SEMIOTIC MODELS IN ARTIFICIAL INTELLIGENCE PROBLEMS

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The paper shows that the state of art in artificial intelligence requires development of a semiotic system theory which should play in this field the same role that was played by formal systems at its initial stages. Basic problems of semiotic model and systems theory are discussed. Illustrating examples are given.

Introduction

At the beginning of this century the classical works of Dunker have led to development of a psychological theory of thinking which is now known as the "maze hypothesis". In this theory human handling oi a creative task is described in the framework of a model in which man faces a maze of possible paths from the initial node in the labixinth to a certain node which is associated with the desired solution. Each intermediate node characterizes the time of selecting a solution and the corridors, implementation of the decision made. The specific of human thinking is that analyzing a maze of choices he finds a path leading to the goal spending not too much time on it. The maze hypothesis came under much fire from psychologists, its fundamentals were experimentally tested and mostly disproved.

Control engineers who workeu on automating the tasks traditionally regarded as creative rendered, however, effective support to the hypothesis. In the fifties and sixties the maze theory reigned unchallenged in all programs for reigned unchallenged in all programs for proving theorems, behaviour programs, arts composition programs, game programs, etc. All heuristic programming was built around maze theory concepts. Therefore the attention of artificial intelligence specialists was focused on search organization and reduction, determining the time of search cessation and ascertaining the advisability of a specific action at a given stage of solution. The early successes seemed to corroborate the validity of the initial psychological concept.

In late sixties it became evident, however, that all problems cannot be solved within the framework of the maze model One should remember development of one of the most powerful maze programs, the General Problem Solver of Newell, Shaw and Simon. The core of the program was a logic theory machine for proving theorems in proposition calculus. In terms of the maze model the routine can be described as follows: the initial spot of the maze is the left-hand or right-hand part of a certain equality which should be proved, the final spot is an equality with identical parts. The intermediate solutions are operators applied to the both parts of the equality. For each intermediate result the selection of decisions is dictated by certain additional considerations related with the form of this intermediate result. The routine proved effective in proving the theorems but direct application of the logic theory machine to the General Problem solver designed to solve a wide spectrum of problems showed that they are inapplicable for example, to chess playing problems.

There is one important feature of the maze model which probably is responsible for its popularity among control engineers. In mathematical logic the analog of a maze model is the well studied formal system model which is the core of proposition calculus, predicate calculus, formal grammars and many other models whereas in formal system theory the output was always understood as search in a maze of possibilities. This interpretation is caused by the fact that formal systems are essentially syntactical systems unaffected by the semiotics and progmatics or phenomena and processes. This is the source of power of formal systems but this reduces their effectiveness in artificial intelligence problems.

The limited capacity of formal systems became especially apparent in development of large man-computer dialog systems using a natural language in planning actions of an integral robot with a model of environment. In most such programs the central subsystem was a certain formal model; as a rule, this was first order predicate calculus, ouch were a number of dialog programs developed by B. Green, the STRIPS system developed in Stanford and a robot activity planning system developed by T. Vinograd. To organize work of a formal system, however, the entire environmental source information should first be translated into a language of correctly constructed formulae of the system used. Following derivation of the result by formal tools the result should be transformed into a form suitable for realization In the environment. It is these transforming systems that are most difficult in all programs of this type, forcing the information into the Procrustean bed of the formal system they take most time in program implementation ana reduce the system effectiveness.

We will deal with another psychological concept which leads to semiotic rather than to formal models. It is my belief that shortly most programs related to description of the environment, behaviour planning in it and man-computer dialog will be built around semiotic models.

The Psychological Concept

Unlike a maze model where the maze of possibilities is assumed to be specified in advance and the entire creative process is reduced to organising a search in this maze, the concept developed in recent years by a Soviet psychologist V.I. Pushkin and his followers proceeds from the assumption that the main creative act in solving a problem is constructing a fragment of the maze in which the path leading to a solution is found with a large probability rather than search for a path in a ready-made maze.

Consequently, the deductive static model which underlies the maze concept is replaced by and inductive dynamic model. This approach was corroborated in numerous experimental studies of human behaviour in solving creative problems and, in particular, in studying human behaviour in chess

In contrast to the maze concept this one may be termed model approach. It is built around the following principles interesting for control engineering applications.

1. The description of the initial problem situation should be structured and then it can isolate basic concepts and their interrelations important for solution of the problem posed.

2. If the objective structure is described in the same language as the problem situation then the maze approach can be used.

3. If the objective structures and

the problem situation are described in different languages, then a language should be found to make them compatible.

4. If there is such a language, then it can be used to construct a fragment of a maze of possibilities.

5. The search in this fragment can be performed in any way as in maze programs.

6. Making the description of the problem situation and objective structures is impossible within the framework of syntactical systems since this process requires a semantic and pragmatic level.

Semiotic models

Let us now describe a certain system which will evidently meet the requirements made by the model concept of thinking to computer programs.

Consider three finite sets:

$$A=\{a_1, a_2, \ldots, a_k\};$$
$$P=\{p_1, p_2, \ldots, p_m\};$$
$$R=\{\tau_1, \tau_2, \ldots, \tau_n\}.$$

ELements of these sets will be referred to as basic concepts, solutions and relations. Introduce now inductively the concept of a correctly stated formula, CSF, a concept common for formal systems:

1. Any element of A is a CSF.
2. Any expression of the form $(a_i \tau_j a_l)$ is a CSF.
3. If α is a CSF, the $(a_i \tau_j \alpha)$ and $(\alpha \tau_j a_i)$ are also CSF's.
4. If α and β are CSF's, then $(\alpha \tau_j \beta)$ is also a CSF.
5. If α is a CSF, then (α, p_i) is also a CSF.
6. There are no other CSF's.

Any totality of CSF s is a text. If there is no CSF of the form (α, p_i) among the CSF's that form the text, then the text forms a fact, otherwise it forms an artifact. Facts are denoted as F_i and artifacts as Φ_i.

A geometrical analog of texts are multigrapbs whose vertices are associated with elements from the sets A and P and arcs, with the relations τ_j between appropriate vertices.

Artifacts of the form (α, p_i) will be referred to as terminal. The derivation in our system will be understood as search of an mapping from a set of texts onto a set of terminal artifacts. One specific feature of the model is that the derivation rules are applied to texts in agreement with certain applicability laws which are formulated in their turn in agreement with the store of artifacts accumulated at the preceding derivation. Let us describe the process in more detail. At the initial stage a certain initial text is specified which acts as a tentative axiom. A certain set of_derivation rules $\Pi=\{\pi_1, \pi_2, \ldots, \pi_s\}$ is specified. These rules specify mappings of the form $\{F_i\} \rightarrow \{F_i\}, \{F_i\} \rightarrow \{\Phi_i\}, \{\Phi_i\} \rightarrow \{\Phi_i\}$ and a particular case of the latter two mappings are the mappings $\{F_i\} \rightarrow L$ and $\{\Phi_i\} \rightarrow L$ where L denotes a set of terminal artifacts. Let $\xi(\pi_i, T_j)$ denote the rule for applicability of the derivation rule π_i to the text T_j. This rule may be either binary predicate with values "applicable" or be of a much more complicated nature (for instance be an attribution function for a fuzzy set in the sense of Zadeh). What is important is to emphasize its dependence on the set L of terminal artifacts stored ty the system during the derivation. If in that process a new terminal artifact has been obtained, this is introduced into the storage of artifacts. If the role of a tentative axiom is played by a text incorporated into a certain artifact already stored in artifact memory then only this artifact is invariable derived from this text.

Introduce now a basic definition. A

semantic system is a six-tuple, A, R, Π, P, M, Ξ where M is the totality of rules for obtaining CSF's and elements of the set L.

Depending on the structure or the sets Π, Ξ different seniotic systems will result. In the following Section we will describe one of such possible systems.

<u>The Gyromat</u>

This Section will be concerned with a hypothetical unit named gyromat in analogy with the facility described in a science fiction novel by Stanislaw Lem. That unit could restructure in response to changes in the environment. Our gyromat which is a certain implementation of a semiotic system is also adaptive in this sense*

A semiotic model of the gyromat relies on a standardized natural language. The part of elements a is played by concepts or the language. There are three types of these: concrete concepts, classes and abstract concepts. Concrete concepts are specified by a set of values of the features $\langle q_1, q_2, \ldots, q_h \rangle$. These values are taken from certain fixed sets of values $Q_1, Q_2, \ldots, Q_h$. If q_i is replaced in the set of values by λ then this concrete concept has no such feature. Classes are specified by certain attribution functions which depend on values of the features. The concepts of class may be made specific by specifying the name of that concept as well as by specifying the set of values of features. The set of names will be denoted as I and its elements as i_j. Abstract concepts are determined by certain texts.

Elements of the set P are imperatives of the natural language. Such as the words and combinations "Go", "A path should be traced" and others.

Elements of the set R are metarelations of the type "Go to . . ", "Object - action", "Cause - effect", "Be Simultaneously", "Have a name", etc.

About the power of the set for a natural language there is a hypothesis that this set is finite- This fact is established for the Italian[5] and Russian language [6],[7]. To find the power of R texts in a natural language were studied and new relations were discovered that were introduced into the list of relations found previously if these new relations were not expressed by super-position of relations found previously. This process was completed when about 200 various relations were found in the list of basic relations.

Let us use a simple example to show translation of a text in a natural language into that of a semiotic system underlying the gyronat structure. The natural text is: "Nick and his dog left the house and went to the forest". The following notation is introduced a_1 - a man, a_2 - a dog, i_1 - Nick, i_2 - Nick's dog, a_3 - the forest, a_4 - the house, τ_1 - to have a name, τ_2 - go from, τ_3 - go to, τ_4 - simultaneously, τ_5 - after that. Then the initial text takes the form

$$((((a_1 \tau_1 i_1)\tau_4(a_2 \tau_1 i_2))\tau_2 a_4)\tau_5 (((a_1 \tau_1 i_1)\tau_4(a_2 \tau_1 i_2))\tau_3 a_3))$$

Note, that the retranslation is not univalent. Thus the text: "Nick and his dog rushed from the house and ran to the forest" has exactly the same structure as the previous one and they are not distinguished in the gyromat. If this difference is essential, names of relations may be introduced. In this case the words "went", "ran", "rushed", "dragged their feet", etc. will be different names of the relation "go to".

It is easy to see that practically any texts of the natural language may be represented by texts of the gyromat. If necessary, the set A can be completed with sets of modalities, estimates and fixation of emotional states related with the gyromat's Ego. Ref.[8] shows how this is done.

Let us now take up the rules for derivation of Π. These rules be are divided into three subgroups. The first one incorporates rules for updating the facta, or rules of the form $\{F_i\} \rightarrow \{F_i\}$. These rules relay on formal properties' of the relations and their semantics. Formally the relations can have or have not properties such as reflexivity, symmetry or transitivity. The presence of such properties may be used to add relations to the text. For instance, the sentence "There are three rooms in the house and two windows in each room" establishes the relation of possession between the concepts of house and room and between the concepts of room and window. Because of the transitivity the relations of possession of the rule Π will establish this relation between the concepts of house and window. The use of semantic properties of the relations May be illustrated with the sentences "In the evening birds fly low over the ground". In this phase there are relations such as "object - action", "action - time" and "action - site". The relation "to be over" between the concepts of a bird and the ground is established through analysis of the composition and structure of relations in the sentence. For the Russian language about 400 rules for facts updating have been found.

A second subgroup of derivation rules controls transformation of facts by introduction of derivative concepts and relations. New relations are introduced in three ways: by elimination of names of concepts and relations, by generalization in terms of the features q_i and by generalization in terms of relation structures. The elimination of names results in replacement of personified facts related to concrete concepts by facts related to classes. Generalization in terms of features is performed by introducing new classes using attribution eigenfunctions. This process is well-known and described in many papers, e.g. in a monograph[9]. This generalization leads to concepts such as "red", "round and sweet", etc. Generalization in term3 of relation structure will be illustrated with the following example. Let a_i be the "man" class and i_j, $j = 1, 2, \ldots, 100$, be certain names. Introduce the relation a_2 - a square and the relations: r_1 - "have a name", r_2 - "to touch", r_3 - "be behind", r_4 -"be simultaneous", r_5 "be in" . . . Consider the following text

$$((\ldots((a_1 r_1 i_1) r_4 (a_1 r_1 i_2)) r_4 \ldots r_4 (a_1 r_1 i_{100}) \ldots) r_5 a_2) \quad , \quad \alpha_j = (a_1 r_1 i_j) .$$

It signifies that 100 people are in the square simultaneously. The symbols are introduced to simplify the notation. Then

$$(\ldots(\alpha_1 r_2 \alpha_2) r_4 (\alpha_1 r_2 \alpha_3)) r_4 (\alpha_1 r_2 \alpha_4)) r_4 (\alpha_1 r_2 \alpha_5)) r_4 ((\alpha_2 r_2 \alpha_3)) r_4 (\alpha_2 r_2 \alpha_5)) \ldots (\alpha_{100} r_2 \alpha_{99}) \ldots) .$$

This signifies that the people are rather dense in the square. The situation is easily generalized into a new concept of a "crowd in a square". The concept of a crowd is generated due to the presence of uniform relations between α_i and because these relations denote "being simultaneous" and "touching". If the relation r_2 is replaced by r_3, then with an orderliness of the type $(\alpha_i r_3 \alpha_{i+1})$ we will have a queue rather than a crowd in the square.

Unlike updating rules, the rules for generalization in terms of features and structures are not specified in advance but formulated during the gyromat functioning as a function of the set of artifacts.

Let us now take *up* the set of rules Ξ. Divide the set of facts into two subsets, F^1 and F^2 Let us assume that the appearance of an artifact $(F_{i,},p_h)$

for which Fi belongs to F1 is a favorable event whilst the appearance of the artif (F_j, P_k)n which Fj belongs to *p2* an unfavorable event. Then the rules Ξ have the following structure: if the application of P_k results in a favorable artifact, this is entered into the artifact store and the rules Ξ which were applied to the initial text to obtain Fi are assumed applicable to that initial text, otherwise their application is banned. But because text transformation is a multi-stage process, Ξ are of a more complicated nature described *in Rets [10],[11].*

The gyromat was used in solving real life problems such a goods handlii^ control in a seaport, solution of game problems, management, etc

To conclude let us note that a gyromat model is being successfully tested in man - computer dialog systems using a natural language. Although not a sole Implementation of a semi otic system, the gyromat demonstrates the potential of such systems handling artificial intelligence problems.

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