On the Logical Approach to the Rationality of an Intelligent Agent

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Abstract
The paper deals with the formalization of an artificial agent activity using the representation of the agent’s actions by logical means. The proposed approach characterizes the rationality of the intelligent (cognitive) agents’ activity from the logical consistency point of view. The dependence of rationality on the chosen logical semantics is shown. The presentation of rationality based on an argued choice of actions using the logic of argumentation is also considered.

Keywords
Intelligent agent, multi-agent systems, rational activity, three-valued logics, argumentation

1. Introduction

From the beginning of Artificial Intelligence (AI)’s development, the notion of “an intelligent agent” is significant for the research area [1]. Moreover, they often see AI as exactly and only a science on agents perceiving the environment and affecting it through executive mechanisms [2]. Agents include a wide range of objects – reactive objects, real time planners, decision-making systems, deep self-learning systems, etc. Thus, one can see that the notion of “an agent” is very vague [3] and may vary from individuals to software.

Theoretically, an intelligent agent must possess a wide range of capabilities such as powers of action, communication, and interaction; reactivity; obligations; intentional features; goal setting; reasoning; etc. [4]. Each of these capabilities is an object of a separate research, so it is natural to consider some of them individually. Modelling agents’ actions, including with methods of logics, is important here (see [7]). They believe that agents engaged into resolving problems are rational, which implies that the agents take the best (according to one or the other criteria) decision.

One can reduce general understanding of rational behavior to the search of optimum relation between the goal of an action, on one hand, and the available knowledge, objective possibilities, and chosen instruments, on the other hand. Contemporary studies on Artificial Intelligence describing behavior of artificial agents and their groups (Multi-Agent Systems, MAS) also accept this all-purpose conception [2].

The development of decision-making theory naturally led to engaging issues related to cognitive mechanisms of human rationality into its scope [8]. It is the awareness of need to secure analysis of rational choice with formal instruments that made researchers turn to ample opportunities of AI methods that, admittedly, make a significant contribution to the development of cognitive studies [9]. Methods of logics for cognitive modelling of agents and multi-agent systems play an important role here [10].
2. Logical consistency as the basis of rationality

Parallels between social networks and Multi-Agent Systems are a source of reciprocal beneficiation for social science and AI researches [3]. Thus, sociologists see MASs as an instrument for modelling social communities. AI in turn develops instruments for imitating and enhancing human intelligent capabilities, including those related to essential aspects of social activity. Accordingly, such instruments can constitute basis for formalizing behavior of artificial agents and their groups. For example, in [11] one finds an approach allowing extending formal methods of analyzing public opinion to Multi-Agent Systems. There are approaches to modelling agents’ actions (largely based upon action theory accepted in social science [12]) considering directed action, individual and group, within certain social group.

Let's consider an algebraic model of a multi-agent system MAS = (Ag, ACT, F, L) [13]. Here Ag = {C₁, ..., Cₙ} is the set of agents; ACT = {p₁, ..., pₙ} is the set of agents’ actions in the MAS, F: Ag→2^{ACT}, ACTCⱼ = Fⱼ is the set of actions of agent CⱼєAg, L is the subset of extended set ACT’, which describes the action of the entire MAS.

We will be interested only in some elements of such a model, namely: the actual activity of agents (without taking into account their interaction) in some En environment, the features of which significantly determine this activity. Let's digress for now also from the sources of motivation that guide the action of agents. The presence of the agent’s intentional characteristics (see [4]) allows to diversify its actions in different environments (situations of action), dividing them into permissible, forbidden and indefinite (nonsense) for each of the dynamically changing environments. Accordingly, three-valued logics with truth values vє{0, 1/2, 1} can be used to formalize the action. The possible semantics of the truth value 1/2 is considered in [14]: strong nonsense (mathematical) in Bochvar logic B₂, weak nonsense (linguistic) in Ebbinghaus logic E₁, uncertainty (unknown, true or false) in the version of Lukasiewicz logic L’₃ proposed by V.K. Finn. If 1/2 is interpreted as a strong nonsense, then a complex statement ϕ(p) containing the occurrence of a nonsense atomic statement p (with truth value 1/2) is also nonsense. When interpreting 1/2 as weak nonsense, a complex statement ϕ(p₁, ..., pₙ) is nonsense if and only if all atomic statements p₁, ..., pₙ included in ϕ are nonsense. Interpretation of 1/2 as uncertainty means that the statement p is either true or false, but its evaluation is unknown.

In all three logics – B₂, E₁ и L’₃ – logical connectives negation ~, conjunction and disjunction on {0,1} are defined as in two-valued logic, and ~ 1/2 = 1/2 (negation of nonsense is nonsense, negation of uncertainty is uncertainty). Disjunction and conjunction for logics B₂, E₁ и L’₃ are defined with idempotence safekeeping (see Table 1 and Table 2 below). The definition of formulae is standard.

### Table 1
Disjunction truth tables

<table>
<thead>
<tr>
<th></th>
<th>B₂</th>
<th>E₁</th>
<th>L’₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>∪</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1/2</td>
<td>1/2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

To represent the possible actions of the agent, we will use the logical connectives Jᵢ, introduced by D.A. Bochvar (named afterwards Rosser-Turquette J-operator), vє{0, 1/2, 1}. Jᵢp = \( \begin{cases} 1, & \text{if } v[p] = v \\ 0, & \text{if } v[p] \neq v \cdot p \end{cases} \)

is a propositional variable, v is the valuation function. Thus, Jᵢ-operators correspond to characteristic functions that recognize truth values vє{0, 1/2, 1}. Then Jᵢp means that the agent performs action p, Jᵢp – the agent refrains from performing action p (for example, the action is prohibited in this
situation/environment), \( J_{2p} \) – the execution of the action is undefined (nonsense). The complete set of actions of the agent \( X_j \) from the set of actions \( ACT = \{ p_1, \ldots, p_n \} \) is represented as \( \{ \varphi_j \} = \{ J_{\varphi}p_1, \ldots, J_{\varphi}p_n \} \), where \( \varphi_j \in \{ 0, \frac{1}{2}, 1 \} \), \( i = 1, \ldots, n; j = 1, \ldots, r; \ r = |Ag| \).

External control influence can impose limitations on the agents’ activities, representing them as dependencies between the performance of certain actions. Let us represent these dependencies in the form of a consistent set of formulae \( \Sigma = \{ \varphi_1, \ldots, \varphi_r \} \) of the corresponding three-valued logic (B3, E3 or L’3), and the conjunction \( \tilde{\psi} = \varphi_1 \& \ldots \& \varphi_r \) is not a tautology (the symbol \& here is conditional, the conjunction is determined by the corresponding truth table of the chosen logic, Table 2).

Table 2

Conjunction truth tables

<table>
<thead>
<tr>
<th></th>
<th>B3</th>
<th></th>
<th>E3</th>
<th></th>
<th>L’3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( &amp; )</td>
<td>0</td>
<td>( \frac{1}{2} )</td>
<td>1</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>( \frac{1}{2} )</td>
<td>0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>( \frac{1}{2} )</td>
<td>( \frac{1}{2} )</td>
<td>1</td>
<td>( \frac{1}{2} )</td>
<td>1</td>
<td>( \frac{1}{2} )</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>( \frac{1}{2} )</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Consistency of \( \Sigma \) can be established by the method of analytic tableaux for the logics B3, E3 and L’3, where the so-called designated formulae \( J_\varphi \) are used, \( \varphi \) is an un designated formula, \( \nu \in \{ 0, \frac{1}{2}, 1 \} \). 

Designated formulae \( J_\varphi, J_\varphi (\nu \neq \mu) \) are the contrary pairs. The corresponding inference \( \alpha \)-rules (rules of conjunctive type), \( \beta \)-rules (rules of disjunctive type) and special \( \chi \)-rules are formulated. Analytic tableau \( \mathcal{T}_\Sigma \) for the set of formulae \( \Sigma = \{ \varphi_1, \ldots, \varphi_r \} \) is an analytic tableau such that the root of its inference tree is a sequence of formulae \( \varphi_1, \ldots, \varphi_r \).

\[
\begin{align*}
\psi_1 & \in \mathcal{T}_\Sigma \\
\psi_j & \notin \mathcal{T}_\Sigma
\end{align*}
\]

It is easy to show that \( \mathcal{T}_\Sigma \) is equivalent to the analytic tableau \( \mathcal{T}_{\tilde{\psi}} \) with the root \( \tilde{\psi} \). For a consistent set \( \Sigma \), the analytic tableau \( \mathcal{T}_\Sigma \) \( \mathcal{T}_{\tilde{\psi}} \) is not closed. By the completeness theorem of the analytic tableaux method for B3, E3 and L’3 (see [16]) logics, if \( \tilde{\psi} \) is a tautology, then \( \tilde{\psi} \) is provable in B3, E3 and L’3, respectively, i.e., \( \mathcal{T}_{\tilde{\psi}} \) and \( \mathcal{T}_{\tilde{\psi}} \) are closed.

Let’s assume that the agent’s actions in a certain environment (situation) are characterized by the complete set described above, then the actual activity \( ACT'_{X_j} \) of the agent \( X_j \in Ag \) can be represented by the maximal conjunction \( \varphi_j = J_{\varphi_1}p_1 \& \ldots \& J_{\varphi_r}p_r \) (\( = \) is graphical equality, \( \& \) is a symbol for the conjunction of logics B3, E3 or L’3) of atomic actions \( J_{\varphi_1}p_1, \ldots, ACT'_{X_j} = \{ ACT'_{X_1}, \ldots, ACT'_{X_r} \}, r = |Ag| \). 

This conjunction is determined by analogy with the maximal conjunction of two-valued logic, i.e., \( J_{\varphi_k}p_k \) for each \( p_k (k=1, \ldots, n) \) includes into \( \varphi_j \) without repetitions, and \( J_{\varphi_k}p_k, J_{\psi_1}p_k, \psi_1 \neq \psi_1, \) are not included in \( \varphi_j \) together.

Let \( consis(\Sigma) \) to be the consistency meta-predicate of the set of formulae \( \Sigma \). Then it is possible to determine whether the activity of the agent \( ACT'_{X_j} = \varphi_j \) is in contradiction with \( \Sigma \), i.e. does \( consis(\Sigma \cup \{ ACT'_{X_j} \}) \) hold. For this, we’ll also use the analytic tableaux method. Let’s construct the set of analytic tableaux \( \mathcal{T} = \{ \mathcal{T}_{\Sigma \cup \{ ACT'_{X_j} \}} \mid \mathcal{T} \in \mathcal{T} \} \), choose only such \( \mathcal{T} \in \mathcal{T} \), \( \mathcal{T} \in \mathcal{T} \), \( \mathcal{T} \in \mathcal{T} \), \( \mathcal{T} \in \mathcal{T} \), where \( consis(\Sigma \cup \{ ACT'_{X_j} \}) \) holds, i.e. analytic tableau \( \mathcal{T}_{\Sigma \cup \{ ACT'_{X_j} \}} \) with the root \( \mathcal{T} \) is not closed, \( l = 1, \ldots, k \). We’ll call agents whose activities do not contradict \( \Sigma \) rational. The set of rational agents is

\(^3\) Compare with the method of analytic tableaux for \( J_\nu \)-logics \( (m \geq 3) \) [15], which are an extension of two-valued logics.
\[ Ag^* = \{ X \mid (\text{consis}(\Sigma \cup \{ACT'_X\}) \& (X \in Ag)) \}, Ag^* \subseteq Ag, \mathcal{T}^* = \{ \mathcal{T}_{\Sigma \cup \{ACT'_X\}} \mid X \in Ag^* \}, \mathcal{T}^* \subseteq \mathcal{T}. \] Note that \( \alpha, \beta\), and \( \chi\)-rules for the logics \( B_3, E_3 \) and \( L_3\) are formulated differently. Accordingly, checking whether \( \text{consis}(\Sigma \cup \{ACT'_X\}) \) holds or not is dependent on the chosen logic, i.e. from the semantics of truth values.

The identification of rational agents can be useful for semi-autonomous agents’ control, allowing you to block the activities of non-rational agents in the environment \( En \). If the environment is transformed – as a result of the agents’ actions or under the influence of external control action – non-rational agents can turn out to be rational, and vice versa. Let’s consider the sequence of environment changes \( En_1, …, En_s \). The set of possible action \( ACT = \{ p_1, …, p_n \} \) is assumed to be general for all \( En_q \), \( q = 1, …, s \); at the same time, in each environment, all actions are not necessarily implemented. Accordingly, for \( En_q \), \( Ag_q \) is given \( q = 1, …, s \).

Note that the case \( \Sigma_1 = \Sigma_2 = … = \Sigma_i \) is of no interest, since it initially fixes the sets of rational and non-rational agents. Let for some \( m \sum_{m-1} \cap \sum_m = \emptyset \). In this case, the identification of rational agents for \( En_m \) occurs anew in accordance with the procedure described above, although for some \( l \) and \( m \) \((\neq m)\) it is possible \( Ag_l = Ag_m \).

If \( \sum_{m-1} \subseteq \sum_m \), to identify \( Ag_{m-1} \), it is enough to check whether the activity of rational agents \( Ag_{m-1} \) of the \( En_{m-1} \) environment does not contradict the new dependencies, i.e.

\[ Ag_{m-1}^* = \{ X \mid (\text{consis}(\sum_{m-1} \setminus \{ACT'_X\}) \& (X \in Ag_{m-1})) \}. \]

In the case \( \sum_{m-1} \subseteq \sum_m \) some non-rational agents from the set \( (Ag \setminus Ag_{m-1}^*) \) may turn out to be rational, i.e.

\[ Ag_{m-1} = Ag_{m-1} \cup \{ X \mid (\text{consis}(\sum_m \cup \{ACT'_X\}) \& (X \in Ag \setminus Ag_{m-1}^*)) \}. \]

The case \( (\sum_{m-1} \cap \sum_m = \emptyset) \& (\neg(\sum_{m-1} \subseteq \sum_m) \& (\neg(\sum_m \subseteq \sum_{m-1}))) \) does not allow us to reduce the procedure for dividing the set of agents into rational and non-rational.

### 3. Rationality and argumentation

The development of logical theories of argumentation [17, 18, 19] finds practical application in decision-making theory, conflict analysis, knowledge representation in intelligent systems, and multi-agent systems engineering. The actions of intentional agents can be based on widely understood argumentation, which can be (conditional) beliefs, motivations, obligations, etc. Argued decision making (choice of actions), not reducible to deductive reasoning, is supposed to be rational [20].

Following the logic of argumentation proposed in [21], let \( A \) be the set of arguments (argumentation base) regarding the acceptance or non-acceptance of certain statements, that is, performance or non-performance of some actions from \( ACT = \{ p_1, …, p_n \} \) of a multi-agent system by an intentional agent. Note that the argumentation base \( A \) is considered as common to all agents – it can be, for example, the union of argumentation bases of all agents. Let’s determine functions \( g^+(p_i) \) and \( g(p_i); g^+: ACT \rightarrow 2^A \), where \( \sigma \in \{+, –\} \). These functions give a set of arguments "for" and a set of arguments "against", respectively:

\[
g^+: ACT \rightarrow 2^A, g^+(p_i) \subseteq A, i = 1, …, n.
g^-: ACT \rightarrow 2^A, g^-(p_i) \subseteq A, i = 1, …, n.
\]

A pair of functions \( g^+, g^- \) will be called normal, if for all \( p_i \in ACT \) \( g^+(p_i) \land g^-(p_i) = \emptyset, i = 1, …, n \).

Permissible actions from \( ACT = \{ p_1, …, p_n \} \) take the truth value «1», forbidden – «0», undefined – «\( \tau \)». Let us define the argumentation semantics of the three-valued logic \( A_3 \) by analogy with the semantics of the four-valued logic \( A_4 \) from [21].

Atomic valuations for truth values \( V = \{1, –1, \tau\} \) are defined as follows:

\[
v(p_i) = 1 \iff g^+(p_i) \neq \emptyset, g^-(p_i) = \emptyset;
v(p_i) = –1 \iff g^+(p_i) = \emptyset, g^-(p_i) \neq \emptyset;
v(p_i) = \tau \iff (g^+(p_i) \neq \emptyset, g^-(p_i) = \emptyset) \lor (g^+(p_i) = g^-(p_i) = \emptyset);
\]

(i = 1, …, n).

Of course, each agent \( X_i \) has its own set of argument functions \( g_{X_X}^+, g_{X_X}^-, g_{X_X}^0 = \{ g_{X_X}^0(p_i), …, g_{X_X}^0(p_n) \} \), \( \sigma \in \{+, –\} \). For the agent \( X_i \) to be rational, it is necessary (but not enough) to satisfy the condition \( \forall p_i (g_{X_X}^+(p_i) \land g_{X_X}^-(p_i) = \emptyset), i = 1, …, n \).
The method of analytic tableaux for logics JA₄ and JA₅ (four- and five-valued logics with argumentation semantics) has been formulated in [20]. It is easily transformed for three-valued logic JA₃ with argumentation semantics.

Unary logical connectives $\land$, $\lor$, $\rightarrow$; are used here $t$, $f$ – (external) truth values of two-valued logic “true” and “false”, respectively. $Jp = \{ t, f \mid v[p] = v \}$, $v[p]$ is the valuation function, $v \in \{1, -1, \tau\}$. Accordingly, $v[Jp] = t \leftrightarrow g+(p)$ \n $\neq \emptyset$, $g(p) = \emptyset$ and so on. The analytic tableaux are built by use of designated formulae $t\varphi$ and $f\varphi$, $t$ and $f$ are signs for $\varphi$. Designated formulae $t\varphi$ and $f\varphi$ are contrary pairs so as undesignated formulae $fp$, $fp$, $fp$, $v = \mu$, $v \in \{1, -1, \tau\}$.

As for the three-valued logics B₃, E₃, and L₃ considered above, the corresponding $\alpha$-rules (rules of conjunctive type), $\beta$-rules (rules of disjunctive type) and special $\gamma$-rules are formulated. Accordingly, the set of rational agents is determined by means of JA₃ logic in accordance with the procedure described above.

Let $ACT = \{ \varphi_j \mid \varphi_j = f_{\psi(\sigma)} p_1 \lor ... \lor f_{\psi(\delta)} p_n, v_i^{(j)} \in \{1, -1, \tau\}, i = 1, ..., n; j = 1, ..., r; r = |Ag| \}$ be the set of agents’ activities.

Here $fp$ means that the agent has arguments for performing the action $p$ in the environment and there are no arguments against, $fp$ – there are arguments for refusing the action $p$ and there are no arguments for its performing. $fp$ – the execution of the action is undefined due to the absence of arguments or the presence of both arguments “for” and “against”.

Let’s give a simple example of rational agents’ identification.

Let $Ag = \{ C_1, C_2, C_3 \}$ to be the set of agents, $ACT = \{ p_1, p_2, p_3 \}$ to be the set of agents’ actions. The actions of agents $C_1, C_2, C_3$ in a certain environment are represented by the sets $[\varphi_1] = \{ f_{p_1}, f_{p_2}, f_{p_3} \}$, $[\varphi_2] = \{ f_{p_1}, f_{p_2}, f_{p_3} \}$, $[\varphi_3] = \{ f_{p_1}, f_{p_2}, f_{p_3} \}$, respectively. Then $ACT'_{c_2}$ for agent $C_j \in Ag$ is represented by maximal conjunction $\psi_2 = f_{\psi(\sigma)} p_1 \lor f_{\psi(\delta)} p_2 \lor f_{\psi(\lambda)} p_3, j = 1, 2, 3, ACT'_{c_3}$. Limitations $\Sigma = \{ f_{p_1} \rightarrow (f_{p_2} \lor f_{p_3}) \}$ are imposed on the actions of agents in the environment. To identify non-rational agents whose activities contradict the imposed restrictions and should be blocked, we will construct analytic tableaux $T_{\Sigma \cup \{ f_{p_1} \rightarrow (f_{p_2} \lor f_{p_3}) \}}$, $i = 1, 2, 3$.

For this we need the corresponding $\alpha$-rules $\frac{t_{fp}}{t_{fp}} (v \in \{1, -1, \tau\})$ and $\frac{t_{\psi(\sigma)} \psi(\delta)}{t_{\psi(\sigma)} \psi(\delta)}$ $\beta$-rules $\frac{t_{\psi(\sigma)} \psi(\delta)}{t_{\psi(\sigma)} \psi(\delta)}$ and $\frac{t_{\psi(\sigma)} \psi(\delta)}{t_{\psi(\sigma)} \psi(\delta)}$ $\gamma$-rule $\frac{f_{fp}}{f_{fp}}$ of the method of analytic tableaux of JA₃ logic. Here $\varphi, \psi$ denotes arbitrary formulae of JA₃ logic, $p$ is propositional variable.

The analytic tableau for $T_{\Sigma \cup \{ f_{p_1} \rightarrow (f_{p_2} \lor f_{p_3}) \}}$ is presented below:

\[
\begin{array}{c|c|c|c|c}
\text{f}p_1 & \text{f}p_2 & \text{f}p_3 \\
\hline
\text{f}p_1 & \ast & \text{f}p_2 & \ast & \text{f}p_3
\end{array}
\]

\[
t(f_{p_1} \rightarrow (f_{p_2} \lor f_{p_3}))
\]

\[
f_{p_1} \quad fp_1
\]

\[
f_{p_2} \quad fp_2
\]

\[
f_{p_3} \quad fp_3
\]

\[
\text{Figure 1: The example of the analytic tableau for} \text{JA}_3
\]

The tableau is not closed, there is an open branch, therefore, the activity of agent $C_1$ does not contradict $\Sigma$, $C_1$ is rational agent, $C_1 \in Ag$. Analogously, the tableaux $T_{\Sigma \cup \{ f_{p_1} \rightarrow (f_{p_2} \lor f_{p_3}) \}}$ and $T_{\Sigma \cup \{ f_{p_1} \rightarrow (f_{p_2} \lor f_{p_3}) \}}$ have open branches, hence $Ag^* = Ag$, all agents can act according to their instructions.
However, as mentioned above, the analysis of agents’ rationality is closely related to the interpretation of actions evaluation, on which the choice of the logic depends. The possible semantics of truth values \( \text{v} \in \{0, \frac{1}{2}, 1\} \) are defined in the section 2.

Let us show what the result of the given example will be if we choose the logic \( B_3 \). Then the environment limitations have the form \( \Sigma = \{ p_1 \rightarrow (p_2 \lor p_3) \} \), \( \overline{ACT} = \{ ACT'_{C_1}, ACT'_{C_2}, ACT'_{C_3} \} \), and \( ACT'_{C_1} j_1 p_1 \land j_2 p_2 \land j_3 p_3 \), \( ACT'_{C_2} j_1 p_1 \land j_2 p_2 \land j_3 p_3 \), \( ACT'_{C_3} j_1 p_1 \land j_2 p_2 \land j_3 p_3 \).

To construct the tables \( T_{\Sigma \cup \{ ACT'_{C_i} \}} \), \( i = 1, 2, 3 \), use the corresponding \( \alpha \)-rules and corresponding \( \chi \)-rules of the method of analytic tableaux for \( B_3 \) logic. Here \( \varphi, \psi \) are formulae of \( B_3 \) logic.

The analytic tableau \( T_{\Sigma \cup \{ ACT'_{C_i} \}} \) has the following form:

\[
\begin{array}{c|c|c|c}
& j_1 p_1 & j_1 p_2 & j_1 p_3 \\
\varphi_1^* & & & \\
\varphi_2 & & & \\
j_2 p_1 & j_2 p_2 & j_2 p_3 & \\
j_3 p_1 & j_3 p_2 & j_3 p_3 & \\
\end{array}
\]

**Figure 2:** The example of analytic tableau for \( B_3 \)

The tableau is closed, there are no open branches, the agent’s activity contradicts \( \Sigma, C_1 \not\subseteq Ag^* \).

It is easy to verify that analytic tables \( T_{\Sigma \cup \{ ACT'_{C_i} \}} \) and \( T_{\Sigma \cup \{ ACT'_{C_i} \}} \) for \( C_2 \) and \( C_3 \), respectively, are not closed, i.e., \( Ag^* = \{ C_2, C_3 \}, Ag^* \subseteq Ag \).

It can be seen from the examples given that the formation of groups of rational agents under the environment limitation depends on the semantics of actions’ valuations, in accordance with which the logical apparatus is chosen.

\( JA_3 \) logic formal means also allows an alternative procedure to be used to identify rational agents.

Let, as above, \( \overline{ACT} = \{ \varphi_j \mid \varphi_j = f_{\varphi_j}^1 p_1 \land \ldots \land f_{\varphi_j}^n p_n, \text{v}_i^{(j)} \in \{1, -1, \tau\}, i = 1, \ldots, n; j = 1, \ldots, r; r = |Ag| \} \). Let \( F_{Ag} = \{ \varphi_1 \lor \ldots \lor \varphi_r \}, \varphi_j \in ACT, j = 1, \ldots, r. \)

\( F_{Ag} \) is a perfect DNF, that can be transformed to reduced DNF using the generalized Quine algorithm modified for \( JA_3 \) logic. Thus, the axioms of generalized gluing and absorption are formulated, respectively, as follows (here \( C_1, C_2, C_3 \) are maximal conjunctions of the \( JA_3 \) logic, \( p \) is a variable):

\[(a) \ (j_p \land C_1) \lor (j_p \land C_2) \lor (j_p \land C_3) \Leftrightarrow (j_p \land C_1) \lor (j_p \land C_2) \lor (j_p \land C_3) \lor (C_1 \lor C_2 \lor C_3); \]
\[(b) \ j_p \lor (j_p \land C) \Leftrightarrow j_p.\]

Applying successively \((a)\) and \((b)\) to the \( F_{Ag} = \{ \varphi_1 \lor \ldots \lor \varphi_r \} \) until their applicability stops, we obtain reduced DNF \( (\chi_1 \lor \ldots \lor \chi_h) \) with corresponding implicants set \( \{ \chi_1, \ldots, \chi_h \} \). We assign to each implicant \( \chi_t \ (t = 1, \ldots, h) \) such a set \( Ag \) of agents \( X \in Ag \) that their activity \( ACT'_{X} = \varphi \) is covered by the implicant \( \chi_t \), \( Ag = \{ X \mid \chi_t \subseteq ACT'_{X} \} \).

\* Note that generalized gluing and absorption can also be formulated for logics \( E_0 \) and \( L_3 \), but the axiom of absorption does not hold in \( B_3 \).
Let’s construct the set of analytic tableaux \( \tilde{T} = \{ T_{\Sigma \cup \{ \chi_i \}}, \ldots, T_{\Sigma \cup \{ \chi_m \}} \} \) and choose such \( \chi_{j_1}, \ldots, \chi_{j_m} \), where \( \text{consis}(\Sigma \cup \{ \chi_i \}) \) holds, i.e., the analytical table \( T_{\Sigma \cup \{ \chi_{j_l} \}} \) with the root \( \Sigma \cup \{ \chi_{j_l} \} \) is closed, \( l = 1, \ldots, m \). Then \( AD_{j_l} \) agents are not rational, and their activities in \( En \) environment should be blocked.

It should be noted that the choice of one of the two described procedures for constructing a set of rational agents depends on their comparative efficiency, which is determined separately in each case.

4. Conclusion

One often sees agent approach in AI as a universal one. However, diversity of conceptions of essential features, attributes, powers of the agents often makes this approach speculative. Gradual progression from Intelligent Systems to Cognitive Systems and further, to Intelligent Robots, appears promising. Intelligent Robots are a type of Intelligent Agents imitating and reinforcing certain intelligent capabilities that designate phenomenalology of natural intelligence [22, pp. 99–121].

Clarifying the notion of rationality by methods of logics contributes to exercising by an agent of one of the core powers of natural intelligence – the power of argued decision-making. This power allows us to talk about a rational choice of action. Owing to the suggested methods, we can distinguish agents whose actions are adequate to the features of an environment, and avoid use of actions inadequate to it. Further development of these methods may result practical for describing, researching and understanding of Multi-Agent Systems as well as of social systems and society.

5. References


[18] V.N. Vagin Znaniya i ubezhdeniya v intellektual’nom analize dannyh [Knowledge and Believe in Knowledge Discovery], Fizmatlit, Moscow, 2019.


