prompt a bad decision. So the best way is when opinions on all of parts of the conflict will be taken into consideration to an equal degree. This enables the consensus methods characterized in this article.

2. Structure of a decision

Every decision should be represented by a concrete structure. Such a structure was defined in the paper [Sobieska-Karpińska, Hernes 2006]. A decision is a set of decision elements which describe an object of the real world. These elements are ordered according to a sequence of procedures during the realization of the taken decision. For example it can be a feature of credit, employee, or product. The formal definition of a decision is as follows:

Definition 1.

Structure of decision P finite set of elementary object $E = \{e_1, e_2, \ldots, e_N\}$ *is called a sequence:*

$$P = \left\langle \{EW^+\}, \{EW^\pm\}, \{EW^-\}, DT \right\rangle,$$

where:

1) $EW^+ = \left\langle e_o, pe_o \right\rangle, \left\langle e_q, pe_q \right\rangle, \ldots, \left\langle e_p, pe_p \right\rangle$.

Couple $\left\langle e_x, pe_x \right\rangle$, where: $e_x \in E$ and $pe_x \in [0,1]$, is an elementary object and participation of this object in set EW^+.

Elementary objects $e_x \in EW^+$ will be denoted as e_x^+.

Set EW^+ is called a positive set, in other words it is a set of elementary objects, of which the system node knows that these objects are in the environment.

2) $EW^\pm = \left\langle e_r, pe_r \right\rangle, \left\langle e_s, pe_s \right\rangle, \ldots, \left\langle e_t, pe_t \right\rangle$.

Couple $\left\langle e_x, pe_x \right\rangle$, where: $e_x \in E$ and $pe_x \in [0,1]$, is an elementary object and participation of this object in set $EW^\pm$.

Elementary objects $e_x \in EW^\pm$ will be denoted as $e_x^\pm$.

Set $EW^\pm$ is called a neutral set, in other words it is a set of elementary objects, of which the system node does not know that these objects are in the environment.

3) $EW^- = \left\langle e_u, pe_u \right\rangle, \left\langle e_v, pe_v \right\rangle, \ldots, \left\langle e_w, pe_w \right\rangle$.

Couple $\left\langle e_x, pe_x \right\rangle$, where: $e_x \in E$ and $pe_x \in [0,1]$, is an elementary object and participation of this object in set EW^-.

Elementary objects $e_x \in EW^-$ will be denoted as e_x^-.

Set EW^- is called a negative set, in other words it is a set of elementary objects, of which the system node knows that these objects are not in the environment.

4) DT – date of decision.

This structure meets the following conditions:

1. $EW^+ \cap EW^\pm \cap EW^- = \varnothing$.

Elements of positive, neutral and negative sets must be parity, because the system node must clearly determine to which set a given elementary object belongs. This is assumed, because knowledge about the environment must be concrete.

2. $EW^{+} \neq \varnothing \Rightarrow \sum_{i=0}^{p} pe_i^{+} \geq 1$.

The sum of shares of all the elementary objects in a positive set must be oversize or equal 1.

3. $EW^{\pm} \neq \varnothing \Rightarrow \sum_{i=0}^{t} pe_i^{\pm} \geq 1$.

The sum of shares of all the elementary objects in a neutral set must be oversize or equal 1.

4. $EW^{-} \neq \varnothing \Rightarrow \sum_{i=0}^{w} pe_i^{-} \geq 1$.

The sum of shares of all the elementary objects in a negative set must be oversize or equal 1.

In a positive set of decisions there are these elements of decisions which are used to achieve a desired rate of return. In a neutral set of decisions there are these elements of decisions which we do not know if to use or not to use. In a negative set of decisions there are these elements of decisions which are not used.

Example 1

Let set $E = \{a_1, a_2, a_3, a_4, a_5, a_6, a_7\}$ be a set of value papers.

Examples of a structure of decision (shareholding of value papers):

$$P1 = \langle \{\langle a_1, 0.2\rangle, \langle a_3, 0.5\rangle, \langle a_5, 0.3\rangle\}, \{\langle a_2, 1\rangle\}, \{\langle a_4, 1\rangle, \langle a_6, 1\rangle, \langle a_7, 1\rangle\}, 19-04-2011\rangle$$

$$P2 = \langle \{\langle a_2, 0.2\rangle, \langle a_3, 0.8\rangle\}, \{\varnothing\}, \{\langle a_1, 1\rangle, \langle a_4, 1\rangle, \langle a_5, 1\rangle, \langle a_6, 1\rangle, \langle a_7, 1\rangle\}, 14-05-2011\rangle$$

In the first example the sets $EW^{+}, EW^{\pm}, EW^{-} \neq \varnothing$. In the second example the set $EW^{\pm} = \varnothing$.

The percent of participation of the element of decisions in a positive, neutral or negative set of decision range from 0 to 1. However, the sum of each percentage participation in the set may be larger than 1 because it is possible to belong to all the elements of decision in the set by 100%.

The presented definition of a decision structure enables formulating all of the node conclusions in a homogenous structure. This is a composite, multivalue structure, there are different types of data in this structure. If the numbers of the elements of decisions or values of attributes in a structure are different, then a knowledge conflict among the nodes of the system takes place [Sobieska-Karpińska, Hernes 2008a]. It is possible to use consensus methods to resolve these conflicts.

3. Determining of consensus

Determining of consensus consists of several steps. First, it is necessary to research the structure of set *Z*. The next distance among subsets of set *Z* is calculated. Determining of consensus is a choice of such sets that the distance among this set and subsets of set *Z* is minimal (according to different criterions).

The theory of consensus is used to resolve conflicts of different data structure in different systems [Condorcet 1974; Hernes, Nguyen 2004; Korczak, Lipiński 2008], for example conflict of expert knowledge, conflict in temporary databases, conflict in multiagent system, retrieving of consistency of replicated data. Consensus methods can be used in distributed decision support systems, too.

Consensus is determining the base to decisions generated by different nodes of system. This set is called profile and defined [Hernes, Nguyen 2007]:

Definition 2.

Given is a set of decision elements $E = \{e_1, e_2, \ldots, e_N\}$.

Profile A = $\{A^{(1)}, A^{(2)}, \ldots, A^{(M)}\}$ *is called set of M decision of a finite set of decision elements E, such that:*

$$A^{(1)} = \left\langle \{EW^{+}\}^{(1)}, \{EW^{\pm}\}^{(1)}, \{EW^{-}\}^{(1)}, DT^{(1)} \right\rangle,$$

$$A^{(2)} = \left\langle \{EW^{+}\}^{(2)}, \{EW^{\pm}\}^{(2)}, \{EW^{-}\}^{(2)}, DT^{(2)} \right\rangle,$$

$$A^{(M)} = \left\langle \{EW^{+}\}^{(M)}, \{EW^{\pm}\}^{(M)}, \{EW^{-}\}^{(M)}, DT^{(M)} \right\rangle.$$

In many papers [Hernes, Nguyen 2007; Sobieska-Karpińska, Hernes 2008b] the consensus is determined taking into account the minimal sum of distance among consensus and profile (it is defined as consensus according to criterion C_1). This distance between positive, neutral and negative sets from consensus to each elements of profile is calculated by the sum of minimal operation of transformation of every set of profiles in a set of consensus [Sobieska-Karpińska, Hernes 2008b]. The distance between *DT* is calculated by the difference in chronons (e.g. seconds, minutes). The distance between two decision structures is a sum of distance between positive, negative, neutral sets and *DT* and it is denoted as Ψ. Consensus according to criterion C_1 is very near to one of the elements of the profile. In this article we present the algorithm of determining consensus by calculating the square power of distance between consensus and profile (so, this is consensus according to criterion C_2). Due to this, consensus is most even, in other words, to an equal degree near to all the elements of the profile. In consequence, decision setting behind assistance consensus to an equal degree takes into consideration every part of the conflict.

This algorithm works as follow:

1. Consensus according to criterion C_1 is setting, and the square of distance between consensus and profile is calculated, and is resulting as minimum.

2. For every element of set *E* it is checked, if it takes place in getting a set in consensus. If it takes place then it is eliminated from this set and it is calculated as

the square of distance. If it is higher than the previous one, then it proceeds to the next set. If it is lower, then it is resulting as a consensus and distance to profile as minimal.

3. If an element does not take place in getting a set in consensus then it is calculated how many times it takes place in this set in every decision in profile. If it does not take place, then it proceeds to the next set; if it takes place once or more, then it is placed in this set in consensus (if necessary it is eliminated from the other set of consensus), and it is checked if the distance given consensus for profile is lower than the distance of the former consensus for profile. If it does not, then the former consensus becomes the best; if it is, then the new consensus becomes the best and its distance to profile is the minimal distance. If it is, every set checked, proceeds to the next element E.

4. If every element of set E was checked, then the consensus of sets $EW^{+}, EW^{\pm}, EW^{-}$ is determined and the consensus of values DT will be determined. After determining this consensus, the algorithm is finished and the resulting consensus is a consensus according to criterion C_2. This algorithm is defined next:

Input: Profile $A = \{A^{(1)}, A^{(2)}, ... A^{(M)}\}$ consists of M decision.
Output: Consensus $CON = \langle CON_{+}, CON_{\pm}, CON_{-}, CON_{Z}, CON_{SP}, CON_{DT} \rangle$ according to criterion C_2.
BEGIN
Step 1: CON is accepted as consensus according to criterion C_1.
Step 2: $CON_{DT} = \frac{1}{M}\sum_{i=1}^{M} DT^{i}$ let

$$d := \sum_{i=1}^{M}\left[\Psi\left(CON, A^{(i)}\right)\right]^2 \text{ and } j:=1.$$

Step 3: If $e_j \in CON_+$ to $CON' := \langle CON_{+} \setminus \{e_j\}, CON_{\pm}, CON_{-}, CON_{DT} \rangle$
Go to: Step 6,
If $e_j \notin CON_+$ go to: Step 4.
Step 4: If $t_+(j) = 0$ go to : Step 7,
If $t_+(j) > 0$ go to : Step 5.
Step 5: If $e_j \cap CON \neq \notin$ and $e_j \in CON_{\pm}$ or $e_j \in CON_{\pm}$ to

$$CON' := \langle CON_{+} \cup \{e_j\}, CON_{\pm} \setminus \{e_j\}, CON_{-} \setminus \{e_j\}, CON_{DT} \rangle,$$

If $e_j \cap CON = \emptyset$ to

$$CON' := \langle CON_{+} \cup \{e_j\}, CON_{\pm}, CON_{-}, CON_{DT} \rangle.$$

Go to: Step 6.

Step 6: If $\sum_{i=1}^{M}\left[\Psi\left(CON', A^{(i)}\right)\right]^2 < d$ to $d := \sum_{i=1}^{M}\left[\Psi\left(CON', A^{(i)}\right)\right]^2$ and $CON := CON'$

Go to: Step 7.

Step 7: If $e_j \in CON_{\pm}$ to $CON' := \left\langle CON_+, CON_{\pm} \setminus \{e_j\}, CON_-, CON_{DT} \right\rangle$
Go to: Step 10,
If $e_j \notin CON_{\pm}$ go to: Step 8.
Step 8: If $t_{\pm}(j) = 0$ go to: Step 11,
If $t_{\pm}(j) > 0$ go to: Step 9.
Step 9: If $e_j \cap CON \neq \emptyset$ and $e_j \in CON_+$ or $e_j \in CON_-$ then

$$CON' := \left\langle CON_+ \setminus \{e_j\}, CON_{\pm} \cup \{e_j\}, CON_- \setminus \{e_j\}, CON_{DT} \right\rangle,$$

If $e_j \cap CON = \emptyset$ then

$$CON' := \left\langle CON_+, CON_{\pm} \cup \{e_j\}, CON_-, CON_{DT} \right\rangle.$$

Go to: Step 10.

Step 10: If $\sum_{i=1}^{M} \left[\Psi\left(CON', A^{(i)}\right) \right]^2 < d$ to $d := \sum_{i=1}^{M} \left[\Psi\left(CON', A^{(i)}\right) \right]^2$ and $CON := CON'$.
Go to: Step 11.
Step 11: If $e_j \in CON_-$ to $CON' := \left\langle CON_+, CON_{\pm}, CON_- \setminus \{e_j\}, CON_{DT} \right\rangle$.
Go to: Step 14.
If $e_j \notin CON_-$ go to: Step 12.
Step 12: If $t_-(j) = 0$ go to: Step 15.
If $t_-(j) > 0$ go to: Step 13.
Step 13: If $e_j \cap CON \neq \emptyset$ and $e_j \in CON_+$ or $e_j \in CON_{\pm}$ then

$$CON' := \left\langle CON_+ \setminus \{e_j\}, CON_{\pm} \setminus \{e_j\}, CON_- \cup \{e_j\}, CON_{DT} \right\rangle.$$

If $e_j \cap CON = \emptyset$ then

$$CON' := \left\langle CON_+, CON_{\pm}, CON_- \cup \{e_j\}, CON_{DT} \right\rangle.$$

Go to: Step 14.

Step 14: If $\sum_{i=1}^{M} \left[\Psi\left(CON', A^{(i)}\right) \right]^2 < d$ then $d := \sum_{i=1}^{M} \left[\Psi\left(CON', A^{(i)}\right) \right]^2$ and $CON := CON'$.
Go to: Step 15.
Step 15: If $j < N$ to $j := j + 1$. Go to: Step 2.
If $j \geq N$ to END.
END.

The computational complexity of this algorithm is $O(N^2M)$.

The calculating consensus according to criterion C_2 for decision structure is NP-complete problem. The consensus calculated by the optimal algorithm is such a consensus, in which the sum of square distance to elements of profile is minimal. To find such a consensus it is necessary to check every combination of elements of set E in every set of decisions. In such a case computational complexity is $O(M(3+1)^N)$. This has a very great computational complexity. The user of the system (decision-maker) cannot wait a long time for the proposition generated by the system because the process of decision-making is stretched. It is necessary to use the heuristic algorithm presented in this article. This algorithm allows to calculate quickly a consensus according to criterion C_2.

The presented algorithm allows to coordinate one decision which is presented to the user by the system. The decision-maker must not think about choosing from many solutions, so the time which is necessary to make a decision is shortened. The decision is taken based on several solutions then the risk falls because the capability of the assignment of the erroneous decision by one of the system nodes falls.

This algorithm can be implemented in every distributed decision support system, on condition that the knowledge of system nodes is represented by the structure described in this article. The algorithm is running automatically after the assigning of the proposal of the decision by the system nodes.

Using consensus methods in decision support allows forceful decision-making, because many proposals of decisions are taken into consideration. In decision support systems these decisions are generated by different system nodes, for example by the agent program which has implemented different methods of decision support. Certainly the decision-maker can choose from among the proposals presented by the system of nodes itself, however it is a time-consuming process. So, using consensus methods will shorten time on decision-making. Consequently, it contributes towards the better functioning of the organization.

4. Summary

In this article was presented characteristics of consensus methods which can be used in distributed decision support systems. Decision supporting by the use of distributed systems is effective on condition that the decision-maker will receive reliable solutions from the system. However, if knowledge conflict of the system nodes takes place, then it lowers the credibility of the decision generated by the system. So it is necessary to resolve this conflict in order that the decision-maker receives the best suggestion from the system. In consequence he will make a good decision which will result in the proficient functioning of the organization. Using the algorithm presented in the article for this purpose allows to get a result which must not be treated as the one absolute solution, but is evenly approximate for these solutions. Certainly it causes a decrease of risk, and in consequence leads to effective decision-making. The next advantage is, as mentioned earlier, the reduction of time needed for decision-making because the decision-maker does not have to think over the choice of the best solution.

References

Condorcet M., *Essai sur l'application de l'analyse à la probabilité des decisions rendues à la prularité des voix*, Chelsea Publ. 6, New York 1974.

Drucker P.F., *Praktyka zarządzania*, AE, Kraków 1994.

Hernes M., Nguyen N.T., Deriving consensus for incomplete ordered partitions, [in:] N.T. Nguyen (Ed.), *Intelligent Technologies for Inconsistent Knowledge Processing*, Advanced Knowledge International, Australia 2004.

Hernes M., Nguyen N.T., Deriving consensus for hierarchical incomplete ordered partitions and coverings, *Journal of Universal Computer Science* 2007, Vol. 13, No. 2, pp. 317–328.

Korczak J., Lipiński P. Agents systems in capital market decision support, [in:] S. Stanek, H. Sroka, M. Paprzycki, M. Ganzha (Eds.), *Evolution Multiagent Information Systems in Socially-economic Environment*, Placet, Warszawa 2008.

Nguyen N.T., *Metody wyboru consensusu i ich zastosowanie w rozwiązywaniu konfliktów w systemach rozproszonych*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2002.

Sobieska-Karpińska J., Hernes M., Metody reprezentacji wiedzy agentów w multiagenckich systemach wspomagających podejmowanie decyzji, [in:] A. Nowicki (Ed.), *Informatyka Ekonomiczna 9. Wybrane zagadnienia*, Prace Naukowe Akademii Ekonomicznej nr 1144, AE, Wrocław 2006.

Sobieska-Karpińska J., Hernes M., Rozwiązywanie konfliktów w systemach rozproszonych za pomocą metod consensusu, [in:] A. Nowicki (Ed.), *Informatyka Ekonomiczna 12. Wybrane zagadnienia*, Prace Naukowe Uniwersytetu Ekonomicznego nr 23, UE, Wrocław 2008a.

Sobieska-Karpińska J., Hernes M., Metody consensusu w systemach wspomagających podejmowanie decyzji, [in:]: J. Dziechciarz (Ed.), *Zastosowania metod ilościowych*, Prace Naukowe Uniwersytetu Ekonomicznego nr 6, Ekonometria 21, UE, Wrocław 2008b.

Sobieska-Karpińska J., Hernes M., Value of information i distributed decision support system, [in:] M. Pańkowska (Ed.), *Infonomics for Distributed Business and Decision-making Environments: Creating Information System Ecology*, IGI Global, Hershey, New York 2009.

WYZNACZANIE KONSENSU W ROZPROSZONYCH KOMPUTEROWYCH SYSTEMACH WSPOMAGAJĄCYCH PODEJMOWANIE DECYZJI

Streszczenie: W artykule przedstawiono problem wykorzystania metod konsensu w rozwiązywaniu konfliktów wiedzy w rozproszonych systemach wspomagania decyzji. Przedstawiono sposób reprezentacji decyzji za pomocą struktury wieloatrybutowej i wielowartościowej oraz scharakteryzowano profil decyzji i problem wystąpienia konfliktu wiedzy. Następnie opracowano algorytm heurystyczny wyznaczania konsensu dla profilu składającego się ze zbioru struktur decyzji.

Słowa kluczowe: systemy rozproszone, systemy wspomagania decyzji, konflikty wiedzy, metody konsensusu.