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The Language Grounding Problem and its Relation to the Internal Structure of Cognitive Agents

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Abstract: An original approach to modelling internal structure of artificial cognitive agents and the phenomenon of language grounding is presented. The accepted model for the internal cognitive space reflects basic structural properties of human cognition and assumes the partition of cognitive phenomena into conscious and 'non-conscious'. The language is treated as a set of semiotic symbols and is used in semantic communication. Semiotic symbols are related to the internal content of empirical knowledge bases in which they are grounded. This relation is given by the so-called epistemic satisfaction relations defining situations in which semiotic symbols are adequate (grounded) representations of embodied experience. The importance of non-conscious embodied knowledge in language grounding and production is accepted. An example of application of the proposed approach to the analysis of grounding requirements is given for the case of logic equivalences extended with modal operators of possibility, belief and knowledge. Implementation issues are considered.

Keywords: Language Grounding, Communication, Cognitive Agent, Formula Satisfaction, Modal Logic
Categories: H.1.0, H.1.2, H.5.2

1 Introduction

In this paper a relation between internal organization of a simple intelligent agent and its external semantic language is discussed. The semantic communication of cognitive agents is an intensively developing area of modern artificial intelligence and cognitive science. From the formal point of view semantic languages are treated as sets of interpreted and materialized signs (written, spoken, etc.) produced externally by intelligent agents in order to communicate particular content. The fact that signs of a semantic language are interpreted means that they are treated as symbols representing particular content (objects). The concept of the symbol has got a long tradition in cognitive science. However, its meaning differs depending on particular streams of cognitive science research. Therefore only some interpretations of the idea of symbols seem useful to model semantic communication. Three approaches to defining the role of symbols in cognitive behaviour are worth mentioning in the context of communication.

In *classical* cognitive science the idea of symbol is fundamental due to the fact that cognitive behaviour is understood as transformation of symbols [Anderson, 03]. Symbols are treated as internal structures of a cognitive agent, each state of the agent's cognition is defined by certain collections of symbols and changes of cognitive states are equivalent to mechanical transformation of symbols [Newell, 90]. Although important and influential, this interpretation of symbols is not always accepted in modelling semantic communication [Vogt, 02].

Another approach to modelling cognitive behaviour rejects symbols as unnecessary. Namely, it claims that intelligent behaviour is produced directly by purely reactive architectures in which no symbol processing appears and symbol conceptualization is required. Cognitive intelligence is assumed to be embodied and does not need symbols as its carriers [Brooks, 91]. Although intellectually fruitful, such approach does not correspond fully to more advanced forms of semantic communication, too.

The third approach to defining and understanding the role of symbols in language behaviour accepts the so called semiotic definition of symbols [Eco, 91]. In this approach semiotic symbols are always considered in relation to cognitive agents that are carriers of their sense. Their role in semantic communication is defined by three elements: the 'material' form of the symbol (as perceived by a group of cognitive agents), the sense assigned to the 'material' form of semiotic symbol by a certain cognitive agent, and a real object usually located in an external world to which the semiotic symbol is referred by a certain cognitive agent. The form of a semiotic symbol is a certain material entity that can be copied and send by cognitive agents as external messages. The sense of the symbol is the meaning (the content) located internally in the body (perhaps virtual) of a cognitive agent. In this approach the meaning 'mediates' between the form and the related actual object (see Figure 1). These three elements constitute the so called semiotic triangle [Eco, 91] [Vogt, 02] and can be effectively used in modelling and analysis of semantic communication regardless of the implementation nature of communicating agents. In semiotic approach to semantic communication of agents the language of communication is treated as a set of semiotic symbols. This approach is assumed below.

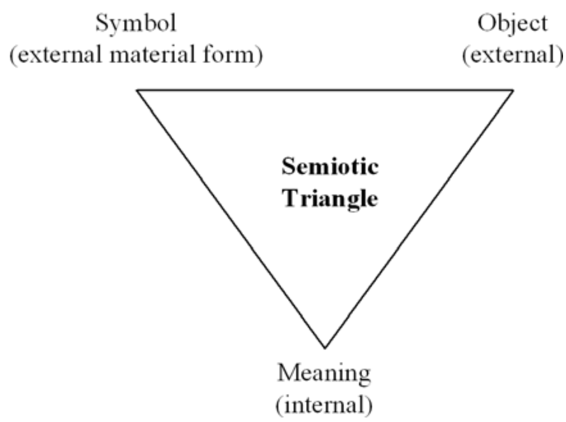

Figure 1: Semiotic triangle and the meaning of symbols.

The idea of semiotic symbols has already been effectively considered by some cognitive scientists in the context of semantic communication of robots. An interesting example can be found in [Vogt, 02], in which robots (materialized cognitive agents) are assumed to learn the so-called lexicons. Lexicons are considered and created by robots (cognitive agents) in and only in social context. Each lexicon L is defined as a set L={FM_t} of form-meaning associations, where FM_t =<F_t, M_t, p_t>} is a lexical entry. F_t denotes the material form of an entry which is a consonant-vowels stream, M_t is a memorized part of a meaning represented internally by the agent, and p_t is a score that indicates the socially verified effectiveness of the use of F_t to name (denote) the situation corresponding to M_t. Obviously, such lexicons are strictly related to the idea of corresponding semiotic triangles in this sense that they are internal implementations of the meaning M_t assigned to the form F_t. In the approach given in [Vogt, 02] the semiosis (in this particular case treated as equal to the lexicons acquisition process) and the social coordination of the meaning stored in lexicons are both treated as a part of the physical grounding of symbols in cognitive structures of materialized agents.

The model for semiosis and suggested solution of the semiotic symbol grounding presented in [Vogt, 02] are considered for the case of relatively simple agents and a relatively simple language of communication (namely, the set of simple names). Its importance is unquestionable for it constitutes an effective example of the practical symbol grounding and actual semiosis in artificial communities of cognitive-like agents. However, the actual internal structures of cognitive agents and semantic languages of communication are usually more complex. Therefore in this paper the above mentioned issues are considered from a slightly different (at the same time more theoretical) perspective and for more advanced forms of communication carried out by internally developed cognitive agents. In particular, the situation considered below is featured by the following assumptions:

At first, the suggested model for internal structure of communicative cognitive agents reflects fundamental partition of natural minds into conscious and non-conscious cognitive subspaces e.g. [Freeman, 00] [Paivio, 86], where the term 'non-conscious' states for both preconscious and unconscious aspects of cognitive processing.

At second, the role of non-conscious cognitive subspace is treated as crucial. Namely, it is accepted that in semantic language generation both conscious and non-conscious content of knowledge databases is important.

At third, the semantic language of communication is assumed to be a restricted set of modal logic formulas. These formulas can be used to describe ontological relations between exactly two properties (in the strictly private empirical perspective of particular agent).

At fourth, the considered modal logic formulas are material forms of semiotic symbols. They represent externally individually developed meaning that is a certain individual way in which in some 'mental' states cognitive agents capture external objects. In this paper particular attention is paid to the role of conscious and non-conscious cognitive subspaces.

The remaining text is organized in four paragraphs. In the second paragraph original models of internal organization of cognitive agent and its external world are presented. At the beginning the cognition is assumed to be divided into conscious and non-conscious cognitive subspaces in order to reflect one of the most important properties of natural agents' cognition. Then the relation between conscious and 'non-conscious' cognitive subspaces and semiotic symbols is discussed. A certain material sign (material form) is treated as a part of a semiotic symbol if and only if it is bound to a certain embodied meaning. Due to its nature any semiotic symbol is also grounded. The accepted cognitive capacity of considered agents is relatively simple and is dedicated to conceptualize knowledge of regularities observable in an external world consisting of atom objects. At the end a model of two level cognition is formally introduced. In the third paragraph an original idea of the so-called epistemic satisfaction relation is generally presented. Its role in grounding semiotic symbols (and semantic languages of communication) and fundamental difference to Tarskian definitions for satisfaction relations are discussed. The fourth paragraph is organized in three sections and is devoted to a more detailed discussion of grounding three classes of semiotic symbols. These classes consists of logic equivalences extended with modal operators of possibility, belief and knowledge. Certain definition for epistemic satisfaction relation for modal equivalences is given. Related commonsense rationale for the accepted requirements are also given. In the third section of this paragraph the main implementation problem and some applications issues are mentioned. The fifth paragraph consists of final remarks. A list of references to related research is also given.

2 Cognitive Agent and the External World

2.1 Conscious and Non-Conscious Levels of Cognition

It has already been accepted in basic models for human mind that in the mental perspective experienced by a cognitive agent its internal processes are distributed among two cognitive subspaces e.g. [Freeman, 00] [Paivio, 86]. The first cognitive subspace is defined by all mental processes that are perceived as conscious ones. The other cognitive subspace embraces preconscious and unconscious levels of mental phenomena that are not experienced in a direct way. The role of conscious and 'non-conscious' mental phenomena in the production of external behaviour is well known in case of human agents. Unfortunately, as some cognitive researchers say this division of mental processes is not present in this stream of cognitive sciences that deals with artificial systems and therefore needs to be introduced [Anderson, 03]. In the field of semantic multiagent communication this situation seems a little bit strange and unsatisfactory because each deeper examination of the commonsense semantics for simple natural language statements suggests a strong influence of unconscious levels of cognition on the meaning of semiotic symbols. Another theory related to cognitive sciences that can contribute to the study of semantic communication of artificial cognitive agents is the theory of mental models [Johnson-Laird, 83]. It is claimed in this paper that both of these approaches (the theory of two level cognition and the theory of mental models) can contribute to deeper understanding of the way in which semiotic triangles are involved in actual acts of communication (provided that mental models are extracted from embodied empirical experiences).

The internal structure of artificial cognitive agent that has been accepted in this paper reflects the above mentioned aspects of natural human cognition. Figure 2 shows what is the role of particular elements of this structure and relates it to the idea of semiotic triangle. The external material form of a semiotic symbol (in this case a formula ϕ) is related to its mental model. This mental model is placed in the conscious cognitive subspace of the agent's mind. It represents a cognitive state in which an agent experiences the meaning of ϕ in a conscious way. However, the mental model is not the only 'structure' that is embodied in the cognitive agent and caries the meaning of the material formula ϕ. In this paper mental models are treated as reflections of previous experience and in this sense are higher level representations of relevant content. In this sense they are induced from related sets of individual empirical experiences. At the very basic level of cognition the empirical experiences of each cognitive agent are assumed to be given as simple (individual) perceptions of an external world that has ever been collected (realized) by the cognitive agent.

The actual empirical experience of a cognitive agent is usually given as a massive set of realized perceptions. In case of human cognitive agents such perceptions are stored in non-conscious memory due to the fact that the volume of consciously 'captured' data is strongly constrained and can consist of a very limited content. Realized perceptions can however be present in conscious cognitive subspace, too. Two situations are taken into account in this paper, namely, when a perception is relatively fresh and is still the “up-to-date” reflection of current state of an external environment and when it has been re-called by cognitive processes from non-conscious to conscious cognitive subspace by certain processes.

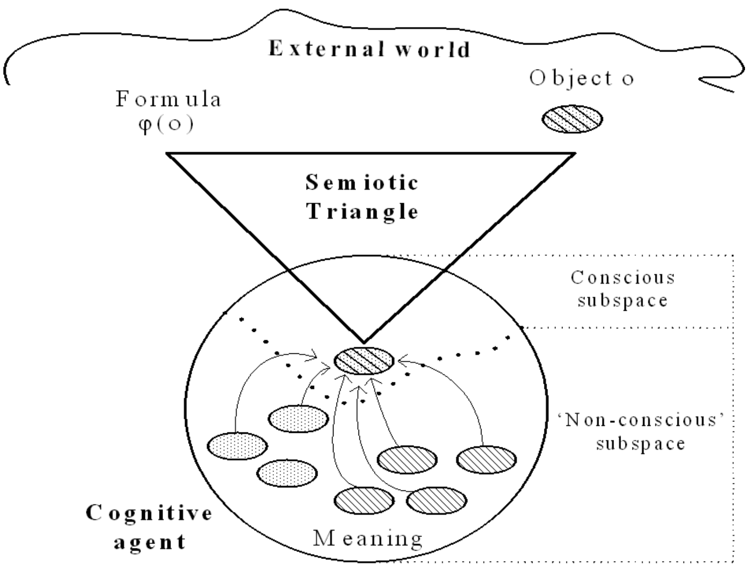

Figure 2 : Cognitive agent and semiotic triangle.

The material form of a semiotic symbol (in this case the formula ϕ), the related mental model and the underlying embodied empirical experiences are combined together. In an obvious way they cover the related parts of semiotic triangle and represent the result of semiosis (the completed meaning creation processes). In this particular sense the material form ϕ of the symbol is physically grounded in the overall body of relevant empirical data. However, the relation between the material form (sign), the mental model and the underlying embodied experience is not apparent and depends on the socially accepted meaning of ϕ. (An example of such a socially realized process of learning has already been considered for a case of another class of simplified agents in [Vogt, 02].) It means that in each case of semantic communication and for each cognitive agent that is able to recognize a certain incoming material form (in this case a certain formula ϕ) and interpret this form as a semantic message, a certain semiotic relation between the above mentioned parts of semiotic triangle is assumed as internally embodied and grounded. Obviously, this approach to understanding particular elements of the structure given in Fig. 2 leads to the necessity of developing a certain model for this kind of semiotic relation.

In our approach to modelling internal organization of cognitive agent each cognitive state is given by a particular distribution of internal content in both cognitive sub-areas. Moreover, if a particular distribution of content is realized, the related material forms can be defined in order to represent it in the external world. In order to capture the suggested semiotic relations between states of cognition and external material form of semiotic symbols the following definitions have been proposed elsewhere.

2.2 Structure of the World

The world considered in this paper as an external environment of cognitive agents is a dynamic system of simple atom objects. The world is assigned a line of time points $T=\{t_1, t_2, ...\}$ to which particular states of the world are related. At each time point all objects are characterized as exhibiting or not exhibiting properties $P_1, \ldots, P_K$. Formally [Katarzyniak, 00, 02]:

Definition 1. (World Profile) Each state of the external world related to the time point t is represented by the relational system

$$WorldProfile(t) = \langle O, P_1(t), \ldots, P_K(t)\rangle.$$

The following interpretation of WorldProfile(t) is assumed:

- *The set $O= \{o_1, \ldots, o_M\}$ is the set of all atom objects of the external world.*
- *The symbols $P_1, \ldots, P_K$ are unique names of properties that can be attributed to the objects from O. In particular, each object $o\in O$ may or may not exhibit a particular property $P\in\{ P_1, \ldots, P_K\}$.*
- *For $i=1,...,K$ and $t\in T$ the symbol $P_i(t)$ denotes a unary relation $P_i(t)\subseteq O$.*
- *For $i=1,...,K$ and $o\in O$ the condition $o\in P_i(t)$ holds if and only if the object o exhibits the property P_i at the time point t.*
- *For $i=1,...,K$ and $o\in O$ the condition $o\notin P_i(t)$ holds if and only if the object o does not exhibit the property P_i at the time point t.*

2.3 Internal Cognitive State

The cognitive agent is equipped with dedicated sensors that make it possible for it to observe particular parts of the external world. Each observation results in an individual perception that is introduced into the agent body and represented as embodied structures. This way regularities of the external world are constantly reflected in the agents knowledge bases and are the basic source of its model of the world. The internal system of concepts accessible for cognitive agents is assumed to be strictly related to the structure of external world. Namely, it is assumed that the cognitive agent can store internally reflections of particular states of properties $P_1,\ldots,P_K$ in individual objects $o_1, \ldots, o_M$. It means that each aspect of the external world is recognizable for the agent and can become a part of the body of its empirically originated knowledge.

An individual perception can be formally described by a formal structure similar to world profiles and called *base profile*. It is further assumed that the content of such a description needs to be related to and only to a constrained part of external world that has actually been captured (covered) by realized perception. Such solution corresponds to natural cognitive agents' abilities because in actual settings cognitive agents can observe at most parts of their surroundings. The formal structure to represent individual perception can be given as follows [Katarzyniak, 00, 02]:

Definition 2. (Base Profile) The internal representation of observation of the external world realized by the agent at the moment t is given by the relational system

$$BP(t) = <O, P_1^+ (t), P_1^- (t), P_2^+ (t), P_2^- (t),\ldots, P_K^+ (t), P_K^- (t) >\},$$

where the following interpretations and constraints are assumed:

- *The set $O= \{o_1, \ldots, o_M\}$ consists of all representations of atom objects $o\in O$, where the symbol o (used as a part of base profile) denotes a unique internal cognitive representation of a related atomic object located in the external world.*
- *For each $i=1,2,...,K$, both $P_i^+(t)\subseteq O$ and $P_i^-(t)\subseteq O$ hold.*
- *For each $i=1,2,...,K$ and $o\in O$ the relation $o\in P_i^+(t)$ holds if and only if the agent's point of view is that the object o exhibited the atomic property P_i and this fact was empirically verified at the time point t by the cognitive agent itself.*
- *For each $i=1,2,...,K$ and $o\in O$ the relation $o\in P_i^-(t)$ holds if and only if the agent's point of view is that the object o did not exhibit the atomic property P_i and this fact was empirically verified at the time point t by the agent itself.*
- *For each $i=1,2,...,K$, the condition $P_i^+(t)\cap P_i^-(t)=\emptyset$ holds.*

Due to the fact that base profiles cover parts of related external worlds certain type of natural epistemic ignorance appears in knowledge processing. This ignorance can be defined as follows [Katarzyniak, 00, 02]:

Definition 3. (Situational ignorance) The scope of situational ignorance related to a base profile BP(t) and a property $P\in\{P_1,\ldots,P_K\}$ is given as the set $P^{\pm}(t)=O/(P^+(t)\cup P^-(t))$ consisting of all internal representations of objects which has not been externally observed by the agent in order to determine the property P (at the time point t).

It has already been accepted in this paper that all basic knowledge of the world is treated as resulting from the agent's interactions with external objects. It means that it is the set of all embodied (internally stored) perceptions that induces the private model of the world individually created by cognitive processes of the agent. The following definition is accepted:

Definition 4. (Knowledge base) At each time point $t\in T$ the overall state of basic empirical knowledge embodied in the cognitive agent can be conceptualized as a temporally ordered set of base profiles $KS(t)=\{BP(t_n): t_n\in T$ and $t_n\trianglelefteq t\}$.

However, cognitive science states that the content of KS(t) is not the only element of the agent, which determines the state of agent's cognition at each time point t. The dimension that is still not present in this conceptualization is the natural division of empirical experience into the conscious and 'non-conscious' material. Such a division is always present and is an integral property of each cognitive state. In other words, each cognitive state is always given by the distribution of embodied experience over both cognitive subspaces of the mind. In order to capture this element of internal organization of cognitive agents in our model the following symbols have been proposed (see also [Katarzyniak, 04a]):

Definition 5. (Levels of cognition) At each time point $t \in T$ *the actual state of cognition is described by a binary partition* $CS(t)=\{CM(t), NM(t)\}$ *of the set* $KS(t)$*, where* $CM(t)$ *states for this part of experience that is located in the conscious cognitive subspace,* $NM(t)$ *is the remaining empirical material located in non-conscious cognitive subspace,* $CM(t) \cup NM(t)=KS(t)$ *and* $CM(t) \cap NM(t)=\emptyset$.

The concepts of base profiles, the state of knowledge and the state of cognition can be treated as formal elements that define a certain class of artificial cognitive agents. These agents imitate at least some fundamental properties of natural human cognition. Obviously, they do not cover all basic aspects of human knowledge processing but make it possible to introduce new dimensions into the study of artificial cognition.

3 Epistemic Satisfaction Relation and the Result of Semiosis

The epistemic satisfaction relation is another original concept proposed in our approach to modelling semiotic symbols. Another important characteristic is that it relates to the idea of semiotic triangle to the idea of the semiotic symbol grounding. In particular, it is assumed here that the epistemic satisfaction relation binds the material form of semiotic symbols with its embodied meaning. In this sense semiotic symbols are interpreted and represent the result of a certain semiosis (the result of meaning creation processes).

Obviously, the epistemic satisfaction relation reflects a particular social consensus over the meaning of a material form commonly used in individual acts of communication. Moreover, it has always to be treated as developed in a certain social context and reflects common point of view accepted by a certain population of communicative agents.

The epistemic satisfaction relation is complementary to the classic Tarskian satisfaction relation proposed for the case of formal languages [Tarski, 35]. The difference between both approaches to defining the meaning is fundamental (see Figure 3). In particular, Tarskian satisfaction relation realizes the so called classic definition of truth which 'equals' the truth to the ontologically existing being. However, in order to understand Tarskian definition one needs to assume that the considered language (a language symbol) has been assigned a socially accepted and embodied meaning. Otherwise the application of Tarskian approach is not possible [Tugendhat, 60]. This meaning assumed in Tarskian definitions defines a certain way in which a symbol is compared with externally existing objects (and states of these objects). The internal and embodied meaning of symbols mediates between the language and external world (although it is not spoken in a direct way). It can however be rediscovered by careful analysis of truth verification procedures based on the classic truth tables. In consequence, the epistemic satisfaction relation proposed in our approach captures and describes in a direct way what is indirectly assumed in Tarskian definitions. The result is that it covers another part of semiotic triangle, namely this part that consists of internal intention directed at an ontologically existing object and the related language symbol.

It is quite obvious that the epistemic satisfaction relation given for a certain language of communication needs to be grounded in communicative agents. Moreover, effective communication of agents can be realized if and only if similar implementations of epistemic satisfaction relations are grounded in all participants of information exchange. In forthcoming sections the concept of epistemic satisfaction is used to analyze the commonsense semantics and pragmatics for modal extensions of a logic formula consisting of two atoms joined with the equivalence logic connective. It is assumed that these semiotic symbols are grounded in artificial cognitive agents defined in section 2.

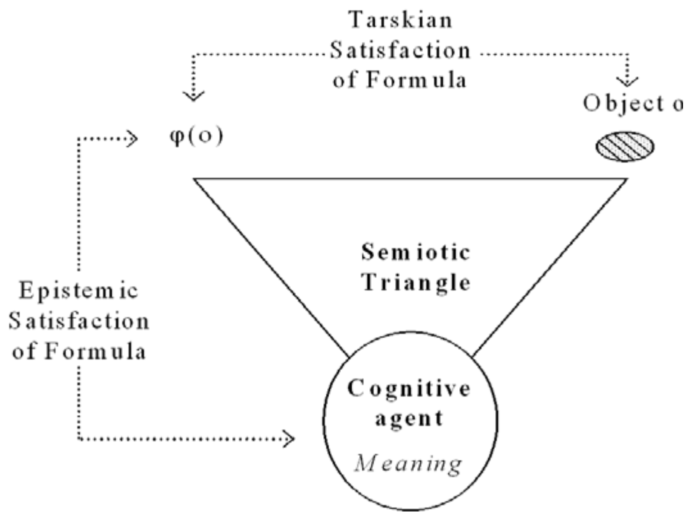

Figure 3 : Classic and Tarskian satisfaction of formulas.

4 Extended Example of the Approach

4.1 Material Form and Commonsense Meaning

The semiotic symbols that are considered in this section are interpreted modal formulas in which modal operators of knowledge, belief and possibility extend two atom formulas joined with the interpreted logic connective of equivalence. The syntactical structure of this material form is given as follows:

Definition 6. (Material Form of Semiotic Symbols) Let the following alphabet be given:

- *The set $O = \{o_1, \ldots, o_M\}$ consisting of all individual constants.*
- *The set $NP = \{p_1, \ldots, p_K\}$ consisting of unary predicate symbols related to properties $P_1, \ldots, P_K$, respectively.*
- *The symbols Pos, Bel, Know called the modal operator of possibility, belief and knowledge, respectively.*

- *The symbol $\Leftrightarrow$ called the connective of logical equivalence.*

For each $i,j\in\{1,2,...,K\}$, $i\neq j$, and $k\in\{1,2,...,M\}$ the following formulas $Pos(p_i(o_k)\Leftrightarrow p_j(o_k))$, $Bel(p_i(o_k)\Leftrightarrow p_j(o_k))$ and $Know(p_i(o_k)\Leftrightarrow p_j(o_k))$ are well built material forms of considered semiotic symbols.

The commonsense meaning that is assigned to the above forms of semiotic symbols is given by the following definition:

Definition 7. (Commonsense Meaning of Semiotic Symbols) The following intentional interpretations are assumed:

- *The formula $Pos(p_i(o_k)\Leftrightarrow p_j(o_k))$ states for "It is possible that the object o_k exhibits the property P_i if and only if the object o_k exhibits the property P_j."*
- *The formula $Bel(p_i(o_k)\Leftrightarrow p_j(o_k))$ states for "I believe that the object o_k exhibits the property P_i if and only if the object o_k exhibits the property P_j."*
- *The formula $Know(p_i(o_k)\Leftrightarrow p_j(o_k))$ states for "I know that the object o_k exhibits the property P_i if and only if the object o_k exhibits the property P_j."*

Three situations are possible and for each of them a unique case of epistemic satisfaction relation has to be proposed. It can easily be seen that in this approach formulas are treated as well grounded if and only if they are proper representation of a particular state of cognition embodied in the agent. It means that if the epistemic satisfaction relation holds for a particular formula this formula can be treated as adequate external representation of a propositional attitude directed towards co-existence of properties P_i and P_j in the object o_k. This way a deeper understanding of the phenomenon of propositional language grounding is achieved.

4.2 Grounding Requirements

In order to define cognitive requirements for adequate grounding of the above semiotic symbols one needs to refer to basic assumptions of the theory of mental models [Johnson-Laird, 83]. This reference is introduced by the following definition:

Definition 8. (Mental models) Let the following symbols be introduced:

- *m_1^E denoting a mental model of a situation in which the object o_k exhibits the property P_i and exhibits the property P_j.*
- *m_2^E denoting a mental model of a situation in which the object o_k exhibits the property P_i and does not exhibit the property P_j.*
- *m_3^E denoting a mental model of a situation in which the object o_k does not exhibit the property P_i and exhibits the property P_j.*
- *m_4^E denoting a mental model of a situation in which the object o_k does not exhibit the property P_i and does not exhibit the property P_j.*
- *$m_5^E=\{ m_1^E, m_4^E\}$ denoting a mental model for the language formula $p_i(o_k)\Leftrightarrow p_j(o_k)$ understood as logic equivalence (see above).*

This understanding of mental models m_1^E, m_2^E, m_3^E and m_4^E are classic and do not differ to definitions suggested in [Johnson-Laird, 83]. However, the equation $m_5^E=\{m_1^E,m_4^E\}$ represents an extended understanding of a mental model of logic equivalence $p_i(o_k)\Leftrightarrow p_j(o_k)$. Namely, it is intended to represent an original point of view that the mental model for equivalence involves both models m_1^E and m_4^E as its integral parts to be considered simultaneously. It differs to the approach in which each separate model m_1^E or m_4^E is treated as a model for logic equivalence [Johnson-Laird, 83].

The extended understanding of our mental model for interpreted language formula $p_i(o_k)\Leftrightarrow p_j(o_k)$ is strongly supported by the accepted assumptions that mental models are abstractions (generalizations) induced by overall relevant empirical experience embodied in the agent. Such an approach makes it possible to introduce certain statistical measures for the strength assigned to particular mental models provided that these measures are determined by the overall volume of inducing sets of perceptions. To capture this dimension of relation between states of cognition and considered semiotic symbols the following classification of the embodied base profiles is introduced:

Definition 9. (Classification of base profiles) Let the sets $C_i(o_k,t)$ (further denoted by C_1) be given in relation to each mental model m_i^E, i=1,2,3,4:

- $C_1(o_k,t)=\{t_n:t_n\leq t$ *and* $BP(t_n)\in KS(t)$ *and* $o\in P_i^+(t_n)$ *and* $o\in P_j^+(t_n)$ *hold*$\}$
- $C_2(o_k,t)=\{t_n:t_n\leq t$ *and* $BP(t_n)\in KS(t)$ *and* $o\in P_i^+(t_n)$ *and* $o\in P_j^-(t_n)$ *hold*$\}$
- $C_3(o_k,t)=\{t_n:t_n\leq t$ *and* $BP(t_n)\in KS(t)$ *and* $o\in P_i^-(t_n)$ *and* $o\in P_j^+(t_n)$ *hold*$\}$
- $C_4(o_k,t)=\{t_n:t_n\leq t$ *and* $BP(t_n)\in KS(t)$ *and* $o\in P_i^-(t_n)$ *and* $o\in P_j^-(t_n)$ *hold*$\}$

It is claimed in this approach that the role of the above sets is fundamental for the creation of meaning which the cognitive agent can assign to both the semiotic symbol $p_i(o_k)\Leftrightarrow p_j(o_k)$ as well as to its modal extensions $Pos(p_i(o_k)\Leftrightarrow p_j(o_k))$, $Bel(p_i(o_k)\Leftrightarrow p_j(o_k))$ and $Know(p_i(o_k)\Leftrightarrow p_j(o_k))$. Indeed, these sets consists of all embodied pieces of experience (basic perceptions) that can be treated as inducing in the internal cognitive space a reflection (a model) of the regularities perceived in the external environment. In case of equivalence a particular inductive role is given to the sets $C_1(o_k,t)$ and $C_4(o_k,t)$. It results from the fact that these two sets consist of base profiles that confirm the truth of the equivalence $p_i(o_k)\Leftrightarrow p_j(o_k)$. At the same time the content of the sets $C_2(o_k,t)$ and $C_3(o_k,t)$ can prove possible falsity of the equivalence $p_i(o_k)\Leftrightarrow p_j(o_k)$. In order to capture such an intuition of inductive strength of the sets $C_i(o_k,t)$, i=1,2,3,4, the following (relatively simple) concepts are proposed (based on the idea of classic cardinality of crisp sets):

Definition 10. (Relative Grounding Value) Let $G^1= card(C_1(o_k,t))$ and $G^4=card(C_4(o_k,t))$. The relative grounding value $\lambda(p_i(o_k)\Leftrightarrow p_j(o_k))$ related to the equivalence $p_i(o_k)\Leftrightarrow p_j(o_k)$ and cumulated in the body of communicative cognitive agent is given as $\lambda(p_i(o_k)\Leftrightarrow p_j(o_k))=\dfrac{G^1}{G^1+G^4}$.

The rationale underlying this definition of the strength of empirical material inducing the meaning of equivalence $p_i(o_k)\Leftrightarrow p_j(o_k)$ can be given as follows: If there exists any empirical material that can support the commonsense meaning of $p_i(o_k)\Leftrightarrow p_j(o_k)$ it has to be included in either $C_1(o_k,t)$ or $C_4(o_k,t)$. These sets are the only sets in which simultaneous coexistence or simultaneous inexistence of both properties P_i and P_j in the object o_k has been experienced by the cognitive agent up to the time point t. The set $C_1(o_k,t)$ seems to be more important in the equivalence grounding due to the fact that its content supports this dimension of equivalence that is related to the actually verified existence of properties rather then their inexistence. It can be claimed that if a cognitive agent would intend to stress the negative aspects of the equivalence $p_i(o_k)\Leftrightarrow p_j(o_k)$ then it would tend to use the strictly related equivalence $\neg p_i(o_k)\Leftrightarrow\neg p_j(o_k)$. At the same time the role of $C_4(o_k,t)$ cannot be neglected because it does support the equivalence of properties, too.

In order to capture the above informal intuition in a formal system of concepts it is further assumed that each cognitive agent is equipped with a certain system of modality thresholds $Min_{Possibility}$, $Max_{Possibility}$, Min_{Belief}, Max_{Belief} related to the relative grounding value $\lambda(p_i(o_k)\Leftrightarrow p_j(o_k))$. Particular values of these thresholds are introduced purposely to reflect the individual tendency of a cognitive agent to accept (use) modal operators Pos or Bel as parts of the materialized semiotic symbols $Pos(p_i(o_k)\Leftrightarrow p_j(o_k))$, $Bel(p_i(o_k)\Leftrightarrow p_j(o_k))$ (provided that these symbols are used to communicate empirical content related to coexistence of both properties P_i and P_j in the object o_k).

It seems reasonable to copy some commonsense intuitions known from human information processing and related to the use of possibility and belief. It is accepted that the relative grounding value increases if and only if the cognitive agent's tendency to perceive the properties P_i and P_j as coexisting in the object o_k increases. High relative values inform us that the volume of empirical experience related to the material coexistence of properties is also high and this fact is reflected in communicative acts by the use of belief operator. Lower values are assumed to refer to possibility operator. In consequence, the relative grounding value and the internally accepted modality thresholds will strongly influence the choice of a certain semiotic symbol as the best representation of internal state. The modality threshold $Min_{Possibility}$ determines the level of relative grounding value which is the lowest value with which possibility operator is accepted. The interpretation of $Max_{Possibility}$, Min_{Belief} and Max_{Belief} is obvious. It has also be assured that the following relations between the thresholds hold: $Min_{Possibility} < Max_{Possibility} < Min_{Belief} < Max_{Belief}$.

An important research issue of practical and theoretical importance is to develop effective procedures for determining values of modality thresholds. It must be stressed that establishing certain values of modality threshold requires a social context, in which the semiosis related to the system of applied semiotic symbols is carried out. Obviously, it is consistent with basic assumptions of semio-cognitive approach to the language grounding which is presented in [Vogt, 02]. In this work it is assumed that values of modality thresholds $Min_{Possibility}$, $Max_{Possibility}$, Min_{Belief}, Max_{Belief} are established for each cognitive agent due to the fact that they have already been determined by them in a certain social process of semiosis. Moreover, each copy of these values embodied in a certain cognitive agent has to be treated as ontologically unique because it has been developed by strictly private processes of language learning. An additional requirement resulting from the language pragmatics is that the modality threshold values need to be at least similar in the overall population of agents to make their communication possible and effective.

The next dimension of the cognitive state that needs to be considered when state of grounding is determined, is the distribution of $C_i(o_k,t)$, i=1,2,3,4 among conscious and non-conscious cognitive subspaces. In is claimed in this paper that this distribution is important because the equivalence (as a semiotic symbol of a natural language) requires modal extensions of possibility or belief if and only if the related and embodied empirical material is not given to the agent as conscious content. This issue will be discussed in forthcoming sections. Such a distribution is a natural phenomenon known from human information processing and can be generally captured into a formal system of concepts as follows:

Definition 11. (Base Profiles' Distribution) Let for each i=1,2,3,4 both $CC_i(o_k,t)=C_i(o_k,t)\cap CM(t)$ *and* $NC_i(o_k,t)=C_i(o_k,t)\cap NM(t)$ *hold. The base profiles'* *distribution is given as the classification $CS(o_k,t) = \{CC_1(o_k,t), NC_1(o_k,t), CC_2(o_k,t), NC_2(o_k,t), CC_3(o_k,t), NC_3(o_k,t), CC_4(o_k,t), NC_4(o_k,t)\}$, which gives a detailed description of base profiles' location in conscious and non-conscious cognitive subspace.*

The above concepts of the relative grounding value and the base profiles' distribution are the key concepts used in the definition of epistemic satisfaction relation that describes socially accepted grounding of semiotic symbols. In this particular example the semiotic symbols under consideration are modal extensions of interpreted logic equivalence. The following definition is proposed in order to formally capture informal intuitions discussed above:

Definition 12. (Grounding Semiotic Symbols) Let the following be given:

- *a time point $t\in T$,*
- *a state of cognition $CS(o_k,t\ t) = \{CC_1(o_k,t), NC_1(o_k,t), CC_2(o_k,t), NC_2(o_k,t), CC_3(o_k,t), NC_3(o_k,t), CC_4(o_k,t), NC_4(o_k,t)\}$*
- *a system of modality thresholds $0 < Min_{Possibility} < Max_{Possibility} < Min_{Belief} < Max_{Belief} < 1$*

It is assumed that:

1) *The epistemic satisfaction relation $CS(t)|=_G Pos(p_i(o_k)\Leftrightarrow p_j(o_k))$ holds if and only if $C_2(o_k,t)=\varnothing$, $C_3(o_k,t)=\varnothing$, $CC_1(o_k,t)\neq\varnothing$, $NC_1(o_k,t)\neq\varnothing$ and $Min_{Possibility}\leq \lambda(p_i(o_k)\Leftrightarrow p_j(o_k)) \leq Max_{Possibility}$.*
2) *The epistemic satisfaction relation $CS(t)|=_G Bel(p_i(o_k)\Leftrightarrow p_j(o_k))$ holds if and only if $C_2(o_k,t)=\varnothing$, $C_3(o_k,t)=\varnothing$, $CC_1(o_k,t)\neq\varnothing$, $NC_1(o_k,t)\neq\varnothing$ and $Min_{Belief}\leq\lambda(p_i(o_k)\Leftrightarrow p_j(o_k))\leq Max_{Belief}$.*
3) *The epistemic satisfaction relation $CS(t)|=_G Know(p_i(o_k)\Leftrightarrow p_j(o_k))$ holds if and only if $C_2(o_k,t)=\varnothing$, $C_3(o_k,t)=\varnothing$, $CC_1(o_k,t)\neq\varnothing$ and $NC_1(o_k,t)=\varnothing$.*

It has been mentioned in section 3 that this epistemic satisfaction relation captures the relation between external material form of particular semiotic symbols and their internal representations understood as the relevant corpora of embodied empirical data. Namely, this relation defines what kind of content needs to be embodied in the cognitive agent to assure the socially accepted interpretation of semiotic symbols. (*Nota bene* this relevant content can also be understood as a factor that shapes the embodied intention of mind that directs this mind towards an external object. This interpretation results from this phenomenological assumption which assumes that any mental content can be reduced to basic and embodied pieces of empirical experience collected during the agent's interactions with external world [Husserl, 13, 21]).

The commonsense rationale for the proposed set of sub-definitions can be summarized as follows:

Points 1 and 2 are strictly related by the common reference to the idea of relative grounding value. The use of this measure is crucial. Namely, in commonsense semantics belief is usually experienced as stronger than possibility. Therefore in this approach the belief operator is treated as satisfied if and only if the relative grounding value belongs to the interval [$\mathrm{Min}_{\mathrm{Belief}}$, $\mathrm{Max}_{\mathrm{Belief}}$] which values are higher than values in the interval [$\mathrm{Min}_{\mathrm{Possibility}}$, $\mathrm{Max}_{\mathrm{Possibility}}$].

Another important dimension of commonsense cognitive experience related to the use of belief and possibility operators in the context of equivalence connective is the experience of uncertainty bound to the belief and possibility. If a cognitive agent were certain about something it would use the modal operator "Know" and avoid operators

Pos and Bel as related to uncertainty. Obviously, a very important question (perhaps a fundamental one) is what is the actual internal source of this uncertainty that is related to equivalence. It is assumed that this type of uncertainty that requires the use of modal operators Pos and Bel results from the presence of non-conscious cognitive subspace in which at least part of $C_1(o_k,t)$ and $C_4(o_k,t)$ needs to be located. It seems to be grounded in commonsense language experience. Namely, if all content of $C_1(o_k,t)\cup C_4(o_k,t)$ were located in the conscious cognitive subspace then the cognitive agent would grasp all embodied empirical experience related to the coexistence or non-existence of properties named in the equivalence $p_i(o_k)\Leftrightarrow p_j(o_k)$). In this sense the agent would be certain about the actual (ontological) forms of this object existence and would have to use the modal operator Know. The induced model of the world would not be different. In consequence, the use of Pos and Bel would not be justified.

The influence of unconscious content related to the equivalence $p_i(o_k)\Leftrightarrow p_j(o_k)$ on the agent's intention to apply particular modal operator is a very subtle issue and a very hard concept to be captured in a formal system. The author's opinion is that it is caused by the nature of unconscious content that influences conscious knowledge processing but is not experienced in a direct way [Freud, 23]. Therefore the actual technical problem is that cognition has to be treated as holistic system of conscious and non-conscious structures and processes that influence each other and produce external behaviour. In other words, the artificial cognitive agent has to be treated as always inclined to use this external semiotic symbol that represents the overall content of embodied relevant experience. It is worth mentioning that in human agents the influence of non-conscious levels of cognition on conscious ones is transferred by means of neural mechanisms. Moreover, this transfer is unconscious, too. Unfortunately, if the target is to reflect the above natural phenomena in artificial agents and implement them in a symbolic paradigm, new classes of technical solutions are required (see section 4.3). It has to be strongly stressed, too, that if in an approach to grounding the equivalence $p_i(o_k)\Leftrightarrow p_j(o_k)$ the lack of non-conscious cognitive subspace is assumed, then there is no need in this approach to consider semiotic symbols $Pos(p_i(o_k)\Leftrightarrow p_j(o_k))$ and $Bel(p_i(o_k)\Leftrightarrow p_j(o_k))$. In such agents all embodied experience is accessible in a direct way and cannot be the source of uncertainty of the forms of properties' coexistence.

Another important factor that is captured in the above definitions is non-emptiness of the set $C_1(o_k,t)$ which assures that the model of external environment consists of at least one empirically verified and embodied perception in which ontological coexistence of both properties P_i and P_j has been experienced. In consequence related mental model could be induced. This factor and its role have already been discussed above.

Another commonsense requirement is that the cognitive agent has to embody no relevant negative perception in its body. If such an empirical experience were present, the agent would have the proof that the equivalence does not hold in the external world and there would be no sense to treat material representations $Pos(p_i(o_k)\Leftrightarrow p_j(o_k))$, $Bel(p_i(o_k)\Leftrightarrow p_j(o_k))$ and $Know(p_i(o_k)\Leftrightarrow p_j(o_k))$ as grounded. Formally, this fact is represented by the conditions $C_2(o_k,t)=\emptyset$ and $C_3(o_k,t)=\emptyset$. However, it must be stressed that this particular form of requirements related to the content and to the role of $C_2(o_k,t)$ and $C_3(o_k,t)$ is rather arbitrary. Namely, in relation to each cognitive state one can consider the distribution of $C_j(o_k,t)$, j=2,3 over the conscious and non-conscious cognitive subspaces.

4.3 Implementation Issues and Applications

The most difficult structural element to be implemented in the proposed communicative cognitive agents is the original partition of artificial cognition into the conscious and non-conscious cognitive subspaces. This partition is required in these implementations which are directed at the creation of artificial communicative agents equipped with uncertain semiotic symbols as $Pos(p_i(o_k) \Leftrightarrow p_j(o_k))$ or $Bel(p_i(o_k) \Leftrightarrow p_j(o_k))$. In case of real (living) cognitive systems the choice of the most adequate semiotic symbols is a result of simultaneous activity of many factors. A part of these factors is never conceptualized at the conscious level and is not accessible in a direct way to the above choice procedures. It is the nature of human-like unconscious that is applied in the proposed model of language behaviour. Even if the 'non-conscious' content is not present at the conscious level of knowledge processing, it influences external behaviour of agents in a constant and effective way. It usually happens that this influence can be observed by and only by external observers e.g. [Freud, 23].

In living cognitive systems the influence of non-conscious content on conscious processes is realized by biological neural networks. This neural network assures the effective and constant influence of lower (deeper) cognitive levels on higher ones. Therefore conscious decisions are strongly shaped by the content which is embodied in the cognitive agent but is not accessible to decision procedures in a direct way.

The above comments lead to the following practical question: *In what way the artificial information systems implemented without the use of neural networks can contribute from the above proposed models of internal organization of cognition and related definitions for semiotic symbols meaning?* Two issues are related to this question:

First of all, the proposed model for internal organization of a cognitive agent and the related understanding of language behaviour is useful for designing external language behaviour of these artificial systems which are structurally and functionally isomorphic with the proposed two-level model of cognition. In particular, it means that an artificial information system can be treated as communicative cognitive agent if and only if it is possible to determine in this information system a sub-module in which decision procedures for the choice of linguistic knowledge representation are computed and these decision procedures do not have a complete access to the overall corpora of relevant information content stored in knowledge bases. It means that these decision processes need to experience objectively existing constraints in the access to pieces of knowledge stored in the system. Examples of such constraints are: ineffective technical means for data access and transfer and low volume of the working memory used by decision procedures. In consequence the representations of overall knowledge about an object and embodied in a system are uncertain and approximate.

This approach to model information environments seems acceptable in the field of organizational semiotics [Katarzyniak, 04b].

If the above conceptualization of an information environment is possible and necessary, the next problem is related to possible implementations of the original influence of the non-conscious cognitive subspace onto the conscious one. In case of natural cognitive systems this influence has got an interesting characteristic. Namely, due to the biological neural network all non-conscious and embodied content relevant to a certain decision influences this decision simultaneously even if the content is distributed over all knowledge base. In artificial systems based on symbolic and non-neural representations the implementation of such a mechanism is very difficult. The most promising approach is to design mechanisms that make it possible to fill 'conscious' decision procedures with some generalizations computed within non-conscious cognitive subspaces provided that these generalizations are approximate. Situations in which all the content is accessible for computational processes does not require uncertain linguistic representations such as $Pos(p_i(o_k)\Leftrightarrow p_j(o_k))$ or $Bel(p_i(o_k)\Leftrightarrow p_j(o_k))$. In consequence, the application of uncertain semiotic symbols such as $Pos(p_i(o_k)\Leftrightarrow p_j(o_k))$ or $Bel(p_i(o_k)\Leftrightarrow p_j(o_k))$ is necessary if the non-conscious cognitive subspace is equipped with and only with some *approximate* procedures for knowledge processing and knowledge mining. Otherwise the use of the semiotic symbol $Know(p_i(o_k)\Leftrightarrow p_j(o_k))$ is possible.

5 Final Remarks

The above presentation of our original approach to modelling intelligent systems can be interpreted in many ways. First off all, it should be perceived as an approach in which physical symbol grounding problem is modelled for a class of artificial cognitive agents. However, at the same time our results are strongly related to the 'theory' of natural semantic communication. Therefore an example of modelling grounding has been given for a certain class of intentionally interpreted logic formulas. Weaker results have already been presented elsewhere. In particular, the grounding and epistemic satisfaction has been considered for a simplified model of cognitive agents in which no non-conscious cognitive subspace is assumed. However, this simplification has been accepted for these classes of modal logic formulas in which uncertainty does not need to result from natural constraints in cognition. For instance, various models for simplified epistemic satisfaction (and grounding requirements) have been given for simple atom modalities [Katarzyniak, 03], modal conjunctions [Katarzyniak, 04c] and modal alternatives [Katarzyniak, 01]. For some of them particular models of implementation have also been discussed (see [Katarzyniak, 02, 04c]). The extended model for cognitive agent in which two levels of cognition are assumed (similarly to the case of human agents) has been discussed, too. In particular, original models for epistemic satisfaction (and grounding) in which conscious and non-conscious cognitive subspace is assumed have been discussed in [Katarzyniak, 04a, 04b].

This approach to information environments seems acceptable in the field of organizational semiotics [Katarzyniak, 04b].

It has to be stressed that the above approach to defining the semantics for at least some modal logic formulas is complementary to the so-called BDI approach (e.g. [Cohen, 90], [Hintikka, 62]). It is however not fully equivalent to possible worlds semantics [Kripke, 63] due to the fundamental reasons that have already been mentioned in [Katarzyniak, 01] for the case of modal alternatives.

Further research needs to concentrate on practical and theoretical problems related to semantic communication and symbol grounding. As regards to future applications (and creation of an original class of communicative intelligent systems) this research should concentrate on developing more effective implementations of proposed definitions for epistemic satisfaction of semantic languages. As regards to more basic but fundamental theoretical issues a substantially deeper research into similarity and difference between the well known (and sometimes problematic) possible worlds semantics and the proposed approach is badly needed. Some relevant results have already been presented in a brief way for the case of modal alternatives (see paragraph 2 in [Katarzyniak, 01]). However, a deeper discussion would be required for other classes of logic formulas.

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