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Abstract

Considered is the problem of goal formation modelling in human mental activity as a basis of the construction of automatic systems possessing properties of autonomy and intellectual activity. The characteristic of the psychology of goal formation is given. The necessity of use of semantic languages for modelling of independent goal formation is substantiated. The structure of semantic language based on the principles of situational control is described.

Modern formal-logical metasystems, if they are considered as means of modelling human thinking, reveal a very essential shortcoming: they do not permit a description of such an important component of mental activity as a goal formation. The most intensive creative work of the makers of programs designed for thinking modelling, if only it is brought about on the basis of existing metasystems, do not lead to construction of programs reconstituting an independent goal formation process. As a result, the automated systems proved to be, in essence, doomed to passivity: they can work only by instructions or perform reactions to stimuli known beforehand.

The creation of active cybernetic systems, i.e. those which could be able to form independently a goal, presupposes a development of language of thinking modelling corresponding to a greater extent than formal metalanguages to goal formation process regularities in intellectual human activity. One of the difficulties of creation of such a language is the absence in modern structural linguistics of means of description of mechanisms of human cognitive activity which underlie problem solving models construction. Leading with Chomsky's investigations, the works in the field of structural linguistics were directed towards the study of natural language functioning mechanisms and the construction of its formal models. Problem solving language turned out to be out of the field of vision of these works.

Investigations into thinking modelling, the results of which formed the basis of the present work, have begun in the middle of 60-thies within the frameworks of the methodology of operative thinking in big systems and the situational control based on this methodology which found at present practical application in automation of control processes, robot construction, pedagogics, etc.(1)

One of the essential prerequisites

for the development of situational control was the psychological investigation into solving operative problems appearing at complex objects control (3). The essential characteristic of many operative problems is that their conditions are usually presented to man as a set of separate dynamic elements capable of moving in a discrete static space (problems of dispatcher's railway transport control, chess, - game "15" problems, etc.). The solving of these and other problems may be characterized as interaction of two components - the environment, i.e. the situation, and the process of modelling of this situation which is brought about in the head of man solving the problem. By solving the problem, the subject models, reconstitutes in his internal informational plan dynamic elements and that static system (the tracks of a railway station, the fields of chess-board etc.) on which these elements are situated. Psychological investigations suggest that such a reconstitution of situation in the internal plan occurs at the level which is essentially more abstract than information process. At informational modelling the subject abstracts himself from purely visual properties of objects, for example, when solving a chess problem, the shape of chess bishop staying on the board makes absolutely no difference to him. Each of the dynamic elements of situation is allotted first of all in informational aspect with the ability to move in the static system. Such an ability proves from the very outset to be rather an abstract conceptual characteristic. The model of some or other element of a situation in man's head embraces the multiplicity of characteristics of this element which can be characterized as its conceptual span. In problem solving the models of elements interact with each other, in other words, conceptual spans, for example, of two elements interact, so that one element becomes a predicate of another. The interaction of such kind between the models of situation elements in problem solving can be characterized as a relation between these models.

The problem solving process can be presented as a process of the construction of conceptual models of situation elements (situational concepts) and of the formation of systems of relations between them. This activity is, however, a controlled component of the problem solving process. The number of characteristics which may be revealed in some or other situations, and the number of re-

lations which can be established between elements of this situation is, as a rule, potentially very great. The presence of the regulator, which directs a cognitive process in some or other way, is characteristic of human intellectual activity. This regulator is a goal of activity which is coded in terms of relations between situation elements. Investigations into the psychology of thinking testify to the fact that goal transformation at the different stages of statement and solution of a problem is characteristic of man's intellectual activity. This dynamics of goal may be observed on the examples of well known chess problems. The initial situation is given in these problems as a set of separate elements situated on the chess board fields. Simultaneously with such a situation, the initial goal is fixed, for instance, to make the mate to the blacks in three moves. In such a formulation of the goal, instructions about the concrete actions are not given; the subject is only informed about relations in which the chess figures must be found in the final situation. In the course of solution, this initial goal relation undergoes changes; in this case the counter-process is taking place: due to the construction of situational concepts, the initial goal is transformed into the concrete system of relations which are essential for the given situation. As a result of the situation modeling process, the concrete situational goal appears, for example, not to give the possibility to the king of an adversary of retreating on certain fields of the chess board. It is this situational goal that gives birth to a means of its achieving - a certain sequence of operations which must lead to the final situation corresponding to the set initial goal. When this final situation is achieved, the problem is solved. If the sequence of operations does not lead to the necessary result, a new situational goal is constructed and a new sequence of operations corresponding to this goal is formed.

Thus, when dealing with the goal formation process in human activity, one should bear in mind regularities of appearance of two goals: initial and situational. The regularities of situational goal formation can be traced on the basis of materials of the psychology of thinking. It is much more complicated to ascertain how the human being carries out an independent formation of an initial goal. The regularities of emerging of this goal on the basis of independent activity are not yet revealed, since the most spread model in the psychology of thinking is the experiment in which external goal formation takes place - the initial goal is put before the subject from the outside. In this connection, both for the psychology of thinking and for cybernetics intellectual processes which lead the human being to an indepen-

dent statement of the problem, or, in other words, to an independent formation of the initial goal are of special interest. It is the presence of these processes that permit one speak about intellectual activity proper.

Analysis shows that initial goal formation under the influence of needs and motives occupies a great place in human activity. In this case the initial goal appears as a result of combination of motivation engendered by need (for instance, strive for the satisfaction of hunger or thirst) and man's past experience.

Another variety of goal formation finds its expression in the effect of an independent statement of the problem. In this process there is a link which is in a certain sense opposed to the direct formation of situational goal in problem solving. If the situational goal turns out to be a concretization of the initial goal, then the independently stated problem appears as a transition from the level of initial goal suggested from the outside to higher and more abstract levels. Only after such a leap upwards, the intellectual process passes on to the usual formation of a situational goal.

Inventor's activity may serve as a typical example of how external goal formation passes on to an independent statement of the problem. In this case the initial goal is often suggested to the inventor by a customer from the outside in the form, for example, of a task to automatize a certain industrial operation. On the basis of an analysis of working processes in the different branches of industry, the inventor refuses the goal suggested from the outside and proposes his own version of the statement and the solution of the problem, as a result of which not a separate link of the industrial system, but the system as a whole is optimized.

The independent statement of the problem differs from the usual formation of the situational goal by the transition to a more abstract level of consideration, which bears the title of generalization in psychology. That is why the process of independent statement of a problem, which is characteristic of higher forms of intellectual activity, may be characterized as a generalizing goal formation. This is already an internal goal formation. It is usually connected with human work in several object fields and is a result of transfer of relations from one object field to another.

Of course both forms of emergence of the internal goal in human activity (motivated and generalizing goal formations) appear as a unity, because there is a unity of regulation of motivational

-personalistic and intellectual processes proper. The mechanism of goal formation as a function of self-regulation of mental activity makes the human being as an autonomous system possessing own activity. The problem of goal formation is one of the central problems in the cybernetic theory. The solution of this problem determines in many respects the level of practical possibilities of automatic control systems. Leading with the fundamental works of A. Rosenblut and N. Winer the cybernetic analysis of goal formation is, however, carried out within the frameworks of theoretical bases of behavioral psychology. When working out various versions of programs, goal is considered as a certain final site of a maze having a definite structure. As to the intellectual activity involved in achieving the goal, it is understood as a movement in this maze.

The summarizing book of P. Akoff and F. Emery devoted to the analysis of systems possessing purposefulness, yield nothing new in principle in psychology and cybernetics about goal formation. In complete correspondence with the principles of behavioral psychology, the purposeful system is considered in this work as a mechanical system possessing of certain structural and functional possibilities. The external dynamic characteristics of this system connected with the choice of a behavioral pattern leading to a certain result are essential. At this approach, the ability characteristic of man to build internal conceptual models of surrounding world is not considered at all. As a result, it turns out to be that goal formation analyzed in cybernetics is an external goal formation, is a movement in the space of goals which is set beforehand and forms a ready maze.

Some psychological regularities of goal formation revealed in the analysis of human mental activity may be used in working out of the theories of cybernetic systems possessing properties of activity and autonomy. For instance, the modelling of internal goal formation (characteristic of human being) in cybernetics presupposes a use of semantic language permitting a meaningful description within a cybernetic system of the medium in which the behaviour of a cybernetic system must be formed.

Let us dwell upon the characteristic of this language more in detail. The basis of semantic language is a semiotic engendering system imitating processes of formation, generalizations and transformations (transpositions) of relations. The operational part of the system appear formally as three sets: (X, R, G) , where X is a set of basic concepts; R is a set of the basic binary relations between concepts; G is a set of the rules of formation of derivative concepts when goals

emerge. The concepts of natural language such as words, expressions, sentences, etc., characterizing the most general peculiarities of functioning of objects which are essential for goal appearance play a role of basic concepts. For instance, in the problem of sea port control such concepts are "moorage", "storehouse", "highway", "roadstead", "cabotage harbour", etc. The vocabulary of basic concepts for a large sea port contains about 1000 concepts of the indicated kind. The vocabulary of concepts depends on required completeness and precision of the description of a controlled object. For instance, control over a separate vessel is connected with the necessity of having a detailed description of concepts characterizing the structure of a vessel. Such a description becomes unnecessary in case of control over several vessels. Here it is the concepts related to maintenance-technical characteristics of vessels that play an important role, i.e. the characteristics which determine transport possibilities of a vessel, the degree of fitness to the performance of loading-unloading works, etc. Since in each class of controlled systems (for example, the class of sea ports) the problems solved are of the same type, the vocabulary of basic concepts built for one system may be used with insignificant changes for another system of this class.

The elements of the set R characterize spatio-temporal and other relations which are established between concepts in problem solving. For instance, an "object X is a part of an object Y "; an "object X is an element of a class Y "; and "object X moves towards an object Y "; an "object X is situated over an object Y without being contiguous with it", etc. As distinguished from the basic concepts, the basic relations are of a more universal character and practically do not change when passing on from the solution of one problem to another. The results of analysis of many concrete control problems in the different classes of complex systems (technical, socio-economic, biological, etc.) showed a community of relations used in them. As a result, a universal vocabulary of basic relations containing about 200 elements was constructed. The derivative concepts are formed from the basic concepts and basic relations in terms of three engendering grammars: correlational, categorial and transformational. This semantic language was used for describing the goal formation process when controlling over industrial systems.

The set of microgoals of the problem to be solved is enumerated in terms of correlation grammar. The idea of expressing the sense of concept by the set of other concepts which are in certain relations to a certain concept underlies

this grammar. For instance, the concept "cargo hatch" is in the simplest case defined as a set of concepts: "quadrangular deck opening" and a "device for hermetic shutting", which are in relations to the determining concept, respectively: an "object X is an element of a class Y" and an "object X has in its composition an object Y". Formally the goals are written down in terms of syntagmatic chains representing an expression of the following kind:

$$(X_i \xrightarrow{r_1} X_b^j) \wedge \dots \wedge (X_e^k \xrightarrow{r_2} X_d^j) \wedge \dots \wedge (X_m^q \xrightarrow{r_n} X_n^u)$$

where i, j, u are the orders of derivation of concepts, arrows $\rightarrow, \leftarrow$ indicate the orientation of relations. Owing to the fact the real relations between objects of the problem to be solved are reflected in the structure of goal being as its sense, the adequacy is ensured of the structure of goal to the structure of situation. The rules of output, in terms of which the set of microgoals is enumerated, are written down in syntagmatic chains in which the elements $X_i^j, X_b^j, \dots, X_n^u$ play a role of object variables. The formation of relations between basic concepts is brought about on the basis of structural identification of concepts and object variables. If there is a rule $X_1 \xrightarrow{r_1} X_2$, where X_1 is a "passenger ship", X_2 is a "free passenger moorage", r_1 means that an "object X moves towards an object Y", then one of the possible goals, which may be formed with the aid of this rule, is: $X_1 \xrightarrow{r_1} X_2$, where X_1 a "passenger ship" "Russia", X_2 is a "free passenger moorage", since the concepts X_1, X_2 have structural entry into the concepts X_i, X_j , respectively.

The rules of goal formation are determined in terms of the classes of concepts characterizing problem requirements. The structure of concepts being a part of rules of formation of goals in a sea port control problem contains the information about cargo, the technological scheme of its processing, instructions about the ways and methods of works, etc. The number of rules of correlations grammar for real big systems control problems (transport, computer, industrial, etc.) reaches several hundreds. The formal comparison of the structures of goals constructed in correlation grammar permits an ascertainment of the character of logical connections between goals and a construction of structural-equivalent classes of goals. The construction of classes of goals is brought about in terms of categorial grammar. The idea of combination in one class of goals having similar fragments accurate to isomorphism underlied this grammar. The characteristic of the class is the generalized structure (macrogoal) entering into the structure of each goal of the class. The macrogoals are formed in computer memory as

a result of programs of generalizations and decisions made on computer by man knowing the control goal and the evaluative functional corresponding to this goal. The enumeration of sequences of goals at set time intervals as well as the transposition of relations at these intervals is carried out in terms of transformation grammar. The rules of output represent substitutions of the kind $X_i \rightarrow X_j$, where X_i, X_j are goals.

The rule is considered as applied to the goal X_i , if X has entry into X_i . The realization of the rule is brought about by the substitution of X_i for X_j . The process of transformation of goals in a real problem continues until the next goal hits the class fixed beforehand or the set interval of extrapolation is exhausted. The formed sequence of goals plays a role of problem solving. When controlling over objects, such sequences correspond to the plans of functioning of objects at set time intervals. In the process of realization of a plan on a real object, the difference is fixed between the real situation and the situation formed in the language. If this difference exceeds a set magnitude, then the correction of the plan is made. Analysis shows that the use of semantic language permits an advancement in cybernetic goal formation modelling, i.e. permits a reconstitution of some essential features of internal goal formation.

The realization of semantic language on a computer is brought about in terms of a module system of mathematical provision. This system is used at present for solving problems of control over complex objects, the formation of data banks for decision-making, the generalized models of external world, integral robots, etc. The accumulated experience in maintenance of this system testifies to its sufficient efficiency and universality. The variable part of the system, when passing on to a new class of problems, makes up 20% on the average.

References

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