KNOWLEDGE REPRESENTATION FOR ANIMAL REASONING

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ABSTRACT

Many experiments and observations indicate that such cognitive abilities as understanding and reasoning may be assigned also to (higher) animals. We are aiming at a construction of a semantic framework appropriate for an elaboration of the intuitive idea about animal understanding and reasoning, or more generally: about understanding and reasoning of agents with a pre-language behaviour. Meanings and knowledge representation are specified in this paper in terms of distinguishing criteria. A special attention is devoted to distinguishing criteria of situations and events. It is said, that an agent understand a situation or an event, if it has a corresponding distinguishing criterion at its disposal. Rules of reasoning are special distinguishing criteria - they assign some distinguishing criteria (meanings of the consequences) to other distinguishing criteria (meanings of premises). Knowledge representation and reasoning based on distinguishing criteria is adaptive - distinguishing criteria are formalized as functions and a fine-tuning of distinguishing criteria is possible as a result of interactions with an environment. We believe that the investigation of formal models of animal reasoning is important for understanding of a quick extra-logical human reasoning and for a construction of artificial reasoning agents.

1. INTRODUCTION

Background

Investigation of reasoning is a traditional domain of logic. Mathematical logic established an ideal construct of a proof, which is independent on intuitions and content. Results of mathematical logic enabled to comprehend fundamental properties of deductive theories, which accept proof as the only method of demonstrating validity. Mathematical logic shed light up on algorithmic computability, too. Deep results of mathematical logic influenced also conceptions of scientific method in an essential way. The approaches based on a kind of logic are dominating in the contemporary knowledge representation and reasoning research, too. Logical point of view and logical methods enabled a breakthrough insight and many important results in the field of knowledge representation and reasoning.

Problem

On the other hand, the paradigm of mathematical logic does not provide sufficient concepts, methods and tools for an expression and solving of some problems of knowledge representation and reasoning. Mathematical logic does not study even mathematical reasoning in its full complexity. An idealized presentation and communication of mathematical results is the domain of mathematical logic according to ((Barwise and J.Etchemendy, 1998)).

Many logicians comprehended - thanks to inspirations, goals, tasks and challenges of artificial intelligence - that new logics and new ways how to do logic are needed, in order to be able to express and to solve important problems, see ((Makinson, 2003)). Nonmonotonic logics represent one response. Anyway, there are many open problems of crucial importance and many fundamental problems have not been expressed. It is a gap between logical theories and the ways how human reason. Each attempt to bridge that gap is challenging, see for example ((Stenning and van Lambalgen, 2007)).

Biological roots of reasoning and representation belong among crucial open topics of cognitive science. However, they do not attract an attention which they deserve. In particular, investigations in the field of semantics and logic completely ignore kinds of reasoning, which occurred on lower evolutionary levels and which are the hidden components of our reasoning apparatus.

Goal

First a terminological convention in order to simplify our phrasing. We introduce the notion of an agent with a *pre-language behaviour*. The notion means an agent, that does not use a language (understood in a usual sense) and it is not handicapped, i.e. the other agents of that kind do not use a language, too,

We are going to propose a conceptual apparatus enabling to speak about reasoning, understanding, representation of agents with a pre-language behaviour. We believe that such a conceptual apparatus can contribute also to a proposal of interesting experiments and, as a consequence, to a bridging the gap between formal models of reasoning and empirical investigations of reasoning. See ((Stenning and van Lambalgen, 2007)) for a pioneering work in that direction.

However, our point is different - we are looking for new formal models of reasoning, understanding and representation, which are not bound to a language.

Proposed solution

A conception of meaning and semantics, which is independent on a language, is presented. The conception is based on a notion of *distinguishing criterion*, see ((Šefránek, 2002; Takáč, 2006b; Takáč, 2006a; Takáč, 2008)). The semantics enables to speak about understanding, meaning, representation and reasoning also in the case of pre-language agents.

We are not aware of a similar research, therefore no comparison our results with other approaches is presented in the paper.

Main contributions

Distinguishing criteria of situations and events has been defined. Rules as distinguishing criteria has been specified and analyzed. A conception of understanding and reasoning without a use of a language has been presented. Finally, it has been shown how this conceptual apparatus can be applied to a description of the experiments presented in ((Bräuer et al., 2006)), of course, also to similar experiments and observations.

2. MOTIVATION

According to ((Kováč, 2000)), only a tiny part of what we know today of human heredity has been obtained in studies on human subjects. Kováč formulated a *principle of minimal complexity* as follows: The most efficient way to study a concrete biological phenomenon is by studying it on the simplest organism in which this phenomenon can be found. He dubbed it Delbrck's principle in honor of Max Delbruck's investigations using that point of view and method.

First, we believe, that understanding and reasoning is a *biological phenomenon*. Some biological kinds (even people :-) make decisions on the basis of information acquired not directly from the environment. We follow up on observations and experiments recording, describing and analyzing a phenomenon, which can be classified as understanding and reasoning of animals. ((Lorenz, 2002)) writes about a dog, which "understood a situation", "understood surprisingly quickly", "understood precisely" etc. Scientists from the Max Planck Institute for Evolutionary Anthropology investigated experimentally reasoning abilities of the domestic dog and of the chimpanzee, see ((Bräuer et al., 2006)).

Of course, it is a hard problem to identify the lowest evolutionary level at which reasoning and understanding occurs. Our goal is more modest. We are aiming to develop a conceptual apparatus enabling to speak about understanding and reasoning of pre-language agents. It is possible that such framework will be useful for identifying some evolutionary levels at which reasoning occurs.

According to ((Bräuer et al., 2006)) also a part of animal cognition goes by making inferences beyond the information given. Domestic dogs and chimpanzee were tested on a series of object choice tasks. The results of their study provide support for the social-dog, causal-ape hypothesis. Dogs were especially skillful at finding hidden food when the human experimenter gave a communicative cue, but apes were not sensitive to such cues. On the other hand, apes were especially skillful at finding the hidden food when the food itself caused some perceptible change of state in the physical world e.g. by making a noise, but dog's behaviour has been rather poor in tasks of that kind.

The results of ((Bräuer et al., 2006)) and many other experimental results indicate that it makes sense to speak about animal understanding and reasoning (making inferences). Information about causality or about the meaning of human signals can not be acquired directly by an observation of environment. Cognitive operations as understanding and reasoning are necessary for obtaining such kind of information. Hence, we can interpret the results of ((Bräuer et al., 2006)) in terms of "understanding" and "reasoning" as follows. It has been shown by the experiments, that chimpanzee are more weak in understanding the meaning of human signals and also in reasoning, based on those signals. On the other hand, chimpanzee are skillful in understanding some causal relations in the environment and in using that understanding in making inferences. Dogs understand better human signals and they can use that understanding, when they do inferences.

Sciences, which are traditionally devoted to investigation of reasoning, understanding and related phenomena as knowledge and meaning (for example also logic, semantics, theory of knowledge representation), are focused on knowledge and inferences expressed in a language. We believe that a big challenge for those sciences is to investigate also reasoning and understanding, which occurred in nature in pre-language agents and, possibly, is preserved in a quick and spontaneous human reasoning.

We believe that with such a goal in view it is possible to comprehend human reasoning, knowledge, knowledge representation and meanings more deeply, in a new light. Remind the idea of Konrad Lorenz, that his phylogenetic method of research enables to view what is essentially human.

Moreover, also other recent investigations of reasoning indicate that it is important to attempt at re-comprehension of the phenomena of reasoning, understanding, meaning.

((Barwise and J.Etchemendy, 1998)) described how a use of a courseware[1] in logic courses has changed their view on the nature of logic. They turned their attention to the use of heterogeneous representations in reasoning with special interest on visual representations.

Problems and tasks of artificial intelligence turned attention of logicians to non-monotonic logics, to formalizations of reasoning with incomplete, evolving, contradictory and uncertain knowledge. This field (more precisely, those fields) is a field of hot research, but there are many open problems and according to our opinion some fundamental problems are not expressed or not expressed in an adequate way. For example, it is always not clear how to understand the slogan "jumping to conclusions" in a productive way, the way leading to tractable computational problems.

[1] A software used for educational goals.

As regards the attempts to bridge the gap between logic and cognitive science, a more deep comprehension of animal reasoning may show a way how to proceed in investigation of (quick) human reasoning, which is not completely understood and caught satisfactorily by the point of view and by the methods of the contemporary logic.

3. REPRESENTATION

Knowledge representation can be specified as a triple

$$(L, E, Cn),$$

where L is a formal language, so called knowledge representation language, E is a set of formulae of L, a knowledge base (a basis of explicitly expressed knowledge) and Cn is a consequence operator. Semantic investigations in knowledge representation are oriented towards a characterization of L and Cn.

However, we are aiming to propose a formal model of understanding and reasoning, appropriate for the pre-language agents. So, we have to specify knowledge representation and meaning[2] without a language.

One of the options is the semantics of *distinguishing criteria*, see ((Šefránek, 2002)). For a detailed and precise elaboration of the distinguishing criteria, applied to computational modelling of evolution and acquisition of meanings and language see ((Takáč, 2006a; Takáč, 2006b; Takáč, 2008)).

Our starting point is an assumption that also pre-language organisms use a kind of representation and meaning. They construct a representation of an environment and of their own goals. The existence of such representation is justified by an observable ability of pre-language organisms to distinguish. The notion of distinguishing criterion is used as an abstraction of this ability to distinguish. *Meanings* are for us distinguishing criteria.

A more general remark: The ability to distinguish is a universal cognitive ability. We (and also little children or animals) distinguish basic objects in our environment, their observable properties, changes in the environment, actions, observable relations. But our ability to distinguish is oriented toward a much more broader spectrum of entities up to such abstract objects as syntactic correctness of a natural language sentence, soundness of an argumentation, validity of an attempt to solve a hard mathematical problem, sincerity of emotions etc. etc.

Now, back to the biological roots of understanding and reasoning. If an organism is able to distinguish what is (and what is not) eatable (dangerous, moving etc.), it understands, it acquired a meaning, in a sense. Little children, before they use the word ”dog”, are able to distinguish dogs from non-dogs (even if they consider also some cats to be dogs)

[2]A comment to meanings without a language: we believe, that little children, animals, but also adult people are able to understand a word only if they are able to distinguish its referent in environment. The meaning is acquired before the ability to use the word. For more details see the argumentation below.

We classify distinguishing criteria into two classes, long-term and short-term distinguishing criteria. The former represent meanings used persistently (individuals - my mother; properties - yellow; actions - jump etc.). The later are used only one-off time (this situation).

Long term distinguishing criteria are specified as *functions* assigning to an individual (property, class, relation, action etc.) a value. The value can be for example from the interval $\langle 0, 1\rangle$, but there are other, also more abstract options for a set of values. Note that a distinguishing criterion is parameterized by a specification of an agent and by a specification of the entity.

A more formal definition of distinguishing criteria requires a specification of a set of agents $\mathcal{A}$, of a set $\mathcal{E}$ of possible entity types (f.ex. individuals, properties, classes, changes etc. but also distinguishing criteria[3]) and of a range $\mathcal{R}$. Moreover, a set $\mathcal{O}$ of objects should be specified – an object can be recognized from more points of view, sometimes a concrete property may be interesting, sometimes a change of its relation to other objects etc.

After such introduction we can proceed to a definition of the distinguishing criterion.

A function $f^{a,e} : \mathcal{O} \longrightarrow \mathcal{R}$ represents a distinguishing criterion of an entity e of the type E for an agent $a \in \mathcal{A}$. If $o \in \mathcal{O}$, then the value $f^{a,e}(o)$ represents a measure how the agent a is convinced that o can be considered as e.

Example 1 Let $d \in \mathcal{A}$ be a dog, let $c \in \mathcal{O}$ be a container and x, intended as *contains some food*, is a property (if a more cumbersome expression is needed: the abstract entity x belongs to the entity type *property*).

Then the value of $f^{d,x}(c)$ represents the conviction of d that c has the property x (i.e., it contains some food).

Short term distinguishing criteria are also functions, but they are defined on a special abstract object – the *focus*. The focus represents that part of an environment, on which the attention of an agent is focused. The values of such functions represent (schematically) situations or events. Notice that those values depend on an agent and also on the context, determined by the focus. We are going to specify distinguishing criteria of situations and events in a more detail.

3.1. Situations

The basic idea is as follows. When we (or an arbitrary agent) understand a situation, we (it) can extract a schematic view from the current observations (perceptions). We formalize that idea by a function from the focus to a *labeled oriented graph*. The vertices and the edges of the graph are labeled by distinguishing criteria. The graph is a schematic representation of the situation. The vertices may represent individuals or classes. The edges represent

[3]Reasoning, inferencing is modelled in our approach as an application of distinguishing criteria to another distinguishing criteria. It is quite natural to condition reasoning by a processing of representations in a representation.

relations. In this paper only binary relations are considered. If more-dimensional relations are relevant, hypergraphs may be used instead of the graphs.

Example 2 Suppose that a dog recognized a situation – a woman is near a cat. If the dog can distinguish both from other people and other cats, its representation of the situation is formalized by two vertices labeled by distinguishing criteria of the corresponding individuals, an edge is labeled by a distinguishing criterion of a relation of neighborhood. If the dog is able to classify both individuals as exemplars of women and cats, then the representation contains two additional vertices (labeled by the distinguishing criteria of the corresponding classes) and two additional edges (labeled by a distinguishing criterion of the relation "is").

Some operations on graphs are useful - we mention *refine, zoom-in, zoom-out, abstract* as examples.

The operation *refine* is applied to vertices and it returns a graph. Intuitively, a vertex of a graph can "hide" a further graph.

Example 3 Let a vertex be labeled by a distinguishing criterion of the class *meadow*. We can switch (*refine*) to another representation, where the meadow is represented by some vertices and edges (plants, trees, a brook, topological relations between them etc.).

Such graphs are called *layered* graphs. Operations *zoom-in* and *zoom-out* add (remove) vertices and edges. Intuitively it corresponds to narrowing and extending the attention. *Abstract* is essentially such zoom-out, which forgets vertices labeled by distinguishing criteria of individuals and the edges outgoing from those vertices (it is possible to abstract further from those "basic-level abstractions", but we do not discuss here that case).

An understanding of a situation is modeled as assigning of a (layered) labeled oriented graph to the focus. We interpret this as follows: an agent assigns a meaning to a situation. We will see below that also problems have a meaning in that sense.

3.2. Problems

Some vertices or edges may be labeled by a standard value *unknown*. In such a case it is said that a problem is identified in the given situation. The situation is not completely understood.

Example 4 Suppose that an ape does not know what is contained in a container. It may be represented by a vertex labeled by distinguishing criterion of *container*, an edge labeled by a distinguishing criterion of *containing* and a vertex labeled by *unknown*.

A solution of the problem can be defined as a transfer from a problem to a representation of the situation, when the labels unknown are replaced by some distinguishing criteria.

Example 5 Let us continue with the previous example. If the ape find out that a food is in the container, the label unknown is replaced by the distinguishing criterion of the food.

3.3. Events

We understand events as sequences of situations in a discrete time. However, a distinguishing criterion of an event may not be proposed as a simple sequence of distinguishing criteria of situations. It is expected that the situations are linked to each other in a way. We use the construct of the distinguishing criterion of a change, see ((Takáč, 2008)). A special case of the change is an action.

The distinguishing criterion of an *event* is then a function which assigns to the focus a *sequence of pairs*. The first member of a pair is a distinguishing criterion of a situation, the second is a distinguishing criterion of a change, The distinguishing criterion of a situation in the next pair is the result of the change (specified in the previous pair) of the situation from the previous pair.

We can introduce some operations also on events. The operations *refine, condense a abstract* are discussed in this subsection.

Refine decompose a pair of the form

$$\langle \text{ situation, change } \rangle$$

onto a sequence of such pairs. Intuitively, a more detailed view on the given situation and change is selected. On the other hand, *condense* replaces a given sequences of pairs $\langle$ situation, change $\rangle$ by a shorter sequence. Intuitively, a more compact representation of an event is chosen. *Abstract* is composed from the abstractions of all situations occurring in the sequence.

3.4. Rules

Rules are introduced as a special case of distinguishing criteria. We begin by an example.

Example 6 Remind a result of the experiment described in (Brauer et al. 2006). Apes understood such event, where a container shaken by the experimenter made a noise. The apes were able to conclude from that event that food is in the container.

Our interpretation is as follows. The apes are able to distinguish a hidden information connected to some events. It leads us to a formalization as follows. The apes created in this case a distinguishing criterion which assigns a distinguishing criterion of a situation (food occurs in the container) to a distinguishing criterion of an event (a noise caused by the shaken container). Similarly, distinguishing criteria of actions may be assigned to some distinguishing criteria of situations (or events) - if a situation is recognized, then an action is undertaken. In our example - food in the container is consumed.

Animal reasoning can be sometimes characterized also in the form of *default rules*. A default rule has besides a prerequisite and a consequence also a third component, a *justification*. The rule is applicable, if the prerequisite is satisfied and there is *no evidence against* the justification in the given context. Default rules are context-dependent (and non-monotonic). An illustration of a use of default rules in animal reasoning is presented below, in the case study.

We now proceed to a more formal introduction of rules (distinguishing criteria on which reasoning is based). First we need distinguishing criteria of *situation types* and *event types*. Both are considered as results of the abstraction operation on distinguishing criteria of situations or events. The interval $\langle 0, 1\rangle$ is assumed as the range below.

A distinguishing criterion of a *situation type* is a function, which assigns a value from the interval $\langle 0, 1\rangle$ to a situation, more precisely – to the layered oriented labeled graph, which is a schematic value of the corresponding distinguishing criterion of the situation. Similarly for event types: a distinguishing criterion of an *event type* is a function, which assigns a value from the interval $\langle 0, 1\rangle$ to a sequence of pairs, which is a schematic value of the corresponding distinguishing criterion of the event.

Example 7 Suppose that an agent used (created) a distinguishing criterion (function[4]) f for an event, where some shaking occurred. Assume also that a distinguishing criterion (function) g of an event type is defined on the value of f (which is a sequence of some pairs) and the values of g are from the interval $\langle 0, 1\rangle$. Hence, $g(f(focus)) \in \langle 0, 1\rangle$.

If the agent has a distinguishing criterion of the event type *shaking* at its disposal, then it probably assigns – thanks to that criterion – a value near to 1 to the representations of the event mentioned above.

In general, *rules* are distinguishing criteria which assign some distinguishing criteria (consequences) to distinguishing criteria of situation types or event types (premises). As an optional parameter of rules are considered justifications (for the case of *default rules*). Justifications are distinguishing criteria of situation or event types, too.

We need two kinds of rules for the purpose of this paper – action rules and situation rules. The consequences of former are distinguishing criteria of actions, the consequences of later are distinguishing criteria of situations.

Intuitively, the use of the former cause an action of the agent, the use of the later results in a recognition of a state of the environment.

A distinguishing criterion of a *change* is a function which assigns a value to a pair of distinguishing criteria of situations:

$$c(s_1(\text{focus}), s_2(\text{focus}) = v$$

If v is close[5] to 1, then the function represents a change of the first situation to the second situation.

A more general distinguishing criterion of change can be defined, which is parameterized in addition also by other entities. Then we can distinguish change of properties, of relations, of changes etc.

A distinguishing criterion of an *action* is a special case of a distinguishing criterion of a change. An action changes an event to a situation. A description of an action requires a specification of some participants of the action – a representation of an actor, of an object, of an instrument and of other relevant roles. All those participants are represented by labels in corresponding representations of situations.

An *action rule* is defined on a distinguishing criterion f of an event type or a situation type (premises) with distinguishing criteria α of actions as values (consequences), if the value of the premise is close to 1.

A *default action rule* is defined on a distinguishing criterion of an event type or of a situation type (the premise f) and on an arbitrary distinguishing criterion g (the justification) and its value is a distinguishing criterion of an action, if the value of f is close to 1 and the value of g is close to 0.

As regards our default rules, we are not aiming at a global characterization of a correct and saturated application of rules in the style provided by the notion of extension of a default theory.

A *situation rule* is defined on a distinguishing criterion f of an event type or a situation type (premises) and its value (the consequence of the rule) is a distinguishing criterion of a situation.

A *default situation rule* differs from the default action rule only by the occurrence of a distinguishing criterion of a situation instead of the distinguishing criterion of an action in the consequence of the rule.

3.5. Problem solving

Problem is represented in our framework as a situation with an incomplete information. Approaches to knowledge representation, based on a kind of logic reduce knowledge completion to a kind of reasoning. Notice however, that often the considered reasoning is a hypothetical one – it generates a kind of hypotheses, which provide a completion of the given representation (for example, closed world reasoning or abduction).

In our context except of reasoning (applying of rules) also an exploration of the environment by the agent is considered as a component of problem solving.

4. CASE STUDY

In this section one of the experiments discussed in ((Bräuer et al., 2006)) is considered. A part of the experiment has been devoted to understanding of causal cues. Experiments with the causal auditory cues are described and analyzed below. Our analysis is in terms of distinguishing criteria. Our goal is to propose some rules, which cover adequately some reasoning patterns identified by the experiment.

Experimental conditions

Three experimental conditions representing causal auditory cues has been investigated in ((Bräuer et al., 2006)).

[4] We abstract from parameters of functions in this example.

[5] Of course, a more detailed elaboration requires a specification of "close".

First, the *noise* condition. The experimenter shook the cup containing food four times so that the food (and a small stone that enhanced the sound) made a noise.

Second, dubbed *noise empty*, has been the same as in the noise condition, except that the experimenter acted on the empty cup.

Third, dubbed *noise ghost*, has been the same as in the noise condition except that the experimenter left the cup untouched. Instead, the cup was shaken by a second experimenter by pulling on a fishing line connected to the cup. Apes did not see the humans manipulating the cup.

Finally, the control condition, dubbed *noise arbitrary*, in which no cue was given, has been investigated: the cup contained (besides the food) a cellular phone that rang three times.

In ((Bräuer et al., 2006)) the results of experiments with causal auditory cues and apes has been summarized as follows. Apes did not treat causal and non-causal noises equally, they understood the causality. Apes were also capable of inferring - to some extent - the absence of the food on the basis of a silent shaken cup. It is worth to note, that apes did differentiate between causally relevant noises and arbitrary noises in a social setup (noise vs. noise arbitrary conditions), but they did not differentiate between them in a non-social setup (noise ghost vs. noise arbitrary).

Applied rules

We are going to analyze the experimental conditions and results described above in terms of distinguishing criteria (rules).

We assume that agents have a rather extensive set of rules (distinguishing criteria) in their representations. We believe that only some distinguishing criteria from the set are activated in each situation. The criteria are probably built in the respective representations and linked to events (and situations) of some type. Chimpanzee select spontaneously the rules relevant for the given situation. The same holds also for all biological organisms, which infer some conclusions. Of course, people, too, infer spontaneously – at least sometimes – and they use some *dynamic preferences*.

Our interpretation is presented in a series of examples of rules. Remind that rules are distinguishing criteria assigning some distinguishing criteria to other distinguishing criteria. Each rule has a premise and a consequence. Default rules have in addition also a justification. Each component of a rule is labeled below by the corresponding label (premise, justification, consequence). We repeat that premises, justifications and conclusions are distinguishing criteria.

A default rule can be presented as follows

$$\frac{\text{premise : justification}}{\text{conclusion}}.$$

Other rules do not contain justifications. We do not use this schematic presentation of rules because of long texts describing the respective distinguishing criteria. Reader could view the rules specified below in a similar schematic manner.

Example 8 In the case of *noise* condition we can speak about an application of the following rule:
BEGIN
the premise
a distinguishing criterion of an event type (a container producing a noise when shaken)
the consequence
a distinguishing criterion of an action (leading to an identification of the cup containing food).
END

The results of the experiment show, that the application of that rule is rather successful and used by a substantial part of the population.

Example 9 The case of the *empty noise* can be interpreted as an application of two rules.

The *first* is a situation rule.
BEGIN
the premise
a distinguishing criterion of an event type of shaking a container without producing noise
the consequence
a distinguishing criterion of an empty container (the shaken container is empty).
END

The *second* rule is an action rule.
BEGIN
the premise
a distinguishing criterion of a situation type with two containers and one of them is empty
the consequence
a distinguishing criterion of an action, where the action is an exploration of the container, which is not empty.
END

The results of the experiment show, that the rules of that kind are used only to some extent in the population. Our interpretation shows a possible cause of that: an application of two consecutive rules has been required.

Example 10 The case of *noise ghost* can be reconstructed using a default rule. A default version of the rule from the first case can be considered:
BEGIN
the premise
a distinguishing criterion of an event type (a container producing a noise when shaken)
the justification
a distinguishing criterion of a shaking such that an actor of the shaking is distinguished
the consequence
a distinguishing criterion of an action (leading to an identification of the cup containing food).
END

The proposed default rule is applicable for a reasoner (f.ex., for an ape), if the premise is satisfied and if the justification of the default rule is not falsified. The justification of the proposed default rule is focused on an actor of the shaking: if a noise is produced while shaking a container and an actor of the shaking is not present, then the rule is not applicable. If a chimpanzee is not sure, that there is an actor of the shaking, the rule is not applicable and the consequence about the location of food and corresponding action is not derived.

The identification of an actor is a hard problem in the noise ghost condition. The results of the experiment show that an application of such type of a rule is stressing – some apes reacted with caution and withdrawal. It is possible that some apes identified some problems with the justification of the rule.

Anyway, more than half of the population identified the cup containing food.

Example 11 Finally. also *noise arbitrary* can be interpreted in terms of a default rule.
BEGIN
the prerequisite
a distinguishing criterion of the source of a noise inside a cup
the justification
a distinguishing criterion of a natural source of the noise
the consequence
the same as in the noise case.
END

If no natural cause of the noise is identified, the rule is not applied.

The experiment has shown according to ((Bräuer et al., 2006)), that apes did not treat causal and non-causal noises equally.

Finally, we emphasize that we do not assume a conscious application of the rules (accessible by a kind of introspection). Our idea is that the rules are built-in (learned or innate) mechanisms of behaviour.

5. CONCLUSION

Summary

We have analyzed the experiments of ((Bräuer et al., 2006)) in terms of the semantic framework of distinguishing criteria. Distinguishing criteria of situations, events, situation types, event types, problems, rules has been defined.

Important are rules – the distinguishing criteria, which assigns distinguishing criteria to other distinguishing criteria. This kind of distinguishing criteria represents naturally reasoning as a derivation of meanings (information) from other meanings (information). In a case study we tried to describe possible rules applied by apes in a part of the experiment of ((Bräuer et al., 2006)).

According to our best knowledge, we presented a first attempt to characterize reasoning of pre-language agents in a semantic (or knowledge representation, if you do not like the adjective "semantic" in this context) framework.

Open problems

Of course a fine-tuning, refining and a further elaboration of our framework is necessary. More examples of animal reasoning should be analyzed in much more detail. An experimental implementation should be useful.

An attempt to consider also positioning of this work within a larger framework of research is missing. For example a relation of our approach to the question of symbol grounding could be discussed. Really, distinguishing criteria, evolved thanks to the interactions with an environment provide a possible solution of the symbol grounding problem, see ((Takáč, 2008)).

May be, some personal comments to that topic are needed. I consider the attempts to solve the symbol grounding problem (i.e. to design and implement such software, which do not work with meanings introduced from outside and interpreted only by users of the software) as very challenging. Anyway, I consider the very origin of the symbol grounding problem as the product of an "alchemistic" phase of artificial intelligence (the phase aiming at mysterious "intelligent machines" or "artificial minds") and I have not a sufficient motivation to be involved explicitly in tackling the problem.

Stimulations for knowledge representation theory

The framework of distinguishing criteria is a flexible one. It can be used from very simple cases of distinguishing to sophisticated cases, where distinguishing is supported by a syntactically rich structured language with a model-theoretic semantics or by the subtleties of a natural language. We believe that an analysis, formalization and implementation of a quick (human) inference (using a language) can take a significant advantage of the attempts to comprehend animal reasoning.

Ideas of the heterogeneous representation – graphical, visual etc. combined with sentential, see ((Barwise and J.Etchemendy, 1998)), can be incorporated into the apparatus of distinguishing criteria. Heterogeneous representations provide an interesting challenge for the knowledge representation research.

Investigation of animal reasoning, of heterogeneous representations and other challenges can contribute to a more deep and more manifold characterization and comprehension of reasoning than that, which is provided by the contemporary logic. On the other hand, each investigation of reasoning should be aware of the deep results of contemporary logics and of the logic-based research of knowledge and reasoning.

Adaptivity

Animal reasoning evolved thanks to an adaptation of animals to the living conditions in their environment. We did see that dogs and apes did not understand cues, which are not important from the point of view of their experience and living conditions. The ability to understand a kind of cues is demonstrated by making some inferences. Making some inferences can be interpreted as an adaptation to the living conditions.

We believe that our framework of distinguishing criteria is well suited for a development of an adaptive knowledge representation.

Distinguishing criteria are functions. Their application in interaction with an environment may lead to a fine-tuning of the functions, to their adaptation to new observations, experience (using standard or nonstandard techniques of machine learning). Promising results can be find in ((Takáč, 2006a; Takáč, 2006b; Takáč, 2008)).

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