Ontological approach of designing a multi-agent behaviour model in the internet environment

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Abstract. The paper deals with design of the model of the subsystem of environment assessment (SEA). The authors develop the ontological approach of building the model of the subsystem, which is considered as one of the main subsystems of community organization of intelligent agents working in the integrated information environments. The approach is based on distribution of invariant aspects of building of the SEA as a multi-level architecture of semantic relations between actors, passive entities (objects) and knowledge which depends on the subject area and describes the intelligent agents’ operational environment and target use.

1. Introduction

Owing to the growing popularity of the intelligent agents and an increasing amount of ways of their application, improvement in the effectiveness of software design and development processes for intelligent agent systems is a relevant problem today.

Traditional ways for solving the problem of automated software development are based on the models and code reuse. Implementing these approaches suggests distinguishing the abstract (invariant) and specific components of the subsystem of environment assessment (SEA) of intelligent agents [1].

The invariant part of the SEA model includes distinguishing levels of the processing of the information process and three main types of functions: creating, connecting and focusing functions.

The specific part of the SEA model is determined by the features of the concrete subject area for which the intelligent agent is designed. These features include sets of the concrete object types and properties of the objects and relations between them, which are important for the target use of the designed agent [2-4].

2. Subsystem of environment assessment

The subsystem of environment assessment (SEA) is one of the main subsystems of organization of communities of intelligent agents working in the integrated environments. The suggested approach is based on distribution of invariant aspects of building the SEA as a multi-level architecture of semantic relations between actors, passive entities (objects) and knowledge which depends on the subject area and describes the intelligent agents’ operational environment and target use [5].

The intelligent agent is considered as the architecture of autonomous purposeful behavior in the open dynamical multi-agent space of distributed and heterogeneous knowledge. The architecture is built on the basis of soft intelligent agent’s structure, which is denoted by the following expression [7]:

\[
\text{Architectural expression} = \text{Ontological structure} \times \text{Operational environment} \times \text{Target use}.
\]
\[ A_i = \langle L_i, B_i, C_i, T_i, P_i, D_i, S_i \rangle, \] (1)

where \( L_i \) (level) is the model of the required knowledge level of the soft agent; \( B_i \) (base) is the model of the initial knowledge potential of the soft agent; \( C_i \) (conduct) is the model of the soft agent’s behavior in terms of providing the information about the intentions; \( T_i \) (type) is the model of individual parameters of the soft agent; \( P_i \) (process) is the model of the soft agent’s learning process; \( D_i \) (distribution) is the model of the soft agent’s resource distribution; \( S_i \) (storage) is the soft agent’s resources and instruments (Figure 1). The main feature of the intelligent agent of this class is the possibility to schedule and reschedule its actions in the dynamic multi-agent environment in real time.

In the context of the agents’ architecture, the subsystem of environment assessment plays a very important role. Its purpose is to form the high-level semantically and pragmatically valuable concepts of the real world based on the low-level data and a priori knowledge about the world given by the subsystem of processing. The set of concepts in the agent’s memory is called the world model (WM).

![Figure 1. Architecture of the autonomous purposeful behavior](image)

The following features of the integrated operational environment of intelligent agents are considered for building the SEA [8]:

- openness – the set of the objects (including other agents) in the agent’s environment at a certain time affecting its schedule is a priori undefined and can be changed in the operational process quantitatively and qualitatively (object types);
- dynamism – the world state is changed quite fast and indeterminately due to the purposeful actions of agents, which intentions are unknown (only hypotheses can be suggested based on the observed behavior);
- group actions execution – during the operational process the agents from the opposite groups can act in a coordinated manner, dynamically forming different groups at different levels of hierarchy;
- At each new cycle of knowledge accumulation and processing, the SEA updates the internal world model and forms descriptions of the situation allowing us to compare the world state with the current schedule of intelligent agent.

3. Knowledge search algorithm based on the ontology graph model

The ability to adapt to the concrete search tasks, considered context and the user’s individual characteristics is the main requirement to multi-agent intelligent systems used in the multidisciplinary knowledge space. The mentioned problem can be solved by means of search procedures based on the multidisciplinary system of relations between the knowledge elements, which is built with the use of a
functional areas set. In that regard, relations between the concepts are represented by the reference edges of the concept vertexes in the ontology graph model.

The required composition of knowledge elements is defined by semantic net navigation. Navigation is based on building the simulation model using a certain concept at the beginning. The mentioned concept represents meta-knowledge built on the basis of multidisciplinary relations between several functional areas with some search depth and neighborhood rate, and the list of concepts related with each current concept, forming its neighborhood. The analyzed concepts allow us to create a list of knowledge elements to define the current concept. In terms of the described approach, adaptation is implemented by selecting the paths of semantic net navigation and decision making on choosing the concept in each vertex in the net.

Let us describe a priori data for the algorithm of building the knowledge search path based on the ontology graph model. To define the initial level of knowledge processing and accumulation, we propose using the set $K_{\text{now}}$. The relative goal set $K_{\text{goal}}$ is used to characterize the needed level. The path between $K_{\text{now}}$ and $K_{\text{goal}}$ has a number of intermediate links characterized by the synthesized set $D_{tr}$, which contains the description of the processed knowledge elements.

Let us propose the following rules of building the described sets.

**Rule 1:** concepts included in the set $K_{\text{goal}}$ are considered as the concepts of some knowledge elements containing valuable information in accordance with the available query.

**Rule 2:** each input concept is either included in the subset of output concepts of the set $D_{tr}$ or is related to the set $K_{\text{now}}$.

**Rule 3:** revealing the properties and relations between the concepts is implemented in such way that the input concepts of the formalized ontologies are ordered and uniquely defined before using.

**Rule 4:** the effectiveness of the knowledge search path is evaluated by the additive objective function on the basis of investigating the simulation model of the search process.

Let us present the model of building the knowledge search path as the AND/OR graph $G=\langle K,C,D,O \rangle$ (Figure 2). In terms of the proposed model, $K$ denotes a set of OR-vertexes corresponding to one of the concepts representing the meta-knowledge level; $C$ denotes a set of OR-vertexes corresponding to one of the concepts representing the query features and the user’s characteristics; $D$ denotes a set of AND-vertexes corresponding to one of the concepts representing the knowledge elements corresponding to the obtained path; $O$ denotes a set of edges corresponding to the relations $K_i \& C_j = D_{ij}$.

![Figure 2. Graph model of the task of building the knowledge search path.](image)

Let us present the detailed description of the algorithm of building the knowledge search path:

1. select randomly a vertex $K_i$ from the set of OR-vertexes corresponding to one of the ontology concepts representing the meta-knowledge level;
2. define the vertex $C_j$ from the set of OR-vertexes corresponding to one of the ontology concepts representing the query features and the user’s characteristics on the basis of the obtained query processing and comparing it with the precedent bases and case-models;
3. define if there exists a vertex $D_{ij}$ from the set of AND-vertexes corresponding to one of the
ontology concepts representing the knowledge elements of the searched path on the basis of the edges of the relation $K_i \cap C_j = D_{ij}$;

4. save the ordinal numbers of the vertexes $K_i$ and $D_{ij}$;

5. verify the fulfillment of the condition $K_i \neq K_n$. If the condition is fulfilled, go to step 6; if not, the algorithm work is finished;

6. find the vertex $K_n$, which is directly related to the vertex $D_{ij}$ found at step 3. To take the detected vertex $K_i$ as $K_i$ and go to step 3.

The sequence of ordinal numbers of the detected vertexes is the desired knowledge search path.

4. Development of the model

The developed approach suggests using the same model of the integrated information environment and modifying the scheme of analyzing the relations between the objects excluding the integration of the functional areas and using the potential of finding the multidisciplinary relations only between the elements of the first level.

Let us determine the concept of centroid – the element of the first level structure (object, entity) of a randomly selected functional area $F_i$ with the greatest value of the neighborhood rate $\varepsilon$ [14]. The value of search depth $\lambda$ being the maximal number $n$ of sequentially analyzed relations in the set of elements at the first level is assigned by the expertise.

The model of the environment assessment subsystem is represented as follows (Figure 2).

![Figure 2. Model of the environment assessment subsystem.](image)

Figure 3. Model of the subsystem of intelligent agents environment assessment

In terms of each cycle, the SEA updates the internal world model and compares the world state with the intelligent agent’s current schedule. To calculate the new elements of the model based on the available ones, we propose using the following types of functions [3,7,15]:

- creating function $f_c$ which creates and deletes the entities of the model in accordance with the current agent’s concepts on the structure of the environment objects;
- connecting function $f_a$ which calculates the new relations between the entities for the purpose of building the new entities of the higher hierarchical level.

The calculating process is performed on several levels. On each level the system can create new elements of corresponding hierarchical level, and there can be any number of levels. The first level elements are directly formed by the subsystem of processing.

The calculation flow in the SEA can be organized either in the forward direction (from the perceived
5. Experimental research

To estimate the effectiveness of the developed ontological approach, we carried out a set of experiments. To demonstrate the time complexity, we used different amounts of objects and the relationships between them. The results show that the algorithm time complexity is polynomial and represented as $O(\alpha^*n^2)$. The diagram of time complexity is shown in Figure 4.

![Figure 4. The diagram of time complexity](image)

The results of the experiments carried out on different amounts of objects and relationships are shown in Table 1. Experiments compare the developed ontological and classical approach.

| Number of the objects | Number of the relations | Ontological approach | Classical approach |
|-----------------------|-------------------------|----------------------|--------------------|
| 1000                  | 700                     | 40.25                | 35.5               |
| 2000                  | 900                     | 120.23               | 106.56             |
| 3000                  | 1100                    | 285.8                | 254.92             |
| 4000                  | 1300                    | 450.85               | 419.23             |
| 5000                  | 1500                    | 560.23               | 529.87             |
| 6000                  | 1700                    | 670.89               | 642.87             |
| 7000                  | 1900                    | 790.25               | 768.59             |

As shown in Table 1, the developed approach is 12% more effective than the classical one.

6. Conclusion.

In connection with the extending application of the intelligent agents, the problem of increasing the effectiveness of the processes of design and software development of such systems is relevant today.

The traditional approaches to solving the problem of automated software development are based on models and the code reuse. The implementation of these approaches suggests distinguishing the invariant and specific components of the designed class of systems – subsystem of environment assessment (SEA) of intelligent agents. The invariant part includes distinguishing levels of the processing information and three types of functions: creating, connecting, and focusing functions. The specific part is determined by the features of the concrete subject area, including concrete object types and properties and relations between them.

The invariant and specific parts of the SEA are described by their sets of models allowing us to automate the process of the program code generation. The invariant part models must be focused on creation of the invariant framework providing the opportunity to adjust it for different software.
7. **Acknowledgments**
The reported study was funded by RFBR according to research project № 18-29-22019.

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