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A COMPARATIVE ANALYSIS OF CONFLICTS RESOLVING METHODS IN MULTIAGENT DECISION SUPPORT SYSTEMS

Introduction

Present socio-economic conditions seem to favor fast and accurate decisions as one of the most important elements of company competitiveness. Company decision makers typically operate under the constraints of uncertainty and risk, since results of most decisions in turbulent environment cannot be readily foreseen or can only be appraised with a marginal level of probability. Consequently, the decision-making processes are more and more complex.

Decision processes in modern companies are often supported by IT decision support systems (DSS), also in the form of multiagent systems, i.e. systems based on several agent applications that analyze data and present the user with optimal decisions in response to particular problems. Multiagent systems allow for rapid collection and processing of data, but the ultimate choice of decision is in the hands of the user, as a person responsible for the decision making process and its results. Multiagent decision support systems offer considerable reduction of decision time, since they replace the user in the arduous task of selecting and processing of information. Multiagent DSS can also draw conclusions and make suggestions based on collected data.

However, in practical application of multiagent DSS, some tasks may generate conflicts between the constituent agents. The problem of selecting appropriate conflicts resolving methods in multiagent DSS has not yet been addressed in professional literature nor the economic practice, although this type of problem seems crucial in system development and should be addressed in the early stage of system design.

Therefore this paper presents an attempt at evaluation of conflicts resolving methods employed in multiagent DSS, based on comparative analysis of methods and determination of their benefits and shortcomings.

It should be noted, that conflicts, for example, may arise if individual agents operate under different decision support methods [SoHe12], while input information used for decision-making process is drawn from heterogeneous sources. Conflicts may also result from contradicting objectives or methods employed in individual agents. Consequently, individual agents may suggest different decisions or solutions. In the face of conflict, the DSS is unable to provide a single solution (i.e. one that satisfies criteria defined by user as process parameters, for example – a rate of return on investment at a given risk level). Consequently, the user is faced with an extra task of manually analyzing and selecting an appropriate decision from the array of suggestions postulated by individual agents. This is, obviously, a time-consuming process and decisions made in this way bear the risk of being outdated. In the turbulent environment of modern economy, decisions must be made in (or close to) real time. Moreover, decisions based on incomplete information are burdened with high level of risk. Therefore, conflicts in multiagent systems may have a negative effect on company operation.

In this context, it seems that automatic conflict resolving should be regarded as one of the most important features of an effective decision support systems. DSS employs many different methods of conflicts resolving, and their effectiveness largely depends on suitability of a particular method for decision-making context, and the structure of the DSS. For example, decisions involving organization of features of an object under analysis require different methods of conflicts resolving than those in the realm of financial management. Other determinants include the type of multiagent DSS or its size (the number of agents).

Results of comparative analysis of conflicts resolving methods may be used as basis for their selection in particular applications (tasks) and their suitability for different types of multiagent decision support systems. The selection can be made early in the design process, offering considerable improvement of system effectiveness.

Types and the methods of resolving of conflicts in multiagent systems

Proper functionality of multiagent systems requires accurate interpretation of the type of conflicts identified or anticipated in the course of system operation. Liu [LGMB98] identifies the following types of multiagent system conflicts:

1. Conflicting goals – if two goals cannot be reached within the same timeframe, they are considered to be in conflict (a good example of such conflict is an exclusive lock on a resource used by two agents). This type of conflict requires modification of agent goals.
2. Conflicting plans – if one agent's post-action conditions conflict with pre-action conditions of another agent, while timeframes defined for both actions overlap (for example, when one agent moves X file from B directory to C directory, while another agent moves X file from A to B). This type of conflict requires modification of agent plans.
3. Conflicting beliefs – for learning agents, if the process of reasoning results in conflicting goals or conflicting plans (for example, when two agents, acting independently, arrive at the conclusion that they have the right of exclusive use of the same resource A). This type of conflict requires modification of the reasoning processes.

According to Nguyen [Nguy02], the above types of conflict in multiagent systems are also accompanied by knowledge conflicts, resulting from inconsistent or contradicting knowledge of individual agents [KaNg00]. Knowledge conflicts occur when the same real world objects and the same features are attributed different values by conflicting parties. This type of conflict can be exemplified by different decisions on portfolio structure postulated by agents of a system designed to support financial investment decisions.

Conflicts classification allows for identification and design of various conflict resolving methods, such as:

a) negotiation methods,
b) deductive-computing methods, based on:
   – game theory,
   – classical mechanics,
   – operational studies,
   – behavioral and social sciences,
   – choice,
   – consensus.

Professional literature provides various definitions of negotiation methods. For example, in [DyLe06], negotiation is defined as "any communication process that results in mutually acceptable agreement". In [ShKY99, Jenn01], negotiation is defined as a process involving two or more agents, with parties communicating with one another, exchanging information and declaring their objectives, in an attempt to reach a compromise or arrive at mutually acceptable agreement on beliefs, plans of action or objectives that cannot be reached unaided or if unaided realization of which may prove impractical. In the course of the negotiation process, agents exert influence on one another, in an attempt to induce certain actions.

Conflict resolving in multiagent systems can also be based on deduction and computation methods. A good example of this trend is the use of methods evolved from game theory. Game theory is a discipline of science closely related to the problems of cooperation and conflict resolving in multiagent systems. It involves construction of mathematical models of conflicts and cooperation as elements of human interaction. Game theory models are highly abstract representations of various everyday interactions involving different goals and preferences [RoKr12].

Methods based on classical mechanics are another subset of deductive-computational group [Teyl06]. Those methods are employed in multiagent systems that require cooperation between a large number of agents – hundreds or even thousands of agents – such as in systems designed to reach highly distributed and dynamic goals (those typically include a large number of agents) [RoKr12].

Conflicts resolving methods based on operational studies involve the search for best ways of design and implementation of organization systems, typically operating on limited resources [Całc00]. Agents cooperating within the DPS framework (distributed problem solving) can be viewed as examples of such organization systems, therefore they can employ techniques and methods designed and identified through operational studies as applicable for human organizations. Operational studies apply to problems involved in calculation of set division and set coverage representations [HeNg07], representing NP-complete class of problems. Solutions postulated by operational studies can be used to tackle problems of coalition formation in DPS operating on a given set of agents and a list of tasks, i.e. identifying assignments to agent groups (or individual agents, if the task can be accomplished by a single agent).

Often, in the case of solving inadequately structured problems, a range of informal conflicts resolving methods are employed as basis for agent cooperation. These include formalization and application of solutions originated in behavioral sciences and sociology [SaKa12]. Analyses and studies of human behavior, human cooperation and coordination of human activities, developed by social sciences, offer a number of models used to describe human organizations and communities. These heuristic models can be employed to good effect in the context of non-structured and unpredictable multiagent environments, to describe cooperation and coordination between agents based on well-studied and verified models of human interactions.

Theory of choice developed in the context of sociology and social sciences [Abba09] dates back to antiquity and deals with sociological methods of decision support. Let us assume that a given set Z (e.g. a set of objects0) represents a subset of a larger set of X. Choice, in this example, involves a selection of a subset Y out of set Z, based on a range of criteria. In decision-making scenario, set Z represents a set of decisions generated by other methods, set X represents a set of acceptable decisions, and subset Y represents a decision presented to the user.

Theory of consensus stems directly from the theory of choice. In literal terms, consensus stands for agreement. Thus, in the context of consensus theory, the actual choice does not necessarily represent a subset of Z, and is not necessarily presented in the same structure or form as elements of the Z set [Nguy02]. Therefore, decision presented to the user does not necessarily represent an actual decision established on the basis of decision support methods. It may just as well be a unique decision formed on the basis of those suggested by the system. Initially, the theory of consensus referred to structures organized in a linear or partial order. Later on, it was applied to more complex structures, such as divisions, hierarchies, n-trees, as well as multi-attribute and multiple-valued structures (the latter referencing also decision structures) [SoHe11]. Consensus methods are applied for the purpose of determining such solutions to a given set of data which best represent the original versions generated by the system or those that represent a compromise accepted by all parties involved in generation of preliminary versions of potential solutions. Consensus determination is a multi-stage process. The first stage involves careful analysis of Z set structure, i.e. the structure of decisions generated by individual decision support methods. The next step is the determination of distance between individual elements of the Z set. Consensus determination involves selection of a set (i.e., decisions) found minimally distant from all other subsets of the Z set (according to a range of criteria).

After these preliminary observations, let us now proceed to discussion on the results of comparative analysis of conflicts resolving methods.

Comparative analysis of conflicts resolving methods

Comparative analysis of conflicts resolving methods is an extremely important element of the discourse, since – as already mentioned – correct choice of methods early in system design helps adjust the process to the type of task at hand and to the characteristics of the multiagent system used. Proper selection of method ensures effective reconciliation of potential conflicts between agents and, consequently, warrants proper identification a single solution that brings tangible benefits to the user. The analysis was conducted on the basis of the following criteria: type of conflict addressed, benefits, flaws, the range of method application. Results of comparative analysis are presented in Table 1.

Results of the analytical study show that, due to a large variety of potentially applicable methods of conflicts resolving in multiagent systems, design teams face a difficult decision of selecting the most adequate method, suited both to system architecture and the type of problems being addressed by the system. Proper method selection ensures proper resolving of future conflicts. As shown in Table 1, both negotiation and consensus methods offer best conflicts resolving capacity.

Table 1

Results of comparative analysis of the conflicts resolving methods

Method/types of conflicts	Benefits	Shortcomings	Scope of the applications
Negotiation Conflicts: goals, plans, knowledge	Getting a good compromise, and property conflict resolving in consequence; possibility of communication between agents; agents can generate arguments, to support his adopted point of view on the case, agents can influence each other in their views; possession by agents information about other agents	High computational complexity; the agent must have the skills for the submission of proposals and counter proposals to accept or decline offers of other agents; If the information about other agents is incomplete, incomplete, this agent may represent a valid offer to other agents; agent must allow changes to the objectives, plans, beliefs or knowledge structure without any external pressures	All kinds of problem and all types of systems
Game theory Conflicts: goals, plans,	With a small number of agents it is possible to obtain a good compromise; abstract models of game theory can be used as a basis for interaction protocols agents in multiagents systems	High computational complexity; require a large number of, often quite complex calculations and a lot of time is being sacrificed on the communication between agents	Used in systems where agents are striving to maximize the goal, systems can consist of a small number of agents or interactions between them are limited to a small number of it

Table 1 continued

Classical mechanics Conflicts: beliefs, knowledge.	Low computational complexity; the possibility of using large scale multiagents systems; do not require communication links between agents; the properties of the system as a whole can be analyzed using statistical techniques	Conflicts are solved not always correctly; designers of these systems must determine in advance certain principles and protocols of interaction agents	Used when required is cooperation between a large number of agents, when agents work together to reach a common, distributed, used for example in support the production processes in large companies
Operational studies Conflicts: goals, plans, knowledge	Getting a good compromise, and property conflict resolving in consequence; possibility of resolving NP-complete problems	High computational complexity; performance significantly decreases with increasing size of the system; agents must have the ability to use large computing power processors	Usually used in conditions of limited resources; applies, inter alia, to the problems of forming the coalition, where given a set of agents, and a collection of tasks that they must perform together, looking for, a way of allocating each task to a group of agents that perform this task
Behavioral and social sciences Conflicts: beliefs, knowledge	Getting a good compromise, and property conflict resolving in consequence; agents have the communication skills, builds on the experience and expertise developed by many scientists	High computational complexity, the number of agents in this type of systems that may not be a large; before using the simulation should be carried out	Used in solving the poorly structured problems and in the systems that are usually automatic systems agents react with other automated agents as well as with people
Choice Conflicts: goals, plans beliefs, knowledge	Low computational complexity	Conflicts are solved not always correctly; using the choice method decision-maker receiving the decision generated by one of the methods of decision making support, other methods are not taken into account	All kinds of problem and all types of systems
Consensus Conflicts: goals, plans beliefs, knowledge	Low computational complexity; getting a good compromise, and property conflict resolving in consequence; allow to quick decision determining; allow you to change the status of agent knowledge under different conditions; all parties to the conflict to be taken into account; allow for the reduction in the level of risk	Not all conflict situations are susceptible to consensus; elaboration of heuristic algorithms, which allow to resolving conflicts related to NP-complete problems, is difficult	All kinds of problem and all types of systems; applied, for instance, to experts conflicts resolving, conflicts in temporal database, multiagents conflicts, restoring consistency of replicated data, supporting the decision process

Source: Own work.

It should be noted, however, that consensus methods, as opposed to negotiation methods and similarly to methods based on classical mechanics, do not require large computing power. The remaining methods of conflicts resolving represent a tradeoff between good resolving potential and large computing complexity.

Let us emphasize at this point that the choice of the most appropriate conflicts resolving approach ensures proper operation of the multiagent DSS, i.e. its capacity to produce the most suitable decision, bringing tangible benefits to the end user and the organization. Conflicts resolving in multiagent systems ensures that decisions generated by the DSS are best for the user, that is – they best satisfy all user-defined criteria.

Conclusion

To sum up, it must be noted that conflicts are an inherent element of mostly all multiagent systems. Proper classification of conflicts is of great significance, particularly in multiagent systems design to support decision-making processes, since their functionality has a direct effect on user decisions and – ultimately – affects the organization as a whole. Such conflicts should be resolved automatically, otherwise the system will be unable to provide correct solutions. This is why system design teams should examine and select best conflicts resolving methods early in design process. Implementation of new methods in existing systems may be problematic, since it requires coding modifications of individual agents. Proper selection of conflicts resolving method ensures effective operation of the DSS, offering users the most beneficial solutions to problems at hand. If this aspect of system operation is neglected, users may face the problem of being unable to make prompt and adequate decisions since the system may produce an incorrect decision or an array of applicable solutions that requires further analysis and time-consuming selection on the part of the user.

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ANALIZA PORÓWNAWCZA METOD ROZWIĄZYWANIA KONFLIKTÓW W WIELOAGENTOWYCH SYSTEMACH WSPOMAGANIA DECYZJI

Streszczenie

W artykule dokonano analizy porównawczej metod stosowanych w rozwiązywaniu konfliktów wiedzy w odniesieniu do wieloagentowych systemów wspomagania decyzji. Dobór odpowiedniej metody, w zależności od rodzaju konkretnego zadania oraz od charakteru wieloagentowego systemu wspomagania decyzji, jest niezwykle istotny już na etapie jego projektowania, gdyż w konsekwencji może prowadzić do zwiększenia skuteczności wspomagania procesu podejmowania decyzji.

W pierwszej części artykułu przedstawiono rodzaje konfliktów w systemach wieloagentowych. Następnie dokonano przeglądu metod rozwiązywania konfliktów. W końcowej części artykułu przeprowadzono analizę porównawczą tych metod ze szczególnym uwzględnieniem ich zalet i wad oraz zakresu zastosowania.