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Incremental Solution of the Second Kind Problem on the Example of Living System

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This article describes the solution of complex problems, which are called second kind problems. It provides the distinction between the first kind and second kind problems. Solution of a second kind problem is based on the modification of the well-known ant algorithm of decision-making. Modification involves the transition from multiple points of solution searching to the single point. Modification involves incremental resources acquisition and accumulation of experience in solving. Such experience is stored in the database. This model is applicable for searching mathematical and management solutions.

Key words: Problem solving, Ant algorithm, second kind problem, complexity.

Problem solving[1, 2] and decision making[3, 4] have much in common. In essence, a solved problem is the basis for decision-making. When making decisions, a decision-maker faces an information field[5] or a complex system of parameters that need to be analysed and reduced. In this case, there arises a contradiction: the more a person delves into the problem, the better formally are the taken by him decisions; however, the deeper a person delves into the problem, the higher is the complexity level of the problems solving by him, and this implies result mistakes. Facing a set of parameters, which reflect a difficult situation, the human mind combines them into groups according to the qualitative characteristics[6]. In the process of decision-making, person or living creature analyses objects and relations between them. If any difficulties arise, a person performs the decomposition of a complex phenomenon or object. Fundamental process, underlying the problem solving, involves decomposition and synthesis. Although carried out by different people, decompositions may differ from one another; logic method underlying decomposition[7] makes it possible to obtain close enough assessments of the situation. This is particularly evident at the necessity of achieving common goals. Therefore, it is necessary to simulate reality in such a way to extract common sense and exclude individual matters.

Methodology

The technique is based on the development of the concept of complex situations' decomposition on the basis of collective behaviour modelling. Ant algorithm is taken as a basis. It is widely used in multi-agent systems.

Main part

There are different methods of decision-making, depending on the structural complexity[8] of the problem. The simplest decision is based on

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the "If A, then B" rule. This means that if there is informational situation [9] "A", then it is necessary to take a decision "B". Such a decision is called simple or single-link and is described by the following single link

$$A \rightarrow B \quad ...(1)$$

Such key chains occur in simple situations, such as "normative" management, when the situation "A" occurrence is provided by the regulations or standards. Such norm prescribes action "B" for the situation "A". In this case, the system simply executes the instructions given. In biology, the chain (1) describes the conditioned reflex.

If the ultimate goal A_T cannot be achieved in one step, then occurs a sequential decision, when for decision acquisition there is required a link chain of the following type

$$A_1 \rightarrow B_1 \rightarrow A_2 \rightarrow B_2 \rightarrow .....B_{N-1} \rightarrow A_T \quad ...(2)$$

Expression (2) is interpreted as follows. Informational situation [9] A_1 entails action of the system B_1, which leads to the informational situation A_2. Informational situation A_2 implies action B_2 and so on until the desired state is reached. Such a chain of actions is also called a "way of decision" or a "route of decision". They serve as a basis for constructing sequential algorithm, which leads to the decision from the initial situation $_1$. A set of actions B characterizes the processes of calculations or decision-making, if the algorithm is associated with the decision. Calculations are related to computer technologies, decision-making relates to the living and intelligent systems.

If the chains (2) are repeated, they are recorded in the system's memory and stored as stereotyped decisions. Expression (2) characterizes the complexity of the first kind problem solving, while for decision acquiring there is used only one chain of decisive actions.

There may be a group of alternative routes of decisions, for example, D→E, H→P, X→Y, etc. However, they are all stereotypes and do not allow the transition from one route to another. A decision-maker needs to select the optimal, in his opinion, route and act as it is prescribed by this route. All this is demonstrated by an algorithm or a set of unrelated algorithms.

In some cases, for a decision within the complexity of situation[10], it is necessary to select a "way of decision". Figure 2 demonstrates the situation when from the initial point A_b it is required to obtain a decision A_e or a final situation. The way to obtain situation A_e is a multivariate one. At the first stage of decision, there should be chosen a variant of decision. It defines the process of decision and the next state and the process that leads to this state. If the quantity of such and following them conditions is big, then the process of finding a "way of decision" becomes boundless. In this case, it is difficult or impossible to find the best way of decision. These problems are called the second kind problems. It should be noted that not the multi-variance, but the impossibility of constructing a way of decision characterizes second kind problems.

Let us make a distinction between the problems of the first and the second kinds. Problems of the first kind are characterized by uniqueness of their decisions, and an algorithm that leads from the initial situation to the final (target situation). From a topological point of view, a graph of the first kind problem has no cycles.

Problems of the second kind are characterized by non-uniqueness of their decisions and absence of a single algorithm, which leads from the initial situation to the final point. Graph of the second kind problems has cycles.

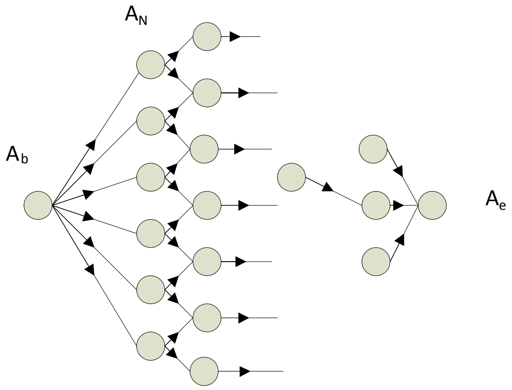

Fig. 1. Graph of the second kind problem

One of the methods for solving second kind problems may be the so-called ant algorithm[11]. Ant algorithm simulates the behaviour of the ant colony optimization when searching for food. It is used for finding approximate decisions of a transportation problem, as well as to search for routes in the graphs.

The essence of the algorithm consists in analysing and using models of individual and group behaviour of ants seeking the path from the colony to a source of feeding. The first version of the algorithm proposed by Marco Dorigo, Ph.D.[12], was aimed at finding the optimal path in the graph.

In terms of informational language, a model of decision is searched using the "greedy algorithm"[13] supplemented by the ability to transfer information from one agent to another with the inclusion of the algorithm "greed" and "herd instinct" parameters. The "greed" parameter describes motivation; the "herd instinct" parameter characterizes the repeatability behaviour and is the antonym of the term "randomness". Transmission of information creates the possibility for self-organisation of an ant colony system to achieve the goal. This model is used in multi-agent systems.

A multi-agent system[14] is in search for the best solution of the problem without outside intervention. Under the optimal solution we mean the solution, which requires the least amount of energy spent in the face of limited resources. Thu, this solution provides an additional effect of saving resources. The work begins with the placement of ants at the graph's vertices (cities), and then begins the ant movement. Their direction is determined by a probabilistic method[12]. Let us recall the essence of the algorithm. Ants initially move randomly according to the graph in Figure 1. After finding food, they return to the colony meanwhile marking the path of motion with pheromones. Pheromone is a substance that evaporates over time. If other ants find such paths, they will follow them. At finding food and returning back to the colony, they reinforce this route with their own pheromones.

Over time, the pheromone trail starts to evaporate, thus reducing its attracting power. The more time it takes to follow the path to the target and back, the stronger evaporates the pheromone trail. The more food is at the end of the trail, the more ants will follow the path, and the stronger will be the attractiveness of pheromones. This motivates the movement along the paths leading to the maximum resources. This is an example of a greedy algorithm. Since the algorithm ensures the resource potential of the problem solution.

Another aspect of the algorithm is a spatial solution. Passing a short path is faster and as a result, the density of pheromone remains at a high level. This motivates the ants to move along short routes to the food sources.

Evaporation of pheromones creates a condition of locally optimal solution exception. If the pheromones were not evaporated, the first chosen path would be the most attractive. In this case, spatial solution studies would be limited. However, in practice, there is a different situation. If another ant finds a shorter path from the colony to a food source than the first ant, it creates a high level of pheromone density along this path. Other ants are likely to go down this path, and the algorithm of such behaviour eventually leads all the ants to the optimal path.

The disadvantage of the method is the requirement for an ant colony existence. Mathematically, this requirement is to place the start of searching for a solution not in the initial point A_b, in the aggregate of set of points of the row A_N. This algorithm is justified in complex situations, such as route searching in the GRID systems[15] or in combination with genetic algorithms[16]. But fundamentally, it requires a set of search points, or

In solving practical problems, the Ant Colony Algorithm (ACA) model is supplemented by a chain of feedback and data bank. This leads to an additional mechanism: the incremental accumulation of knowledge and resources; implementation of incremental knowledge and resources to address the next stage of the problem[17].

As a result of this mechanism, at each stage are received incremental resources (IR) and incremental knowledge (IK). These incremental values are placed in storage in the data bank and used to solve the challenges of the next stage. Each stage is characterised by problems solving with the help of ACA and accumulation of resources and knowledge. The result of repeatable problem's solutions will be the total information resources (TIR) and total knowledge (TK).

$$TIR = IR1 + IR2 + \ldots IRn$$

$$TK = IK1 + IK2 + \ldots IKn$$

Where *n* is the number of problem solving stages

Based on the accumulated knowledge, there can be formed rules for routs searching or rules for passing certain situations.

One of the main characteristics of this solution is a tolerable solution time, which is the amount of time allowed for solving the problem. There is no such limitation in the ant algorithm. Informational technological support of incremental solutions includes a set of rules.

CONCLUSION

In the course of this work, the author used the duality of concepts: mathematical solution and decision-making (in management). The distinction of these concepts was not required, which gives the basis of universality of this method. Supplementing of the ant algorithm with an incremental mechanism for obtaining and accumulating resources allows transferring a solution of this problem into the area of computer and informational modelling. Accumulation of resources in the data bank allows conducting a systematic analysis of decisions and conducting additional optimizations for solutions found. The drawback of the algorithm is limiting the type of tolerable solution time. This lack of involvement requires large computational resources.

Summary.

The results of studies demonstrated the applicability of the method for searching mathematical solutions and management decisions. This increases the value of the method. Expansion of the ant algorithm with the mechanism of incremental resource capacity building, allows, while accumulating experience, to transfer complex problems of the second kind to the category of foreseeable problems of the first kind, and simplify the management of complex systems. This mechanism allows for better management of energy and information resources.

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