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= DECISION-MAKING AND EXPERT SYSTEMS =

A Model for the Verbal Explanation of Results of Expert System Operation for an Individual User

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Abstract—A model for the verbal explanation of results of expert system operation intended for the generation of explanation texts in accordance with the demands of an individual user of this system is considered. A text of explanation is generated based on the database and knowledge base of the expert system and a formal description of the explanatory text given in the model. The model may be used in the development of an interface for generating individual explanations of the expert system in application domains, in which a text explanation of the results of the operation is required.

INTRODUCTION

A specific feature of expert systems (ESs) is the ability to generate verbal explanations of the results of their operation. This provides an increase in users' credibility to ESs and a better understanding of results of operation of the ESs. Verbal explanation means an explanation that has the form of ordered and structured text. It is essential that each particular user of an ES can obtain an individual (in content and form) explanation that suits his knowledge level with the level of going into detail, the structure, and the succession of presentation necessary for him. However, although there exist different approaches to explanations based on predetermined texts of explanation [1, 2], responses to user queries [3, 4], explanations generated in accordance with the user's goals and background [5-7], and so on, they do not provide an opportunity to generate explanations that satisfy the requirements of a particular user of an ES. This is because of the fact that, as shown in [8, 9], a particular user frequently cannot be classified into any group of users specified by designers of the ES, or there is no concept of an explanation (among different proposed concepts) that fits his demands. Another significant disadvantage of the existing approaches is the integration of a component generating an explanation into the mechanisms of logical inference. This requires the expansion of a knowledge base, i.e., the incorporation of additional knowledge into it for more sophisticated and detailed explanations. Moreover, this sufficiently affects the modifiability of a core of the ES [8]. In addition, there exist a number of application domains such as medicine, jurisprudence, military domains, etc.,

which require textual representations of the results of operation, i.e., it is necessary to have a printed document (conventional for this application domain) presenting the results of operation of an ES.

The problem of generating an individual explanation is considered in [10], where the author proposed to define an individual explanation as an explanation that, with the details, structure, and orderliness required for a specific user, describes fragments of a model constructed by the expert system with the use of the knowledge base. Besides, an approach and tools for generating such explanations are also suggested in this work. The crux of this approach reads in the following. Each definition of an explanation consists of two parts. The first part contains a plan for a text of the explanation in terms clear for a user. In the second part, necessary fragments of the database and the knowledge base in the form that allows one to implement their retrieval are described. The language for a description of the structure and content of an explanation comprises three constructions: a string, a choice, and a query to the frame database (knowledge base). The text of the explanation is constructed in accordance with its model by a system of text synthesis. However, a method for describing a database and a knowledge base is fixed in the form of frames. As a rule, this is not supported by languages of implementation. A process of generating the explanation is also complicated because of the absence of the loop construction in describing a plan of the explanation, the necessity of describing a linguistic model of the text in addition to its plan, as well as through a supplementary component, namely, a system of text synthesis.

An approach to generating an explanation proposed in this paper is a further development of a scheme of constructing individual explanations proposed in [10]. The language for describing a structure and the text content is defined as a macrolanguage. In contrast to [10], this makes it possible to eliminate auxiliary components of generation of an explanation, like a model of the explanation text and a system of the text synthesis. A query language for a frame database is replaced by a query language for a relation database (this provides its greater independence of tools of implementation of knowledge-based systems), and the construction of a loop for description of the explanation content is introduced.

A model of explanation proposed in this paper is intended for application domains and problems. Here, an explanation is represented in the form of a text of a given structure and content and is generated in accordance with the needs of a specific user in which an ES is required (besides, this explanation must not degrade a modifiability of the ES core).

1. STATEMENT OF THE PROBLEM

A model of generating explanations of the results of operation means a computational model [11] whose universal recipe generates a text explanation on the basis of a formal assignment of an explanation and the results of operation of an ES.

An explanation text T consists of a sequence of elements of the explanation t_1, \ldots, t_n . The results of operation of the ES ξ are represented in the form of a finite set of relations. Each relation A is a finite set of *n*-tuples $A = \{ \langle a_1, ..., a_n \rangle \}$, where $a_1, ..., a_n$ are the elements of *n*-tuples. We also assume that a formal assignment of the explanation W is a compound operator. A compound operator means a sequence of elements for describing the explanation w_1, \ldots, w_n . Each element of the description w_i is a text construction that defines the content of the explanation text according to the results of operation of the ES. Text constructions in the model of explanation are the constructions of string, loop, output set, and alternative. In turn, the constructions of loop and alternative contain a compound operator as a component.

The text construction of *string* in a formal assignment of an explanation is intended for the representation of various fixed phrases. The text construction of *output set* specifies that it is necessary to list in the text of the explanation all values of a variable in a certain (in accordance with a condition) order. The text construction of *loop* is employed to represent in the text of the explanation a sequence of repeated parts such that, in each repetition, these parts somewhat differ from each other, with these differences being dictated by the

results of operation of the ES. The text construction of *alternative* is employed in the case where a fragment of the text of the explanation depends on a value of a variable (or subset of its values).

We assign to each construction w_i of the compound operator a positional number *i*. The positional number of a construction consists of a positional number of the compound operator to which this construction belongs and a serial number of the construction in the compound operator.

It should be noted that, on the one hand, the same formal assignment of the explanation W can correspond to different results of operation of the ES ξ , but, on the other hand, a formal assignment of W must be coordinated with the results of the ES ξ . The text of the explanation T generated on the basis of W may be different depending on ξ .

2. UNIVERSAL RECIPE OF COMPUTATIONAL MODEL OF EXPLANATION

We define the state of a computational process at the step *m* as a quadruple $q_m = (A^m, P^m, T^m, N^m)$, where A^m is the vector of values of variables, P^m is the vector of relations of loops or alternatives, T^m is the explanation text, and N^m is a positional number of the executed element of a description of an explanation.

The vector of values of variables has the form $A^m = \langle a_1, a_2, ..., a_{Nm} \rangle$; in this case, Nm is the number of elements of the vector at the step m and each element of the vector a_i for all i = 1, ..., Nm is the pair $a_i = (nma_i, VAL_i)$. Here, nma_i is the name of the variable, VAL_i is the set of values of the variable nma_i such that $VAL_i = \{val_1^i, ..., val_p^i\}$, where val_j^i is a value of the variable $nma_i, j = 1, ..., p$, and p is the number of values of the variable.

The vector of relations of loops and alternatives P^m has the form $P^m = \langle p_1, ..., p_{Km} \rangle$, where *Km* is the number of elements of the vector in the state at the step *m* equal to the number of nested loops and alternatives executed at the step *m*. Each element of the vector p_i for i = 1, ...,Km is related to one of the constructions of loops and alternatives executed at the step *m*. As this takes place, the element of the vector of relations p_1 relates to the most outer construction of the loop or alternative. The element of the vector of relations p_2 refers to loops or alternatives immediately nested in this construction, and the element of the vector of relations p_{Km} relates to the most inner loop or alternative. Each element of the vector p_i for all i = 1, ..., Km has the form $p_i = (p_i, nmv_i)$ Nc_i , Nqn_i , $VALVC_i$), where p_i is the name of the relation included in the heading of the *i*th nested loop or alternative, nmv_i is the name of the variable of the *i*th nested loop or alternative, Nc_i is the number of repetition of the *i*th loop or 0 for an alternative, Nqn_i is the number of the state of the computational process before execution of

the *i*th loop or alternative, and $VALVC_i$ is the set of already passed values of the loop variable nmv_i by the step *m*. Here, $VALVC_i = \{valvc_1, ..., valvc_m\}$, where $valvc_j$ is a value of the loop variable, j = 1, ..., m or $\{\emptyset\}$ for an alternative.

Now, we represent an algorithm for constructing an explanation text according to its description. The initial state of a process for generating the explanation text is $q_1 = (A^1, P^1, T^1, N^1)$, where the vector of values of variables A^1 and the vector of relations of the loop and alternative P^1 are empty (have zero dimension). The explanation text in the initial state is an empty string, and $N^1 = 1$.

Let us introduce a notion of *description of a set*, which has the form $A_i \times (c_1^i, ..., c_m^{i^*}, ..., c_n^i)$:con, where A_i is the name of one of the relations that represent the results of operation of the ES and $c_1^i, ..., c_n^i$ are the names of variables. A set of values for each variable c_j^i is the set of all *j*th elements of *n*-tuples $\{a_j\}$ of the relation A_i from ξ , $c_m^{i^*}$ is a labelled variable (possessing its own semantic interpretation) described in the context of constructions considered below, and *con* is the condition imposed on the values $c_m^{i^*}$ (this condition may be omitted). The condition gives an order in which the values of the variable $c_m^{i^*}$ are arranged.

The process of generating an explanation text based on its description consists in a sequential execution of elements of the compound operator of a formal assignment of the explanation beginning with the first element. In this case, at each step, the next state of a computational process is formed. This state depends on the executed element of a description w_i , the state of the computational process, and the results of operation of an ES ξ . We assume that, at the state $q_s = (A^s, P^s, T^s, N^s)$, the relation $N^s = i$ holds.

Consider generation of the next state for each construction of formal assignment for the explanation.

2.1. Assume that the executed element of a description of the explanation w_i is a construction of a *string*. Then, the next state of the process of generation of the explanation is $q_{s+1} = (A^{s+1}, P^{s+1}, T^{s+1}, N^{s+1})$. Here, $A^{s+1} = A^s$, $P^{s+1} = P^s$, and $T^{s+1} = T^s + w_i$, where "+" denotes concatenation and the value of N^{s+1} is a positional number following *i* in the lexicographic order. If there is no such number, then the execution of the universal recipe ends.

2.2. Assume that the executed element of the description of the explanation w_i is a construction of a *loop* $\langle \sigma, \alpha \rangle$, where σ is a loop heading, $\sigma = A_i(c_1^i, ..., c_n^i)$

 $c_m^{i^*}, \ldots, c_n^i$):con (in this case, we call $c_m^{i^*}$ a loop variable), and α is a loop body (a compound operator).

The execution of the loop begins with the determination of the number of loop iterations *r*. In its determination, two variants are possible: (1) in the results of operation of the ES ξ , the relation with the name A_i is empty; in this case, the number of loop iterations r = 0; (2) in the results of operation of the ES ξ , the relation with the name A_i is nonempty; in this case, the number of loop iterations *r* depends on ξ and the state of the process of generating the explanation text q_s . Here, two cases are possible:

(1) The state of the process of generating the explanation text $q_s = (A^s, P^s, T^s, N^s)$ is such that the vector of values of the variables A^s is empty (Nm = 0) or, in the vector of values of the variables A^s , the variables $nma_g, ..., nma_h$ such that $nma_g = c_k^i, ..., nma_h = c_p^i$, where $1 \le p$ and $k \le n$, are absent. Then, $r = \mu \{a_m | A_i(a_1, ..., a_m, ..., a_n) \in \xi\}$, where a_m is the *m*th element of the *n*-tuple A_i , i.e., the number of loop iterations are equal to the cardinality of the set of values of the loop variable c_m^{i*} in ξ .

(2) The state $q_s = (A^s, P^s, T^s, N^s)$ is such that the vector of values of the variables A^s has the variables $nma_g \dots nma_h$ such that $nma_g = c_k^i, \dots, nma_h = c_p^i$, where $1 \le p$ and $k \le n$. In this case, the number or loop iterations are dictated by the results of operation of the ES ξ according to the values of the variables $nma_g = c_k^i$,

..., $nma_h = c_p^i$ from A^s in the following way.

Assume that ξ has the corresponding *n*-tuples $zn_q \in A_i, ..., zn_r \in A_i$ such that

$$zn_{q}[k] = val_{n}^{g}, ..., zn_{q}[p] = val_{m}^{g}$$

$$...$$

$$zn_{r}[k] = val_{n}^{h}, ..., zn_{r}[p] = val_{m}^{h}$$

$$(2.1)$$

where zn[f] is an element of the *n*-tuple zn with the number f, val_n^g , ..., $val_m^g \in VAL_g$, and val_n^h , ..., $val_m^h \in VAL_h$. Then, $r = \mu\{zn_q[m], ..., zn_r[m]\}$.

If in ξ , there are no values such that condition (2.1) is satisfied, then r = 0. If r = 0, then the loop is terminated and the next state of the process of generating the explanation text $q_{s+1} = (A^{s+1}, P^{s+1}, T^{s+1}, N^{s+1})$ is formed. Here, $A^{s+1} = A^s$, $P^{s+1} = P^s$, $T^{s+1} = T^s$, and N^{s+1} is the positional number of the construction that follows the executed loop in the compound operator.

If $r \ge 1$, then further loop execution depends on which one of the following situations takes place:

(1) The given loop is not nested into other loops.

(2) The given loop is nested into the body of some other loops, but no constraints on the values of vari-

ables in the loop heading (by the loops or alternatives that are external relative to the given loop) are imposed.

(3) Constraints on some variable relations A_i are imposed by outer loops or alternatives.

In [12], the generation of the next state for each case is described. For example, we consider generation of the next state in the first case. The next state of generating the explanation is $q_{s+1} = (A^{s+1}, P^{s+1}, T^{s+1}, N^{s+1})$. Here, $A^{s+1} = A^s \oplus \langle a_{Ns+1}, \dots, a_{Ns+n} \rangle$, where $A_{Ns+1} = \langle nma_{Ns+1}, VAL_{Ns+1} \rangle$, $\dots, a_{Ns+n} = \langle nma_{Ns+n}, VAL_{Ns+n} \rangle$, and $nma_{Ns+1} = c_1^i, \dots, nma_{Ns+n} = c_n^i$. The result of the operation \oplus on the vectors A^s and $\langle a_{Ns+1}, ..., a_{Ns+n} \rangle$ is the vector $\langle a_1, ..., a_s, a_{Ns+1}, ..., a_{Ns+n} \rangle$. Each variable nma_{Ns+j} , j = 1, ..., n is related to the set of its values VAL_{N+i} from ξ . The vector of relations of the loop and alternative takes the form $P^{s+1} = P^s \oplus \langle p_{Ks+1} \rangle$; in doing so, $p_{Ks+1} = (p_{Ks+1}, nmv_{Ks+1}, Nc_{Ks+1}, Nqn_{Ks+1}, VALVC_{Ks+1})$, where $p_{Ks+1} = A_i$ is the name of the relation in the loop heading; $nmv_{Ks+1} = c_m^{i^*}$, where $c_m^{i^*}$ is the name of the loop variable; $Nc_{Ks+1} = r$ is the number of loop iterations; $Nqn_{Ks+1} = s$ is the number of the state prior to the loop execution; $VALVC_{Ks+1} = Y^{s+1}(c_m^{i^*})$ is the value of the loop variable $c_m^{i^*}$; and $T^{s+1} = T^s - N^{s+1}$ is the positional number that ranks below N^s in the lexicographic order.

Then, the loop body is executed *r* times. After each execution of the loop body, a new state is generated.

Finally, we consider the last case where the loop body is already executed *r* times and the state q_s is obtained. In that event, $q_s = (A^s, P^s, T^s, N^s)$ is such that $p_{Ks} = A_i$ and $nmv_{Ks} = c_m^{i^*}$. Then, the new state q_{s+1} is generated in the following way: $q_{s+1} = (A^{s+1}, P^{s+1}, T^{s+1}, N^{s+1})$ such that $A^{s+1} = A^f$ and $P^{s+1} = P^f$, where $f = Nqn_{Ks}$ is the number of a state of the computational process prior to the execution of the loop; $T^{s+1} = T^s$; N^{s+1} ; and N^{s+1} is the positional number that follows N^s in the lexicographic order.

2.3. Assume that an executed element of the description of the explanation is *output set* $\langle \gamma = A_i(c_1^i, ..., c_m^{i*}, ..., c_n^i):con \rangle$, i.e., γ is the description of the set (we call c_m^{i*} an output element). The execution of this construction depends on which of the situations listed below takes place.

(1) In the results of operation of the ES ξ , the relation, whose name coincides with the name of the relation in the description of the output set, is empty.

(2) In the description of the output set, no conditions on the values of variables are imposed by the loops' and alternatives that are external relative to the given construction.

(3) In description of the output set conditions, the values of some variables are imposed by the outer loops and alternatives.

If, in the results of operation of the ES ξ , the relation with the name A_i is absent, then the execution of the construction of the output set ends. In this case, the next state of the process of generating the explanation text $q_{s+1} = (A^{s+1}, P^{s+1}, T^{s+1}, N^{s+1})$ is formed such that $A^{s+1} = A^s, P^{s+1} = P^s, T^{s+1} = T^s$, and N^{s+1} is the construction's positional number that follows the positional number N^s in the lexicographic order.

If no conditions are imposed on the values of the variables in the description of the output set by loops and alternatives, then $q_s = (A^s, P^s, T^s, N^s)$ is such that, in the vector of values of the variables A^s , the relation $nma_j \neq c_k^i$ for all $1 \leq j \leq Nm$ and $1 \leq k \leq n$ holds. In this case, the next state of the process of generating the explanation $q_{s+1} = (A^{s+1}, P^{s+1}, T^{s+1}, N^{s+1})$ is formed such that $A^{s+1} = A^s, P^{s+1} = P^s$, and $T^{s+1} = T^s + t$, where *t* are all the values of the variable $c_m^{i^*}$ (set off by a comma) from the ordered set $\mathbf{M}(c_m^{i^*})$. The ordered set $\mathbf{M}(c_m^{i^*})$ is formed from the set of the variable $c_m^{i^*}$ (all *m*th elements of *n*-tuples with the name A_i from ξ are used).

If, in the description of the output set, conditions on the values of some variables are imposed by the outer loops and alternatives, then the state of the process of generating the explanation text $q_s = (A^s, P^s, T^s, N^s)$ is such that the vector of values of the variables A^s includes the variables $nma_g \dots nma_h$, for which $nma_g =$ $c_k^l, \dots, nma_h = c_p^l$, where $1 \le p$ and $k \le n$ (some variables of the relation A_i in the description of the output set coincide with some variables of the vector of values of the variables A^{s}). Here, the next state of the process of generating the explanation $q_{s+1} = (A^{s+1}, P^{s+1}, T^{s+1}, N^{s+1})$ is formed such that $A^{s+1} = A^s$, $P^{s+1} = P^s$, and $T^{s+1} = T^s + t$, where t are all the values of the variable $c_m^{i^*}$ (set off by a comma) from the ordered set $\mathbf{M}(c_m^{i^*})$. The ordered set $\mathbf{M}(c_m^{i^*})$ is generated from the set of the values of the variable $c_m^{i^*}$. This latter set is obtained by the results of operation of the ES ξ in accordance with values of the variables $nma_g = c_k^i, ..., nma_h = c_p^i$, where $1 \le p$ and $k \le n$, from A^s .

2.4. Assume that the executed element of the description of the explanation w_i is a construction of *alternative* $\langle \beta, \{\Omega_1, ..., \Omega_m\} \rangle$, where β is the description of a variable, i.e., $\beta = A_i(c_1^i, ..., c_m^{i^*}, ..., c_n^i)$ (we call

 $c_m^{i^*}$ an alternative variable) and $\{\Omega_1, ..., \Omega_m\}$ are descriptions of alternatives. The description of each alternative is $\Omega_k = \langle \delta_k, \psi_k \rangle$, $1 \le k \le m$. The set of selection conditions is $\delta_k = N$, where *N* is a number that denotes the possible number of values of the alternative variable, or $\{value_i\}$, where $i \ge 1$, i.e., the given set of values of the alternative variable in accordance with the results of operation of the ES. For δ_m , the set of choice conditions can also be the label # to which the jump is performed if none of the given conditions of choice are fulfilled, i.e., δ_m is either a number or $\{value_i\}$, where $i \ge 1$, or a label. The variant ψ_k is the compound operator, which is executed if values of the variable satisfy the condition of choice δ_k .

The execution of an alternative begins with finding the set of values of the alternative variable $c_m^{i^*}$ based on the description of the variable, the state of the process of generating the explanation text q_s , and the results of operation of the ES ξ . The method of finding the set of the variable $c_m^{i^*}$ coincides with the method of finding the set of values for the construction of an output set.

The further execution of the construction of alternatives depends on the conditions of choice.

Assume that the cardinality of the set of values of the alternative variable $c_m^{i^*}$ coincides with the number in one of the conditions of choice, or the given subset of values in one of the conditions of choice is the subset of the set of the alternative variable, or these conditions are not satisfied, but the last condition of choice is a label. Then, the formation of the next state of the process of generating the explanation depends on the method of finding the values of the alternative variable $c_m^{i^*}$. As this takes place, in each of the possible cases,

After that, the chosen compound operator, i.e., the operator ψ_k , whose condition of choice δ_k is the first condition of choice among all the conditions of choice satisfying the value of the alternative variable, is exe-

cuted. Otherwise, the operator Ψ_m is executed if $\delta_m = \#$.

the next state is generated.

Assume that, after the execution of the chosen compound operator, the state $q_s = (A^s, P^s, T^s, N^s)$ is obtained. In that case, the next state $q_{s+1} = \langle A^{s+1}, P^{s+1}, T^{s+1}, N^{s+1} \rangle$ is generated such that $A^{s+1} = A^f$ and $P^{s+1} = P^f$, where $f = Nqn_{K_s}$ is the number of the state of the computational process before the execution of the alternative; $T^{s+1} = T^s$; and N^{s+1} is the positional number of the construction that follows the alternative in the compound operator. If none of the conditions of choice is fulfilled and, among the conditions of choice, there is no condition of choice that is the same as the label, then the next state of the process of generating the explanation takes the form $q_{s+1} = \langle A^{s+1}, P^{s+1}, T^{s+1}, N^{s+1} \rangle$, where $A^{s+1} = A^s$, $P^{s+1} = P^s$, $T^{s+1} = T^s$, and N^{s+1} is the positional number of the construction that follows the alternative in the compound operator.

CONCLUSIONS

Based on the model described above, a system of organization of explanations was developed and implemented. This system is an element of the tool complex for development of an interface of an ES and is intended for generating an explanation text based on its formal description in the DOK language [13] and the results of operation of the ES. In addition to the constructions considered in the model, this language includes a number of constructions of control of the structure and format of the generated explanation text. Besides, an additional text construction "table" is included (it is often convenient to represent an explanation of an ES in the form of this construction). The employment of the subsystem for control of visualization of an explanation makes it possible for a user to organize a library of scenarios of explanation (decompose the explanation into fragments convenient for the user) and to manage the process of explanation in the mode of his or her decision, as well as to determine which aspects of the obtained results are necessary for him or her in a particular situation.

The tool for the development of an interface of an ES supports the principle of independent design of the interface and the ES proposed by J. Lowgren [8]. The implementation of the principle of independent design implies the separation in time of stages of problem solving and generating explanations. With the help of the system for organizing explanations, the explanations for special ES (military domain); ES Konsul'tant-2, whose application domain is the diagnosis of specific acute surgical diseases of abdominal-cavity organs; and the explanations for ESs developed by students in geometry, culinary art, and cosmetology were produced.

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