EXFERMERTAL STUDIES 0? HUMAN DECISIOR-MAKIHG AND ITS SIMULATION BT SITUATION CONTHOL TBCHNIQUB (ON THE BASIS OF A CHESS ENDGAME)

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Abstract

The paper examines the simulation of the basic mechanisms of the chess endgame problem solution by man. The experimental results of a psychological investigation into the mechanics of structurisation,generalization, and goal formation of a situation have been presented and a semi - otic system of formation of generalised imitation models have been discussed which forme the basis for human decision-making.

The analysis of the literature on the simulation of chess game have led to a conclusion that various chess programs were considered by their originators as a theory or model of real activity of human chess-player. In this connection,to clarify the nature of the difficulties in simulating chess game is to clarify to what extent chess programs are actually in compliance with a chess player's real activity they are to simulate.

The majority of program designers who simulated the activity of a chess player considered this activity as passing through a labyrinth having a certain initial stage (area,graph vertex) and the labytinth point which is to be reached.

If the activity is understood as above, it is of prime importance to find the ways of reducing the volume of the chess labyrinth. A special problem presents Itself - the problem of redicing the tasks of the tree of chess game.

This limitation of chess programming is especially clear when one approaches the final stage of the game - the endgame. An optimum endgame suggests, to a greater extent than the other game stages,a calculation for many moves ahead. It is this circumstance that makes ineffective, in respect to endgame, the majority of existing programs designed for computerising a chess game. Limited possibilities of the depth of analysis and the fact that the planning in these programs does not exceed several moves ahead has led to a conclusion that the problems of chess endgame cannot be solved with existing means of programming.

A correlation between the principles of programming and the results of analysts of human activity shows that the basic difficulty of the programming lies in that the available means of mathematical description of activity fail to adequately describe the process of establishing relations, the process of comprehending a position, which precedes and determines the formation of a variant. It can be concluded that the use of a language describing the process of establishing relations will enable one to get over some difficulties of chess programming and to lay down the ways of computerising endgame problems.

It is apparent that the use of new languages describing activity, the languages which are capable of describing the process of establishing relations, should bring about serious changes in the total structure of the theory which forms the basis for chess programming.

Thus, one of the basic notions in chess programming is calculation depth.In cybernetics by depth is generally meant the number of moves of any chessman controlled by the program. As indicated by the evidence obtained, the depth of analysing a position by man is determined by the presence of a system in the formation of a position in the course of establishing relations between the pieces. In other words, central to a traditional understanding of a depth in cybernetics is a graph whose vertices are successively altered situations while the depth of analysis in human activity is determined by a graph whose vertices are formed by the pieces of a particular position and the edges by the relations between these pieces.

Hence, from the correlation between the principles of existing chess programming and real activity in the solution of endgame problems, the consequence derives that the development of a chess program which is capable of successfully solving endgame problems is related to the construction of a language which would enable us to describe the process of establishing relations and forming generalised notions. It is only languages of this kind that can produce perceptible results in such a large space as is a chess endgame.

The new method of programming should permit of forming the solution variant not only for a definite predetermined number of moves. The number of moves in the variant should change with the structure and properties of each new position.

The analysis of experimental results showed that of all existing methods for describing mental activity, the situation control of big systems developed by D.A. Fospelov and Yu.I.Klykov (U.S.S.R.) is in the closest agreement with endgame solution process* An attempt was now made to employ this method for simulating human activity when solving chess endgame problems.

The practical use of situation control In chess is connected with the development of a system of semiotical models through the use of which a generalised model of chess game solution can be formed.

By the language of situation macro-description in a chess endgame problem is meant a semiotical system comprising an aggregate of three basic sets i I is a set of base notions; E is a set of base relations; and G is a set of formation rules for derivative notions and rela - tions. Base notions include a set of natural language units (words,expression^ sentences.etc.; used for the decription (designation) of the chess endgame problem objects for which it is not necessary to disclose the contents in order to solve the problem. These notions are:

X_1^0=piece; X_2^0=field; X_3^0=king; X_4^0=knight;

X_5^0=black-field bishop; X_{10}^0=engaged; X_{11}^0=vacant

$X_{20}^0 = c_1$; $X_{21}^0 = c_2$, etc.

The language has about 100 notions of this type.

The Bet of base notions has a hierarchic structure, there are notions of zero order and those of higher orders (derivatives). According to (4),the notion of the ith order (i=0.1. . . . . .n) is the characteristic of the class of a problem element. Base notions have the greatest volume. Reduction of the notion volumes occurs when the notion is included into another class. The rule of identical transformation of notions is X symmetric substitution: $X_a^i \rightleftarrows z_1 X_b^m z_2 X_c^k \dots z_\mu X_d^l$

When simulating chess endgame, the base scope of knowledge is formed according to this rule.

$X_1^2 = z_1 X_1^1 z_3 X_3^0 z_5 X^0_{(K)1,2,3}$ - "white king"

$X_2^2 = z_1 X_2^1 z_3 X_3^0 z_5 X^0_{(K)1,2,3}$ - "black king"

$X_4^2 = z_1 X_1^1 z_3 X_5^0 z_5 X^0_{(B)1,2,3}$ - "white black-field bishop", ete

A correct definition of a notion enable one to expand it into elementary components. For example, the expansion of the notion "white king" is:

$X_1^2 = z_1(z_1 X_1^0 z_4 X_8^0) z_3 X_3^0 z_5 X^0(K)_{1,2,3}$

where $X_1^1 = z_1 X_1^0 z_4 X_8^0$ = white piece

X_1^0=piece; X_8^0=white; X_3^0=king; $X^0(K)_{1,2,3}$ = movement of the king.

The rules of moving the chessmen are realized within the software system in the block "determination of potential relations". The block "determination of potential relations" is used to determine the relations arising in the process of considering the position in terms of its dynamics.

For the model, this block is, to some extent, an analog of a "mental look" which is inherent in man analysing a problematic situation. Due to its performance, the position under analysis appears as a set of ordered triplets $\langle X_i R_m X_j \rangle$,where X_i and X_j are the elements of situational position and R_m is a beam of potential relations determined for these elements.

Base relations include a set of matural language units denoting static and situational links established between situational objects when solving the problem. They are binary relations such as z_1, z_2, z_3 etc, which mean:

$X_i z_1 X_j$ i.e. X_i is an element of X_j class;
$X_i z_2 X_k$ i.e. X_i is on X_k ;
$X_i z_3 X_q$ i.e. X_i has a name X_q , etc.

Base static relations feature permanent links between the elements of the problem, the links being independent of the situation in which these elements are*

In contrast to static relations, situational relations link the elements not permanently but only in a particular situation*

Thus, if the white king at a given moment is on the e1 field and the black king is on the e4 field, the specified information is entered in the descriptive lists for the given pieces and the relations of properties make is possible to describe each of the objects (chesaaen) in terms of ZX - codes.

$X_{11}^2 = z_1 X_1^1 z_3 X_3^0 z_2 X_{20}^0 z_5 X^0(K)_{1,2,3}$

$X_{68}^2 = z_1 X_2^1 z_3 X_6^0 z_2 X_{69}^0 z_5 X^0(B)_{1,2,3}$

By this means any piece being on any square at a given moment can be described in terms <of zX - codes.

The set G is given as a population of generating procedures denoted as generative grammars which are employed for formalizing structurization mecnanlms of generalization and extrapolation of the situations*

Four types of generative grammars are used in a semiotic system: correlation, categorial, transformation and commanding grammars which are correspondingly intended for:

1)ennumerating the multitude of micros!-tuations of a chess endgame;
2)forming a set of generalized situation structures in the course of the solution of a chess endgame problem;

5)preeetting the process of functioning of a problem solution model on the given time intervals;
4)ennumerating the set of solutions generated by the model.

Let us now describe the above grammar in an abridged and interpreted form for a chess endgame which was offered in a psychological experiment to two groups of people with markedly different level of chess qualification. Both psychological and more detailed results of the computer experiment will be discussed in the paper.

A message has arrived from the environment at the input of the "Input" program at a discrete moment of time:
#object - piece, name - king, colour - white, square - e1;#
#object - piece, name - white-field bishop, colour - black, square - d2;#
#object - piece, name - pawn, colour - white, square - h2;#
#object - piece, name - king, colour - black, square - e4;#
#object - piece, name - knight, colour - white, square - f7;#
#object - place, name - black-field bishop, colour - black, square - f8;#
#object - piece, name - black-field bishop, colour - black, square - b8.#

The specified information is recored in the descriptive lists for the given figures.

$$X^2_{1_1} = \tau_1 X^1_1 \tau_3 X^\bullet_3 \tau_2 X^\circ_{20} \tau_5 X^\bullet_{(K)1,2,3}$$
$$X^2_{6_8} = \tau_1 X^1_2 \tau_3 X^\bullet_6 \tau_2 X^\circ_{69} \tau_5 X^\circ_{(B)1,2,3}$$
$$X^2_{7_{50}} = \tau_1 X^1_1 \tau_3 X^\bullet_9 \tau_2 X^\bullet_{77} \tau_5 X^\circ_{(P)1,2,3}$$
$$X^2_{2_{36}} = \tau_1 X^1_2 \tau_3 X^\bullet_3 \tau_2 X^\bullet_{55} \tau_5 X^\bullet_{(K)1,2,3}$$
$$X^2_{5_{47}} = \tau_1 X^1_1 \tau_3 X^\bullet_4 \tau_2 X^\circ_{66} \tau_5 X^\bullet_{(Kn)1,2,3}$$
$$X^2_{3_{31}} = \tau_1 X^1_2 \tau_3 X^\circ_5 \tau_2 X^\bullet_{67} \tau_5 X^\bullet_{(B)1,2,3}$$
$$X^2_{4_{23}} = \tau_1 X^1_1 \tau_3 X^\bullet_5 \tau_2 X^\circ_{35} \tau_5 X^\bullet_{(B)1,2,3}$$

All interrelations between the objects (pieces) are analysed in the blocks "Analyser" and "Determination of potential relations" by observing the list of objects involved in 6(ti) and their descriptive lists.

An array of elementary syntagmata and' -chains is then constructed which forms the basis for the further decision-making model. At the output of the "Analyser" block is formed an array of syntagmatic chains describing the pieces of different classes in terms of the presence of common features in all descriptions.

Possible relations between different classes of chessmen are determined in the block "determination of potential relations".

If we assume now that each piece of any situation may be potentially linked with other pieces by a set of relations, the correlation rules can be considered as singling out essential relations between pieces.

All data formed into arrays of syntagmatic chains enter the "Correlator" block.

The program employs the array of correlation grammar rules, the left parts of each rule comprising limitations of the features while the right part is a commanding syntagma, i.e. the direction as to what relation (derivative) connects the pieces under study if the above limitations are implemented.

The critical condition for the formation of derivative notions is the verity of predicates by the aid of which a variety of relations between the situational elements are established.

By analysing the information fed to the computer, we can find the class of situations comprising the initial situation. The vertices of the classifier specify the maximum general part according to which correlation grammar rules are derived. The route of each piece is determined by the "Determination of potential relation" block and is included into the left part of the correlation grammar.

There is a maximum of 175 correlation grammar rules for every endgame with a definite number of pieces (in this case 7 pieces) irrespective of whether Black and White move first. A maximum of six relations can be established between every two pieces by these rules.

Let us discuss some grammars in our position with the white moving first:

25. $\forall X^2_{1_1}, X^2_{6_n} (X^2_{1_1} \supseteq X^2_1 \wedge X^2_{6_n} \supseteq X^2_6)(\exists X^K_{M_2}(X^2_1))$
$[X^2_6 \tau_6 X^K_{M_2}(X^2_1)) \wedge (X^1_2 \tau_7 X^\circ_{12})] \supset$
$\supset X^2_{1_1} \tau_{21} X^2_{6_n} \wedge X^2_{6_n} \tau_{22} X^2_1$

which means: "White King, potentially in two half-moves, attacks the black white-field Bishop".

4. $\forall X^2_{1_1}, X^2_{7_9} (X^2_{1_1} \supseteq X^2_1 \wedge X^2_{7_9} \supseteq X^2_7)(\exists X^K_{M_3}(X^2_1))$
$[X^2_7 \tau_6 X^K_{M_3}(X^2_1) \wedge (X^1_1 \tau_7 X^\circ_{12})] \supset$
$\supset X^2_{1_1} \tau_{35} X^2_{7_9} \wedge X^2_{7_9} \tau_{36} X^2_{1_1}$

"White King, potentially in 3 half-moves, defends the white Pawn".

94. $\forall X^2_{5_m}, X^2_{1_1} (X^2_{5_m} \supseteq X^2_5 \wedge X^2_{1_1} \supseteq X^2_1)(\exists X^B_{M_2}(X^2_5))$
$[X^2_1 \tau_6 X^B_{M_2}(X^2_5) \wedge (X^1_1 \tau_7 X^\circ_{12})] \supset$
$\supset X^2_{5_m} \tau_{21} X^2_{1_1} \wedge X^2_{1_1} \tau_{22} X^2_{5_m}$

"Black black-field Bishop, potentially in 2 half-moves, attacks the white King", etc.

τ_{21} = be a potentially attacking piece in 2 half-moves
τ_{22} = be a potentially attacked piece in 2 half-moves
τ_{35} = be a potentially defending piece in 3 half-moves, etc.

About 20 derivative relations of this kind were found in designing the model. The other relations in the rules

are:
$\tau_6 =$ be o n , $\tau_7 =$ o have the right to move, etc.

At any moment of time before moving a piece, 14 to 15 correlation grammar rules are sufficient to define the situation, construct the micro structures and display them as syntagmatic chains. With 175 correlation grammar rules, the number of syntagmatic chains was 31, the chains taking the forms

$$\begin{aligned} \rho_1 = {} & (X^2_{1i}\,\overrightarrow{\tau_{13}}\,\overrightarrow{\tau_{14}}\,X^2_{7g}) \vee (X^2_{1i}\,\overrightarrow{\tau_{19}}\,\overrightarrow{\tau_{20}}\,X^2_{7g}) \vee \\ & \vee (X^2_{1i}\,\overrightarrow{\tau_{23}}\,\overrightarrow{\tau_{24}}\,X^2_{7g}) \vee (X^2_{1i}\,\overrightarrow{\tau_{35}}\,\overrightarrow{\tau_{36}}\,X^2_{7g}) \vee \\ & \vee (X^2_{1i}\,\overrightarrow{\tau_{34}}\,X^2_{7g}) \end{aligned}$$

$$\begin{aligned} \rho_2 = {} & (X^2_{6n}\,\overrightarrow{\tau_{15}}\,\overrightarrow{\tau_{16}}\,X^2_{7g}) \vee (X^2_{6n}\,\overrightarrow{\tau_{11}}\,\overrightarrow{\tau_{12}}\,X^2_{7g}) \vee \\ & \vee (X^2_{6n}\,\overrightarrow{\tau_{17}}\,\overrightarrow{\tau_{18}}\,X^2_{7g}) \vee (X^2_{6n}\,\overrightarrow{\tau_{21}}\,\overrightarrow{\tau_{22}}\,X^2_{7g}) \vee \\ & \vee (X^2_{6n}\,\overrightarrow{\tau_{37}}\,\overrightarrow{\tau_{38}}\,X^2_{7g}) \vee (X^2_{6n}\,\overrightarrow{\tau_{34}}\,X^2_{7g}), \text{ etc.} \end{aligned}$$

The predicates of applicability of correlation rules in forming situational structures are formed in the course of education with the help of notion generalisation rules. The use of a paeudophysical situation-describing language representing actual relations between the pieces anables the situations to be classified on the basis of their structural generality.

The term "structural generality" as used in forming a generalized model of a chess endgame is defined as a determination of identical relations between the pieces in different changing specific conditions. Thus, the given position cab be assigned to a particular class and one or another approach can be employed to describe it.

To illustrate, if two totally different positions of the same pieces such as

I.White Nf1	2.White Na2
Black B e7,B c4,K h6	Black B b8,B d3, K e7

are considered, a generalized notion

$$\begin{aligned} J_i = {} & (X^2_{3k}\,\overrightarrow{\tau_{17}}\,\overrightarrow{\tau_{18}}\,X^2_{6n}) \wedge (X^2_{3k}\,\overrightarrow{\tau_{37}}\,\overrightarrow{\tau_{38}}\,X^2_{5m}) \wedge \\ & \wedge (X^2_{3k}\,\overrightarrow{\tau_{37}}\,\overrightarrow{\tau_{38}}\,X^2_{2j}) \end{aligned}$$

is established between the pieces which is independent of both the position of pieces and dimensions of the chessboard (number of fields in the chessboard). The most important condition here is the recognition of indentleal relations in a set of different positions.

The psychological esperijuental results have corroborated an important fact that the higher the qualification of a chess-player, the faster he can discover these relation and find the optimum solution variant.

When formed, the generalized notion structure enters the "Decision-making" block which, in turn, verifies that the structure is introduced into the left part of decision-making rules. In this condition is satisfied, a decision is made in the right of the rules.

The following rule can be applied for the above examples

$$\begin{aligned} 41.\ & \forall X^2_{3k}, \forall X^2_{2j}, X^2_{5m}, X^2_{6n}\,(X^2_{3k} \supseteq X^2_3 \wedge X^2_{2j} \supseteq X^2_2, \\ & X^2_{5m} \supseteq X^2_5, X^2_{6n} \supseteq X^2_6)[(X^2_{3k}\,\overrightarrow{\tau_{17}}\,\overrightarrow{\tau_{18}}\,X^2_{5m}) \wedge \\ & \wedge (X^2_{3k}\,\overrightarrow{\tau_{37}}\,\overrightarrow{\tau_{38}}\,X^2_{2j}) \wedge (X^2_{3k}\,\overrightarrow{\tau_{37}}\,\overrightarrow{\tau_{38}}\,X^2_{6n})] \supset \\ & \supset X^2_{3k}\,\overrightarrow{\tau_{41}}\,(X^2_{2j} \wedge X^2_{5m}) \end{aligned}$$

that is "Knight attacks black King and black black-field Bishop in three half-moves".

There are about 50 rules of this kind in the language of the generalization of situations.

At an initial stage of education, these rules proved to be essential since they included, among other things, such important chess notions as "fork", "pin", etc. A model of the extrapolation of situations is formed from the models of description and generalization of situ - ations.

The solution of the problem with the aid of the extrapolation model is effected as follows: a situation is held on the input of the extrapolation model ;situation class is determined; an action is selected which is consistent with the class and transformation of situations is accomplished. The above procedure is repeated for a new situation, etc.

An extrapolation tree is constructed in a general case. The best branch is selected on the basis of the specified criterion. One of the basic criteria in constructing the decision-making model is the detection of the routes of activization and safety of one's own chessmen in the course of extrapolation and also the routes of minimizing the mobility of the opposite number' s chessmen. This process is effected in the block "Optimization of commanding decisions". The condition for a halt is the assigument of the extrapolation result to a specified class.

It can be seen that the endgame problems under study are constructed by a model based on a semiotic language which contains the means to simulate the process for the formation, generalization and extrapolation of the situations.

It is hoped that the correlations between psychological experiments and the evidence being currently obtained by a Minsk-32 electronic computer will permit the proposed method to be successfully realized in working chess problems.

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