Modeling Human Dialogue Transactions in the Context of Declarative Knowledge

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Abstract: *The paper deals with an investigation and modeling of dialogue and dialogue transactions. An ontological model of human dialogue interaction, underlying follow-up reasoning, is obtained on the basis of analysis of human-human dialogues and illustrated by one of Plato's dialogue Protagoras. In the sequel, attention is focused on one type of human-human dialogues, called erotetic dialogue and on the structure of erotetic dialogue transaction from the viewpoint of knowledge interchange within the transaction. A spectrum of formal models, oriented towards discovering the inner logical structure of erotetic transaction is offered. The distinguishing feature of all models is their orientation on language-independent entities representing declarative knowledge associated with a transaction's elements.*

1. Introduction

Dialogue is an essential phenomenon of human mental and intellectual activity and outwardly represented by a chain of interdependent information transactions generated during knowledge interchange between partners of dialogue interaction. Purposefulness is one of the fundamental characteristics of dialogue, and purposefulness necessarily implies a logical dependency not only between a transaction's components but between adjacent dialogue transactions as well. Analysis of practically any cognitive activity of humans reveals that its basis is a dialogue process. For instance, reasoning and inference, in broad and narrow interpretation, are in fact, a "conversation with the self" or a dialogue interaction in which both dialogue partners are represented by one and the same person.

Dialogue transaction serves as a means of knowledge interchange between dialogue partners and, therefore we can qualify dialogue processes as knowledge-based processes and dialogue systems as knowledge-based systems. The vast majority of researchers explicitly or implicitly presuppose that knowledge in dialogue transactions is represented in a form of propositions and hence:

1. Verbal examples of transactions and their elements prevail in relevant publications.
2. Notation of first order logic uses, as a rule, for formal representation of propositions [6, 17].

Such orientation on propositional understanding and modeling of dialogue transactions determines by a traditional way of knowledge representation in this area of research and from our point of view must not be considered as the only possible way.

The bulk of journal publications with the word combinations "dialogue process" and "dialogue agent" reflect a purely pragmatic attitude towards the study of dialogues. Usually the goal of these publications is not a deeper understanding of the phenomenon, but rather constructing various artificial systems that are able to work as a verbal interface between end-users and applied computer systems. For instance, searching the Web generates more than seven million references to Web-pages which include the word combination "dialogue agent" and describe systems realizing mainly communicative functions.

We believe that formal modeling of the dialogue process must begin from detailed investigation of natural dialogues in all their diversity. We also, believe that if models of dialogue agents rely on fundamental principles of human dialogue, then we can expect that artificial dialogue agents will inherit rich cognitive abilities of natural human-human dialogue process. An artificial dialogue agent can be considered as such if it is able to maintain the dialogue, with a degree of complexity commensurable with the complexity of natural dialogue.

The final goal of this article is to create formal models of dialogue transactions, oriented mainly on more comprehensive understanding of the inner logical nature of the dialogue, but at the same time definite enough to serve as a framework for artificial dialogue

agents engineering. As a first step towards achieving this goal we found it necessary to develop an initial ontological model of natural dialogue. Further speculations completely rest upon this ontological model and are oriented towards synthesis of formal models of classes of declarative knowledge, associated with question-answering pairs based on ideas of Uyemov's Language of Ternary Description (LTD) [13, 14, 15].

2. Ontology

Investigations related to dialogue interactions can be found in different and often not close scientific areas. The list, which is probably incomplete, includes artificial intelligence, cognitive psychology, erotetic logic, and epistemology.

One of the well-known confirmations of importance of the dialogue process, which we find in artificial intelligence, is a test, offered by Turing [12] for operational verification of intelligence in technical systems, which is completely based on a dialogue between human and a technical system. Modern exposition of artificial intelligence, integrates all main ideas in an area into a coherent subject, based on the conception of intelligent agents [10]. Intelligent agent is dialogue agent. It can't exist outside its task environment, and transactions between the task environment and the intelligent agent determine behavior of the latter.

Piaget's theory of cognitive development, which usually ascribes to the areas of cognitive psychology and epistemology implicitly presupposes that a "moving force" for schemata development is dialogue [2]. If human beings come into the world with a certain number of innate schemata, needed for survival during the initial period of life, and that acquired knowledge determines by further development and growth of these schemata, then method, which realizes evolution of innate schemata is the dialogue process. In the area of cognitive psychology there are some more theories and models that also, make contribution to understanding the essence of the dialogue. For example, the cyclical model of perception offered by Neisser [9] is in fact, a model of the dialogue process if the source of a flow of sensory events is considered as one of the partners of the dialogue.

Since dialogue transactions, in all their polyformity, serve as a means of knowledge interchange between dialogue partners and the vehicle of this interchange is an inquiry-response pair, then results obtained in question-answering logic [1] are applicable to the study of dialogue transaction logical structure.

Epistemology has direct relation to investigation of the nature of the dialogue process, as this science is directed mainly on study and modeling of those types of knowledge, which circulated within dialogue transactions and are essential for dialogue partners.

Especially interesting is the version being called Socratic Epistemology, where separate question-answering pairs and question-answering dialogue play the key role [7].

To build formal models, designated as a final goal of the article, we began from an ontological model of natural dialogue, constructed on the basis of analysis of a certain quantity of protocols of real dialogue processes with all their logical and operational diversity. There is a great number of such protocols. For instance, protocols of crime suspect interrogation in which an investigator is trying to prove the guilt of a suspect and the latter is trying to convince the investigator of his innocence. However, a more accessible and rich source of natural dialogue protocols is dialogical literature, especially from the areas of philosophy and theology. One of the most significant sources of this kind is Plato's dialogues [5]. It is reasonable to begin forming an ontological model of natural dialogue from analysis of a small fragment of one of Plato's dialogue called Protagoras. The protocol, given below, presented in the form, slightly differs from the original text. Insignificant changes and additions have been included into the dialogue to make it more structured. For example, we marked beginning and ending of each transaction and definitely indicated partners of the dialogue. The dialogue occurs between Socrates (S) and Hippocrates (H) before their conversation with Protagoras. Terms "active" and "reactive" will be explained in the following parts of the article.

Beginning of transaction 1. S is active.

> S: *Then we are going to pay our money to Protagoras in the character of a Sophist?*
> H: *Certainly.*

End of transaction 1.

> S: *But you should not assume, Hippocrates, that the instruction of Protagoras is of this nature: may you not learn of him in the same way that you learned the arts of the grammarian, musician, or trainer, not with the view of making any of them a profession, but only as a part of education, and because a private gentleman and freeman ought to know them?*
> H: *Just so, and that, in my opinion, is a far truer account of the teaching of Protagoras.*

End of transaction 2.

> S: *I wonder whether you know what you are doing?*
> H: *And what am I doing?*

End of transaction 3. Role interchange. S becomes reactive.

> S: *You are going to commit your soul to the care of a man whom you call a Sophist. And yet I hardly think that you know what a Sophist is; and if not, then you do not even know to whom you are committing your soul and whether the thing to which you commit yourself be good or evil.*

H: I certainly think that I do know.

End of transaction 4. Role interchange. S becomes active.

S: *Then tell me, what do you imagine that he is?*
H: *I take him to be one who knows wise things as his name implies.*

End of transaction 5.

S: *And might you not affirm this of the painter and of the carpenter also, : Do not they, too, know wise things? But suppose a person were to ask us: In what are the painters wise? We should answer: In what relates to the making of likenesses, and similarly of other things. And if he were further to ask: What is the wisdom of the Sophist, and what is the manufacture over which he presides? - how should we answer him?*
H: *How should we answer him, Socrates? What other answer could there be but that he presides over the art which makes men eloquent?*

End of transaction 6. Role interchange. S becomes reactive.

S: *Yes that is very likely true, but not enough; for in the answer a further question is involved: Of what does the Sophist make a man talk eloquently? The player on the lyre may be supposed to make a man talk eloquently about that which he makes him understand, that is about playing the lyre. Is not that true?*
H: *Yes.*

End of transaction 7. Role interchange. S becomes active.

S: *Then about what does the Sophist make him eloquent? Must not he make him eloquent in that which he understands?*
H: *Yes, that may be assumed.*

End of transaction 8.

S: *And what is that which the Sophist knows and makes his disciple know?*
H: *Indeed I cannot tell.*

End of transaction 9.

S: *Well, but are you aware of the danger which you are incurring? If you were going to commit your body to someone, who might do good or harm to it, would you not carefully consider and ask the opinion of your friends and kindred, and deliberate many days as to whether you should give him the care of your body? But when the soul is in question, which you hold to be of far more value than the body, and upon the good or evil of which depends the well-being of your all,-about this never consulted either with your father or with your brother or with any one of us who are your companions. But no sooner does this foreigner appear, than you instantly commit your soul to his keeping. In the evening, as you say, you hear of him, and in the morning you go to him, never deliberating or taking the opinion of any one as to whether you ought to intrust yourself to him or not;-you have quite made up your mind that you will at all hazards be a pupil of*

Protagoras, and are prepared to expend all the property of yourself and of your friends in carrying out at any price this determination, although, as you admit, you do not know him, and have never spoken with him: and you call him a Sophist, but are manifestly ignorant of what a Sophist is; and yet you are going to commit yourself to his keeping.
H: *No other inference, Socrates, can be drawn from your words.*

End of transaction 10.

S: *Is not a Sophist, Hippocrates, one who deals wholesale or retail in the food of the soul? To me that appears to be his nature.*
H: *And what, Socrates, is the food of the soul?*

End of transaction 11. Role interchange. S becomes reactive.

In the beginning let us change the previously used term "dialogue partner" to the term *dialogue agent*. Dialogue agents create dialogue transaction. Although an arbitrary number of members can take part in the dialogue, dialogue transaction is always created only by a pair of dialogue agents. In Plato's dialogue Protagoras, in different time points, transactions are created by the following pairs of agents: Socrates-Hippocrates, Socrates-Protagoras, etc.

Dialogue agents, in the process of dialogue interaction, play one of two roles: the role of the active dialogue agent or the role of the reactive dialogue agent. An agent plays the active role in cases when he/she needs some knowledge and supposes to get it from the opposite dialogue agent, and, correspondingly, an agent plays the reactive role in cases when he/she grants some knowledge, he/she possesses to the opposite dialogue agent.

In the fragment cited, Socrates, initially, plays the role of active agent and Hippocrates-the role of reactive agent. They then changed their roles several times. An analysis of the given fragment allows us to make the preliminary conclusions that, as a rule, the initiator of role switch is the reactive agent. The active agent is normally satisfied with his/her role and after role-interchange tries to restore his/her active status at the first chance.

In the case when dialogue interaction occurs between two persons, we will say that an outer dialogue takes place. However, dialogue transaction can be formed by only one agent. In this case one agent alternately plays both roles. Such a type of dialogue we will call an inner dialogue. Verbal inner dialogues are often called monologues, and mental inner dialogues are thoughts.

In the case of an outer dialogue, knowledge, requested by the active agent, is kept in the long-term memory of the reactive agent, and the knowledge to which the reactive agent refers in his answer-is in the long-term memory of active agent. In the case of an inner dialogue, the requested and returned knowledge

are in the long-term memory of the same agent.

Most part of the dialogue given above illustrates the outer type of dialogue however it includes examples of inner dialogue as well. In eleventh transaction Socrates carries on a dialogue with himself, and what he says can be presented by the following way:

> *S(active): Is not a Sophist, Hippocrates, one who deals wholesale or retail in the food of the soul?*
> *S(reactive):To me that appears to be his nature.*

The outer manifestation of a dialogue is a chain of dialogue transactions where each transaction is a complete cycle of knowledge interchange between the active and reactive agents. The distinguishing feature of a dialogue, which distinguishes it from other forms of interactive communication (for instance, from the communication with an applied data base system) is the presence of strong logical dependencies, not only within separate transaction, but, what is more important, between links of the transaction chain. Precisely because of such logical dependencies, a set of separate transactions is transformed into a goal-oriented intellectual process.

Every dialogue transaction is represented by two information messages. An information message from the active agent has the status of a question. The word "status" here means that an information message from an active agent is not necessarily a question in grammatical or linguistic sense. It can take various forms. The form of an information message does not affect either the goal of a single transaction or the goal of the dialogue as a whole. What is really important for the active agent is an access to the requested knowledge, but not the form of the request. So, an active agent can get access to the same chunk of knowledge by means of a series of different information messages. In several epistemic publications this natural free choice of the form of access to the chunk of knowledge by the active agent is treated as a problem and called "the problem of convergent knowledge" [11].

Analysis of natural dialogues shows that information messages of an active agent can vary from simple yes/no questions to a long-lasting inner dialogue. However, even when an information message of an active agent is a long-lasting reasoning, it all the same has status of a question with respect to the reactive agent. Therefore, we can consider the degree of interrogativness of the active agent's information message.

The information message of the active agent can be understood as a search prescription needed to get access to the knowledge of the reactive agent, or as a reference which provides an access to the section of the reactive agent's long-term memory. Similarly, the information message of the reactive agent has the status of an answer and can be interpreted as a search prescription needed to get access to the active agent's

knowledge, or as a reference to a section in his/her long-term memory, where the required knowledge resides.

In the cited fragment of the Plato's dialogue, one of the simplest transactions, from the point of view of the structure of the information message, is the transaction number one.

> *S: Then we are going to pay our money to Protagoras in the character of a Sophist?*
> *H: Certainly.*

In this transaction the active agent Socrates transmits to the reactive agent Hippocrates an information message to provide Socrates access to the knowledge, possessed by Hippocrates and not possessed by Socrates. Socrates does not know whether Hippocrates is going to pay money to Protagoras only on the ground that Protagoras is Sophist. This information message has a high degree of interrogativness because it is represented by a purely interrogative sentence. In the tenth transaction, the information message of Socrates, who plays the role of the active agent, has a more complex structure. It is represented by a certain preliminary reasoning conducted by Socrates but, however, has some degree of interrogativness.

> *S: Well, but are you aware of the danger which you are incurring? If you were going to commit your body to someone, who might do good or harm to it, would you not carefully consider and ask the opinion of your friends and kindred, and deliberate many days as to whether you should give him the care of your body? But when the soul is in question, which you hold to be of far more value than the body, and upon the good or evil of which depends the well-being of your all,-about this never consulted either with your father or with your brother or with any one of us who are your companions. But no sooner does this foreigner appear, than you instantly commit your soul to his keeping. In the evening, as you say, you hear of him, and in the morning you go to him, never deliberating or taking the opinion of any one as to whether you ought to intrust yourself to him or not;-you have quite made up your mind that you will at all hazards be a pupil of Protagoras, and are prepared to expend all the property of yourself and of your friends in carrying out at any price this determination, although, as you admit, you do not know him, and have never spoken with him: and you call him a Sophist, but are manifestly ignorant of what a Sophist is; and yet you are going to commit yourself to his keeping.*
> *H: No other inference, Socrates, can be drawn from your words.*

Socrates intends to know whether Hippocrates agrees with his conclusions that someone cannot entrust his/her soul to a man with whom he/she is not familiar and whom people call sophist if someone doesn't know what this word means, because his/her soul can be damaged just like the body. Socrates' information message is an inner dialogue beginning with a

question. Socrates poses the question, then explicates and answers it. We can assume that Socrates' inner dialogue has the goal to specify requested knowledge and that without this additional specification, his information message will be excessively ambiguous and won't get access to the knowledge he really needs. So, we can state that dialogue transaction is a fundamental structural element of dialogue interaction and in all cases has interrogative nature.

Dialogue is a goal-driven intellectual process. Each dialogue agent tends to achieve his/her own goal and therefore generates flows of information messages, which conforms with their goals. From this point of view dialogue processes are problem solving processes. It's easy to notice the purposeful nature of Socrates' information messages in the cited fragment of Plato's dialogue. The sequence of his messages directed to achieve the goal, which we could formulate, for instance, as to convince Hippocrates that his initial wish to become a pupil of Protagoras by paying him any money, is wrong.

Because of obvious correlation of the natural dialogue process with the area of problem solving, it is reasonable to introduce the concept of dialogue behavior, and interpret it as a realization of a problem solving method by means of the dialogue process. The cited fragment of the Plato's dialogue is one of the protocols of Socrates' dialogue behavior, which implements his method called, in some modern publications, Socratic Inquiry Method [16].

Consider briefly the essence of this method. Socrates could reach his goal in several ways. For instance, he could, referring to his authority, offer Hippocrates his final conclusions at once, saying: "Dear Hippocrates, you shouldn't try to become Protagoras' pupil at any cost without clarifying what subject he will teach you and whether knowledge acquired from him will be useful for you". In this case Socrates transmits to Hippocrates his belief, based on his authority, but not knowledge, justified by logical inference. However, Socrates prefers to enter into a dialogue with Hippocrates and offers him a series of interrogative messages with predetermined variants of answers. Socrates' information messages are formulated in such a way that Hippocrates's answers establish a chain of reasoning, which finally generates the above formulated conclusions. This is a more efficient method, because Hippocrates, guided by Socrates, deduces the above formulated conclusions by himself. This is the essence of the method invented by Socrates. Playing the role of the active agent Socrates manages the dialogue in such a manner to induce his opponent to answer in the way, which is necessary to form a chain of reasoning leading to the target conclusions. The secret of Socrates' success is in knowing that each question is associated with the set of possible answers, which does not depend on the reactive agent's knowledge, but merely on the question

itself. Be aware of this fact Socrates, playing the role of the active agent, constructs his information messages in such a way to narrow the number of possible answers as much as possible, or even reduce it to unity.

The subsequent parts of this article rely on several simplifying assumptions regarding natural dialogue. First of them is that instead of a full-scale human-human dialogue we will consider a simplified version called erotetic dialogue [3, 4].

Within erotetic dialogue, information messages from the active agent have hundred-per-cent degree of interrogativness and in a linguistic sense are questions, while information messages from reactive agent are answers on these questions. Erotetic dialogue is a step towards simplification of real situations, but it appears to be rational for several reasons. Firstly, as a rule, it is possible to convert protocols of natural dialogues into erotetic ones keeping initial goal and method; secondly, an investigation of an erotetic dialogue can be based on more or less formal theories, and thirdly, results obtained from erotetic dialogue research can be a good foundation for generalization to a full-scale natural dialogue.

In erotetic dialogue, knowledge requested by the active agent and returned by reactive agent, has declarative nature. Therefore, a model of the logical structure of an erotetic transaction, in the context of knowledge representation, must be based on certain plausible conceptions of declarative knowledge representation. Although, human's system of knowledge, seemingly, is one and indivisible, where adjacent parts concatenate with each other, questions and answers operate with small separate parts or chunks of a human's system of declarative knowledge. Therefore, for our purpose, we'll need only means for representing chunks of declarative knowledge associated with erotetic transaction.

Epistemologists usually don't use terms "declarative knowledge" and "procedural knowledge" and declarative-procedural dichotomy of knowledge. However, from the context of some publications it is clear that knowledge-wh and knowledge-that are no other than epistemic names of chunks of declarative knowledge, associated with erotetic transaction [11]. These chunks represented by natural-language propositions and are answers on wh- and that-questions respectively. Wh-question is a class of questions generalizing six subclasses: 1). Who-question, 2). What-question, 3). When-question, 4). Where-question, 5). How-question, and 6). Why-question. Epistemic understanding of knowledge-wh can be illustrated by examples of the following six natural-language sentences: 1). "I know who is Protagoras", 2). "I know what he will speak about", 3). "I know when he will begin his conversation", 4). "I know where the conversation will take place", 5). "I know how he will begin his speech", and 6). "I know why he

is wrong". This classification reflects and illustrates definite linguistic orientation of the epistemic representation of knowledge associated with question-answering transactions.

In erotetic dialogue we consider a question as a search prescription which determines the area in the long-term memory of the reactive agent, which contains requested knowledge. Such an interpretation means that the reactive agent already possesses requested knowledge. However, it is only one of several possible cases. It is easy to formulate examples of questions that request knowledge that is absent in the memory of the reactive agent. Such questions presuppose certain mental work or mental effort involving attentional resources. Therefore, with respect to the participation of attention in the process of constructing the answer, we can divide questions into two classes: "search prescription" question type, and "task" question type.

To answer the "task" question type, the reactive agent must activate his/her attention and solve the task, associated with the question. The answer is a variant of solution, obtained by the agent. Consider the example:

How old would be Socrates today, if he was born in 469 B.C?

It is clear that the reactive agent does not keep in mind the requested knowledge and needs to activate his/her resource of attention to form the answer. The "search prescription" question type presupposes that all possible answers are already in the memory of reactive agent and that the structural elements of the question position memory to the required part. To prepare the answer of the "search prescription" question type the reactive agent does not need to activate attention. The example is as follows:

What is your name?

The class of "search prescription" questions type is not final and can be divided into subclasses. When the active agent constructs a "search prescription" question type he/she doesn't know, in advance, whether or not the reactive agent possesses the requested knowledge. The question, which requests missing knowledge, is able to put the reactive agent into impasse. For example, the question:

Why are you concealing the fact that you are a man?

Can put the normal woman into impasse. The classification of questions into "search prescription" type and "task" type is not absolute and must be considered with respect to the reactive agent's knowledge. If the task, caused by the question, is solved by the reactive agent for the first time or very seldom (so, seldom that the process of forgetting prevails), then to solve the task, according to Kahneman's theory [8], resource of attention is needed. In the case of repetitive answers to the same

or similar "task" question type, the solution is eventually stored in memory, the mechanism of attention is not needed any more, and the question turns into "search prescription" question type.

Classification of questions into two classes, with respect to the participation of attention in the process of constructing the answer, is not the only one of its kind. Analysis of examples of natural dialogues allows us to find out that each question can be characterized by a certain degree of uncertainty. Therefore, with respect to the degree of uncertainty, questions can be divided at least into two classes: uncertain questions and certain questions. This classification is obviously inaccurate because it does not take into account the actual degree of uncertainty, but it should be enough for the purpose of the article.

Uncertain question means that its answer belongs to one of several classes of answers. If the reactive agent did not receive special instructions on how to answer the question, he/she can act according to one of the following strategies: 1). Chooses the class of answers follows his/her own way, 2). With the purpose to reduce or even remove uncertainty, formulates an additional question. The latter case means that agents interchange their roles and can be considered as one of several possible reasons for role interchange in the erotetic dialogue. Apparently, the process of clarification of uncertain question can be iterative, when the reactive agent considers the new question as uncertain as well. For example, the question:

Who is living behind this door?

Is uncertain, because requested knowledge belongs to one of several classes: 1). Knowledge regarding the passport data of the tenant, 2). Knowledge regarding the tenant's appearance, etc. When the reactive agent gets such a question and wishes to clarify what concrete knowledge the active agent is requested, he/she could transmit to the active agent a clarifying question instead of the answer. For instance:

You wish to know the name of the person who is living behind this door, or something else?

If the active agent returns to the reactive agent the question:

Could you describe me this person?

Then we have an uncertain question once again.
Certain questions presuppose that the requested knowledge belongs to only one class:

Tell me the name of the man living behind this door?

3. Formulas

In the second part of the article we will use the concepts offered in the first part for formal modeling of the logical structure of dialogue transaction. The peculiarity of our approach to the modeling of dialogue

transaction is focusing attention on the fact that the main purpose of dialogue transaction is to operate with declarative knowledge of the reactive agent. The models, that we construct, give possible variants of the logical structure of erotetic transaction in the context of representation of knowledge, associated with the transaction. Our modeling will be limited to questions of the type "search prescription", and this is our second simplifying assumption.

In epistemology and erotetic logic declarative knowledge participating in question-answering transactions usually represented in the form of propositions and, hence, an elementary chunk of declarative knowledge is considered as a sentence. A generally accepted way of formalization of such a method of knowledge representation is the translation of natural-language sentences into sentences written in first-order logic notation.

We guess that modeling of erotetic transaction, in the context of declarative knowledge representation, can be realized by means of a more unified ontology than of First-Order Logic. Under unified ontology we understand ontology based not on language-depended variables (as in First-Order Logic) but on language-independent fundamental entities of declarative knowledge. In this regard we considered the LTD, initially suggested by Uyemov, for the formal description of parametric variant of the general systems theory and then developed into independent non-classical logic [13, 14, 15].

A fundamental entity of LTD is object. An object, depending on its place in the knowledge structure, exists in one of three forms: object-thing, object-property, and object-relation. The categories "thing" and "property" have traditional meanings in LTD, while the category "relation" differs from the traditional. It is generally accepted to use the "relation" concept as a name of the mutual influence between things, i.e., relation between things. For instance, between two men can exist "fatherhood" relation. In LTD context, a relation is something that forms a thing, i.e., relation on a thing, or relation that takes place in a thing. In other words, an LTD-relation is, in some sense, another name of the inner structure of the thing. The binary association of object-thing with object-property generates two prototypes for representation entities in LTD:

1. The name for the first prototype is "thing, which possesses property" and formal notation has the following form: (*)*.
2. The name for the second prototype is "property, which attributed to thing" and formal notation has the form: (*))*.
   The binary association of object-thing with object-relation generates two more prototypes:

3. The name for the third prototype is "thing, in which relation takes place" and formal notation has the following form: *(*).
4. The name for the fourth prototype is "relation, which takes place in thing" and formal notation has the form: *((*).

For the formal representation of entities in LTD a specific parentheses notation is used. The symbol "asterisk" indicates a place for the symbol of an object. The symbol of an object-thing is written down inside parentheses, the symbol of an object-property - outside and on the right side of the parentheses, and the symbol of an object-relation also, is written outside parentheses but on the left side.

The association of an object-thing with an object-property or an object-relation has direction. If a symbol of an object-thing is in normal (single) parentheses, this means that the association is directed from the object-thing to the object-property or object-relation. In natural language it can be expressed as a "thing, which possesses property" or a "thing in which relation take place". Asymmetric (doubled) parentheses means that the association is directed from the object-property or the object-relation to object-thing and expresses as "property, which is attributed to thing" or "relation, which take place in thing".

It should be noted that in publications, which deal with LTD, a place inside parentheses is used only for the object-thing symbol. This limitation excludes from the set of prototypes the following two: "relation, which possesses property", and "property, which attributed to relation". An object, depending on the degree of uncertainty of knowledge about it, exists in one of three alternative forms:

- *Definite* (asterisk in the prototype substituted by symbol *t*).
- *Indefinite* (asterisk in the prototype substituted by symbol *a*).
- *Arbitrary* (asterisk in the prototype substituted by symbol *A*).

The categories "thing, property, and relation" as well as "definiteness, indefiniteness, and arbitrariness" are independent and form nine classes of objects: 1). Definite object-thing, 2). Indefinite object-thing, 3). Arbitrary object-thing, 4). Definite object-property, 5). Indefinite object-property, 6). Arbitrary object-property, 7). Definite object-relation, 8). Indefinite object-relation, and 9). Arbitrary object-relation.

Substitution of the symbol asterisk, in the prototypes, by symbols *t*, *a*, and *A*, gives us a collection of possible models of chunks of declarative knowledge in LTD ontological basis.

$$\text{Model} \quad (t)a \quad\quad\quad (1)$$

Represents knowledge regarding certain definite thing which possesses some sort of (indefinite) property. The direction of association is from thing to property.

$$\text{Model} \quad (t))a \quad\quad (2)$$

Represents knowledge regarding some sort of (indefinite) property, which is attributed to certain definite thing. The direction of association is from property to thing.

$$\text{Model} \quad (a))A \quad\quad (3)$$

Represents knowledge regarding arbitrary property, which is attributed to some sort of (indefinite) thing. The direction of association is from property to thing.

$$\text{Model} \quad a(t) \quad\quad (4)$$

Represents knowledge regarding a certain definite thing, in which some sort of (indefinite) relation takes place. The direction of association is from thing to relation.

Since there are four prototypes and each prototype can be filled by objects from nine classes, the total number of models for elementary chunks of declarative knowledge in the ontological basis of LTD is thirty six.

The structure of a question of erotetic transaction in the context of knowledge representation will be considered as a further development of the idea of basic interrogative formula of Belnap and Steel [1], which postulates that the inner logical structure of the question is determined by two components: question's subject and question's request.

$$Que = <Subj, Req> \quad\quad (5)$$

An important element of the Belnap and Steel philosophy, underlying their theory, is the concept of the question's subject. From this concept it follows that those questions, which include subject, for instance "search prescription" questions type, not only predetermine answers, but moreover include them. This means that we can think a question's subject as an answer with some degree of uncertainty.

A question's subject is a key component of erotetic transaction. The essence of the work, which the reactive agent fulfills while constructing the answer, is the transformation of uncertain knowledge, on which the subject points out, into more definite knowledge associated with the answer. Using other words we can say that the reactive agent reduces the degree of uncertainty of knowledge, corresponding to the subject of the question, to the level appropriate for the answer. We will model chunks of declarative knowledge, on which question's subject points out, by the following alternative formulas:

$$K_{subj} = (t)a \quad\quad (6)$$

$$K_{subj} = (a))t \quad\quad (7)$$

$$K_{subj} = a(t) \quad\quad (8)$$

$$K_{subj} = t((a) \quad\quad (9)$$

Models 6-9 obtained from the four, considered earlier, LTD-prototypes for the case of the association of definite and indefinite objects. There are several reasons for selection of the Models 6-9 for representing declarative knowledge. Firstly, subjects of all instances of questions, mentioned for example in [1, 11, 17], can be represented by one of the Models 6-9. Secondly, these models are exactly the sort of models (from the thirty six, that are possible), which accord with the idea that the reactive agent, while constructing an answer, transforms uncertain knowledge of the subject into certain knowledge of the answer.

One of the objects in Models 6-9 is indefinite, and the active agent is waiting for more concrete knowledge regarding this object from the reactive agent. On conceptual level, Models 6-9 can be elucidated in the following way:

- Model $K_{subj}=(t)a$ represents knowledge regarding a given definite thing, which possesses an indefinite property. Questions with such a subject are generated by the active agent when he/she wants to know *which properties have given thing*.

- Model $K_{subj}=(a))t$ represents knowledge regarding some given definite property, which is attributed to an indefinite thing. Questions with such a subject are generated by the active agent when he/she wants to know *which things have given property*.

- Model $K_{subj}=a(t)$ represents knowledge regarding some given definite thing in which an indefinite relation takes place. Questions with such a subject are generated by the active agent when he/she wants to know *which relations take place in given thing*.

- Model $K_{subj}=t((a)$ represents knowledge regarding some given definite relation, which occurs in an indefinite thing. Questions with such subject are generated by an active agent when he/she wants to know *in which things occurs given relation*.

The shortcoming of Models 6-9, from the point of view of engineering of knowledge-based program systems is their poor suitability for mapping into relevant data structures. These models could be practically suitable for software engineering in the case, when we find out the way of their transforming into types or data structures of modern systems of programming. It is talked, first of all, about datalogical interpretation of an indefinite object.

One of the possible datalogical interpretations of indefiniteness is multiplicity. An indefinite object can be understood as a set of definite objects and the cardinality of this set as a degree of indefiniteness. Then decreasing of the degree of indefiniteness is equal to decreasing of the cardinal number of the corresponding set. An indefinite object turns into an absolutely definite one when the cardinality of the corresponding set is equal to unity, or when the set is represented by one object.

Taking into account such kind of interpretation of

indefiniteness, we may substitute indefinite objects by lists of definite objects and express Models 6-9 in the following way.

$$K_{subj} = \text{<object-thing>}\{\text{list of objects-properties}\} \quad (10)$$

$$K_{subj} = \text{<object-property>}\{\text{list of objects-things}\} \quad (11)$$

$$K_{subj} = \text{<object-thing>}\{\text{list of objects-relations}\} \quad (12)$$

$$K_{subj} = \text{<object-relation>}\{\text{list of objects-things}\} \quad (13)$$

The Models 10-13 are datalogical counterparts of Models 6-9 and represent declarative knowledge, transmitted to the reactive agent via the question's subject. Two additional models, inexpressible within LTD notation (inside parentheses we may use only object-thing symbols), are introduced by equations 14 and 15.

$$K_{subj} = \text{<object-property>}\{\text{list of objects-relations}\} \quad (14)$$

$$K_{subj} = \text{<object-relation>}\{\text{list of objects-properties}\} \quad (15)$$

As the subject of the question is, in fact, an answer with some degree of uncertainty, and the reactive agent, while constructing the answer, reduces this degree of uncertainty to the level appropriating for the answer (determines by a question's request *Req* in interrogative equation 5), then models of chunks of declarative knowledge, associated with the answer should be similar to 10-15. The difference is in cardinality of the set of objects. Hence, we can express them in the following way.

$$K_{ans} = \text{<thing>} \text{ possesses properties } \{\text{properties}\} \quad (16)$$

$$K_{ans} = \text{<property>} \text{ attributed to things } \{\text{things}\} \quad (17)$$

$$K_{ans} = in \text{ <thing>} \text{ take place relations } \{\text{relations}\} \quad (18)$$

$$K_{ans} = \text{<relation>} \text{ occurs in things } \{\text{things}\} \quad (19)$$

$$K_{ans} = \text{<property>} \text{ attributed to relations } \{\text{relations}\} \quad (20)$$

$$K_{ans} = \text{<relation>} \text{ take place in properties } \{\text{properties}\} \quad (21)$$

The Models 16-21 represent declarative knowledge, which the reactive agent returns to the active one via the answer on the question with the corresponding subject.

The Models 16-21 can be relatively easily illustrated by numerous examples of transactions, built on whether-questions, used, for instance by Belnap and Steel [1]. Consider the transaction.

Active: What is the freezing point of water, in degreesFahrenheit, under standard conditions?
Reactive: The freezing point of water under standard conditions is 32°F.

The subject of the question in given transaction provides access to declarative knowledge, represented by the equation 10:

$$K_{subj} = \text{<water under standard conditions>}$$
$$\{\text{temperatures of freezing for liquids by Fahrenheit}\}$$

The model represents knowledge regarding given the definite thing "water under standard conditions", which possesses an indefinite property-some sort of freezing point. Active agent, posing the question with such a subject wants to go from uncertainty to certainty and get access to the reactive agent's knowledge regarding the concrete property of "water under standard conditions". Uncertainty in knowledge, which the subject points out, expressed by the list with a relatively large number of alternatives. Knowledge, associated with the answer of the reactive agent, is quite certain and represented by the model 16.

$$K_{ans} = \text{<water under standard conditions>}$$
$$\text{possesses property } \{\text{freeze at } 32°F\}$$

Consider the question.

Which primes lie between 10 and 20?

The subject of this question provides access to declarative knowledge, represented by the equation 11:

$$K_{subj} = \text{<be prime number>}$$
$$\{10,11,12,13,14,15,16,17,18,19,20\}$$

The model represents knowledge regarding given definite property "be prime number", which attributed to an indefinite thing-numbers between 10 and 20. The active agent posing the question with such a subject wants to go from uncertainty to certainty and learn from the reactive agent which concrete things have the property "be prime number". Uncertainty in knowledge, which the subject pointed out, expressed by the list of eleven elements. Knowledge, associated with the answer of the reactive agent represented by the equation 17.

$$K_{ans} = \text{<be prime number>}$$
$$\text{attributed to things } \{11,13,17,19\}$$

As our next example consider transaction taken from Plato's dialogue Protagoras. The fragment of this dialogue, given at the beginning of the article, is not purely erotetic, because the information messages of the active agent do not always have the form of questions. However, some transactions in this dialogue are erotetic. Consider the first one.

S: Then we are going to pay our money to Protagoras in the character of a Sophist?
H: Certainly.

The subject of Socrates' question in this transaction provides access to declarative knowledge, represented by the model 10. The model represents knowledge regarding given definite thing "Socrates& Hippocrates," which possesses an indefinite property-willingness/unwillingness to pay money to Protagoras only because he is Sophist. Socrates, posing the question with such a subject, wants to move from uncertainty to certainty and learn from Hippocrates which concrete property is possessed by "Socrates &Hippocrates". Socrates expects a certain answer and

based on this expectation, he constructs the subject of his question in such a way that uncertainty in knowledge, which the subject points out, represented by a list of only several alternatives.

$$K_{subj} = <Socrstes\&Hippocrates>$$
$$\{to\ give\ money\ to\ Sophist\ Protagoras,$$
$$not\ to\ give\ money\ to\ Sophist\ Protagoras\}$$

Hippocrates' answer is, in fact, a pointer to a chunk of declarative knowledge, represented by the equation 16.

$$K_{ans} = <Socrstes\&Hippocrates>\ possesses\ property$$
$$\{to\ give\ money\ to\ Sophist\ Protagoras\}$$

4. Conclusions

Erotetic dialogue is one of several types of natural dialogue, which can be employed by artificial dialogue agents, demonstrating anthropomorphic behavior. Erotetic dialogue transactions are limited to question-answering pairs and therefore, externally, erotetic dialogue is not so, various as a freewheeling natural dialogue, but it can achieve the same goals and solve the same problems as a full-scale dialogue between humans.

It is rational to construct models of logical structure of erotetic dialogue transaction based on the structure of knowledge associated with the transaction. In this case models obtained not only assist better understanding of the inner nature of a dialogue transaction, but also, have a pragmatic value, because they can serve as a theoretical foundation for engineering of the dialogue agent knowledge base.

In one of our previous publications [4] we introduced the idea of a dialogue knowledge base in the form of composition of the Memory of Questions (QueMem) with direct access to its elements, and the Dialogue Access Method (DiAM). From the point of view of procedural-declarative dichotomy of knowledge, DiAM is a repository of procedural knowledge of an active agent, and converts each answer of the reactive agent into QueMem address. The present article develops the idea of the dialogue knowledge base in the light of representation of chunks of declarative knowledge, associated with dialogue transactions. It seems more rational to consider a memory of declarative knowledge associated with questions' subjects (K_{subj}Mem) instead of the memory of questions. In this case:

1. K_{subj}Mem stores all subjects, which are necessary for synthesis of those questions that the active agent constructs within the concrete dialogue process.
2. DiAM converts K_{ans} of the current answer into the address of K_{subj} of the following question. If, for example, we represent the fragment of the dialogue, given at the preamble of the article, in the form of erotetic dialogue, then Socrates' knowledge needed for computer synthesis of this dialogue, can be

stored in the dialogue knowledge base. In this case, DiAM should store knowledge of Socrates' dialogue behavior (Socratic Inquiry Method) with regard to his dialogue with Hippocrates, and K_{subj}Mem-subjects of questions needed for synthesis of Socrates' questions.

The goal of the article and it size do not allow us to develop the idea of applicability of models of logical structures of dialogue transactions, offered in the article, to the architecture of the dialogue knowledge base. Authors suppose to introduce the results of this investigation in their subsequent publication.

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