# Remarks on Concept Processing for Cognitive Robotics

*Bernd S. Müller*
*Biomimetic Autonomous Robots Team*
*Institute for Autonomous intelligent Systems (AiS)*
**GMD – German National Research Center for Information Technology**
*D-53754 Sankt Augustin*

**Abstract**

*We present preliminary considerations on the architecture of a* CONCEPT *processing system for robots. With the help of* CONCEPTS *cognitive robots will be able to structure their sensory input, access their inner motivational states, and gain flexibility for reacting on changing circumstances. Concept is a theoretical construct in Cognitive Science for which considerable experimental evidence from psychological experiments exists. We propose that* CONCEPTS *should be considered to be pre-linguistic, language agreement processes making use of them in forming the* **CONCEPTS** *we "see through" natural language. As pre-linguistic concepts,* CONCEPTS *may also be generally assumed for living beings. A tentative comparison with Natural Language Semantics, concept theory in Cognitive Science, and Jackendoff's Conceptual Grammar is tried.*

– Es werden erste Überlegungen zu einem CONCEPT-Verarbeitungssystem für Roboter angestellt. Mit der Hilfe von CONCEPTS sollen kognitive Roboter in die Lage versetzt werden, ihren sensorischen Input zu strukturieren, auf ihre inneren Motivationszustände zugreifen zu können und Flexibilität beim Reagieren auf wechselnde Umstände zu erlangen. "Konzept" ist ein theoretisches Konstrukt in der Kognitionswissenschaft, für dessen Existenz einige Evidenz aus psychologischen Experimenten abgeleitet werden kann. Wir meinen, daß CONCEPTS vorsprachlich sind; mit ihrer Hilfe bilden Sprachvereinbarungsprozesse die **CONCEPTS**, die wir "durch die Sprache" sehen. Als vorsprachliche Konzepte können CONCEPTS bei allen Lebewesen angenommen werden. Ein vorläufiger Vergleich mit Aussagen aus der Semantik natürlicher Sprachen, aus der Konzepttheorie der Kognitionswissenschaft und aus der Conceptual Grammar Jackendoffs wird versucht.

## 1 Introduction

For purposes of Cognitive Robotics, we introduce a construct called CONCEPT. We think that CONCEPTS would be of great importance for Cognitive Robotics. Cognitive robots, most probably, will get at least part of their autonomy from the stable recognition of known situations with the help of CONCEPTS, and from the flexibility with which they can react on changing circumstances via modified or new CONCEPTS. We present preliminary considerations on the architecture of a CONCEPT processing system for robots. Concept is also a theoretical construct in Cognitive Science for which considerable experimental evidence mostly from linguistically oriented psychological experiments exists, and which can also look back on a long tradition of philosophical thinking. According to these considerations, concepts play an important role in representing circumstances accessible through the sensors of a cognitive agent like living beings are, and in accessing inner states necessary for an overall problem-solving by the cognitive agent.

In the first part of this paper, we give a broad introduction, concentrating on answering the following questions in a first attempt: What is the role of CONCEPTS in robot cognition, what is their structure and what are the processes working on that structure? We do not describe any implementation on a robot. In the second part, we raise more theoretical questions: What is the status of our approach in relation to the problem of the infinite regression when defining new concepts (and their attributes) using known concepts and attributes? We will propose two ways to overcome the problem at least partially. What is the relation of CONCEPTS to **CONCEPTS** we see "through" natural language? We will propose that CONCEPTS should be considered to be pre-linguistic, language agreement processes making use of them. At the end of the paper, a tentative comparison with Natural Language Semantics, concept theory in Cognitive Science and Jackendoff's Conceptual Grammar will be tried.

We are well aware that fundamentally different approaches exist, either philosophically different, like radical constructivism, or technically different like the dynamical systems approach (Bajscy&Large 1999), and the hope to solve everything by applying current function approximation methods like training of artificial neural nets; reinforcement learning, etc. (Müller 1997). But we think, our approach has the advantage of being conceptually nearer to solutions in natural cognitive agents.

## Concept notation

As the reader may have already realized, we use the following notation for concepts when writing about them in meta-language (i.e. in the plain text): If we emphasize the pre-linguistic character of concepts, as we mostly do in this proposal, we write CONCEPTS; if we write about concepts emphasizing their provenience from natural language, we write **CONCEPTS**; if we write about concepts in more general terms we write: concepts. Similarly, in the following, our notation for examples of pre-linguistic concepts will be small capitals (our default) and for examples of natural language concepts bold small capitals.

# 2 Concepts and concept processes for cognitive robotics

CONCEPTS are structural elements of the memory of cognitive agents, natural and artificial. They play an important role in representing and accessing circumstances with the help of the sensors. CONCEPT processes also access inner states, as part of the general problem-solving necessities, of the (artificial) cognitive agent. CONCEPT processes are part of different cognitive processes. Typically, if, e.g. in a recognition process, parts of the sensory input match parts of the inner structure of a concept exemplar, the process can work with the whole concept as an hypothesis, speeding up the recognition, as not the rest of the whole inner structure must be checked. CONCEPTS are products of the CONCEPT formation process. As a first approximation, lacking the experience from experiments with artificial agents or the definite certainty from analyzing natural cognitive agents scientifically, we propose a concept system that is influenced by representational theories in cognitive science and artificial intelligence.

## 2.1 Structure of CONCEPTS

A CONCEPT is an entity that serves as an unit in cognitive processes. CONCEPTS have an inner structure which is accessible by these processes through CONCEPT processes. It is common to think of the inner structure of concepts as consisting of attributes that can take certain values: A set of attributes and their values together make up a specific CONCEPT. A CONCEPT may be part of another CONCEPT. Such aggregates of CONCEPTS may themselves be processed as wholes.

The exact nature of the inner structure of concepts is still under discussion in cognitive science. After we have introduced our view on concepts in this and the next section, we will have glimpse on this discussion in section 4.

## Advantage of CONCEPTS in cognitive processing

CONCEPTS are important, if not the central, tools for a cognitive agent in handling the world by generalization and abstraction. Also, processing CONCEPTS as whole entities has advantages: As we have seen the recognition process is speeded up. Generally in cognitive processes, due to the CONCEPT structure, only parts of the input necessary for a certain cognitive process must match parts of the inner structure of a CONCEPT relevant for that process. The process can work with the whole CONCEPT as an hypothesis already in early states of processing. Only if this "early" hypothesis fails, (parts of) the rest of the whole inner structure of the CONCEPT must match.

## CONCEPTS as entities

A CONCEPT becomes an entity, that serves as an unit in cognitive processes, during CONCEPT formation, CONCEPT verification and CONCEPT use as influenced by the general problem solving needs of the artificial cognitive agent, and taking into account the needs of the complete cognitive apparatus of the agent. A CONCEPT as a whole is referred to by its name.

## Inner structure of CONCEPTS

The name of a CONCEPT is unique in a specific cognitive agent. This name is not decomposable, it has no meaning of its own. CONCEPTS consist of attributes that can take values, and, optionally, hierarchy markers that relate the CONCEPT to the CONCEPT aggregates it is part of. Attributes and hierarchy markers together "define" the CONCEPT. There are two types of attributes: features and propositional attributes. Features and propositional attributes take different types of values: the value of a feature is descriptional and qualitative in character; the value of a propositional attribute is a truth value telling if the proposition must be true or not if the CONCEPT has to be applied successfully. During CONCEPT formation, it is decided whether a CONCEPT is "defined" by using propositional attributes or features, or a mixture of both. In most cases, propositional attributes can be expressed as features, and vice versa. This decision must also be made when displaying CONCEPTS for inspection purposes during the implementation of cognitive agents.

Attributes are generated by the CONCEPT formation process. They can be understood as special kinds of CONCEPTS, having values as their attributes. Values are also generated by the CONCEPT formation process, in cases of observable values respecting the physical nature of the sensors.

Between the name of a CONCEPT (standing for the CONCEPT as a whole) and an attribute, a relational operator holds; similarly, relational operators connect an attribute with other attributes of a CONCEPT. Semantically, these relational operators are very elementary. In concept display they often are left implicit (like the relations between the elements of natural language expressions).

CONCEPTS contain pointers to the snapshot sequence they are "made of" (see paragraph on CONCEPTS and time below).

Examples of CONCEPTS can be found in the section 2.3 and 3. Our notation for attributes are small capitals, for values plain roman letters.

## Aggregates of CONCEPTS, composition of concepts

CONCEPTS can be parts of aggregates of CONCEPTS that may themselves be processed in a similar way as CONCEPTS (i.e. as wholes). This hierarchical CONCEPT composition makes use of relational operators. CONCEPT composition typically takes place in a given situation, time-slot, or sensory context. While it is a fact that we find non-hierarchical composition of natural language concepts in natural language syntax, it is not so obvious if or how non-hierarchical composition of pre-linguistic concepts is possible. In Example 1 we use sentence-like constructs that are meant as descriptions of pre-linguistic circumstances, in the first place.

## Recursive definition of CONCEPTS

If world facts allow, CONCEPTS that are made of CONCEPTS can be simplified by introducing recursion. If, e.g., a tree has to be conceptualized, there are different possibilities to conceptualize its parts: branches up to which branching depth do we conceptualize as **BOUGH**, which as **TWIG**, just the ones with leaves at their ends? A **BOUGH** may be a (main) **BRANCH**, a **TWIG** may be a **BRANCH**, too. Theoretically, all non-stem parts of a tree, except leaves and fruits, could become concepts of their own. While the choice has to do with the general cognitive goal governing the CONCEPT formation process, in some situations the recursive definition of the CONCEPT could also be a good optimization. A **BOUGH** is a **BRANCH** which branches from a **STEM** or from a **BRANCH** unless it has a leaf at its end.

### CONCEPTS and time

CONCEPTS describe circumstances in time. There are no timeless CONCEPTS. Even a seemingly “static” CONCEPT like CHAIR is not timeless since **CHAIRS** are viewed at in time: from different perspectives, under changing light conditions, as moveable parts of a room, experienced in different situational contexts at different times, etc.; all these time-dependent aspects of a **CHAIR** are important for the concept formation process that generates the CONCEPT CHAIR which further on can be used in cognitive processes.

CONCEPTS describe changes: they may be compared to a sequence of snapshots. These changes over time that a CONCEPT represents can be traced by the cognitive processes. Introducing time dependency for CONCEPTS must be seen in the context of the ongoing discussion on representation (Bajscy&Large 1999).

### Exemplars of CONCEPTS

While CONCEPTS are abstractions a cognitive agent makes from its outer and inner world guided by its needs and goals, exemplars of CONCEPTS are the results of analyzing a given situation with the help of the CONCEPTS, i.e. they are instances of CONCEPTS; as such they are abstractions drawn from a given situation with the help of memorized abstractions. Exemplars are products of the CONCEPT use process. An exemplar of a CONCEPT consist of its name and a hierarchy marker that refers it to its CONCEPT.

## 2.2 Processes working on concepts

Three types of processes can be discerned: concept use, concept formation, and concept verification. In *concept use* the different cognitive processes that access the outer world of an agent via sensors, or the inner world of an agent, e.g., its disposition of what to do next, make use of concepts for their process-internal considerations, inferences, and conclusions. *Concept formation* is the process that acquires new concepts as outer or inner circumstances of the cognitive agent change in a way that makes a restructuring or complementation of the concept set necessary. Like concept use, concept formation is a continuous process that never ends in an agent. Likewise, *concept verification* works continuously, confirming concept use decisions or refuting them as values for attributes of an already inferred concept come into the focus of the governing cognitive process. All these CONCEPT processes are governed by general cognitive processes (as vaguely defined in cognitive science like perceiving, categorizing, problem solving, remembering, learning, communicating with language, reasoning, imagining (see, for instance, Müller (1998)) and depend on the motivational and emotional systems and other parts of the cognitive system of the agents. The concept processing decision procedures, active in what we call CONCEPT processes, are not yet well understood.

### CONCEPT **use**

In CONCEPT use, cognitive processes access the memory in order to interpret the sensory impressions of the outer world with the help of already formed and memorized CONCEPTS. The inner world of an agent is also accessed via CONCEPTS, e.g., its factual and episodic memory, its motivational disposition, or its action control.

Categorization is CONCEPT use applied to the sensory input of a cognitive agent. It can only be successful if memorized concept structures are consulted. There are also cases of CONCEPT use working completely "internally", i.e. only with already formed CONCEPTS and other parts of the cognitive system.

CONCEPT use usually works top-down: the concept is compared with the "facts" (sensory or inner) up to a degree that a "first or crude" hypothesis becomes "reasonable". At that moment cognitive control is handed back to the governing cognitive process. As soon as CONCEPT verification intervenes CONCEPT use has to refine its decision by consulting more attributes. This iterative process ends with a "final" decision of CONCEPT verification.

### CONCEPT **formation**

CONCEPT formation is activated when a general cognitive process that evaluates the overall performance of the cognitive agent signals a failure that is not ultimate, but can be circumvented. A failure of the cognitive agent in a certain situation can be caused by a too coarsely grained conceptual structure. CONCEPT formation restructures the concept set, or adds new concepts. New CONCEPTS are formed when they are needed and allow new differentiations ("when they are useful"). See Example 2 (in paragraph 3.1) for an example.

### CONCEPT verification

CONCEPT verification verifies hypotheses brought forward by the other CONCEPT processes, CONCEPT use and CONCEPT formation. In CONCEPT verification CONCEPT use decisions are confirmed, if values for attributes of an already inferred concept meet the expectations of the governing cognitive process, or are refuted, if they contradict them. Furthermore, CONCEPT verification results are used to improve the performance of the other CONCEPT processes.

### Sensors and CONCEPT use and formation processes

The processing of the sensory input is a central problem in concept use and formation processes. CONCEPTS are most probably useful in deciding what to accept as useful "information" and what to regard as noise. One way of tackling the problem is a binary dichotomy of sensor scales and sensor fields: Dichotomy points (that divide the scale of linear sensor) or dichotomy lines (that divide a sensor field into areas) are chosen according to process needs.

### Concept display

Concept display is not part of a conceptual system, but part of the support system for the description, construction, analysis, and evaluation of a conceptual system. Concept display we call the tools and structures that are used for displaying of a concept set, for instance, for introspection purposes.

## 2.3 A concept system in action: A small predator looks at a changing scene

The following example would better be a series of sketchy drawings, certainly closer to the "representational reality" in animal cognition than the natural language expression we used, which too easily allow a anthropomorphic interpretation. Using Example 1, we will try to make our terminology, concerning the structure of a concept system and the processes working on it, a little bit more clear. For purposes of illustration, we assume the following situation: A small hungry predator is sitting in the grass behind a small rock on a slope overlooking a meadow with brushes in its center. As time passes by, different circumstances must be conceptually handled by the small predator (see left column of Example 1; as concept display form we use propositions in natural language). By reading the

## Example 1: A small predator looks at a changing scene

| | |
|---|---|
| robin | known ROBIN, a BIRD, a harmless one, could be prey |
| a robin sings | hear a ROBIN SING; |
| the robin sings | see the ROBIN that SINGS, I am hidden by the rock, attack possible, as bird does not see me, but it is too far off |
| hawk | known HAWK, a bird, a dangerous one, minor attention, as I am hidden by the rock! |
| the hawk attacks robin | see THE HAWK ATTACK the ROBIN |
| the robin sings and the hawk attacks | THE ROBIN SINGS AND THE HAWK ATTACKS; ROBIN does not see the HAWK; danger for the ROBIN |
| many birds attack the hawk | see MANY BIRDS ATTACK THE HAWK |
| the hawk disappears | THE HAWK DISAPPEARS; attention no longer necessary? |
| birds sing | hear BIRDS SING; attention no longer necessary! BIRDS could be prey; attack possible? |
| two hawks appear | TWO HAWKS APPEAR; I am hidden by the rock, but increase attention! |
| two hawks attack me | TWO HAWKS ATTACK ME; alarm! I am not hidden from HAWKS by that rock |
| I must flee | I MUST FLEE; prepare quick flight action! I am not hidden from HAWKS by that rock! [modification of protection attributes in rock and hawk CONCEPTS] |

propositions from top to bottom, we as meta-observers can infer what is happening. For the predator, as a cognitive agent, things are not as easy, because it has to identify objects as objects, even if they are moving, or if the view is deteriorated by that upcoming rain. The small predator has to analyze many details omitted in our description of the scene. In its action planning and memorizing, it has to omit them, too, and keep only details relevant for its survival and other central motives. That exactly is the main function of conceptualization. In the right column of Example 1 we verbally circumscribe the concept processes active in the small predator..

In Example 1 we see the interaction of concept use and the motivational system of an animal in a normal situation, though with a remarkable demand on perceptual processing, even under time constraints. There is no situational slot where the cognitive agent has to learn (form) a new concept or attribute of a concept: all the concepts necessary to solve the problems of the present situations have already been formed. During the last time slot, it has to modify an ATTRIBUTE. Purposefully, we choose an animal as actor in our example. So, we hope to have illustrated that concept processing is not a privilege of the highest evolved living beings.

# 3 Theoretical problems: attribute formation, language dependency of concepts

## 3.1 The attribute formation problem

Concept formation must make use of known attributes and their applicable values. To a certain degree, in acquiring a new concept, attributes from existing concepts may be used. Or, if this is not possible, the formation of a new attribute may be tried by applying a process similar to concept formation to form the attribute needed, using more elementary attributes. As can easily be seen, this leads to an infinite regression, letting the whole conceptual building of concepts "tumble". Unless, something like atomic attributes and values could be identified. Work of this type is currently in progress, trying to understand the basis (Roth&Menzel 1996) and the evolution of cognition (Lengeler/Müller/diPrimio 2000, Stewart 1996):

In a description of the neurobiological architecture of cognition, Roth and Menzel (1996) see as basic processes that must be distinguished from cognitive processes: "Precognitive processes like constancy processing (color and form constancy), simple perception processes like the differentiation of figure and background, or the automatic segmentation of complex scenes into "good gestalts", the detection of simple states of order, of patterns and objects (p. 539)". As we have argued in Lengeler/Müller/diPrimio (2000) and in diPrimio/Müller/Lengeler (2000) these order-analyzing processes are very elementary and cognitive processes that may well be found in earliest forms of life. May be that in their context atomic attributes and values can be found.

Let us look at an example: The concept BIRD is known. It has the attributes (features) shown in Example 2, part 1:

## Example 2 (part 1): The CONCEPT

| BIRD | | |
|---|---|---|
| | FLIES | yes |
| | SINGS | yes |
| | LAYS EGGS | yes |
| | NESTS IN TREES | yes |
| | EATS INSECTS | yes |
| | SIZE | small |

To introduce the concept ROBIN the new attribute HAS A RED BREAST has to be added to the description of the exemplar of a bird we conceptualize as ROBIN (see Example 2, part 2):

## Example 2 (part 2): An exemplar of BIRD

| ROBIN | | |
|---|---|---|
| is a BIRD | | |
| | HAS A RED BREAST | yes |

Propositional attributes are only accessible for CONCEPT use "as a whole". If we want to break down the propositional attribute HAS A READ BREAST into observable features, we have to introduce several new attributes, that could be also important for the conceptual processing of BIRD in some later context. Note that a considerable CONCEPT formation effort, namely observing the details of a robin body and inferring the function of its parts, is necessary before the new attributes can be formed. The following could be an intermediate result (see Example 2, part 3):

Example 2 (part 3): New attributes to discern a ROBIN from other birds.

| | | | | | |
|---|---|---|---|---|---|
| ROBIN | | | | | |
| IS A BIRD | | | | | |
| | BODY | BODY-PART | HEAD | | |
| | | | BACK | | |
| | | | FEET | | |
| | | | TAIL | POSITION | |
| HORIZONTAL | back | | | | |
| VERTICAL | middle | | | | |
| LATERAL | no | | | | |
| | | | BREAST | COLOUR | red |
| | | | | POSITION | |
| HORIZONTAL | front | | | | |
| VERTICAL | middle | | | | |
| LATERAL | left-right | | | | |
| | COLOUR | light-brown | | | |

Attributes are displayed here as having a hierarchical structure for illustration (they can easily be transformed into a non-hierarchical form). As we know that ROBIN is a BIRD, to end up this intermediate attribute formation process, the new attributes must become part of the description of BIRD.

## 3.2 Concepts and language

It is a common understanding that language and concepts come together: no concepts without language. As may be inferred from the statements above, concepts can also be considered as pre-linguistic. We think that CONCEPTS play an important role in living beings not capable of language. CONCEPTS take part in, or are crucial building blocks of, cognition of animals, primates, and men; and once, hopefully of man-built artefacts. Pre-linguistic CONCEPTS are the basis of **CONCEPTS** as seen via language. Without pre-linguistic CONCEPTS, the mutual agreement process, that forms a common language, would not be possible. Language is a tool for communication between agents which have a common set of pre-linguistic CONCEPTS and agree upon the naming of them. The question if phenomena like "prototypicality" ("a robin is a typical bird"), as inferred from the analysis of **CONCEPTS** in language (Fodor 1998a/b, Smith&Medin 1981, Laurence&Margolis 1999), are "universal" phenomena also found in pre-linguistic CONCEPTS, cannot yet be answered (may be they are epiphenomena stemming from psycholinguistic tests or from language agreement).

## Pre-linguistic CONCEPTS

Language and concepts are often seen as being inseparable: we think that language is a tool that allows to communicate about concepts which themselves have an important function in cognitive and cognition-like systems, independent from a language capacity. Evidence from the functionality of natural agents leads to the assumption that there must be structures very similar to the concepts known from cognitively highly developed beings that play an important role in many living beings, even those not capable of language. If natural agents can tackle the situations they are confronted with in their life, they must have command over an apparatus which in the most evolved living beings is associated with concepts. CONCEPTS simplify the problem-solving of living agents.

The substrate of CONCEPTS, or CONCEPT-like structures, and their exact form is not yet known. Our proposals concerning CONCEPTS in this article are working hypotheses. We hope to learn more about them when we implement CONCEPT processing features into robotic artefacts. CONCEPT processing is also part of joint efforts of biology and cognitive science in redefining cognition; efforts which we support and are already involved in (diPrimio/MüllerLengeler 2000, Lengeler/Müller/diPrimio 2000).

We assume that pre-linguistic CONCEPTS are the basis of **CONCEPTS** expressed in language.

## CONCEPTS in language formation and learning

Language is a tool for communication between agents which have a common set of pre-linguistic concepts and agree upon how to name and arrange them. Without pre-linguistic CONCEPTS, this process of mutual agreement, the forming of a common language, would have no basis, and could never start.

If two or more agents independently from each other formed the CONCEPT CHAIR because, in solving problems, they needed it, they can agree upon naming it in the language formation process with the word "chair" or with other elements of their common language, having afterwards (after a certain experience in linguistically referring to CHAIR) a common **CONCEPT CHAIR.** For a cognitive agent, the **concept chair** refers to both language immanent experiences with **chair** (e.g., using **chair** in language expressions and experiencing **chair** being used in language expressions, including defining and redefining **chair** via language expressions) and to problem solving experiences with CHAIR (e.g., categorizing objects as CHAIRS when having the need to sit down, thereby integrating over complicated form and aspect differences).

In Example 3 we illustrate the assumption that there is no one-to-one relation between pre-linguistic CONCEPTS and natural language **CONCEPTS**.

### Example 3: From CONCEPT to **CONCEPT**

| *conceptualized prelinguistically in Agent 1* | *conceptualized prelinguistically n Agent 2* | *conceptualized linguistically in Agent 1 and Agent 2* | *commentary* |
|---|---|---|---|
| LEAF | LEAF | **LEAF** | as communication affords the naming of this shared CONCEPT |
| LEAF-WITH-HOLE | LEAF-WITH-HOLE | **LEAF** | as communication does not afford the naming of this shared CONCEPT |
| LEAF-WITH-YELLOW-TIP | LEAF | **LEAF** | as the agents do not share this CONCEPT |

## Concept phenomena and epiphenomena

Which of the **CONCEPT** phenomena can be found in CONCEPTS? Do, for instance, CONCEPTS show "prototype" effects ("a **ROBIN** is a typical bird")? One of the following may be the case, and we do not know enough about CONCEPTS to decide which one without further research and experimentation:

1. CONCEPTS do not show the prototype phenomenon as in a "mute" problem-solving context it is not advantageous to be able to refer to the most typical exemplar or subconcept of a CONCEPT, because would have the same advantage as to go to the next higher level in the CONCEPT hierarchy.

2. Prototypes are epiphenomena generated during the mutual agreement on a language (which can also be in learning one's mother language). Causes could be teaching preferences or cultural preferences; it might be that the first **CONCEPT** verbalized is a candidate for becoming the prototype of its class.

3. The prototype effect is a result of the psycholinguistic experimentation itself, because it very much depends on the choice of the features for the concepts that are used for the experiments (see Example 4 below. If, for instance, the attribute SIZE in BIRD would allow larger sizes, the prototypicality of robin could no longer be explained with that set of attributes.). And it depends on the psycholinguistic task posed and the psycholinguistic question to be answered: If the task is "Bring the **CONCEPTS** in an order, that shows what **CONCEPT** is more typical as compared to another **CONCEPT**!", you cannot help but getting a prototype. We do not want to criticize a long tradition of experiments and we know that this argument might be a bit unfair, as there is also evidence for prototypes that comes from quite different experiments, but we want to emphasize that it is worthwhile to look at the phenomena freshly with the new aspect of linguistically codified **CONCEPTS** and pre-linguistic CONCEPTS in mind.

### Example 4: Prototypes — The concept **ROBIN** has the same attributes and values as **BIRD**, it is a typical **BIRD**.

| | *different "birdy" concepts* | | | |
|---|---|---|---|---|
| *attributes* | BIRD | ROBIN | CHICKEN | VULTURE |
| FLIES | yes | yes | no | yes |

| | | | | |
|---|---|---|---|---|
| SINGS | yes | yes | no | no |
| LAYS EGGS | yes | yes | yes | yes |
| NESTS IN TREES | yes | yes | no | yes |
| EATS INSECTS | yes | yes | no | no |
| SIZE | small | small | middle | large |

## 4 Comparison with selected approaches in the theory of concepts

In this section we take a glimpse at the very old, very broad, and still ongoing discussion of the concept of concept. We picked out natural language semantics (de Swart 1998), Jackendoff's Conceptual Grammar (1994), and Laurence and Margolis' overview of concept theory in cognitive science (1999). The aim of this section is to show where our own assumptions are supported, and where they are decidedly different, or do not cover important phenomena.

Support may be drawn from de Swart, in her exposition of natural language semantics (1998, 1–7), when she argues, that language has content and this content is anchored to reality via some aboutness relation. We assume that the pre-linguistic concepts are this "aboutness anchor". When she says that communication is only successful if the idea the hearer gets is the same as what the speaker intended the hearer to get, she gives a formulation which is not only good for describing communication, but also for describing what is the goal of the language agreement processes. de Swart admits that the construction of complex concepts is a problem which has not yet been entirely understood by natural language semantics. Which is certainly by far more true for our approach: what we call composition of CONCEPTS is formally less elaborated than the theory of the compositionality of meaning in semantics; ours is only one aspect of the latter. This hints at the question of a semantics of pre-linguistic concepts, totally left open in our presentation above.

Our conception of pre-linguistic CONCEPTS is different from de Swart's point of view regarding the *direct interpretation* of natural language with respect to the outside world, which she characterizes as being not easy. Instead of direct interpretation, de Swart advocates the *indirect interpretation* by means of translation into formal languages, which capture increasingly more complex parts of the meaning of natural language, as she says: the exact meaning will be captured, according to her, as long as this translation is perfect. While being a common point of departure in semantics, we nevertheless think it is a problematic one: one problem (direct interpretation) is replaced by another unsolvable problem, the translating perfectly into a formal language. Certainly, this has also to do with a basic shyness of linguistics to tackle the interface between language and world, a sound shyness in many other respects. Pre-linguistic CONCEPTS deal with this interface, hopefully supported by evidence from circumstances in natural agents.

Many aspects in de Swart's description are not covered by our exposition above. This concerns the dichotomy of the scope of semantics in *lexical semantics* and *meaning at the sentence level*, mental states and imaginary worlds (we alluded to it by associating CONCEPTS with internal circumstances in an agent), and the role of natural language as both object language and metalanguage. A lexical semantics phenomenon we referred to is hyponymy (*isa*-hierarchies), but we did not cover ambiguity, synonymy, antonymy, semantic features, thematic roles (argument structure) of verbs). It is to question which of these lexical meaning aspects can be found at the CONCEPT level and which are only found with **CONCEPTS**. The same is true for the meaning at sentence level (coreferentiality, binding (reference of pronoun varies systematically with the choice of the individual determined by a quantifier), forms of semantic inference like presupposition and implicature).

Jackendoff, in his conceptual semantics, as de Swart (1998, p. 5) sees it, mixes ideas from predicate logic, theories about thematic roles (agent, patient), and psychological theories on (visual) perception. We share Jackendoff's interest in perception, as it supports our view that object recognition might be a key to pre-linguistic CONCEPTS, and inversely, CONCEPTS a key to object recognition. We would like to emphasize, with respect to Jackendoff's argument for a mental grammar and innate knowledge, that it is an innate capacity for problem-solving the CONCEPT system can recur to; which Jackendoff expresses as : "… the language capacity must have evolved from other capacities in the brains of our precursors (Jackendoff 1994, 160)". In the conclusions of his 1994 book (p. 203), Jackendoff summarizes his ideas as follows: "Our thoughts are built out of a finite set of unconscious patterns which give us the potential for thinking an infinite number of thoughts of indefinite complexity. … These patterns in turn are constructed from an innate Universal Grammar of concepts …" A more formal comparison with our approach is still to be done.

In the introductory chapter of Margolis & Laurence (1999), Laurence and Margolis give a detailed description of the state and the history of concept theory. They discern several types of concept theories which we will address and evaluate, one after another. Support of our own views comes from the *Classical Theory*, which states that most concepts (esp. lexical concepts) are structured mental representations that encode a set of necessary and sufficient conditions for their application, if possible, in sensory and perceptual terms. (Where this last condition is especially important for us). Important for the assumption of pre-linguistic concepts are also the following parts of their *Summary of Criticism of the Classical Theory* (the order of the arguments differ in Laurence & Margolis (1999): 1. "It is possible to have a concept in spite of massive ignorance and/or error, so concept possession can't be a matter of knowing a definition." As we interpret it, this is supporting the existence of CONCEPTS, and illustrates the fragility of the conversion of CONCEPTS into **CONCEPTS** in language. 2. "Concepts and categorization both admit a certain amount of indeterminacy (fuzziness), not possible in the Classical Theory." As abstractions that are continuously verificated, rearranged and modified, concepts are "fuzzy" in themselves. The language agreement process adds to the indeterminacy, in itself and as it is also continuously active, language agreement results never being completed because accurate. 3. "Typicality effects can't be expressed by classical models." Here, we can only repeat our epipheno-menon suspicion with regard to typicality. The arguments 4 "There are few, if any, defined concepts" and 5 "Lexical concepts show no effects of definitional structure in psychological experiments" are not covered as we do not systematically treat concepts in a "definitional" role in our proposal.

When it comes to *Prototype Theory* Laurence and Margolis argue: "Most concepts (esp. lexical concepts) are structured mental representations that encode the properties that objects in their extension tend to possess". If our assumptions concerning the concept processes are valid, they support the statistical nature of CONCEPTS and **CONCEPTS**. The argumentations of the *Theory-Theory* ("Children and scientists have the same method of exploring the world") and of the *Neoclassical Theory* ("partial definitions are allowed") are not covered by us, whereas we are inclined to support the *Conceptual Atomism Theory* in its coinage of Fodor, at least what regards the general statement that "lexical concepts are primitive", while we think different concerning the statement "they have no structure". It is certainly too general to say that pre-linguistic CONCEPTS are primitive, but in a certain sense they are "more primitive" than lexical concepts. An evaluation of Fodor's concept theory (Fodor 1998a, 1998b) is on our agenda.

## 5 Outlook

In current robotics the concept processing problem has not yet been tackled. An experimental implementation is overdue. Solutions in the line of our argumentation would have a considerably impact on the re-engineering of biological solutions, and thus on the engineering of autonomous robots, and as a source of a tentative verification, on the theory of cognition.

## Acknowledgements

My thanks go to the members of the former Cognitive Robotics group at GMD, to the members of the Biomimetic Autonomous Robots Team, its team leader, Frank Kirchner, and the institute's director, Thomas Christaller, both for discussing the concept of CONCEPTS with me and having patience with me when I insisted on pursuing my own ideas. This applies to a degree worth mentioning separately to Joachim Loosen. Bernhard Schröder (University of Bonn) kindly commented on a draft of this paper.

## References

[Bajscy&Large 1999] Bajscy, Ruzena and Edward W. Large (1999) When and Where Will AI Meet Robotics? *AI MAGAZINE*, Fall, 57–65.

[Chater&Heyes] Chater, Nick; Heyes, Cecilia (1994) Animal Concepts – Content and Discontent. *Mind & Language* 9, 3, 209–246.

[deSwart 1998] de Swart, Henriette (1998) Introduction to Natural Language Semantics. Stanford, Cal.: CSLI Publications.

[diPrimio/Müller/Lengeler 2000] di Primio, Franco; Müller, Bernd S. & Joseph W. Lengeler (2000) Minimal Cognition in Unicellular Organisms. To appear in: Meyer, Berthoz, Floreano, Roitblat and Wilson (Eds.). *Proceedings of the Sixth International Conference on Simulation of Adaptive Behavior (SAB2000) – Supplement Book*. Honolulu: International Society for Adaptive Behavior.

[Fodor 1998a] Fodor, Jerry (1998) When is a dog a DOG? Review of Sloman, Steven A. and Lance J. Rips (Eds.) Similarity and Symbols in Human Thinking, MIT Press 1998. *Nature* 396, 26 November, 325–327.

[Fodor 1998b] Fodor, Jerry (1998) *Concepts: Where Cognitive Science Went Wrong*. Oxford: Clarendon.

[Jackendoff 1994] Jackendoff, Ray (1994) *Patterns in the mind – Language and human nature*. New York: BasicBooks.

[Lengeler/Müller/diPrimio 2000] Lengeler, Joseph W., Müller, Bernd S. & Franco di Primio (2000) Neubewertung kognitiver Leistungen im Lichte der Fähigkeiten einzelliger Lebewesen. *Kognitionswissenschaft* 8.

[Laurence & Margolis] Laurence, Stephen and Eric Margolis: Concepts and Cognitive Science. Introductory chapter in: Margolis, Eric and Stephen Laurence: “Concepts: Core Readings ”, Cambridge, Mass.: MIT, 1999, 1–81.

[Müller 1997] Müller, Bernd S. (1997) *Konzeptbildung und Kommunikation bei Robotern – Problemskizze und Vorschläge zum experimentellen Einstieg.* Arbeitspapiere der GMD Nr. 1080.

[Müller 1998] Müller Bernd S.(1998) *Identifikation elementarer kognitiver Leistungen*. GMD Report No. 17.

[Roth&Menzel 1996] Roth, G. & Menzel, R.. (1996) Neuronale Grundlagen kognitiver Leistungen. In: J. Dudel, R. Menzel & R. F. Schmidt (Hrsg.). *Neurowissenschaft – Vom Molekül zur Kognition* (S. 539-558). Berlin: Springer.

[Smith&Medin 1981] Smith, E.E. & D.L. Medin (1981) *Categories and Concepts.* Cambridge, Massachusetts: Harvard University Press.

[Stewart 1996] Stewart, J. (1996) Cognition = Life: Implications for higher-level cognition. *Behavioural Processes* 35, 311–326.