Information Granulation, Cognitive Logic and Natural Pragmatics for Intelligent Agents

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***Abstract*—The paper is devoted to the development of Cognitive Logic in the framework of building intelligent agents. The drawbacks of classical mathematical logic and automated reasoning are discussed. The difference between classical logic and human cognition is shown on simple examples. The concept of cognitive agent, in particular, cognitive robot, is considered, its architecture is presented. Information granulation based on pragmatics is viewed as a principal capacity of cognitive agent. The role of logical pragmatics in cognitive logic is revealed. The emphasis is made on the development of generalized logical values and formation of various logical worlds to construct granular logical semantics and pragmatics. An extended definition of logical world is proposed. In the context of developing cognitive graphics for applied logics, the colored representation of Hasse diagrams is suggested. Possible applications of colored representation of logical worlds are discussed.**

***Keywords*—Artificial Intelligence; Intelligent Agent; Cognitive Logic; Pragmatics; Pragmatic Truth, Logical World, Cognitive Graphics, Color Metaphor**

I. Introduction

One of the main trends in the development of new generation technologies in the XXI century is the formation of hybrid systems combining advanced information, cognitive and social technologies with biotechnologies and nanotechnologies in the scope of NBICS convergence conception [1]. Up to now, cognitive technologies remain a «bottleneck» in NBICS complex, and the creation of new cognitive microsciences (see[2,3]), such as cognitive graphics, cognitive linguistics, cognitive semantics, cognitive semiotics, cognitive informatics, seems to be a necessary step on the way to autonomous artificial cognitive agents, both individual and collective.

This paper discusses the prospects of Cognitive Logic for Intelligent Agents. It is a new trend in applied logic based on the characteristics of human cognition and developing new logical systems to support cognitive processes in agents. The term «Cognitive Logic» was launched into circulation by Pei Wang [4], who constructed a Non-Axiomatic Reasoning System (NARS) and proposed an experience-grounded semantics. An early precursor of cognitive logics was D.A.Pospelov, the author of pseudo-physical logics [5].

Rather close ideas were proposed by V.K.Finn [6] with his JSM-method, using four-valued argumentation logic, quasi-axiomatic theory and synthesis of various reasoning types, as well as O.M.Anshakov and T.Gergely [7], who introduced the procedures of «cognitive reasoning».

In our paper, the experience is associated with information granulation that is viewed as a crucial cognition and comprehension mechanism. So Zadeh's TFIG (Theory of Fuzzy Information Granulation) [8] and Lin's Granular Computing [9] are seen as a natural basis for Cognitive Logics. The emphasis is made on the development of generalized logical values and formation of various logical worlds to construct granular logical semantics and pragmatics. Our approach is based on D.A.Bochvar's thesis «from logical semantics to logical calculus».

The OSTIS project [10] has been initiated in order to develop open semantic technologies of designing intelligent systems. In this paper we suggest to complement it by open pragmatic technologies for intelligent agents, rising to the ideas of the «Father of Pragmatism» Ch.S. Peirce [11].

The paper is organized in the following way. The reasons for the emergence of Cognitive Logic are revealed in Section II. The structure and operation of classical automated reasoning system is considered in *Subsection A*. The limitations of traditional automated reasoning to compare with everyday human reasoning are shown on many examples in *Subsection B*. The problem of reasoning uncertainty is faced. In this context, the concept of Non-factors is discussed. A classification of Non-factors in knowledge engineering is given. In *Subsection C* the processes of human cognition and their properties are analyzed. Four basic types of cognitons – complex cognitive units, enabling self-organization of agent's activity – are presented.

The fundamentals of Agent Theory are presented in Section III. Firstly, in *Subsection A*, the concept of artificial agent is explained. Some interpretations, classifications and architectures of agents are introduced. The difference between reactive and intelligent agents is discussed. Secondly, in *Subsection B*, the notion of cognitive agent is specified. An example of cognitive robot is considered, specific features of its architecture are pointed out. Finally, an interactive model of robot's dialogue control is suggested.

A main capacity of cognitive agent is a goal-driven information granulation. In *Subsection C* some basic definitions and classifications of granules are given. Two general approaches to constructing granules are analyzed. In particular, non-classical sets are mentioned as rather new and convenient formalisms to create granules.

Section IV is devoted to pragmatics viewed as a keynote attribute of both agent's individual behavior and collective behavior of communicating cognitive agents. Specifically, logical pragmatics is seen as a necessary condition of understanding and applying logics by cognitive agents. Here logical granules are of special concern too. In *Subsection A* the difference between logical semantics and pragmatics is shown on the basis of both meta-logic and communication model. Some intrinsic links between logical pragmatics and pragmatic logics are investigated. Human cognition is based on the unity of descriptions and prescriptions. In this context, a complementary role of Aristotle-Tarski's correspondence truth theory and Peirce's vision of truth as utility (value) is demonstrated.

Subsection B contains some counter-arguments against the universal character of truth in knowledge engineering by cognitive agents. In *Subsection C* some new interpretations of truth values are gathered: from epistemic Dunn's vision of semantics leading to generalized (granular) truth-values to context-dependent considerations like factual truth, concerted truth and measured truth.

In Section II we put the question «Why Cognitive Logic?» and try to justify the relevance of this concept in the modeling of intelligent agents. At last, in Section V we outline a possible answer to the question «How it could be created?» by rethinking the concept of Logical World and applying the ideas of Cognitive Graphics. Some basic definitions of logical worlds and their representative examples are included into *Subsection A*. A visualization of logical worlds through colored logical values in Hasse diagrams is proposed in *Subsection B*. In our opinion, it opens new opportunities in building anthropomorphic interfaces between human and artificial cognitive agents by standardizing the interpretation of logical values used in different applications.

II. Why Cognitive Logic?

A. Classical Mathematical Logic and Automated Reasoning Systems

Reasoning is the ability to make inferences, and automated reasoning supposes the development of computing systems that automate this process. An automated reasoning system usually includes the following basic components [4]: 1) a formal language that represents knowledge; 2) a semantics that defines meaning and truth value in the language; 3) a set of inference rules to derive new knowledge; 4) a memory that stores knowledge;5) a control mechanism that selects premises and rules in each step. Here the former three components are usually related to a logic and form a logical part of reasoning system, and the latter two components responsible for an implementation of this logic are called the control part of the system.

At present, first-order predicate logic remains the basis for the logical part of automated reasoning, and the theory of computability and computational complexity is extensively used in the control part. In fact, these logical theories and tools have been successfully used in many practical domains. However, the continuation of their application in advanced intelligent systems such as cognitive agents and their groups seems very doubtful, due to some fundamental differences between automated reasoning and human cognition.

Classical automated reasoning is based on purely axiomatic systems, certainty conditions and deduction rules of traditional logic, where the truth of the premises guarantees the truth of the conclusion. Contrarily, human cognition and reasoning is deployed under uncertainty by using mainly non-deductive (common-sense) reasoning in semi-axiomatic or non-axiomatic systems. We will give below some examples to clarify the difference between deductive and non-deductive reasoning, as well as a short description of human cognition and its characteristics.

B. From Non-Deductuve to Uncertain Reasoning

Inference rules of classical logic are deduction rules, based in truth preservation and certain conclusion. In a sense, here the information in a conclusion is contained already in the premises, and the inference rule simply makes it explicit. For example, from «Crows are birds» and «Birds have feathers» it is valid to derive «Crows have feathers».

Meanwhile, in everyday life we often use other reasoning types, where the conclusions seem to carry new information not available in the premises. In case of *induction* a broad generalization is made from special cases. Let us use again the previous example. Here we take «Crows are birds» and «Crows have feathers» to derive «Birds have feathers». It is obvious that for inductive reasoning, even if all the premises are true, the conclusion can be false.

Further we consider *abductive reasoning* based on explanations for given case. Example: from «Birds have feathers» and «Crows have feathers» to conclude «Crows are birds».

Finally, *analogical reasoning* is a kind of similarity-based reasoning. Example: «Rooks are similar to crows» and «Crows have feathers», hence «Rooks have feathers».

So both inductive and abductive and analogical inference rules do not guarantee the truth of the conclusion for true premises. Therefore, they are not valid rules in the sense of classical logic. Nevertheless, all these types of inference are widely used in many branches, specifically, in learning and creative design.

Traditional formal theories of reasoning are certain in several aspects, whereas real-world human reasoning is often uncertain in these aspects. Now let us face the problem of reasoning uncertainty or, more generally, Non-factors of reasoning. What are Non-Factors? This is a variety of different factors, which are expressed by the words (linguistic labels) having some negative hints in natural language, remain largely unexplored in traditional mathematics, but are inherent attributes of human knowledge and cognition.

The term «Non-factors» was coined by A.S.Narinyani (see [12]) in early 1980's. He pointed out a universal character of Non-factors: they played a keynote role not only in the structure of real human knowledge, but also in many applications of computational mathematics.

The English counterpart of Non-factors called (Im-In-Un's) was introduced in [13]. Non-factors penetrate all the stages of knowledge engineering: from knowledge acquisition and knowledge representation to knowledge processing and knowledge transfer [14]. Moreover, «the main issue of Artificial Intelligence» (AI) in the first quarter of XXI century should be formulated as follows: «Can a system be considered *intelligent*, if it does not model some Non-factors?» [15].

A classification of Non-factors [16] is shown in Figure 1.

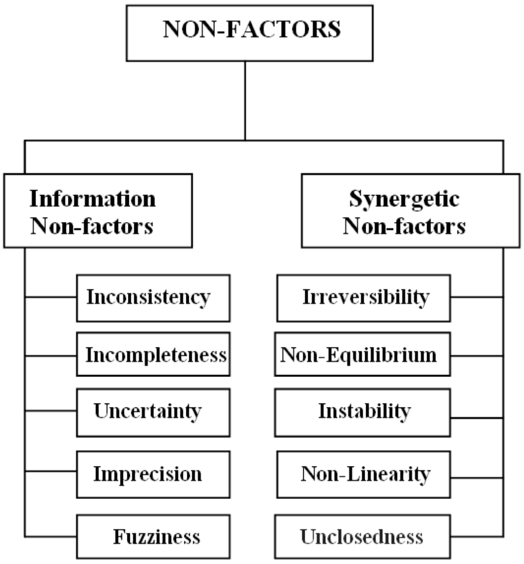

Figure 1. Information and Synergetic Non-Factors

Below we shall specify Non-factors by comparing well-known laws of classical logic (identity. excluded middle, non-contradiction, ex falso quodlibet) with real human logic and everyday reasoning. A more detailed analysis of non-classical logics induced by knowledge Non-factors can be found in [17].

The meaning of a term in mathematical logic is determined according to an interpretation, so it does not change as the system runs. Contrarily, the meaning of a term in human mind often changes according to personal experience and context. Example: What is «truth»?

In classical logic the principle of compositionality is used: the meaning of any complex expression is completely determined by the meanings of its constituent expressions and the combination rules (connectives). On the contrary, the meaning of a compound term in human mind or natural language usually cannot be reduced to that of its components, though is still related to them. Example: «Is really an AI concept «blackboard» a black board?» [4].

In classical logic, a statement is either true or false, but people often take intermediate truth values of statements as between true and false. Such a value can be viewed as «uncertain», «possible», «half true», and so on. The use of such intermediate truth values, the truth graduation makes an appeal to many-valued logics for AI.

Furthermore, classical logic is explosive. It means that from contradiction we can obtain any arbitrary conclusion. However, the existence of a contradiction in a human mind does not interfere common-sense reasoning. Moreover, a detection of technical contradiction is a starting point for Altshuller's algorithm (shortly АРИЗ in Russian) of inventive problem-solving theory (ТРИЗ in Russian) . So paraconsistent logics are in great demand to model human reasoning.

In classical logic, the truth value of a statement does not change over time, it is monotonous. However, people easily revise their beliefs after getting new information. For our through-section example, if we take instead crows some more exotic birds like penguins, then we have to discard an ordinary premise «Birds fly», but can preserve the early used premise «Birds have feathers». Such situations give us good examples of non-monotonous reasoning.

In traditional reasoning systems, inference processes follow strict algorithms, therefore are predictable. On the other hand, human reasoning processes are often unpredictable, and can «jump» on the unexpected side. In is natural for scientific discovery, then a researcher deviates from the research plan and waits for an «inspiration».

In classical logical reasoning, the backtracking procedure is crucial, i.e. how a conclusion is obtained may be accurately explained step by step. Of course, this conclusion can be repeated. Contrarily, the humans are able to generate such conclusions, whose sources and paths contain «blank spots» or cannot be backtracked at all. As an example we cite a typical variant of everyday uncertain reasoning: «I don't know why it will occur. It is only my bad feeling».

Finally, classical reasoning systems meet the Closed World Assumption (CWA) – what is not known to be true must be false. However, the practice of human reasoning shows that Open World Assumption (OWA) – what is not known to be true is simply unknown – is much more realistic.

C. Human Cognition : Processes, Properties and Units

Basically, cognition stands for gaining new information and knowledge by providing the missing knowledge necessary to solve a problem under uncertainty [7]. In other words, cognition may be seen as the ability of intelligent system to find new information, acquire knowledge and reduce its environment uncertainty for the sake of adaptation. It is reached by improving an internal model of this environment.

In psychology, the term «cognition» encompasses various individual mental processes, such as sensation, perception, representation, imagination, cogitation, thinking, memory, learning, attention, explication, comprehension. In particular, cognition can be viewed as a thinking process oriented towards problem-solving; in this sense, it is involved into any human activity. In practice, problem-solving directly connects perception, thinking, memory and learning.

Following T.Gergely [7], let us recall some basic features of cognition, which are of primary concern for developers of artificial cognitive systems. First of all, cognition is an open system based on both available knowledge and current data perception. Secondly, cognition does not provide conclusions, but generates hypotheses, and these hypotheses should be confirmed or denied. Thirdly, cognition is tightly connected with understanding: it leads to knowledge changes and modifies the capacity of information processing. And fourthly, cognition in a purposeful system is intrinsically linked with the organization of action (as information process, local environment change or physical movement).

A suitable way of treating cognition in agent is to divide it into smaller units, called *cognitons* [18,19].These units are open and heterogeneous: they represent from a cognitive angle of view different sides of consciousness – cognition itself, communication, activity regulation. Besides, the notion of «cogniton» is considered here as a basic term to denote principles, mechanisms and models of self-organization in agent from the viewpoint of its cognitive subsystem. The specification of generic classes of cognitons and establishing links between them is the first stage of *cognitive engineering*, extending well-known approaches of knowledge engineering. Good examples of cognitive engineering in creating dynamic mental structures of intelligent agents are BDI-models [20] and WILL-architecture [21]. For instance, the BDI (Belief – Desire – Intention) complex unit shows what an agent thinks to be true, what it would like to achieve and how it expects to do it. A classification of cognitions is given in Figure 2.

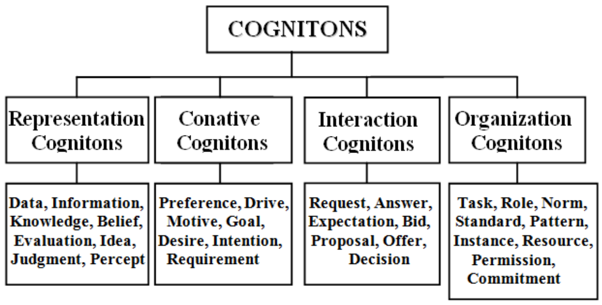

Figure 2. Four Basic Types of Cognitons

Conation is a term that stems from the Latin *conatus*, meaning any natural tendency, impulse, or directed effort. Conative cognitons representing an intentional side of activities are the keystones of agency.

III. Cognitive Agents in Actions

A. What is Agent?

According to Longman Dictionary, *agent* is a person or organization that represents another person or organization and manages their business. From methodological point of view, agent theory is intended to bridge the gap between two poles: active subject and classically passive object [19]. In this context, it is natural to notice two contrary approaches to constructing agent: an *antropomorphic vs programmer's approach*. If we move from «subject pole», then the agent can be seen as a *quasi-subject*, able to substitute his master (owner) and perform necessary task. Here a subject delegates some functions, permissions and rights to his agent. Vice versa, if we start from «object pole», then the agent may be viewed as a sort of *active object* or meta-object capable to manipulate various objects, create or destroy them, and communicate with other agents. In other words, a problem of making the object more active and more intelligent is faced.

Agents are classified into natural and artificial, physical and virtual, static and mobile, reactive and intelligent. For instance, artificial agents can be both physical (autonomous mobile robots, artificial swarms) and virtual (softbots, infobots, mobots). Four basic interpretations of artificial agents are specified [19]: artificial organism, active object, personal assistant, virtual doer. Properties and architectures of artificial agents depend on their definition, interpretation and status.

There are different definitions of agents. S.Russell and P.Norvig [22] gave a very weak definition of agent as an entity that can be viewed as perceiving its environment through sensors, to obtain data about events in this environment, and acting upon it through effectors. In fact, this definition reduces agent to a basic «organism – environment» model by M.G.Gaaze-Rapoport and D.A.Pospelov [23]. In some sense, socially-oriented definition of software agent was given by M.Coen [24]: software agents are programs that engage in dialogs, negotiate and coordinate the transfer of information.

The most popular definition belongs to M.Wooldridge and N.Jennings [25]. They defined artificial agent as an autonomous, reactive, pro-active, communicative system. Let us discuss the components of this minimal «gentleman's set». Here the term «autonomous» means that agents operate without direct intervention of humans and have some kind of control over their actions and internal state. The word «reactive» includes the perception of agent's environment and response in a timely fashion to all the changes in it. «Proactive» means that agents do not simply act in response to their environment, they are able to exhibit goal-oriented behavior by taking the initiative. Communication stands for a social ability, i.e. agents interact with other agents (and possibly humans) via some kind of agent-communication language.

In [19] we proposed the following definition: an agent is an open, active, intentional (goal-directed) system able to generate and perform its proper activity in an uncertain or fuzzy environment.

In our opinion, it is necessary to emphasize an intentional nature of any agent: the reason of agent's activity is the need that is viewed as a difference between desired and current agent's state. The need generates some motivation or forms some preferences, and agent's motive is deployed into its goal – a model of agent's wanted future. Agent's autonomy is ensured by its proper resources; that supposes a periodic resource acquisition from the environment (or other agents).

The behavior of reactive agents is determined by simple impulses and preferences and stimulus-reactive links, whereas the synthesis of intelligent agents supposes the development of internal model for external world, formation of both belief-base and knowledge base, reasoning for planning and performing actions (Figure 3). Besides beliefs and planning, intelligent agents are often equipped with such features as prediction and persistency.

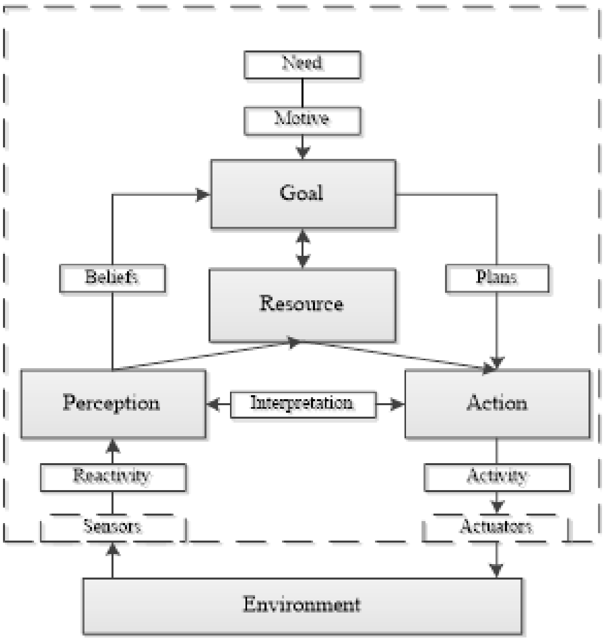

Figure 3. Basic Architecture of Intelligent Agent

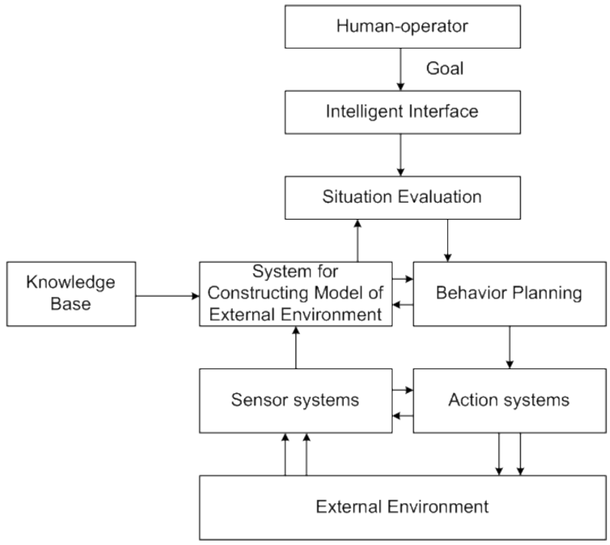

Figure 4. Architecture of Cognitive Agent as Open Semi-Autonomous Goal-Directed System

B. Artificial Cognitive Agents

An artificial cognitive agent possesses a well-developed internal model of its duties, external world, other agents (including human agents in order to understand human needs and queries) and itself. It receives and integrates current information from, at least, three sources: a) its human partner (in the form of goal formulation or adjustment, operating instructions, on-line responses to questions); b) its sensor system; c) its belief/knowledge base (Figure 4). Agent's cognition is the process of acquiring knowledge and understanding through the senses, perception, thought and experience. It opens new possibilities of learning and reasoning about how to behave in order to achieve goals in uncertain or ill-defined environment.

A typical example of physical artificial cognitive agent is cognitive robot (group of cognitive robots). Cognitive Robotics is a new branch of robotics aimed at generating an intelligent behavior in robot by enhancing its cognitive capacities. It studies how cognitive robot obtains and aggregates information on his world, in which form it should be represented and memorized, how this information is transformed into beliefs and knowledge, and how these beliefs govern robot's behavior.

Basic technological problems of cognitive robotics are machine vision, voice recognition, speech synthesis, various types of sensing (proximity sensing, pressure sensing, texture sensing, and so on).

Thus, a central problem of cognitive robotics is data fusion – the integration of multiple data sources to produce more diverse, rich, accurate and useful information, as well as sensor data mining and knowledge discovery.

Cognitive capacities of intelligent robots also include perception processing (specifically, computing with words and perceptions [26]), approximate reasoning, anticipation, attention sharing, ability to learn from mistakes, etc.

Moreover, artificial cognitive agents ought to have the possibility of communicating in a dialogical manner with human agents (users) by applying a restricted natural language (Figure 5). Such a dialogue includes both tasks instructions given by human agent to artificial agent and a feedback from artificial agent (situational information, report about goal achievement or request for additional data)

Both individual and collective behavior of cognitive agents is goal-driven and supposes the study of practical aspects of their acts and actions to obtain useful result. Also communication processes between cognitive agents based on speech theory and conversation rules have situational context, i.e. pragmatic foundations. Therefore, agent-oriented paradigm is closely related to the area of pragmatics.

So the involvement of cognition into action by cognitive agent supposes information granulation [8] or more generally, cognition granulation and aggregation. Below we will consider pragmatic granulation as a basic feature of cognitive agent.

C. Information Granulation by Cognitive Agent

According to Zadeh, *granule* is a collection of objects which are drawn together by the relations of similarity, indistinguishability, functionality or proximity [8]. Generally, information granules are complex dynamic information entities which are formed to achieve some goal. The arrival of information granulation means the transition from ordinary machine-centric to human-centric approach in information gathering and knowledge discovery [27]. The concept of information granulation is closely related to data abstraction and derivation of knowledge from information. By selecting different levels of granulation one can obtain different levels of knowledge.

Granulation theory includes studies in classification, generation, representation, interpretation and use of granules. Typical

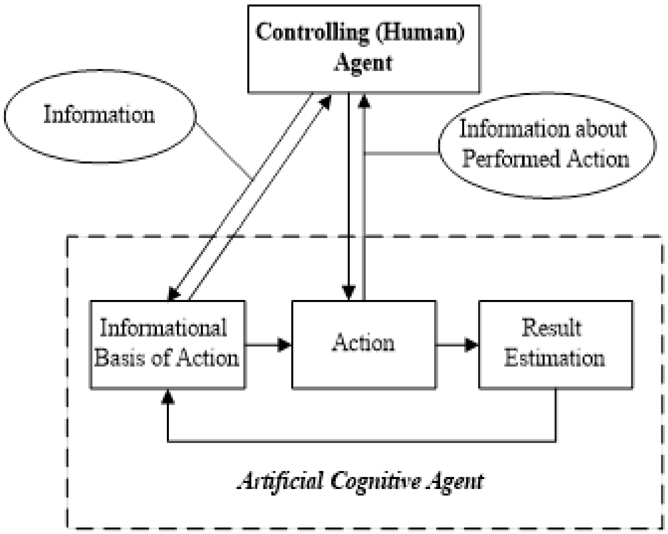

Figure 5. Interactive Model of Dialogical Control

interpretations of granules are: part of the whole, sub-problem of the problem, uncertainty zone, variable constraint.

There are various classifications of granules: physical and conceptual granules, one-dimensional and multidimensional, information and knowledge granules, time and space granules, crisp and fuzzy granules, etc.

Where are two general approaches to generating granules – top-down and bottom-up. A top-down approach is based on a set that is divided into subsets, these subsets – into smaller subsets, etc. Various coverings, partitions, nested sets are typical examples of this approach. Inversely, in case of bottom-up approach we firstly take a point (a singular object) and then construct its neighborhood. As a result, a pre-topology of neighborhood system is obtained. These two approaches show a hierarchical nature of both granules and granulation process itself.

Granules may be obtained by specifying *non-classical sets*. Classical sets have crisp boundaries and additive measure. They satisfy two basic postulates: 1) membership postulate; 2) distinguishability postulate (do not confound with. *Membership postulate* is analogous to excluded middle law in classical logic: Every element of a set must be uniquely specified as belonging to the set or not. According to *distinguishability postulate*, a set is viewed as a collection of different, clearly distinguishable elements which can be enumerated, represented by a list. If either one or both of these postulates are rejected, then we obtain non-classical set theories. Valuable examples of non-classical sets are over-determined and under-determined sets depending on observer's awareness parameter [28]. Another well-known example concerns *rough sets* [29]. These three non-classical variants of sets can be expressed by three-valued characteristic functions.

In Section IV we will focus on logical granules and granulation driven by pragmatics.

IV. Towards Logical Pragmatics: a New Status of Truth Values

A. Logical Pragmatics and Pragmatic Logics

Nowadays, the arrival and intensive development of both Logical Pragmatics and Pragmatic Logics is founded on Ch.S.Peirce's ideas on relationships between information, logics and semiotics. According to Peirce [11], «Logic, in its general sense, is another name for semiotic, a formal doctrine of signs». In information theory, any message can be related to both its author (sender) and its user (recipient): the first relation specifies semantics and the second one – pragmatics.

This pragmatic side of logic was also taken into consideration by N.A.Vasiliev in the context of two-leveled logical hierarchy [30, 31]: «Some logical principles are fixed, unchangeable and absolute, some other principles, such as non-contradiction law and excluded middle law, are relative, changeable and have empirical sources. It means that our human everyday logic is dual, semi-empirical, semi-rational, and we can consider by contrast formal and purely rational discipline, a sort of generalized logic; we call it *meta-logic*».

According to Vasiliev, we ought to make difference between two levels of knowledge: a) empirical level based on real-world's events; b) conceptual level depending on our thinking.

In modern logic, meta-logic means the study of meta-theory of logic, including the construction of logical theories, intrinsic properties of these theories, interpretations of formal systems, etc.

So Pierce's vision of logic encompasses both logical *semantics* and *logical pragmatics*. Semantics is a branch of meta-logics that studies the interpretations of logical calculus. It is worth stressing that these interpretations are context-independent and meet closed-world assumption. Inversely, pragmatics takes into account the dependence of interpretation from context.

Furthermore, Peirce considered logic as a normative science and defined truth as the good of logic [11]. A well-known Peirce's definition of truth as «the concordance of an abstract statement with the ideal limit towards which endless investigation would tend…» [11] and, even, more radical sentence by W.James [32] that «truth is the expedient in the way of our thinking», anticipated modern theories of approximated, partial, gradual, granular truth.

A pragmatic approach gives us a functional (or axiological) interpretation of truth where some proposition or belief is true, if it has some utility (enables us to attain useful practical result).

So *logical pragmatics* are associated with the pragmatic truth theory, whereas *pragmatic logics* suppose an axiological consideration of logical concepts, the specification of pragmatic truth values and the application of effectiveness principle in the form of pragmatic maxim.

To differ from descriptive correspondence theory, here the nature of truth is attributed to the reason of truth and supposes the transition from prescriptive proposition (norm) to reality (Figure 6). Here the opposition «Description-Prescription» clarifies the meaning of the opposition «Truth – Value». Truth is the correspondence between a reality object and a proposition giving its description; inversely, utility is the correspondence between a prescription and the reality object (the usefulness of norm). It is worth noticing that any activity of cognitive agent is based on both descriptions and prescriptions; it supposes a joint use of these two truth theories.

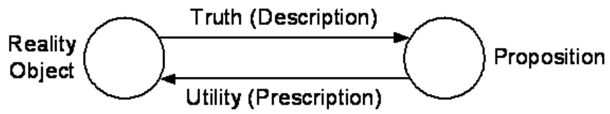

Figure 6. Classical Truth vs Utility: the Opposite Status

The next step on the way from logical semantics to logical pragmatics was made by Polish scientists: K.Ajdukiewich [33], a founder of Pragmatic Logic, and T Kotarbinsky, the author of Praxiology, as well as by Russian logician A.A.Iwin [34], who constructed the logics of values and evaluations. Another Russian logician B.Pyatnitsyn, who specified the class of pragmatic logics, is worth mentioning. Typical cases of pragmatic logics are inductive and probabilistic logics; more recent examples encompass various modal logics such as epistemic, doxastic, deontic, communication, preference, decision logics. All these logics express the relationships between some standards given by modalities and their use in practice.

B. Belief Utility vs Knowledge Truth in Intelligent Agents

In Theaetetus Plato introduced the definition of knowledge which is often translated as «justified true belief». This definition is even today largely accepted by knowledge engineers in Artificial Intelligence. They suppose that knowledge should be strictly true, and the main restriction for knowledge processing is truth preservation. The procedures of knowledge adjunction and correction are oriented to the monotonic increase of «general truth level» of stored knowledge.

However, in cognitive systems beliefs and knowledge are not necessarily based on truth. Instead of truth such criteria as belief value, utility, adequacy, stability can be useful. Moreover, the concept of truth itself undergoes significant changes.

One of the first Russian scientists, who noticed a non-universal character of truth in the context of knowledge engineering was O.P.Kuznetsov. In 1995 in the course of the International Conference «Artificial Intelligence in XXI century», he participated in the Round Table with the talk «About Knowledge Based not on the Truth». According to him, truth is a sort of knowledge values contributing to knowledge stability. However, common-sense knowledge and reasoning is not based on the truth in the sense of classical logic, but it employs suitable knowledge structures (in the sense of Gestalt Psychology) [35].

J Łukasiewicz defined logic is the science of objects of a special kind, namely the science of *logical values* [36]. In this paper the term «logical values» encompasses both truth values, including granular and fuzzy truth values, and axiological, epistemic, doxastic, deontic modal values.

C. Interpretations of Logical Values: From Dunn's Semantics to Natural Pragmatics.

Nowadays we have various novel interpretations of logical values [37], for example: a) values that convey some information on a proposition; b) entities that explain the vagueness of concepts; c) indicators of degree of truth, etc. On the one hand, it is clear that truth values can be used to deal with information and uncertainty, belief and doubt, knowledge and ignorance. On the other hand, these logical values can be gradual and granular.

Let us recall that there exists an epistemic logic that is the logic of knowledge and belief. In the context of knowledge engineering, an epistemic interpretation of truth values is quite natural.

One of the first successful attempts to construct non-standard logical semantics for practical use was performed by J.Dunn [38]. He proposed a new epistemic strategy of constructing logical semantics by rejecting classical principles of Bivalence and Functionality (singularity of both Truth and Falsity). The following three postulates underlie Dunn's approach: 1) information (or knowledge) can be incomplete and/ or inconsistent; 2) some propositions can be neither true nor false; 3) some propositions can be both true and false. This approach means specifying logical values as the set of subsets; it leads to a generalization of the classical notions of the truth value and truth value function. Such generalized truth values are considered as a rational explication of agent's incomplete and inconsistent information states.

Now let us mention some context-based, i.e. pragmatic truth-values. Good examples are: Finn's factual truth, factual falsity and factual contradiction in an argumentation context [6], our concerted truth and concerted falsity in a negotiation context [39], measured truth, measured falsity and measured ambiguity in the framework of cognitive measurement [40], and so on. A natural representation for three-valued and four-valued pragmatics is traffic lights pragmatics.

V. On the Way to Cognitive Logic

The idea of Cognitive Logic (CL) can be interpreted in two ways: a) CL as a logic based on the principles, mechanisms and attributes of human cognition; b) CL as a logical tool for supporting the cognition and understanding processes.

One of the principal mechanisms of human cognition is the construction and use of bipolar (opposition) scales. Bipolarity is referred to as the capacity of human mind to evaluate reason and make decisions on the basis of both positive and negative estimates and affects. Its application in logical investigation brings about the specification of logical worlds.

A. Logical Spaces and Worlds–an Old Vine in New Bottles

The concept of logical space was introduced by L. Wittgenstein in his famous «Tractatus Logico-Philosophicus» [41]. It is based on «possible state of affairs», specified by a proposition. An elementary state of affairs is a point of logical space. If the proposition is not elementary, it corresponds to a region in logical space. Actual states of affairs are called facts. The world is the totality of facts. By taking the condition of logical independence for n states of affairs, we can obtain 2^n combinations of these states. Each combination can be called a possible world.

The term «Logical World» can be defined more generally as a set of logical entities. From a pragmatic standpoint, it can be viewed as any non-empty set of logical values (truth values in [42,43]). According to Ya.Shramko, the elements of logical world meet two basic principles: a) distinguishability (do not confound with distinguishability postulate in set theory); b) designation. Here the word «distinguishability» means that all logical values differ among themselves. Some of them have a particular status, i.e. they are «designated». For instance, classical Frege's world Cl2 is expressed by a pair

$$LW_{C12} = \langle V_2 = \{T, F\}, D_1 = \{T\}\rangle.$$

To specify simple, unidimensional logical worlds, we should give a set of truth values V with its cardinality $\mid V \mid$, a set of designated truth values D with its cardinality $\mid D \mid$, $D \subset V$. For the sake of convenience, we write it in a short form:

$$LW_s = \langle V_i, D_j\rangle, i = 1, 2, \ldots, n, \ldots, \infty, j < i. \qquad (1)$$

Generally $D_j = D_j^+ \cup D_j^-$, where D_j^+ is a set of designated values and D_j^- is a set of anti-designated values. These anti-designated values (truth-values, «similar to falsity») are often used in practice, for instance, when we face the problem of fault diagnosis.

A granular logical world is a pair

$$LW_g = \langle 2^{V_i}, 2^{D_j}\rangle, i = 1, 2, \ldots, n, \ldots, \infty, j < i. \qquad (2)$$

To differ from [42], we shall consider the basis of logical world LW_b as a bipolar scale with a neutrality (midpoint) M, e.g.

$$LW_b = \langle \{T, F\}, D, M\rangle$$

and complete the principles of distinguishability and designation by the principle of structuration. The specification of world supposes the interpretation of neutral value. Generally, T, F, M are granular truth values, for instance, intervals or distributions. In the case of singletons $T = \{T\}$, $F = \{F\}$, $M = \{M\}$ we obtain a minimal logical world.

For example, Lukasiewicz's minimal logical world

$$LW_{L3} = \langle V_3 = \{T, M, F\}, D_1 = \{T\}, M = \text{"}possibility\text{"}\rangle.$$

Kleene's minimal paracomplete world

$$LW_{K3} = \langle V_3 = \{T, M, F\}, D_1 = \{T\}, M = \text{"}ignorance\text{"}\rangle.$$

Bochvar's minimal non-sense world

$$LW_{L3} = \langle V_3 = \{T, M, F\}, D_1 = \{T\}, M = \text{"}non{-}sense\text{"}\rangle.$$

Moreover, Vasiliev's paraconsistent world is a triple

$$LW_{Las3} = \langle V_3 = \{T, M, F\}, D_2 = \{T, B\}, \\ M = B - \text{"}bothtrueandfalse\text{"}\rangle.$$

For Dunn-Belnap's world we have two neutral points

$$M = \{N, B\}, N = \text{"}neithertruenorfalse\text{"}.$$

Finally, Zadeh's logical world

$$LW_Z = \langle V = [0, 1], D = [\alpha, 1], M \approx 0.5\rangle.$$

where $0.5 < \alpha < 1$.

More generally, fuzzy logical worlds can be specified by the set of fuzzy truth values together with fuzzy designated truth values (e.g. Radecky's fuzzy level sets), fuzzy inclusion $D \subset V$ with a grade μ and fuzzy neutralities. We have to make difference between Zadeh's fuzzy world, Atanassov's intuitionistic fuzzy world, Goguen's L-fuzzy world and so on.

Now let us consider two-dimensional logical worlds. According to the *structuration principle*, logical entities, in particular, logical values, form various structures. In other words, various order relations, for instance truth order and knowledge order, win-loss order and consensus order, form various logical structures. So the truth partial order $\leq_T$ generates a truth-value lattice $(V, \leq_T)$ defined on a partially ordered set of truth values V (with at least two elements), the knowledge partial order $\leq_K$ underlies a knowledge lattice $(V, \leq_K)$, etc. It is suitable to uniformly represent the pairs of lattices above by bilattices [44] with double Hasse diagrams. In Figure 7 two Hasse diagrams are drawn to illustrate dialogical bilattices with the consensus order $\leq_C$ and disputation order $\leq_D$, where N_1 and N_2 stand for uncertainty (the indices 1 and 2 correspond to two agents involved in the dialogue).

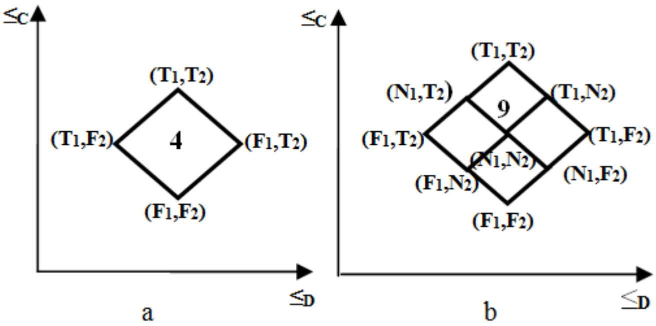

Figure 7. Examples of Dialogical Bilattices: a) the Minimal Dialogical Bilattice 4; b) the Bilattice 9.

A compound logical world is specified by a quadruple

$$LW = \langle V, D, M, R\rangle \qquad (3)$$

where V is the universe of logical values v, $v \in V$, D is the set of designated values, M is the set of neutralities with appropriate interpretations, R is the set of relations in V. Let us note that logical worlds expressed by truth values with order relations play the part of logical ontologies.

B. Cognitive Graphics for Understanding Various Logics

A very important property of graphics is its direct impact on human creative thinking that results in information compression and better understanding of faced problem. In particular, cognitive graphics deals with a computer-based visualization of internal content deploying the sense of scientific abstractions. It was introduced by A.A.Zenkin [45] and D.A.Pospelov to intensify human cognitive processes related to problem formulation, searching for solution and scientific innovations.

Cognitive computer graphics was successfully used in pure mathematics to visualize the distribution of prime numbers by Ulam spiral, invariant sets of a generalized Waring problem, generate cognitive images of such transcendental numbers as π and e.

Two basic functions of graphic images are considered: illustrative function and cognitive one. Illustrative function of graphics visualizes already known objects to ensure their image-based recognition and comprehension. On the contrary, cognitive function of graphics is intended to reveal vague or hidden sense and contributes to a new knowledge generation.

There are fuzzy boundaries between illustrative and cognitive graphics: visual representation and conceptual compression of existing knowledge may inspire some new idea or hypothesis, and its confirmation or demonstration supposes the use of images or diagrams.

The use of graphics in logic has a long history: Euler circles, Venn diagrams are the best known examples of a wide use of diagrammatic tools in representing syllogisms, classical predicates, inference rules, etc. Below we will focus on colored representations of logical scales and Hasse diagrams to understand different multi-valued and fuzzy logical pragmatics (see also a practical example of using colored Hasse diagrams in synthesizing cognitive sensors [46]).

The color metaphor seems to be an adequate pragmatic tool to represent different classes of multi-valued and fuzzy logical worlds. The classical logic can be naturally viewed as a model of «black and white world». The transition to three- or four valued worlds puts into operation the traffic light pragmatics: here the truth corresponds to a green color, the falsity – to a red color, the contradiction – to a yellow color and the uncertainty – to a dark blue color. The pragmatics of Heyting's world LW_{H3} is given by the green color for the truth, the light green color for the half-truth and the red color for the falsity. Inversely, the pragmatics of Brower's world LW_{Br3} is presented by the red color for the falsity, the pink color for the half-falsity and the green color for the truth. The representation of Bochvar's world LW_{B3} can use an analogy to the «black hole»: any logical value encountering a non-sense becomes a non-sense too. So an intense black color is welcomed.

In case of two dimensional four-valued representations of modalities by two criteria of modality strength and modality sign (strong positive, weak positive, weak negative, strong negative) we obtain modal lattices. It is suitable to select a dark green color for a strong positive modality («necessary» in alethic logic, «obligatory» in deontic logic, «certain» in doxastic logic, etc.) and light green color for a weak positive modality («possible», «permitted», «hypothetical». On the contrary, we take red color to explain the role of a strong negative modality («impossible», «forbidden», «denied») and pink color for a weak negative modality («contingent», «non-obligatory», «doubtful»).

A finite-valued logic reflects as much «rainbow colors», as the number of logical values it contains, and a fuzzy logic corresponds to continuous spectrum of colors, including all shades between green and yellow, yellow and orange, orange and red, and so on. For instance, the pragmatics of Godel's world LW_{Gn} is illustrated by (n-1) shades of green from dark green to very light green (grades of the truth) and one red value (the falsity).

VI. Conclusion

The concept of Cognitive Logic for intelligent agents has been developed on the basis of information granulation, generalized logical values, logical structures, logical worlds and their visualization by introducing colored Hasse diagrams. In order to create understanding artificial agents with highly organized cognitive capacities, main properties and processes of human cognition have been considered, and the paradigm of Cognitive Engineering by specifying special cognitive units called cognitons and performing their granulation and aggregation has been proposed. Pragmatic roots of agents and multi-agent systems have been traced back, and the concept of Logical Pragmatics has been clarified. The necessity to introduce pragmatic issues into applied logics for cognitive agents is explained by their role of «logic users» (not «logic developers»). It expresses the importance of contextual factors and norms in the modeling of agent's individual behavior and agent's communication.

Two sides of cognitive logic have been analyzed. The intrinsic connections between cognitive logic and pragmatic logics have been shown. Here the principle «First pragmatics, then calculus» has to be satisfied. So our approach to constructing cognitive logic is based on Logical Worlds. New formalisms have been introduced to model both unidimensional and two-dimensional worlds. Some examples of logical worlds have been constructed and visualized by taking colored representation of logical values.

Our further investigation will be associated with establishing links between opposition scales and logical worlds and building a special cognitive logic to support understanding process in agent.

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ГРАНУЛЯЦИЯ ИНФОРМАЦИИ, КОГНИТИВНАЯ ЛОГИКА И ЕСТЕСТВЕННАЯ ПРАГМАТИКА ДЛЯ ИНТЕЛЛЕКТУАЛЬНЫХ АГЕНТОВ

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В работе предложена концепция когнитивной логики для интеллектуальных агентов, основанная на грануляции информации, обобщённых логических значениях и алгебраических структурах, логических мирах с естественной прагматикой и их визуализации с помощью цветных диаграмм Хассе.