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Situational-Linguistic Modeling in Diagnostic Decision-Making Systems

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Abstract: *Modeling is one of the main elements of knowledge. With the help of modeling, you can study various objects and phenomena; choose the most appropriate solutions for the implementation of the necessary actions. At the same time, modeling does not have a harmful effect on the surrounding world that is being studied. Modeling allows you to set various conditions for the implementation of the model and obtain the necessary knowledge about the corresponding behavior of the processes or phenomena that we are considering. Among the different types of modeling, we single out situational-linguistic modeling. This type of modeling allows you to take into account various situations for decision making. Thus, we can talk about a situational-linguistic model in some environment. We also consider elements of a context-sensitive language for modeling.*

Keywords—modeling, diagnostics, decision making, modeling environment, modeling language.

1. Introduction

Modeling is one of the analysis tools that allow you to explore the world around [1]-[6]. With the help of modeling, we can study the necessary characteristics of the process, phenomenon or objects that we study. Thus, we study the object of knowledge on models and can answer a number of questions that interest us. This leads to the use of modeling in different areas and applications [4], [6], [7]-[10].

Among the varieties of modeling, information, computer and mathematical modeling should be singled out [11]-[15]. Each type of modeling provides answers to separate specific questions. At the same time, the combination of individual modeling processes allows you to more effectively explore the object of study.

Among such combinations of modeling, situational-linguistic modeling should be singled out [16], [17]. This type of modeling, first of all, allows us to take into account a specific situation that affects the object or process that we are studying. At the same time, we form a certain environment that can be described using linguistic variables. This simplifies the modeling process and provides tools for the effectiveness of such modeling.

Combining different approaches to the modeling process also allows you to justify the decisions that are most effective in a particular case. Thus, modeling is the basis for decision making. Moreover, such solutions can be used in diagnostic systems. Then modeling is the basis for effective diagnostics, which is very important, for example, in medicine [18]-[20]. Therefore, modeling plays an important role in the process of learning and making effective decisions.

Therefore, the main purpose of this study is to consider the combined modeling process. At the same time, the following can be singled out as the main tasks: the creation of a context-sensitive modeling language and the development of a situational-linguistic model in the environment. These are the questions that will be considered in the future.

2. Brief Literature Review on the Research Topic

The study by D. H. Park and his co-authors analyzes the justification of decisions using various models [21]. The authors consider unimodal and deep models (multimodal models). Deep models are the most effective and provide the necessary explanations in many cases. The authors also showed that training with text explanations leads to better models. It also better localizes the evidence supporting the decisions made [21].

W. Samek and K. R. Müller consider modeling issues in the development of artificial intelligence [22]. At the same time, special attention is paid to models with machine learning (ML). The authors note that such models are the most effective. However, in this case it is necessary to solve the problem with embedding's of the nonlinear structure. This leads to the need to take into account the features of the modeling environment. The authors also note that this feature is characteristic of many applications, for example, in medicine [22]. Therefore, it is important to use simple algorithms that use special modeling languages.

A. Sidford, M. Wang, X. Wu, L. F. Yang and Y. Ye consider the complexity of choosing the optimal time for decision making using the corresponding model [23]. In particular, the authors solve the problem of calculating the optimal discount policy for a Markov decision process (DMDP). The main condition for such a problem and its solution is access to the transition function only through the generative sampling model [23]. This also confirms the importance of considering the modeling environment when making decisions.

As noted earlier, modeling is widely used in diagnostics, in the study of various diseases, in making decisions regarding the prevention and treatment of such diseases.

M. H. D. M. Ribeiro, R. G. da Silva, V. C. Mariani and L. dos Santos Coelho review the short-term prediction of cumulative confirmed cases of COVID-19 [24]. The authors use various models to predict cases of COVID-19. Such models include autoregressive integrated moving average (ARIMA), cubistic regression (CUBIST), random forest (RF), ridge regression (RIDGE), support vector regression (SVR), and ensemble accumulation learning [24]. At the same time, the authors note that the development of effective short-term forecasting models makes it possible to predict the number of future cases. Therefore, in this context, it is important to develop strategic planning in the public health system in order to avoid fatal outcomes [24].

In [25], the authors use simulation to reduce the impact of COVID-19. At the same time, the authors, first of all, take into account all aspects that are associated with the COVID-19 pandemic. It also discusses how modeling can help decision makers make the most informed decisions [25]. At the same time, the paper notes that models play an important role in decision making. However, it must be taken into account that in each case it is necessary to use your own model in order to find the most effective solution.

In [26], decision-making issues to maintain the operations and productivity of an enterprise during the COVID-19 pandemic were considered. The authors of this study pay special attention to the issues of modeling and decision-making based on such models. It is also important to correctly interpret the simulation results to make the necessary decisions.

A. Singh, S. Sengupta and V. Lakshminarayanan pay attention to modeling issues when considering medical images [27]. The authors present an overview of various methods and approaches to the analysis of visual medical data. At the same time, the authors pay special attention to deep learning methods.

In paper [28] considers machine learning (ML) models for use in clinical practice. But such models require the trust of medical professionals. Thus, the feedback of medical professionals is one of the factors of the modeling environment, which is taken into account when making decisions.

In [29], a modeling system was considered to assess the likely effectiveness of masks in combating the COVID-19 pandemic. The authors consider various mathematical models. Generalization is a comparison of the results of each of the models. This increases the validity of the decisions made and increases the effectiveness of the use of various models.

Thus, we can note the use of various models to justify and make the right decisions. Modeling is also widely used in the healthcare system, where it is important to take into account the specifics of the modeling environment.

3. Creating a Context-Sensitive Modeling Language

First, to create such a language, let us consider the basic concepts. Such concepts will be considered on the example of diagnostics in medicine.

The environment, for which MAS (Multi-Agent Subject) SC (Situation Centre) is being developed and the system of automation of MAS SC development, by means of which the SC design is performed as a set of θ, can be represented by a tuple:

$$\theta = \langle A_p, O, K_p, V, V_p, Z_r, Z_f, W_p, W, P, G, X \rangle,$$

where A_p – MAS SC agents $-\ \theta$;

O – elements of the environment for which the SC is being designed;

K_p – relations between SC agents;

V – viruses that are currently "attacking" humans;

V_p – relations between viruses that are "vying" for priority influence on elements of the human body;

W_p – the elements of the human body which are "attacked" by the viruses;

W – the effects on the body elements taking into account the body's immune response;

Z_f – objectives of the SC;

Z_r – objectives of the development of the SC system;

P – designer;

G – language of the designer (tools). The most important components θ are summarized here.

The sets A_p and K_p reflect the different tools and means used by the developer in their work. When we consider an SC development system, we have a set of goals $Z_r = \left\{ z_{r_j} \right\}$. When analyzing the operation of a dedicated SC complex, we have a set of goals $Z_f = \left\{ z_{f_i} \right\}$. The main goal θ is to create a specialized complex of MCA for effective and timely solution of emergency situations with optimal time and cost costs for the development of SC, and most importantly-reduction of risks regarding emergency situations for people. In general, the purposeful operation of SC and the use of effective tools for its development and modeling of the natural environment, viruses, humans, etc. are characterized by the current situation and objectives [30], [31]. Which solve the problem of modeling and decision-making in an emergency, both in the creation of the SC and in its functioning? Thus, representing both sets Z_f and Z_r in the form of hierarchies of goals, we can say that each goal z_{r_i} corresponds to one or more goals z_{f_j}. Each of the goals Z_f and Z_r is defined for a situation Sit'_i, formed of the elements of A_p. It follows from the above that the developer's goal P is ensured by the development of design solutions Z_{r_i} – that solve the problem of satisfying the goals Z_{f_j} in the situation Sit'_i. A set of local goals Z_{f_j} ensures that the global goal $\Re_J$ for physician action J is met. $X = \{x_j, (j = \overline{1, m})\}$ – Quantitative indicators about airborne virus and natural phenomena (e.g. atmospheric pressure, air temperature, etc.).

The designer P looks for design solutions for different situations Sit'_i Integration into a single model specified for the elements θ of the environment model and the specialized set of MAS SC indicate a close relationship of design goals $\Re_J$, objectives of the decisions made in the subject area.

A set of local objectives z_j provides a global objective $\Re_J$ for the actions of the decision maker – J.

In other words, the designer searches for design solutions for different situations in the process of work.

This section presents our proposed agent-based model to analyze the spread processes of the COVID-19 epidemics in open regions and based on hypothetical social scenarios of viral transmissibility. We borrowed the notions of simple rules of movement, proximity among the agents, probability of infection and evolution of the states (or stages) of the disease in the agents from the work in [32].

However, the proposed model implements several other important characteristics of COVID-19 epidemic spread scenarios. It models exogenous control measures to reduce spread (social distancing policies), it also models physiological and socioeconomic differences between individuals in the same population. Therefore, each agent has its own: (i) probability of contracting the disease; (ii) rules of movement; (iii) recovery time, and; (iv) probability of death. Moreover, the proposed approach allows for agents to move between different types of region in the environment, with different infection exposures. We understand that these notions bring the model closer to COVID-19 real-life scenarios.

We considered epidemic spread in several regions (limited parts of the agent environment), in which there is a variable number of agents at time t. Each individual agent is in one of four states: susceptible; infectious; recovered, or; deceased. A susceptible agent can enter the infectious state when infected by infectious individuals. After a period of time, the infectious individuals will either recover due to the body immunity or pass away, entering the deceased state. The agents in recovered state are assumed not to be infected any more. Every change in state depends on a given average probability.

4. Development of a Situational-Linguistic Model in the Environment

Using product-frame hierarchy architecture, which is based on a frame-based knowledge representation in which a frame hierarchy with an inheritance relationship and active slots is taken as the basis, and output is carried out by product rules.

This approach naturally combines static knowledge for use in regression models of the problem to be solved [33] in the form of slot values, structural knowledge of the domain in the form of an inheritance hierarchy when using global machine learning [33], [34].

Thus, a frame system can be represented in the form of:

$$F : Sit'_i \rightarrow \{f_i\}$$

where $F = \{f_i\}$ — is the set of frames, $Sit'_i = \{Sit'_i\}$, $i = \overline{1, n}$ — is the finite set of slots of the form $\langle v, d, \{D_j\} \rangle$, including the current slot value $v = \langle v_1, v_2, \ldots v_l \rangle \in T$ and the default value $d = \langle d_1, d_2, \ldots, d_k \rangle \in T$, the procedures of the daemons $\{D_{10}\}$.

The inheritance relationship: is induced by a slot with a reserved name parent: $F : G \Leftrightarrow \|F(parent)\| = G$. The typical operation of frame specification by pattern is implemented by implicitly including a rule $F(parent) \leftarrow match(F, G)$ in the model. When considering multiple inheritance, the *parent* slot is assumed to be of list type, and $F : G \Leftrightarrow G \in \|F(parent)\|$.

The output parameter values (resulting frame – I_P) s inferred under the condition of clear values of the input parameters (query frame – I_3, consisting of a subset of $v \times d$) has the following form:

$$L : \begin{cases} IT \left\langle v_1^1, \ldots, v_l^1; d_1^1, \ldots d_k^1 \right\rangle \text{ THEN } S_1^p, \\ IT \left\langle v_1^2, \ldots, v_l^2; d_1^2, \ldots d_k^2 \right\rangle \text{ THEN } S_2^p, \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ IT \left\langle v_1^n, \ldots, v_l^n; d_1^n, \ldots d_k^n \right\rangle \text{ THEN } S_n^p. \end{cases}$$

The resulting frame I_p is a set of v and d, which belong to different frames. Thus I_p is the output of the product system represented by the following view:

$$\left\langle S_1^p, S_2^p, \ldots, S_n^p \right\rangle \rightarrow I^p.$$

In order to obtain the set goal, it is necessary to solve the following problems:

realize the construction of predicate queries and their modification, which will be, the formal-logical apparatus to describe and study the processes of updating and modification of databases and knowledge;

define rules of a logic conclusion on the basis of databases and knowledge.

By a database we will understand a set of facts. The basic ideas of this approach are considered within the framework of specific SQL implementations, or WWW and WEB implementations [31].

However, in the above implementations, the function of logical reasoning for queries is shifted to the database user. In addition, in Prolog - program for checking the correctness of the knowledge representation the construction of the knowledge base by the engineer is envisaged and the user is constantly accompanied by the results of the layout during the logical output session.

A. Description of the database

All decisions in the subject area are made on the basis of analysis of the conclusions of experts and specialists with experience. The knowledge base of the information system is considered according to [30], [31] as a set of information entities of atomic predicates from some information space $\Re$. All changes that occur in the knowledge base are considered as a consequence of x predicate queries Q_m, which have been modified. The predicate queries themselves are based on a set of predicate rules which have been modified:

$$Q_m \leftrightarrow (K_B) << \left\| \begin{matrix} K_{B-}(X) \\ K_{B+}(X) \end{matrix} \right. << \qquad (1)$$

where $X \in \Re, K_{B+}(X)$ means that the atomic predicate O should be included in the knowledge base K_B; K_B means that X should be excluded from the knowledge base; (K_B) << o means modification of the knowledge base at the level of logical connectivity of predicate rules, as a consequence of using operations of adding and excluding rules; $K_{B\pm}(X)$ means possibility of modification not only of the knowledge base, but also protection of the user on the basis of descriptors; << considered as complex arrow, features of which are studied by category theory [31]

B. Knowledge extraction

Knowledge can be represented in the form of productive rules of the type [30]:

«IF $X_1 \& \ldots \& X_K$, THEN $X_{K+1} \& \ldots \& X_{K+L}$»,

where $X_1 \ldots X_K, X_{K+1} \ldots X_{K+L}$ are some predicates.

Definition 1. The content of knowledge «IF $X_1 \& \ldots \& X_K$, THEN $X_{K+1} \& \ldots \& X_{K+L}$» is the set $W = \Pi_1 \times \Pi_2 \times \ldots \times \Pi_{K+L}$. An arbitrary element of this set is called a knowledge content element.

The content of a knowledge condition is the set $W = \Pi_1 \times \Pi_2 \times \ldots \times \Pi_{K+L}$. The arbitrary element of this set is called the content element of a knowledge condition.

The content of a consequence of knowledge is called a set $W = \Pi_{K+1} \times \Pi_{K+2} \times \ldots \times \Pi_L$. The arbitrary element of this set is called an element of the content of the knowledge consequence.

Definition 2. The probability of p_i knowledge content element $w_i \in W$ is the probability of the event that all predicate constants constituting w_i, take the logical value "AND" when substituting objects from the truth domains of the variable predicates constituting this knowledge in the value instead of arguments.

A knowledge content element w_j is a vector whose components are the values of the variable predicates that make up this knowledge. A knowledge content element w_j can be assigned to a vector of $z_j = z_j(1), \ldots, z_j(K+L)$ from R^{K+L}.

A knowledge distribution function is a function of $K+L$ arguments: $F(y) = F(y(1), y(2), \ldots, y(K+L))$, with the domain of definition R^{K+L} and taking values in the space R^1. It is defined by the formula $F(y) = \sum_{z_j \le y} p_j$ $F(y) = \sum_{z_j \le y} p_j$,

where z_j is the mapping of the knowledge content element w_j to R^{K+L}. The expression $z_j < y$ is understood as the fulfillment of the conditions: $z_j < z_j < y(i), \quad i = 1, \ldots, K+L$.

Definition 3. The distance between the comparable knowledge of ZN1 and ZN2 is the Hellinger distance $d(G, Q)$ between two probability distributions of their content elements $G = \{p_{11}, p_{12}, \ldots, p_{1r}, \ldots\}$ and $Q = \{p_{21}, p_{22}, \ldots, p_{2r}, \ldots\}$, which is calculated by the following formula:

$$d(G, Q) = \sum_j \left(\sqrt{p_{1j}} - \sqrt{p_{2j}} \right)^2 . \qquad (2)$$

By calculating the distance between knowledge, we can solve the problem when some new knowledge is fed to the input of the knowledge base. It is required to determine to which subset of knowledge this new knowledge should be attributed. To solve this problem, calculate the distance between the new knowledge and all existing knowledge, and then assign it to the subset containing the knowledge for which this distance takes the smallest value.

C. Decision-making

Despite the fact that decision-making takes place in a selected subset of knowledge, for complex systems and processes adequate mathematical descriptions of decision-making are not available or are rather cumbersome mathematical constructs whose optimization and practical use in real time is not possible. This problem can be solved by using algorithms built on models that simulate the decision-making process of an experienced expert. For a large number of decision-making models, fuzzy sets theory can be used as a mathematical apparatus [33]. In decision-making in Situational Centres (SCs), the aim of the design stages is to select a design option or parameter value from a rather small predetermined set defined, as mentioned earlier, by using formula (2). To model the decision-making process, it is proposed to use decision-making models based on fuzzy modus ponens rule, fuzzy inductive inference scheme and fuzzy expert information of the second kind. An inductive inference scheme of the form will be used [30]-[34]:

$$\frac{\tilde{L}^{(2)} = \begin{cases} \langle \text{IF } \tilde{B}_1, \text{THEN } \tilde{A}_1 \rangle; \\ \langle \text{IF } \tilde{B}_2, \text{THEN } \tilde{A}_2 \rangle; \\ \cdots\cdots\cdots \\ \langle \text{IF } \tilde{B}_m, \text{THEN } \tilde{A}_m \rangle; \\ A' \text{ - true} \end{cases}}{B' \text{ - true}} \quad (3)$$

The statements A' and B' here are clear and have the following form:

$$A' : \langle \beta w \text{ is } w' \rangle; \quad B' : \langle \beta v \text{ is } v' \rangle;$$

$$w' = (x, y, z \ldots) \in X \times Y \times Z \times, \ldots, \quad v' \in V.$$

In this inference scheme statements about values of input parameters are a premise for the scheme itself (statement A') and a consequence within the system $\tilde{L}^{(2)}$ of statements (statements A_j), and statements about values of output parameters are a consequence for the inference scheme (3) (statement B'), but a premise within the scheme $\tilde{L}^{(2)}$ (statements $\tilde{B}_j$). Therefore, in order to select output parameter values v based on the modus ponens rule it is necessary to transform the inference scheme (3) to a view:

$$\left. \begin{matrix} \tilde{L}^{(1)} \\ A' \text{ - true} \end{matrix} \right\} \rightarrow B' \text{ - true}.$$

For this purpose it is proposed to transform the system of statements of the second type into an equivalent system of the first type, using the counterposition rule, according to which for arbitrary expressions A and B the statements "IF A, THEN B" and "IF ¬B, THEN ¬A" are equivalent, i.e.

$$\langle \text{IF A, THEN B} \rangle \equiv \langle \text{IF } \neg B, \text{THEN } \neg A \rangle$$

Here expressions $\neg A$ and $\neg B$ are negative expressions A and B.

Applying the counterposition rule to expressions $\tilde{L}_j^{(2)}, j = \overline{1, m}$ of the second type, we obtain

$$\langle \text{IF } \tilde{B}_j, \text{THEN } \tilde{A}_j \rangle \equiv \langle \text{IF } \neg\tilde{A}_j, \text{THEN } \neg\tilde{B}_j \rangle,$$

where statements $\neg\tilde{A}_j$ and $\neg\tilde{B}_j$ can be considered as statements β_w are α_k and β_v are α_m, in which values of $\alpha_{w_j^*}$ and $\alpha_{v_j^*}$ are defined by the membership functions of $\mu_{w_j^*}$ and $\mu_{v_j^*}$, which are complements of μ_{w_j} and μ_{v_j}:

$$\mu_{w_j^*}(w) = 1 - \mu_{w_j}(w), \quad \forall w \in w = x \times y \times z \times \ldots;$$

$$\mu_{v_j^*}(v) = 1 - \mu_{v_j}(v), \quad \forall v \in V.$$

The above allows you to simulate the necessary situations and make appropriate decisions.

5. Conclusion

Thus, the paper considers the key aspects of modeling, taking into account the analysis of the environment and the current situation. We conducted a brief analysis on the topic of this study and justified the need to analyze the modeling environment to make the necessary decisions. The main points in creating a context-sensitive modeling language are also considered. Particular attention is paid to the development of a situational-linguistic model in the environment. This allows you to make the most effective decisions, taking into account the modeling environment and the current situation.

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