An Approach to Modeling the Behavior of Artificial Entities

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Abstract

The analysis of approaches to constructing artificial entities has shown that there is a gap between the formal models of their behavior and the expectations of users. The paper justifies the approach to their development based on behavior patterns. The purpose of the work: to substantiate an approach to the development of intelligent systems for controlling the behavior of artificial entities that automates the implementation of mission tasks. It also identifies ten components of the pattern. Based on the formal model of the behavior pattern, ten constituent elements are identified. It is shown that these elements form what can be called an "Intelligent Digital Machine" designed to automate the execution of a mission in the interests of the host subject. These components are present when a person performs a mission, including all participants in the project to develop an artificial entity. It is proved that the coordination of ideas about the architecture of an artificial entity through the exchange of information during the discussion allows us to determine the most effective model of the behavior pattern and all its components for its implementation in an artificial entity. It is shown that the coordination of ideas about the architecture of an artificial entity by the TOTHE method allows determining an effective pattern model.

Keywords

decision-making, fuzzy judgment, pattern, choice situation.

1. Introduction

Interest in the problem of constructing “intelligent” machines is associated with the problems of controlling their behavior in organizational and technical systems [1, 6]. The behavior of artificial entities based on formal models is studied in the agent theory, the decision theory, behavioral robotics, and a number of other areas [7–15]. In the agent’s classical BDI architecture, reasoning involves using inference mechanisms based on mental concepts represented by some knowledge structures [3–6]. A consistent criticism of this approach is given in [2, 17]. Therefore, when designing intelligent systems, developers have began to appeal to human behavior in a specific situation. The modeling is based on a prototype – a person (natural entity). The development of this approach based on the theory of fuzzy sets was associated with the substantiation of the concept of a subjectively rational choice, which depends on subjective ideas about the choice situation of a decision maker [1, 6]. It was also shown that when resources are limited, the brain uses energy-saving and cognitive technologies in the form of available patterns. In this regard, the problem of constructing models of behavior patterns that reflect real analogs with the greatest efficiency becomes urgent.

2. The problems of designing entities’ behavior based on pattern theory

The development of digital products in the form of behavioral patterns in artificial entity management systems involves solving at least two problems. First, it is the task of transferring the

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observed behavioral pattern of a leader subject to another subject (acting as a sensor). Second, it is the task for developers, project managers, designers, users to select concepts for the forming a digital description of the pattern model, since they use different ontologies to describe ideas and concepts. The main criteria are as follows: 1) the behavior of an artificial entity must be understandable and predictable; 2) the behavior must be effective; 3) the behavior must be adjustable, i.e., it must allow the experience correction.

3. Components of the behavior pattern

A formal model of the behavioral pattern is given in [16, 18]. It involves developing of the following general mental models designed to structure the amount of information obtained from the observation results: 1) perception of states in the subject area; 2) motivation: why to do something; 3) action modes: how we will affect the environment and ourselves; 4) processes in the subject area: models of control objects – how it works; 5) data: the base of typical situations; 6) the current and possible state values: why it is needed; 7) the target and current tactical situations; 8) the value of purposeful state situations (tactical and strategic) by the results and efficiency; 9) satisfaction with the purposeful state situation in terms of value and efficiency [1]; 10) making decisions with a changing preference structure.

These elements form what can we can call an Intelligent Digital Machine designed to automate the execution of a mission in favour of the host subject. The above models are always present, perhaps unconsciously, when a person performs a mission, including among all project participants when developing an artificial entity.

Coordination of ideas about the artificial entity's architecture by exchanging information during discussion allows determining the most effective model of a behavioral pattern and all its components to implement it in an artificial entity.

The resulting digital machine allows experiments with it using spatial and visual logic to interpret the results as in the TOTE method (input data set → impact → result) in the sense of Miller, Galanter, Pribram [18]. The interpretation logic is based on the following assumptions:

1. The subject's choice is based on the ideas about the purposeful state situation, which is formally defined in [1].

2. The presentation components reflect various aspects of the subject's understanding of the purposeful state situation and form the information structure of the representations. We denoted the set of possible representations as X.

3. For the set of environment states S, the set of observed environment states satisfy the condition $S \cap X \neq \varnothing$, i.e. the subject's representations can contain both an objective component and a phantom one.

4. The subject chooses alternatives depending on the assessments of satisfaction with the values of the purposeful state situation properties.

5. The formation of ideas is based on the procedures of perception, awareness and analysis in accordance with the subject's cognitive capabilities.

In accordance with the introduced assumptions, the subject uses three sets of alternatives when making decisions: control C (action modes), structural G (interests, preferences) and identification X. Therefore, we can assume the existence of three virtual parties that choose the appropriate alternatives. We are going to called the rules for choosing such alternatives depending on the subject's understanding of the situation and the structure of his interests as *strategies*.

A model of percepting states in the subject area. The concepts about the choice situation are based on input information that the subject extracts from the environment and experience. The basic assumption is that representations are not an exact replica of reality. The dynamics of processes in the subject's environment is inaccessible to direct perception, therefore, ideas about it are formed by applying identification procedures, the essence of which is to choose a representation version in the used *description language* depending on the observed state and structure of interests $g \in G$. Moreover, there are known restrictions $X_s \subseteq X$ on the admissibility of representations as identification alternatives depending on the observed states $s \in S$.

A single-valued monotone mapping $\xi : S \rightarrow X$ is such that $\xi(s) \in X_s$, $s \in S$ is called an identification function; an ordered set ($\xi_1, \ldots, \xi_n) \equiv \xi_1^n$ is called an identification strategy on the $n<\propto$ length horizon; the sequence $\{ \xi_1^n,\ n = 1,2,\ldots\}$ is called an identification strategy on a limited horizon. Since the subject seeks to form useful representations, then there is $\lim\{\xi_1^n\} = \xi^\propto$ for $n \to \propto$.

Since S and X sets satisfy the condition $|S| > |X|$, then the single-valued mapping $\xi:S \to X$ generates a partition of the set S into subsets $\xi^{-1}(x) = \bigcup\{s \in S : \xi(s) = x\} \subset S,\ x \in X$.

The subsets $\xi^{-1}(x) \subset S,\ x \in X$ are connected sets, i.e. any element $s \in \xi^{-1}(x)$ uniquely determines the corresponding representation $x \in X$. Therefore, we can say that the subsets $\xi^{-1}(x) \subset S,\ x \in X$ form classes (patterns) of equivalent representations.

Representations are a form for the subject to describe the environment and himself in it as patterns. They play the role of models (using the terminology of the choice theory) which help a person to predict and evaluate possible results from the chosen action modes. The primary task of the strategies for managing representations is to expand and supplement them, which creates great choice opportunities.

Let the agent be able to distinguish factors that are the characteristics of the environment $X^k = \left\{ x_i^k,\ i = \overline{1,N} \right\}$. The agent assesses the influence of each factor using a linguistic variable that is the degree of the factor's influence $\mu_x^k(x_i^k) : x_i^k \to [0,1]$. Let us introduce a parameter for the agent to evaluate his situational awareness in a purposeful state situation $Es^k = \dfrac{\sum\limits_{i=1}^{N} \mu_x^k(x_i^k)x_i^k}{\sum\limits_{i=1}^{N} \mu_x^k(x_i^k)}$.

We can define the following limitation: $\sigma^k(Es^k) \geq \sigma_0^k$, where σ_0^k is a certain threshold level of agent awareness from using his own information sources.

The representations about the choice situation are based on input information that the subject extracts from the environment and experience. The control object model for the "digital machine" defines the structure of patterns, the structure and interconnection of the pattern primary elements.

We assume that to describe how the selected factors affect the results $o_i^k,\ i = \overline{1,m}$ the agent uses an approximation in the form of production rules that are the following:

If x_1 is A_{r1}^k and if x_2 is A_{r2}^k and … and if x_N is A_{rN}^k, then $o_i^k = f_{ir}^k(x_1, x_2, \ldots, x_N)$, $r = \overline{1,R}$, $i = \overline{1,m}$, (1)

where R is the number of production rules, r is the number of the current production rule, $o_i^k = f_{ir}^k(x1, x2, \ldots, xN)$ a clear function that reflects the agent's representations about the causal relationship of input factors with possible results for the r-th rule; A_{ri}^k are fuzzy variables defined on $X^k = \left\{ x_i^k,\ i = \overline{1,N} \right\}$.

Since c_j^k is a function of the external environment state parameters, the system properties taken into account, then a set of assumptions about their possible values forms a scenario of the external environment possible state, the system functionality. Implementation of scenarios using rules (1) allows forming a representation about possible results o_i^k.

User model. A user model describes a consumer that uses an artificial entity (e.g. a drone). It models motivation, goals, values, and evaluations. The construction of such model for a project of creating an artificial entity should be reflected in the document Technical Requirements Specification. User models in the practice of designing interactive digital products, environments, systems and services are considered in [19].

Value model. The value of an artificial entity as a product is determined by a set of its characteristics (parameters). Their values allow a user to make a judgment: 1) what kind of product it is, i.e. what an artificial entity can do – a set of functionalities; 2) how it will automate the mission; 3) why should I use this product, how is it useful for me. The answer to the first question, which is a filter, makes it possible to classify an artificial entity into a certain category. If the user is interested in this category, he will look for answers to the following questions of the value model.

Formally, the value model can be presented in the form of an assessment of the specific value by the result [1]. Since the organization creates conditions for the growth of the specific value in terms of efficiency for a user, the value of the result is primary for him, and the value for the organization is of a derived (dependent) nature. In other words, the organization receives value as a reward for creating value from the user.

The problem is to find wording that defines value for a user, not for the organization that creates user experience. Solving this problem involves: 1) performing a mental simulation using a business model which has an artificial entity as only one component of the overall value proposition of the organization for the user; 2) to create a convincing value model, it is necessary to build it together applying human-centered methods of coordination in the development process, attracting people who are similar to the target user.

Interaction model. The formalization of the interaction model is based on the work results [20]. The design process can be presented as the process of implementing a sequence of situations. At each stage, the “digital machine” state changes at the same time as the environment state changes, which is a generator of conditions that determine the sequence of the stages.

Let decision-making has several cyclical stages, and the action modes are chosen at each stage $n = 1, 2, \dots$ from C set depending on the representation about the state of the environment $x \in X$. This is due to the fact that joint supraconscious (intuitive) and conscious (formal) analyzes of the environmental state allow first to accept a vaguely recognized decision in multiple iterations, and then more and more clearly formulated and grounded decision. Moreover, there are restrictions $C_x \subseteq C$ on the admissibility of the choice of alternatives depending on the representations about the state of the environment $x \in X$.

Based on these assumptions, following [17], we introduce the definitions of strategies. A single-valued presentation $\lambda: X \to C$ is such that $\lambda(x) \in C_x$, $x \in X$ is called a choice or control function; an ordered set $(\lambda_1, \dots, \lambda_n) \equiv \lambda_1^n$ is called a choice strategy on the length horizon $n < \infty$; $\lim\{\lambda_1^n\} = \lambda_1^{n\,\infty}$ for $n \to \infty$ will be called a strategy aimed at achieving a local ideal that determines the of the subject's reason for existence.

The structural alternative $\gamma_n \in G$ chosen at time n is the *structural choice* at the n-th decision-making step; an ordered set $(\gamma_n, \dots, \gamma_1) \equiv \gamma_1^n$ is a *structural choice* strategy on the decision-making horizon of length $n < \infty$; the sequence $\{\gamma_1^n,\ n = 1, 2, \dots\}$ is a structural choice strategy on a limited horizon. Since the subject seeks to match his structure of interests to the requirements of the ethical system accepted by him, then there is $\lim\{\gamma_1^n\} = \gamma^\infty$ for $n \to \infty$.

A decision-making model with a changing preference structure. According to [1] the criterion for choosing a control strategy has the meaning of the expected specific value of the purposeful state by the result, the formalization of which has the form of a utility function $E\varphi^g(C \times S \times X)$, which depends on the structural alternative $g \in G$ as a parameter. Since the control process begins with some situation $x \in X$, the criterion $E\varphi_n(\lambda_1^n \mid \gamma_1^n)$ will also depend on the situation $x \in X$ as on the initial condition. Since in this case the set of situations X is finite, the criterion $E\varphi_n(\lambda_1^n \mid \gamma_1^n)$ will finally be represented as a vector in the space R^X of $|X|$ dimension. We will write its components as $E\varphi_n(\lambda_1^n \mid \gamma_1^n)(x),\ x \in X$. As a result of the choice, the subject goes through an emotional experience; therefore, the quality of the structural choice strategy γ_1^n should be described as a criterion that has the meaning of “satisfaction with the choice results”. Consequently, it is natural to describe the quality of the strategy γ_1^n by the convolution of the expected utility vector $E\varphi_n(\lambda_n \mid \gamma_1^n) \in R^X$ into some functional $\mu: R^X \to R^1$. Then the strategy quality criterion γ_1^n can be written as $\mu_n(\lambda_1^n \mid \gamma_1^n) = \mu(E\varphi_n(\lambda_1^n \mid \gamma_1^n)) \in R^1$.

The subject connects the quality of his representations with assessments of the possibility of achieving the desired states from the control $c \in C$, as well as with the possibility of expanding the set $C\uparrow$ by including effective alternatives in it. In the work [9], the terms of the linguistic variable "utility" based on the values $E\varphi_n(\lambda_1^n \mid \gamma_1^n)$ were used as a criterion for assessing representations. In this case, the utility estimates depend on control strategies λ_1^n, structural choice γ_1^n as on the given conditions. Let us define the criterion "utility" as follows $\psi_n(\xi_1^n \mid \lambda_1^n, \gamma_1^n)$. Since the identification process starts from a certain state $s \in S$, this criterion will depend on the state $s \in S$ specified as an initial condition. Since in this case the set of S states is finite, the identification criterion will be represented by a vector $\psi_n(\xi_1^n \mid \lambda_1^n, \gamma_1^n)$ in the space R^S of the dimension $|S|$.

In the purposeful state situation, the quality of control strategies and structural choice is described by the criteria $E\varphi_n(\lambda_1^n \mid \gamma_1^n) \in R^X$ and $\mu_n(\gamma_1^n \mid \lambda_1^n) \in R^1$, respectively, which have the meaning of specific value in terms of the result and satisfaction with the selection results; the quality of the identification strategy is described by a criterion $\psi_n(\xi_1^n \mid \lambda_1^n, \gamma_1^n) \in R^S$ that has the meaning of the usefulness of representations for achieving the desired states. The use of the introduced criteria assumes defining appropriate information structures or models that allow making the appropriate choice.

We assume the existence of an information structure of representations I that reflects subject's knowledge and experience about: action modes (control), own interests and preferences, the dynamics of the transition of the environment to various states. Then we can assume that there is a structural transformation of this structure into an information structure, which provides the possibility of constructing a specific value criterion $E\varphi_n(\lambda_1^n \mid \gamma_1^n)$ and a subject area model. We will call such transformation as "*specific value transformation"*; the information structure induced by it will be called as "information structure of the specific value of the purposeful state situation by the result" and will be denoted as $U = U(I)$.

Similarly, if there is a structural transformation of the structure I into an information structure that provides the possibility of constructing an identification criterion $\psi_n(\xi_1^n \mid \lambda_1^n, \gamma_1^n)$ and a model of identification procedures, then we will call such transformation an "identification transformation" and denote as R; and the information structure induced by it will be called an "identification information structure" and denoted as $R = R(I)$.

The subject's representations about the purposeful state situation are subjective and qualitative based on observations and analysis of the environment transition process under the action of control $c \in C$ into various states $s \in S$. Let us denote the rule of such a transition through $q^g(S \mid S \times C)$ from $S \times C$ to S. In fact, to assess the value of possible results, the subject uses the model $Q^g(X \mid X \times C)$ from $X \times C$ into X constructed based on the results of the identification strategy ξ_1^n. When constructing it, control strategies λ_1^n, structural choice γ_1^n are taken into account or it is specified by such strategies. This means that the transformation of the actual function $q^g(S \mid S \times C)$ into the function of the subject's understanding of the processes in his environment $Q^g(X \mid X \times Y)$ is possible only in a posteriori mode depending on the strategies used ($\lambda_1^n, \gamma_1^n, \xi_1^n$). Such transformation and construction of the criterion of the expected specific value $E\varphi_n(\lambda \mid \gamma_1^n)$ is possible with the sequential formation of information utility structures depending on the strategies used. We will write this condition in the following form: $U_n = U(\lambda_1^n, \gamma_1^n, \xi_1^n)(I)$, $n = 1, 2, ...$ Since this condition is necessary for forming the expected utility criterion and the domain model, it must be specified every time it is used. It should be noted that the criterion $E\varphi_n(\lambda_1^n \mid \gamma_1^n)$ implicitly depends on the identification strategy ξ_1^n due to the introduction of the induced structure U_n into the choice model. As noted above, the criterion $\mu_n(\gamma_1^n \mid \lambda_1^n) \in R^1$ for the quality of structural choice is determined by the convolution of the criterion $E\varphi_n(\lambda_1^n \mid \tau_1^n) \in R^X$.

To construct an identification criterion, it is required to use some function that has the meaning of “utility”. For this purpose, it is necessary to construct verbal estimates based on the values of the utility function $E\varphi^g(S \times X \times Y)$. The required transformation exists and can be performed in a priori mode (i.e., before the choice of solutions).

Such transformation is determined by the subject with respect to a fuzzy measure that can be constructed if a function $q^g(S \mid S \times C)$ from $S \times C$ to *S* is specified. Since its analogue in the subject's mind has the form $Q^g(X \mid X \times C)$ and he can uniquely set it in the information structure *I*, then additional transformations are not required. The construction of the “representations utility” function exhausts the necessary structural transformation, which we call the “identification” structural transformation and denote as *R*, and the information structure induced by it we call the “representations utility” information structure and denote as *R* = *R*(*I*).

It follows from the introduced definitions and constructions that the quality criteria for these types of strategies are different and interdependent. Then the problem of choice has a game content and is reduced to finding a stable compromise between the desire to maximize the expected specific value of the purposeful state in terms of the result and to minimize possible losses from misconceptions. This kind of compromise is called *equilibrium*.

It should be noted that since the information structure of a “specific value” $U_n = U(\lambda_1^n, \gamma_1^n, \xi_1^n)(I)$, which sets the conditions for constructing the criterion $\mu_n(E\varphi_n(\gamma_1^n \mid \lambda_1^n))$, must be formed sequentially depending on the strategies used, the sought equilibria will be interdependent not only at each stage *n* = 1, 2, ... of decision formation, but they will also depend on the decisions chosen in the previous steps. Thus, the content of the choice modeling problem is in finding a compromise between the desire to achieve the maximum expected specific value by the result and the minimum losses from misconceptions, taking into account their mutual dependence. When reaching such compromise, it can be stated that the subject’s interests are accomplished with the best result. With this in mind, dynamic equilibria naturally define an *internal purpose* when making decisions.

4. Conclusion

The formal model of the behavioral pattern of the leader subject makes it possible to form the architecture of an artificial entity as a type of some digital machine presented as a set of ten models. It is shown that these models in one form or another, unconsciously too, are present both among the developers and consumers of this machine. It is possible to achieve the desired increase in the efficiency of such systems and complexes mainly by communication between the developers of the pattern model individual elements according to certain rules. This allows identifying unconscious assumptions at an early stage and assessing the degree of consistency of the solutions proposed by the project participants. The use of the customer's model forms the so-called “corporate intelligence”, which makes it possible to ensure design in accordance with the functional purpose of an artificial entity in an uncertain and poorly formalized environment.

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6. References

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