Estimating of the Similarity of Agents' Goals in Cohesive Hybrid Intelligent Multi-Agent System

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Abstract

Due to the high heterogeneity of practical problems, relevant to them hybrid intelligent multi-agent systems have to incorporate agents developed by various independent teams. However, there are difficulties in combining such agents into an integral system because of the incompatibility of goals, ontologies, and protocols for solving the problem. In this regard, it is relevant to develop a new class of intelligent systems, namely, cohesive hybrid intelligent multi-agent systems that implement mechanisms for coordinating goals, ontologies, and agent protocols by analogy with how groups of individual experts in the process of joint activities form a cohesive team with a common goal, agreed views on problems, established norms of behavior. The paper considers method for estimating the similarity of agents' goals, which, among others, is necessary for the developing such systems.

Keywords 1

Cohesion, hybrid intelligent multi-agent system, expert team, similarity of goals

1. Introduction

Solving practical problems by expert teams has long roots and is primarily due to such attributes of problems as heterogeneity, incompleteness, weak formalization, the network nature of conditions and goals, as well as subjectivity and dynamism [1]. When forming a team of experts to solve a practical problem posed, it is not enough to select them solely according to functional requirements: they risk not agreeing, getting bogged down in conflicts, and not solving the problem as a whole within the allotted period [2]. To receive stable recommendations of satisfactory quality in a reasonable time, it requires not a group of individualistic experts, but a cohesive team with established norms of interaction, common goals and understanding of the problem.

Similar problems arise when modeling collective problem solving by hybrid intelligent multi-agent systems (HIMAS), which agents are created by independent teams of developers. Agents can exchange messages in different languages, within incompatible protocols, their goals and domain models may contradict each other. In this regard, additional efforts are required for their integration into a single system, to reduce which it is proposed to model mechanisms of cohesive expert team forming within a new class of intelligent systems, namely cohesive hybrid intelligent multi-agent systems (CHIMAS). They will make it possible not only to synthesize a method for solving a problem over a heterogeneous model field [3] and simulate the group work of experts [4], but also to form a cohesive team of agents who understand each other and share common goals and norms.

2. Model of the cohesive hybrid intelligent multi-agent system

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Collective mechanisms in small groups, including the formation of cohesion, are studied within group dynamics [5]. Group cohesion is manifested in the creation of a single socio-psychological unity of group members, and presupposes the emergence of group's properties preventing the destruction of its psychological integrity [6]. The fundamental model of group cohesion is A.V. Petrovsky's stratometric concept (SC) [7], considering three levels (strata) of this phenomenon:

1. external level, which describes emotional interpersonal relationships;
2. value-orientational unity (VOU), presupposing that the relations are mediated by joint activities, on the basis of which there is a unity of basic values;
3. core, implying that the group members share the goals of group activity, so here the motives of their choice of each other, which can be mediated by common values, can be revealed.

Based on the HIMAS model [3], the CHIMAS model was developed [8]

$$chimas = < AG, env, INT, ORG, \{glng, ontng, protng\} >, \qquad (1)$$

where AG is the set of agents (2) of the system; env is the conceptual model of its external environment; INT is the set of elements (3) intended for structuring the interactions of agents; ORG is the set of CHIMAS architectures; $\{glng, ontng, protng\}$ is the set of conceptual models of macrolevel processes, including the model of the agents' goals coordination $glng$, ensuring cohesion at the level of the SC's core, the model of the agent's ontologies coordination $ontng$, corresponding to the exchange of knowledge, experience and beliefs between experts at the VOU stratum, the model of forming a cohesive interaction protocol by agents $protng$, which ensures the coordination of the norms of interaction at the VOU stratum. Due to the absence of an emotional component in agents, the stratum of emotional interpersonal relationships is not considered.

The agent $ag \in AG$ from formula (1) is described by the expression

$$ag = < id^{ag}, gl^{ag}, LANG^{ag}, ont^{ag}, ACT^{ag} >, \qquad (2)$$

where id^{ag} is the agent identifier; gl^{ag} is the fuzzy goal of the agent, i.e. fuzzy set $\mu_{id}(pr^{cs}_{id\,1}, \dots, pr^{cs}_{id\,N_{prid}})$ with a membership function defined on the set of concept-properties $PR^{cs}_{id} = \{pr^{cs}_{id\,1}, \dots, pr^{cs}_{id\,N_{prid}}\}$, contained in the set of concepts $PR^{cs}_{id} \subseteq PR_{id} \subseteq C_{id}$ of the agent's ontology ont^{ag} (4); $LANG^{ag}$ is the set of message transfer languages used by the agent; ont^{ag} is the agent's domain model (ontology) (4), including models of the problems to be solved; ACT^{ag} is the set of actions carried out by the agent.

An agent's action $act^{ag} \in ACT^{ag}$ is the tuple containing the problem solving method met^{ag}_{act} and the intelligent technology it^{ag}_{act} implementing it:

$$act^{ag} = < met^{ag}_{act}, it^{ag}_{act} >.$$

As a result, the CHIMAS function is described as follows:

$$act^{chimas} = \left(\bigcup_{ag \in AG^*} ACT^{ag} \right) \cup act^{col}, \quad \left| \bigcup_{ag \in AG^*} \bigcup_{act \in ACT^{ag}} it^{ag}_{act} \right| \geq 2,$$

where act^{col} is the collective function of CHIMAS dynamically constructed by agents; condition requires the presence in CHIMAS of at least two intelligent technologies [3].

Elements of structuring the interactions of agents from formula (1) are described by the expression

$$INT = < prot^{bsc}, PRC, LANG, ont^{bsc}, chn >, \qquad (3)$$

where $prot^{bsc}$ is the basic protocol for organizing the interaction of agents in the process of forming a cohesive interaction protocol; PRC is the set of basic elements for constructing a cohesive interaction protocol between the system's agents; $LANG$ is the set of languages used to exchange messages between system's agents; ont^{bsc} is the basic ontology (4), that is the basis for constructing agent ontologies and ensuring their minimum compatibility; chn is the agent cohesion model (5) used to assess the relationship between a pair of agents and the state of CHIMAS as a whole.

The agent's ontology model ont^{ag} from expression (2) and the basic ontology ont^{bsc} from expression (3) are described as follows:

$$ont =< L, C, R, A, FC, FR, FA, H^c, H^r, INST >, \tag{4}$$

where $L = L^c \cup L^r \cup L^a \cup L^v$ is the lexicon, i.e. the set of tokens, including subsets of concepts L^c, relationships L^r, attributes L^a and their values L^v; C is the set of concepts; $REL = C \times C$ is the set of relationships between concepts; $A = C \times L^v$ is the set of attributes of concepts; $FC = L^c \times C$ is the function, linking the lexicon with concepts; $FR = L^r \times R$ is the function, linking the lexicon with relationships; $FA = L^a \times A$ is the function, linking the lexicon with attributes; $H^c = C \times C$ is the taxonomic hierarchy of concepts; $H^r = R \times R$ is the hierarchy of relations; $INST$ is the set of instances, i.e. concepts of a single volume [9].

The main characteristic of CHIMAS is the value of cohesion of its agents from expression (3). Agents use it as the optimality criterion when they negotiate the goals and ontologies, and develop cohesive problem solving protocol. In addition, the average cohesion indicator of all CHIMAS agents is necessary for the facilitator agent when analyzing the current decision-making situation and choosing methods of influencing expert agents and the decision-making agent in order to improve their efficiency.

The following expression represents the cohesion of the pair of agents $ag_i, ag_j \in AG$:

$$chn_{i\,j}^{ag} =< gls_{i\,j}^{ag}, onts_{i\,j}^{ag}, protc_{i\,j}^{ag} >, \qquad gls_{i\,j}^{ag}, onts_{i\,j}^{ag}, protc_{i\,j}^{ag} \in [0,1], \tag{5}$$

where $gls_{i\,j}^{ag}$ is the degree of similarity of agents' goals; $onts_{i\,j}^{ag}$ is the degree of similarity of agents' ontologies; $protc_{i\,j}^{ag}$ is the degree of consistency of the problem solving protocol.

The cohesion of CHIMAS as a whole is described by the expression

$$chn_{chimas} = \sum_{i=1}^{n} \sum_{j=1, j\neq 1}^{n} \frac{chn_{i\,j}^{ag}}{n(n-1)}, \qquad n = |AG|. \tag{6}$$

This paper is devoted to the method for estimation of the similarity of agents' goals, therefore, the estimation of the similarity of the agent's ontologies and the consistency of the problem solving protocol is not considered.

3. Estimation of the similarity of agents' goals

To estimate the similarity between the goals of two agents $gls_{i\,j}^{ag}$, the method based on the similarity measure of fuzzy goals is used [3]. Compared with the similarity measures based on the Euclid or Hamming distance between fuzzy sets [10], in the considered measure the restrictions on the convergence of the series or integrals used in the calculations are removed. The disadvantage of this measure when estimating the similarity of goals of CHIMAS agents is that it is designed to estimate the similarity of fuzzy goals, which are set at the same ontology. In the case of CHIMAS, it is necessary to take into account that the sets of properties may differ in the ontologies of agents ag_i and ag_j, therefore, this paper modifies proposed measure. A prerequisite for estimating the similarity of fuzzy goals of agents ag_i and ag_j is the compatibility of the types of variables that describe the properties on which the goals are set. Types and transformation functions of types of variables are defined in the basic ontology ont^{bsc} and are the same for all agents of the system.

The process of estimating the similarity of agents' goals begins with establishing a correspondence between the properties on which each goal is set and the concepts of the ontology of another agent, because the identifiers of the concept-properties on which the goals are defined and their number in ontologies ont_i^{ag} and ont_j^{ag} can differ. For this, the lexicographic and taxonomic similarity of concepts are introduced [11].

The lexicographic similarity of concepts is determined by the expression

$$LS(c_k, c_l) = \max\left(0,1 - \frac{ed(FC^{-1}(c_k), FC^{-1}(c_l))}{\min(|FC^{-1}(c_k)|, |FC^{-1}(c_l)|)}\right), \quad (7)$$

where $FC^{-1}: C \rightarrow L^c$ is the function inverse to FC that establishes a correspondence between the concept and the token describing it; ed is Levenshtein's editorial distance [12], defined as the number of characters that must be added, removed, or changed to get one lexeme from another.

To estimate the taxonomic similarity of concepts, a measure based on the upper cotopy is used. Upper cotopy is a set of vertices containing all overlying vertices (superconcepts) in the taxonomic hierarchy H^c with respect to a given vertex [11]

$$UC(c, H^c) = \{c_k \in C | H^c(c, c_k)\}.$$

The measure of taxonomic similarity of concepts is the ratio of the number of common superconcepts of both vertices to the number of all superconceptions of both vertices

$$TS(c_k, c_l) = |UC(c_k, H_k^c) \cap UC(c_l, H_l^c)| \cdot |UC(c_k, H_k^c) \cup UC(c_l, H_l^c)|^{-1}. \quad (8)$$

The similarity of concepts is the geometric mean of lexicographic (7) and taxonomic (8) similarity

$$S^C(c_k, c_l) = \sqrt{LS(c_k, c_l) \cdot TS(c_k, c_l)}. \quad (9)$$

Based on the similarity measure (9), the correspondence is established between the properties on which each agent's fuzzy goal is defined and the concepts of another agent's ontology

$$\begin{gathered} MP_{i\,j} = MP(PR_i, PR_j) = \{(u, v) | (u \in PR_i^{cs} \wedge \underset{v \in PR_j}{\operatorname{argmax}} S^C(u, v) S^C(FO(u), FO(v))) \vee \\ \vee (v \in PR_j^{cs} \wedge \underset{u \in PR_i}{\operatorname{argmax}} S^C(u, v) S^C(FO(u), FO(v)))\}, \end{gathered} \quad (10)$$

where FO is the function, matching the property and the concept, associated with it by the "have property" relationship.

Correspondence (10) defines a complete set of concepts of both ontologies, on which the goals of agents ag_i and ag_j are defined. In this case, the first coordinate corresponds to the concepts of ontology ont_i^{ag}, and the second – ont_j^{ag}. Based on the analysis of each ontology, functionally dependent concepts are determined. When such concepts are found, the correspondence's (10) elements are merged into one element, and the reduced correspondence is formed according to the following rule. Suppose there are two pairs of concepts $(pr_{i\,t}^{cs}, pr_{j\,u})$ and $(pr_{i\,v}, pr_{j\,w}^{cs})$, formed according to expression (10), while there is a functional dependence $FP: pr_{i\,t}^{cs} \rightarrow pr_{i\,v}$ between the concepts $pr_{i\,t}^{cs}$ and $pr_{i\,v}$, then to form $MP'_{i\,j}$ from $MP_{i\,j}$ both pairs must be excluded and the pair $(FP(pr_{i\,t}^{cs}), pr_{j\,w}^{cs})$ have to be added. The procedure for finding functional dependencies and reducing the elements of correspondence is carried out sequentially for each ontology. Thus, the reduced correspondence $MP''_{i\,j}$ between the independent properties on which the fuzzy goals of each agent are defined and the concepts of the ontology of the second agent is determined by the following expressions:

$$\begin{gathered} MP'_{i\,j} = MP_{i\,j} \cup \{(FP(t), w) | \{(t, u), (v, w)\} \subseteq MP_{i\,j} \wedge t \in PR_i^{cs} \wedge v = FP(t)\} \backslash \\ \backslash \{(t, u) | \{(t, u), (v, w)\} \subseteq MP_{i\,j} \wedge ((t \in PR_i^{cs} \wedge v = FP(t)) \vee (v \in PR_i^{cs} \wedge t = FP(v)))\}, \end{gathered} \quad (11)$$

$$\begin{gathered} MP''_{i\,j} = MP'_{i\,j} \cup \{(v, FP(u)) | \{(t, u), (v, w)\} \subseteq MP'_{i\,j} \wedge u \in PR_j^{cs} \wedge w = FP(u)\} \backslash \\ \backslash \{(t, u) | \{(t, u), (v, w)\} \subseteq MP'_{i\,j} \wedge ((u \in PR_j^{cs} \wedge w = FP(u)) \vee \\ \vee (w \in PR_j^{cs} \wedge u = FP(w)))\}. \end{gathered} \quad (12)$$

Correspondence (12) defines the set of independent concepts of both ontologies, on which the fuzzy goals of agents ag_i and ag_j are defined. Based on the correspondence (12), the variables are replaced in the membership functions that determine the fuzzy goals of the agents

$$vr_k = prj_1(mp''_k) = prj_2(mp''_k), \qquad mp''_k \in MP''_{i\,j}, \qquad k \in [1, |MP''_{i\,j}|],$$

where prj_1, prj_2 are the vector projections onto the first and second components.

Thus, the modified measure of the fuzzy goals gl_i^{ag} and gl_j^{ag} similarity for the two-dimensional case, i.e. $\left|MP''_{i\,j}\right| = 2$, is described by the expression

$$gls_{i\,j}^{ag} = \frac{1}{2} S^{MP}\left(MP''_{i\,j}\right)\left(\frac{\int_{vl_2^{mn}}^{vl_2^{mx}} \int_{vl_1^{mn}}^{vl_1^{mx}} \mu_{gl_i^{ag} \cap gl_j^{ag}}(vr_1, vr_2)\, d(vr_1)\, d(vr_1)}{\int_{vl_2^{mn}}^{vl_2^{mx}} \int_{vl_1^{mn}}^{vl_1^{mx}} \mu_{gl_i^{ag}}(vr_1, vr_2)\, d(vr_1)\, d(vr_1)} + \right.$$
$$\left. + \frac{\int_{vl_2^{mn}}^{vl_2^{mx}} \int_{vl_1^{mn}}^{vl_1^{mx}} \mu_{gl_i^{ag} \cap gl_j^{ag}}(vr_1, vr_2)\, d(vr_1)\, d(vr_1)}{\int_{vl_2^{mn}}^{vl_2^{mx}} \int_{vl_1^{mn}}^{vl_1^{mx}} \mu_{gl_j^{ag}}(vr_1, vr_2)\, d(vr_1)\, d(vr_1)}\right), \quad (13)$$

where vl_i^{mn}, vl_i^{mx} are the minimum and maximum values of the corresponding variable vr_i; $S^{MP}\left(MP''_{i\,j}\right)$ is the degree of similarity of the concept-properties, on which the goals of the agents ag_i and ag_j are defined, determined by the expression

$$S^{MP}\left(MP''_{i\,j}\right) = \frac{1}{\left|MP''_{i\,j}\right|} \sum_{m \in MP''_{i\,j}} \sqrt{TS(prj_1(m), prj_2(m)) \cdot TS(FO(prj_1(m)), FO(prj_2(m)))}.$$

As can be seen from expressions (11), (12), the set of independent concepts on which the goals are defined depends on the order in which the ontologies are compared. As a result, measure (13) does not have the property of symmetry, i.e. $gls_{i\,j}^{ag} \neq gls_{j\,i}^{ag}$, which was taken into account when calculating the cohesion of CHIMAS as a whole using expression (6).

4. Conclusion

The paper proposes an approach to simplify the development of heterogeneous intelligent systems by independent teams based on the multi-agent approach and modeling of the stratometric concept of cohesion. The CHIMAS model is presented, in which cohesion is modeled at two of the three levels of the stratometric concept by coordinating goals and ontologies, as well as developing the problem solving protocol. Thanks to these macro-level processes, CHIMAS agents are able to overcome disagreements and avoid conflicts caused by differences in problem models and goals of its solution.

The paper proposes the method for estimating the cohesion of CHIMAS agents, presents a detailed description of one of its parts, namely, estimating the similarity of the agents' goals. Due to it, the agent-facilitator is able to estimate the problem solving situation and develop control actions at other agents to improve the efficiency of the system. In addition, the system's agents use it to estimate the effectiveness of their interaction with other agents. If the estimation is unsatisfactory, they can use the mechanisms for coordinating goals and ontologies, developing the problem solving protocol.

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6. References

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