The Tasks of Observation, Measurement and Evaluation in Intelligent Active Systems

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Abstract. The article examines how agents in intelligent active systems can observe, measure and evaluate their actions, each other's actions, the influence of the external environment on the analysis of possible solutions to the tasks posed and the choice of the optimal solution. Intellectual agents usually operate under conditions of uncertainty, inaccuracy, incompleteness and unclear of information that they have. This is due to the subjectivism of choosing the strategically correct position of each agent in the system and the effectiveness of his work. In the activity of intellectual agents, it is important not only how strongly and in what direction influence the factors of the external environment on each of them, but also how the agent perceives this influence. From the perception of the agent, in the final analysis, decision-making depends. Therefore, the article focuses on the aspects and elements of fuzzy mathematics, allowing to evaluate the effectiveness of the agent's activity in the system and to form a complex of impacts for increasing the effectiveness of the agent, if necessary.

1. Introduction

The object of research in this article is an abstract intellectual active system (IAS) designed to solve specific problems and consisting of a finite number of agents that can be either software or physical entities. Multi-agent technologies are used where it is impossible to solve the task with a single agent. In this case, the problem is decomposed into subtasks. The responsibilities for the solution of these sub-tasks are assigned specific agents. The assignment can be conditional, since the agent can choose the subtask, over the solution of which will work. When assigning sub-tasks to agents, the methods and algorithms proposed in [1], [2], [3], [4], [5] can be applied. After specification of the duties and functions the intellectual agent carries out operations of observation, measurement and estimation. And here it is important to find out how he does it? How does his reaction to the observed object, process or phenomenon change with time? How the intelligent agent performs measurement, and builds up the evaluation procedure and output a final rating in the face of uncertainty, incompleteness, imprecision and vagueness of information, which he has, and taking into account the peculiarities of its own perception of that information? The author tried to give answers to these and other related questions in this article.

The words authored by the French philosopher, mathematician, scientist and encyclopedist of the XVII century Rene Descartes, can be rephrased as follows: I observe, measure, evaluate, consequently, exist. Indeed, any conclusions can be built only on the basis of the results of observation, measurement and evaluation. Intellectual agents in their activities observe, measure and evaluate not only the actions of other agents and entities from the external environment, but also their own actions and results. As a rule, depending on the psycho-behavioral type [3], internal conviction and motivation, some agents tend to improve the results obtained, others are content with what is. In changing the behavior of agents of the second group for the better, external motivation can help, but its action, as a rule, quickly ends. External motivation is an additional incentive in the form of resources, of bonus time and other preferences. But these incentives also affect the behavior of different agents in different ways: some agents are more susceptible to external stimuli, others are less.

The purpose of this study is to develop a methodology for identifying the most effective agents in IAS. The more effective "inhabiting" IAS agents, the more effective the system itself. Therefore, it is extremely important to "populate" the system with only effective agents. An effective agent can be an agent who fully and without mistakes performs tasks in an acceptable time and does not conflict with other participants of the system. Since intellectual agents are characterized by some indistinctness and uncertainty in judgments and actions conditioned by their states, then fuzzy logic, fuzzy algebra and geometry, and cognitive psychology are chosen as methodological tools for the study.

2. The concepts of "observation", "measurement" and "evaluation" in intelligent active systems

In an abstract IAS, each agent can be both an observer and an object of observation. The agent-observer monitors the activities of other agents, compares their actions and the results obtained, forms an opinion on each of the observed agents on the basis of an assessment of their activities. Observation, measurement, and evaluation in the IAS have fairly fuzzy, vague results. This is due to the state of the agent-observer; with the state of its environment; with state of objects, for which he observes. Suppose that the agents that are monitored are evaluated according to three parameters: the correctness of the execution of the sub-task (x), the timeliness of the sub-task (y) and the level of conflict during the execution of the sub-task (z). Timeliness of the execution of the sub-task by the agent depends, inter alia, on the correctness of her fulfillment and on the extent to which the agent is in conflict. The correctness of the execution of the sub-task depends on the knowledge and outlook of the agent. The level of the agent’s conflictuality depends mainly on its provision with the resources necessary for solving the subtask and on the degree of benevolence, the friendliness of his relations with other agents of the system.

2.1. Observation carried out by an intelligent agent

Observation in the IAS is an active, systematic, purposeful, planned and deliberate perception of the agent-object of observation, its actions and the results it receives, during which the observer receives knowledge about the external aspects, properties and relationships of the agent being studied. Elements of observation are: an agent-observer, an agent-object of observation, means of observation. At this stage, the intelligent agent comprehends the existing situation, the situation that surrounds him. He is collecting data.

2.2. The measurement performed by the intelligent agent

The results of observation are transformed into measurement procedures. Intellectual agents compare what they have observed or is observe, with a certain standard − a uniform (with respect to the measured result of observation) value (object), possessing all desirable properties and necessary attributes. The characteristic of the measurement accuracy is its error or uncertainty. If to compare the result of observation with nothing, the intelligent agent creates a certain collective image of the ideal result (object). In this case, for different agents, these images can differ substantially depending on their individual perception. In the absence of a standard, a so-called vague uncertainty arises for measurement. A vague uncertainty can be interpreted as a situation in which the axioms of identity are violated, and the ambiguity of classifications is obvious. A vague uncertainty is described by means of membership functions and, as a rule, is characteristic of linguistic models, although it is also encountered in mathematics [6].

The measurements can be direct and indirect. Intellectual agents get directly the desired value or feature (property) of the observed object or phenomenon at direct measurement. With indirect measurement, the desired value is determined based on the results of direct measurements of other homogeneous quantities, objects functionally related to the desired quantity or with the desired object.

2.3. Evaluation given by the intellectual agent

The interpretation of the term "valuation" in IAS is related to the interpretation of the term "expert judgment". Intellectual agents-observers act in the IAS also as experts, who give their opinion on the activities of the observed agents and the results of this activity. The evaluation can be expressed both quantitatively (for example, a fiveball system) and in a qualitative form (for example, the grade is "bad", "satisfactory", "good", "excellent"). At the same time, in IAS can develop rules for the transition from a qualitative (linguistic) scale of assessments to a quantitative scale.

Thus, the intelligent agent in the system goes from one state to another as shown in figure 1. He consistently tries on the role of an observer, a measurer and an appraiser. The state map is in fact a finite state machine with several important additions proposed by David Harel, accepted by the global modeling community and included in the standard UML (The Unified Modeling Language).

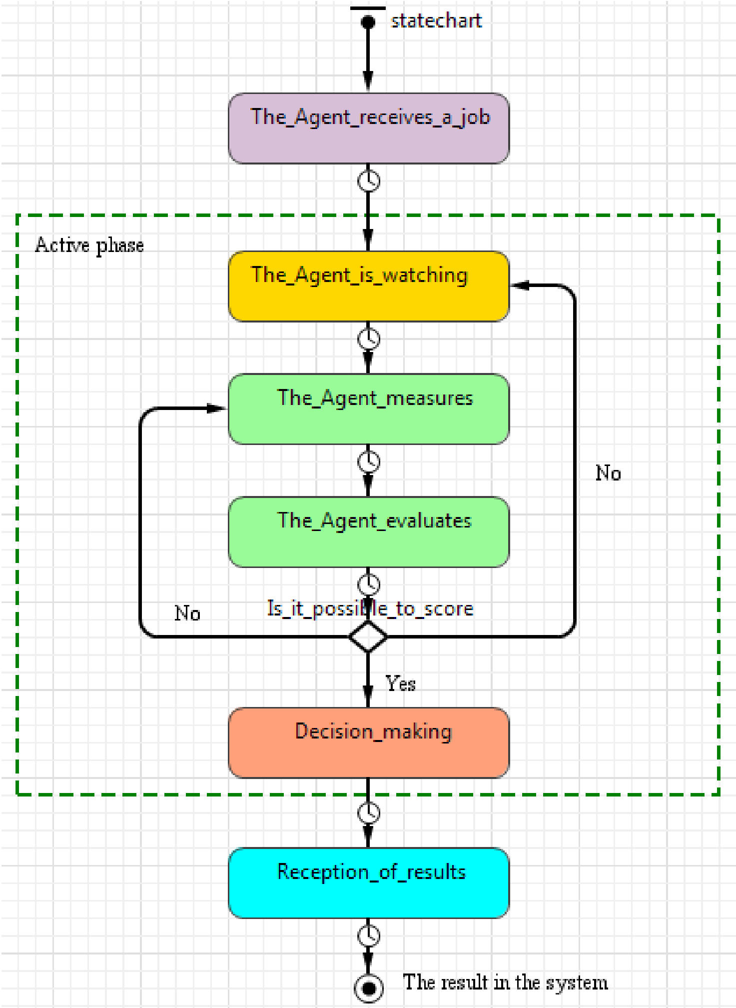

Figure 1. Map of states of an intelligent agent in the IAS.

State maps allow to graphically determine: possible agent states and transitions between them; the events that cause these transitions; time delays and actions committed by the agent throughout their life cycle. Such constructs, as nested states, allow to set the operating modes of the agent [7, p. 7]. Each agent can have several parallel active and interacting state maps, each of which is responsible for some aspect of its activity, for example, for observation, measurement, and evaluation. Software implementation of such agent models is possible in various systems in which there are possibilities of object-oriented programming, for example, AnyLogic, NetLogo, etc.

In the observer state, the agent collects data on the behavior of other agents, fixes the deviations of the position of the agents from the given coordinates in the state space. By moving agents in the state space, one can build their functions of belonging to the notion of "effective agent", determine the level of fuzziness of each agent's behavior.

At the measurement stage, the levels of fuzziness of agents' behavior are compared, their deviations from standards and the mutual deviations are established; critical deviations and admissible deviations are elucidated.

During the evaluation phase are determined by the psycho-behavioral types of agents, which were monitored. The conclusion is made about the effectiveness of their IAS activities and the prospects for their further functioning in the system are forecasted.

3. Application of fuzzy logic in problems of observation, measurement and evaluation

Proceeding from the results obtained in [8], we can state with confidence that there are three aspects of the activity of intellectual agents: they possess certain knowledge, they have a sense and own perception of the environment, they can perform certain actions.

Agents have two types of knowledge: specialized knowledge and familiarization knowledge. Specialized knowledge is knowledge about the subject and problem areas, and familiarization knowledge is knowledge about other IAS agents.

Each agent knows about other agents the following:

- the name of the agent and the group to which the agent belongs;
- the role that the agent performs in his group;
- agent skills, i.e. its functionality in the system;
- the agent's goals, at least, those goals that he broadcasts to other agents of the system;
- agent's plans, i.e. his ideas about the ways and methods of achieving the existing goals.

It does not exclude cases of manipulation and reporting by agents of false information about their skills, goals, intentions and plans. Therefore, an important feature of surveillance in the IAS is the timely recognition of the insincerity of agents on indirect grounds. Such grounds include: excessive mismatch of the agent's performance with the planned results; the agent's behavior does not coincide with his intentions and plans; the agent is the initiator of conflict situations. In the conditions of high fuzziness and uncertainty, which characterize the IAS, the actions of agents in the state space are often unpredictable or difficult predictable, therefore further introduction of the notion "fuzzy agent" is expedient.

We will assume that each agent in IAS occupies a certain characteristic position, which is affected both by the individuality of the agent himself and by the specifics of the other agents of the system. In work [9], observation, measurement and evaluation of agents and their propensity to conflicts were carried out on such parameters as: psycho-behavioral type; the level of purposefulness, interest in the work on the result and the resource potential (the level of provision to the agent's with the resources needed to solve the sub-task). If we talk about the effectiveness of the functioning of agents in the system, then the assessment parameters are established, this listed above (see subsection 2).

A fuzzy agent is an intelligent entity that acts in the *n*-dimensional Euclidean area and is denoted as:

$$\tilde{A} = (\tilde{a}_1, \tilde{a}_2, ..., \tilde{a}_n), \ \tilde{A} \in E_n, \tag{1}$$

where E_n – *n*-dimensional Euclidean area;

$\tilde{a}_i$ – fuzzy numbers (coordinates of agent $\tilde{A}$), $i = \overline{1, n}$, characteristics that describe the state of the intelligent agent.

Fuzzy characteristics $\tilde{a}_i$ may have different degrees of clarity. And if $\mu_{\tilde{a}_i} = \alpha_i$, $\tilde{a}_i \in \tilde{A}_i$, $i = \overline{1, n}$, and the $\tilde{A}$ is fuzzy agent of α -level, then $\alpha = \min\{\alpha_i\}$.

The area of states of a fuzzy agent is a convex region of Euclidean space containing a "precise" agent, i.e. such an agent, whose actions, movements and movements in the system are predictable. The state area of the fuzzy agent can be stretched and compressed to an indefinite value. Figuratively this is shown in figure 2.

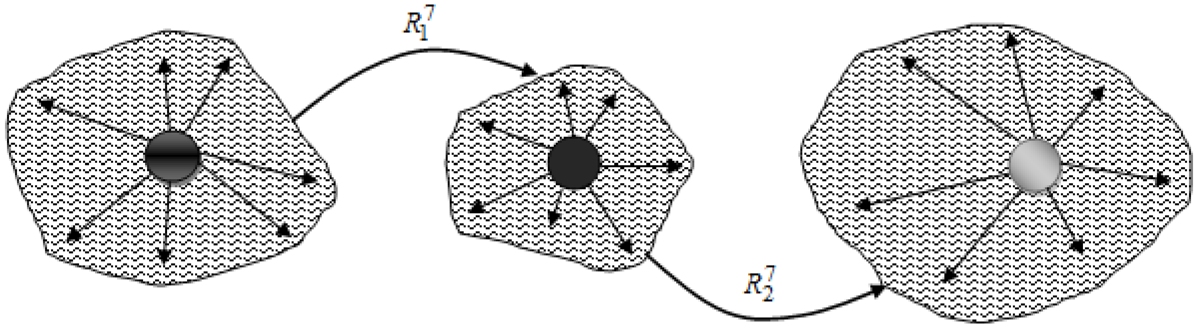

Figure 2. Changing the fuzzy agent state area.

In figure 2 each of the three agent $\widetilde{A}$ states areas consists of seven parameters. The simplest representation of a fuzzy intelligent agent is such, as shown in figure 3, i.e. the coordinate of $\widetilde{a}_i$ is a fuzzy number. On the straight line $(0;\widetilde{a}_i)$ for one membership function there are two fuzzy points of sharpness $\alpha \in (0;1)$ of levels $A_{\widetilde{a}_i L}(\alpha)$ and $A_{\widetilde{a}_i R}(\alpha)$. In figure 3 $A_{\widetilde{a}_i}$ is a clear agent, $A_{\widetilde{a}_i L}$ and $A_{\widetilde{a}_i R}$ are its fuzzy positions on the left and right respectively, d_L and d_R – left and right stretching of the fuzzy agent state area, $S_{\widetilde{A}} = (A_{\widetilde{a}_i} - d_L; A_{\widetilde{a}_i} + d_R)$ – the area of states of fuzzy agent on the axis $O\widetilde{a}_i$.

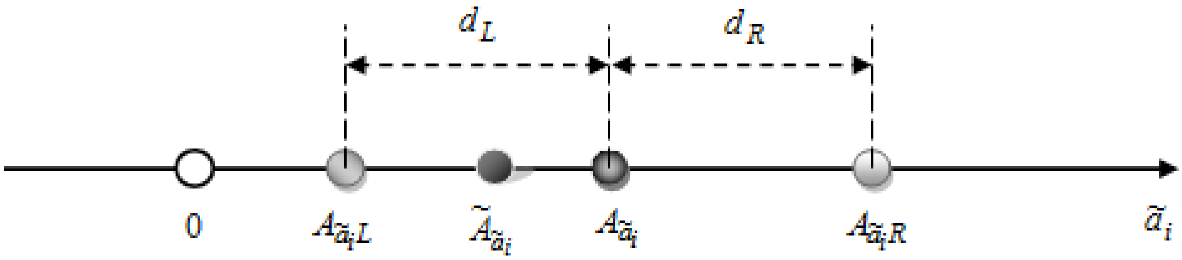

Figure 3. The area of states of a fuzzy intelligent agent, consisting of one parameter.

The area of states of a fuzzy agent, characterized by two fuzzy parameters, for example, $\widetilde{x}$ and $\widetilde{y}$, will be a convex simply-connected plane region (figure 4). If $\widetilde{A} = (\widetilde{x}, \widetilde{y})$, then:

$$S_{\widetilde{A}} = (S_{\widetilde{x}} \times S_{\widetilde{y}}), \tag{2}$$

where $S_{\widetilde{x}}$ and $S_{\widetilde{y}}$ – carriers of fuzzy numbers $\widetilde{x}$ and $\widetilde{y}$.

The multiplication sign ($\times$) means the Cartesian product.

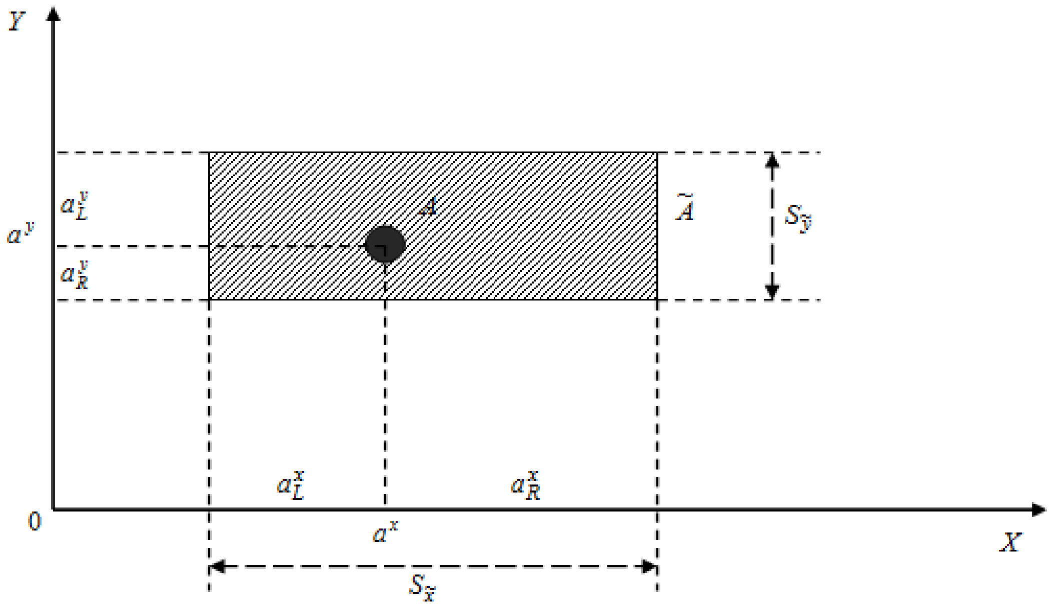

Figure 4. The space of states of a fuzzy agent on the plane.

Coordinates of the fuzzy agent may have different stretches of states area and membership functions. In addition, each coordinate of the fuzzy agent (as a fuzzy number) can have its own level of clarity. In Figure 4, the shaded area is the fuzzy agent state space $\tilde{A}$, $S_{\tilde{x}}$ and $S_{\tilde{y}}$ – the carriers of coordinates of the fuzzy agent in a rectangular Cartesian coordinate system; a_L^x and a_R^x – left and right stretches of abscissa; a_L^y and a_R^y – left and right stretching of ordinate of fuzzy agent $\tilde{A}$; $A(a^x, a^y)$ – position of clear agent.

The three-dimensional state space of the fuzzy agent is the correct region containing the carrier of a clear agent. If $\tilde{A}(\tilde{x}, \tilde{y}, \tilde{z})$ is fuzzy agent, then:

$$S_{\tilde{A}} = (S_{\tilde{x}} \times S_{\tilde{y}} \times S_{\tilde{z}}), \quad (3)$$

where $S_{\tilde{x}}$, $S_{\tilde{y}}$ and $S_{\tilde{z}}$ – carriers of fuzzy numbers $\tilde{x}$, $\tilde{y}$ and $\tilde{z}$.

In a rectangular Cartesian coordinate system in three-dimensional space, the area of states of a fuzzy agent is a four-dimensional prism; in spherical coordinates − a sector of a hollow sphere; in cylindrical coordinates − the sector of a hollow cylinder. If one of the coordinates of the fuzzy agent in three-dimensional space is a clear number, then its carrier turns into a flat region belonging to the plane perpendicular to that coordinate axis, which corresponds to a clear coordinate of the fuzzy agent.

If the sharpness levels α and the coordinates of a clear agent with membership functions are known, then the coordinates of the fuzzy agent in the three-dimensional state space can be found as follows:

$$\alpha = \mu_{\tilde{A}}(x) = \left\{ \frac{1}{1 + \left| \frac{a^x - a_L^x}{\sigma_x} \right|^{k_1}}; \frac{1}{1 + \left| \frac{a_R^x - a^x}{\sigma_x} \right|^{k_1}} \right\}, \quad (4)$$

$$\alpha = \mu_{\tilde{A}}(y) = \left\{ \frac{1}{1+\left|\frac{a^y - a_L^y}{\sigma_y}\right|^{k_2}}; \frac{1}{1+\left|\frac{a_R^y - a^y}{\sigma_y}\right|^{k_2}} \right\}, \quad (5)$$

$$\alpha = \mu_{\tilde{A}}(z) = \left\{ \frac{1}{1+\left|\frac{a^z - a_L^z}{\sigma_z}\right|^{k_3}}; \frac{1}{1+\left|\frac{a_R^z - a^z}{\sigma_z}\right|^{k_3}} \right\}, \quad (6)$$

where σ – stretching of fuzzy agent state space $\tilde{A}$;

a – clear meaning (position) of the intelligent agent;

k – compression factor, depending on the psycho-behavioral type of agent.

The estimation is carried out on the basis of the construction of fuzzy binary relations, which are matrixes of the form (table 1).

Table 1. Example of fuzzy binary relation.

R	y_1	y_2	…	y_j	…	y_m
x_1	μ_{11}	μ_{12}	…	μ_{1j}	…	μ_{1m}
x_2	μ_{11}	μ_{22}	…	μ_{2j}	…	μ_{2m}
…	…	…	…	…	…	…
x_i	μ_{i1}	μ_{i2}	…	μ_{ij}	…	μ_{im}
…	…	…	…	…	…	…
x_n	μ_{n1}	μ_{n2}	…	μ_{nj}	…	μ_{nm}

In Table 1 the set X consists of observing agents, and the set Y consists of agents, which are monitored. It may also be that agents-observers and observed agents are the same entities. Elements $\mu_{ij} = R(x_i, y_j)$ are estimates of agent *j* by agent *i*.

A fuzzy binary relation R between the sets X and Y is any subset $R \subset (X \times Y)$ defined by the membership function [10]:

$$\mu_R(x_i, y_j) : (X \times Y) \to [0;1]. \quad (7)$$

This approach to the definition of a fuzzy relation makes it possible:

- build practical generalizations, relationships and models of agent interactions in the IAS;
- apply the interpretation of various functions as a fuzzy relation to analyze the properties of these functions;
- to link together and consider in coordination many concepts and methods used in the analysis of empirical data.

The final evaluation of the effectiveness of agents is represented as a composition of fuzzy relationships. If $R_1 \subset (X \times Y)$ и $R_2 \subset (Y \times Z)$ – the fuzzy relationships, then the composition (max-min) of the relations R_1 and R_2 is the relation defined by the expression:

$$\mu_{R_1 \circ R_2}(x,z) = \vee_y \left[\mu_{R_1}(x,y) \wedge \mu_{R_2}(y,z)\right] = \max_y \left[\min\left(\mu_{R_1}(x,y), \mu_{R_2}(y,z)\right)\right] \quad (8)$$

and denoted $R_1 \circ R_2$, where $x \in X$, $y \in Y$, $z \in Z$.

4. The abilities of intelligent agents in the process of observation, measurement and evaluation

Solving the tasks of observation, measurement and evaluation, intelligent agents perform the following actions:

- perceive and process incoming data from the external environment;
- draw conclusions based on the results obtained during the processing of data;
- interact with each other, seeking to achieve a state of coherence and cooperation, realizing Nash's equilibrium principle [11], which states that one-sided deviation from the state of equilibrium is not beneficial to any of the intellectual agents;
- form their own beliefs, opinions, make assumptions, individually and not always adequately assessing additional messages (for example, from other agents);
- influence the environment with the aim of transforming it or without it, but pursuing one's own goals.

Each agent has a kind of knowledge base that consists of: ideas about the outside world, knowledge about one's mental space and space of other agents, skills of interaction with the environment, and skills necessary for communication with other agents.

In the processes of observation, measurement and evaluation, such properties of agent interaction as directionality, selectivity, intensity and dynamism are distinguished. Based on the results of the assessment, each agent makes a decision about the need for interaction with agents. The main criteria characterizing the process of formation of interactions in the IAS are:

- compatibility of agents' purposes or intentions;
- the ratio of agents to resources;
- experience of agents in a certain problem area;
- the obligations of agents to each other.

One of the most important reasons leading to interaction between intellectual agents is the discrepancy between the requirements imposed on the subtask being solved by each agent and the possibilities of solving it, which he has. It has been experimentally established that each agent is inclined to interact only with those agents that are sympathetic to it. Agents also come to the conclusions about sympathy or antipathy in time of solving the tasks of observation, measurement and evaluation.

Intelligent agents have a certain independence, are able to choose one option from the set, can be trained, adapt to changing circumstances. Such an agent has the right to be called Intelligent, which interacts with the environment in accordance with the accepted system of requirements. Intelligent agents in the monitoring, measurement and evaluation processes learn, modify and create new ways to solve problems, supplement their own base of examples of various situations, analyze their own behavior using the concepts of "failure or error" and "winning or success".

The agent, correctly assessing the situation, receives a certain reward. She can be expressed in the form of additional resources, time, of raising the status of the agent. The outcomes of any possible agent actions are predicted using behavioral models. The environment surrounding the agents is the field of their activities. She is also subject to observations by agents; certain actions are possible over it. Proceeding from the fact that each agent has a number of goals and permitted actions, his task is to study what actions he should take in every situation in which he may find himself.

The intelligent agent solves its subproblem in accordance with the algorithm, the scheme of which is shown in figure 5. In doing so, he must analyze the changes in the environment that are due to his actions. Observing the environment, the intelligent agent collects data, processes and analyzes them, based on which it gives its forecast of the development of events. This allows him to choose the optimal action or their sequence in the direction of solving his subtask. For example, such an action may be to seek help from other agents of the system, or, conversely, to refuse assistance. The result of the action should also be analyzed by the agent for the timely detection of errors and deviations from the planned effects. If the agent's actions led to the decision of the sub-task, then the next task is assigned to him. If the actions of the agent only brought him closer to the solution of the sub-task, he continues to observe the environment and act in accordance with the strategy developed earlier. If the agent's actions have alienated him from the goal (in comparison with the situation that was before the action was committed), the agent determines the amount of deviation, updates his behavior model, corrects the strategy of actions and, if necessary, changes the forecasting model. The agent rebuilds the forecasting model depending on how far the actions accomplished by him have brought him closer to the goal, or distanced him from her.

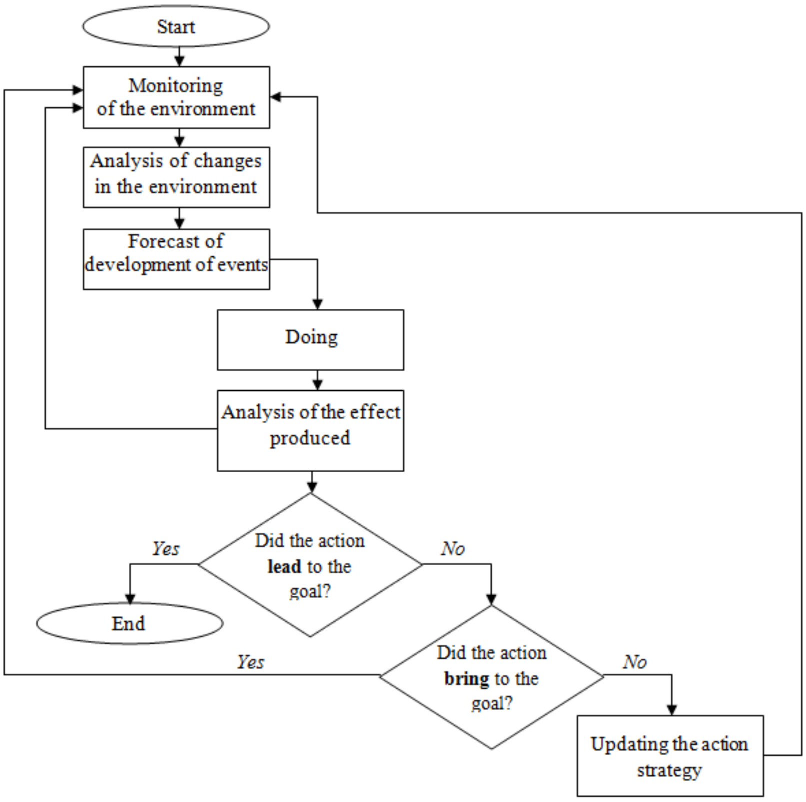

Figure 5. Algorithm for performing a sub-task.

Repeating the described process, the agent learns to take the most optimal actions to achieve the goal in each individual situation.

5. Conclusions

Monitoring, measurement and evaluation are integral tasks of the agents in the IAS. Observing, measuring and evaluating, each agent perceives the situation in his own way. The tasks of observation, measurement and evaluation, as a rule, arise for the purpose of clarification:

- effectiveness of intellectual agents in the system;
- sub-tasks, tasks and the results of their decision in the IAS;
- the reaction of the environment and its subjects to the activities of agents in the system.

Basically, the solution of the tasks of observation, measurement and evaluation in IAS takes place in conditions of limited resources. The main limitation is time. Therefore, intelligent agents must quickly respond to any changes in the environment, evaluate them and make appropriate decisions. The results of the conducted research confirm that the effectiveness of the activity of intellectual agents strongly (from 63% to 87%) depends on their psycho-behavioral type. In particular, it is established that the psycho-behavioral type of intellectual agents has a direct impact on the quality of observation, measurement and evaluation. These tasks are best handled by agents of a compromise type. Agents of the forcing type are too "picky", they notice things that are not factually and are prone to conflict. Agents of an evasive type exhibit certain indifference and often overlook important things. Therefore, the most effective IAS is the system in which most agents have a compromise psycho-behavioral type. The tasks of observation, measurement and evaluation in such systems are solved faster, more qualitatively, which facilitates the adoption of better solutions.

The method proposed in the article was applied in solving practical problems at the Department of Accounting and Finance of Tver State Technical University. In particular, this technique is well established in the formation of curricula in the economic direction of bachelors and masters.

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