Knowledge Representation as a tool for Intelligence Augmentation

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ABSTRACT

The goal of Intelligence Augmentation (IA) is the development of tools that improve the efficiency of human intelligence. To this end we introduce a model of human conceptualization on the basis of a cognitive theory of information processing and a Peircean theory of signs. An account of two experiments is provided. The first concerns conceptualization by individuals, the second describes how we approach problem elicitation by a team of participants. A preliminary analysis of the results shows that the proposed model is congruent with multi channel and multi purpose human information processing. This implies that the cognitive model can be used as a model for knowledge representation in various fields of human-computer interfacing such as computer aided problem solving and problem elicitation.

INTRODUCTION

Intelligence Augmentation (IA) research aims at the development of tools that improve the efficiency of human intelligence. This form of enhancement contrasts with Artificial Intelligence (AI), whereby intelligence would be produced in an entirely artificial form. According to D.C. Engelbart (1962, p.1), "by 'augmenting human intellect' we mean increasing the capability of a man to approach a complex problem situation, to gain comprehension to suit his particular needs, and to derive solutions to problems".

Due to the importance of man in problem solving, computer systems augmenting intelligence demand a 'human-compatible' formal model of knowledge representation (KR). Important characteristic properties of human KR are flexibility (for adjustments) and portability (knowledge in one domain can be directly used in another domain). Experience with static, fact-based KR in past decades has shown that it is inflexible and non-portable. We believe that process-based, dynamical KR offers better perspectives. An illustration of the differences between static and dynamic KR may be found in natural language (NL) processing. Traditional (static) language modeling, characterized by large formal grammars and relatively small lexicons is not robust against modifications. By separating static and dynamic aspects of language symbols, respectively, in a lexicon (which is apt for modification) and a relational process (which can be invariantly used), dynamic modeling enables a more robust alternative (Sarbo, Farkas & van Breemen, 2007).

A philosophically informed dynamic view of KR has been introduced in (Breemen & Sarbo, 2009). The most important conclusion of this work is that the processes of perception and cognition can be modeled in the same way . We grounded our model in the theory of the American philosopher, C.S. Peirce (1839-1914) for two reasons. On the first hand, Peirce's sign theory (cf. semiotics) provides a unique classification of signs and sign aspects. On the other, his category theory enables categorical classification to be applied recursively hence it enables the development of ontological specification in a systematic fashion.

Here we start with a recapitulation and definition of our cognitively based, semiotically inspired model of KR that complies with those philosophical considerations. This model of knowledge representation models conceptualization as a process. A characteristic property of all processes, including conceptualization, is their teleological, goal-driven character. Such a goal is the generation of an appropriate response to the input problem. In practice this comes down to the generation of a response that is appropriate from a certain point of view as, for instance, when the response is mathematically well-formed (in the case of a mathematical problem).

Since in conceptualization it is only the final interpretation that really is of interest, intermediate representations can be considered as expressions of the input from the perspective of their contribution to the (desired) result. Such intermediate interpretations can be associated with Peircean sign aspects (Peirce, 1931-58). On the basis of the dependency and subservience relations between different sign aspects that are identified by Peirce, we suggest that intermediate representations can be ordered in a dependency structure.

The focus of this chapter is on an application of our theory of IA in human conceptualization. We will consider two fields: problem solving (Bruner, 1966) and problem elicitation (Krogstie, Sindre & Jorgensen, 2006). Utterances generated during problem solving and problem elicitation can be associated with sign aspects and ordered accordingly. Following this line of thinking, the quality of a conceptualization process can be characterized by the relation between the structure induced by the generated sign aspects, and the dependency structure defined by Peirce. In our first experiment, the quality of conceptualization is determined statistically. As an analysis of conceptualization by teams of participants can be more complex, in the second experiment we restricted our focus to a qualitative analysis of contiguous segments of a single process. Ontology specification is beyond the scope of this paper. An illustration of such a definition of syntactic symbols may be found in (Sarbo, Farkas & van Breemen, 2007).

TOWARDS A MODEL OF CONCEPTUALIZATION

Process model

Human conceptualization can be characterized by an interaction, between an input stimulus and the observer, and the generation of an explanatory response: why this input is occurring to us. For instance, if we, see a traffic light to switch from green to red, our reaction can be “Stop!”. A model of information processing underlying response generation can be the following (Sarbo, Farkas & van Breemen, 2007) . See also fig.1. Below, square brackets are used to indicate that an entity is not yet interpreted as a sign; no bracketing or the usual bracket symbols indicate that some interpretation is already available.

The input stimulus is affecting the observer occurring in some state. By denoting the qualia representing that state and the input stimulus, by q_s and q_e, respectively, the input of information processing can be defined by the collection of qualia or the '*primordial soup*': [q_s, q_e, C]. Here, “C” stands for the memory information (memory response qualia) or the *context* triggered by q_s and q_e. In order to generate a response, the brain/mind as an interpreting system has (1) to sort out the input qualia in the primordial soup (cf. *sorting*; $[q_s]$, $[q_e]$, [C]), (2) to represent them separately from each other (cf. *abstraction*; q_s, q_e), (3) to complement them with memory information (cf. *complementation;* (q_s,C), (q_e,C)), and (4) to establish a relation between them (cf. *predication*; (q_s,C)-(q_e,C)). For an in-depth analysis of the 'primordial soup' see the Jamesian based research program "Empirical Modelling" (Beynon, Russ & McCarty, 2006).

An example for the input can be the qualia of the appearing red light (q_e), affecting us when we are in a state of moving (q_s). In context, red light can associated with "warning" and moving with "stopping" ([C]). The relation between the input qualia can be paraphrased by the expression: "The appearing red light is a warning for stopping moving" or, briefly, "Stop!".

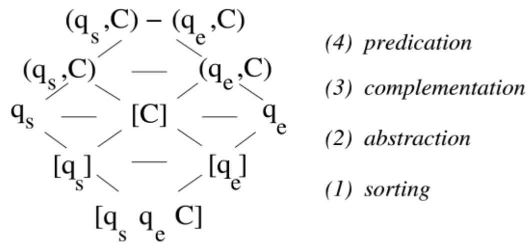

Figure 1. A model of cognitive information processing. A horizontal line stands for an interaction between interpretation moments

Although the above model of information processing can be plausible, it may not enable us to interpret it as a meaning generation process. In order to associate the events of the model with an element of meaning, first we need to delve into a theory of conceptualization which is the subject of the next section.

Received view of ontology

A domain specific ontology is a generalization of 'individual' conceptualizations. According to the Tractatus logico-philosophicus (Wittgenstein, 1922), truth preserving conceptualization ought to restrict itself to a specification of entities coverable by statements of fact. This view is also adopted in computer science. Gruber (2008) nicely illustrates this point when he writes:

> *In the context of computer and information sciences, an ontology defines a set of representational primitives with which to model a domain of knowledge or discourse. […] In the context of database systems, ontology can be viewed as a level of abstraction of data models, analogous to hierarchical and relational models, but intended for modeling knowledge about individuals, their attributes and their relationship to other individuals.*[i]

It must be admitted that Wittgenstein intended to cover all of reality while Gruber modestly states that ontology in computer science is a technical term. The background scheme of thinking, however, is the same: propositions form the key entrance to ontological thinking. But what if the formation of the proposition is the true ground on which to base the most general ontology?

In the Philosophical Investigations, (Wittgenstein, 1971) shifts from a detached view to a more inside perspective. The meaning of an expression no longer depends solely on the pictured facts: instead meaning is determined by the role the expression plays in the language game in which it figures. Uttering a sentence is like doing a move in a game of chess. Using language is rule governed. Learning language is learning to do the right moves and picturing facts is only one of the families of games, that has to be sub-divided according to its variant forms on top of that.

Peircean ontology

A shift from a static to a dynamic view of the world is an essential element of modern ontology. According to Peirce, our understanding of phenomena is marked by three categeories which he called Firstness (being), Secondness (existence) and Thirdness (reality, lawfullness or mediation)[ii]. Because whatever appears requires a certain shock or contrast, it may be said that the appearance must be distinguished from the *event* of appearing, for the latter requires two elements which by themselves must be said to be mere 'possibles'. Thus the appearance of red undoubtedly requires 'red' though this red does not *really* appear unless it is *perceived*. Thus the firstness of pure red appears only in the event of the perception consisting in the interaction of the perceiver and the perceived. And thus, the appearance in the event of appearing constitutes the aspect of Secondness. But the perception, to the extent that it is the merely brute fact of meeting, appears only insofar as it reveals itself as this particular perception, for instance the perception of this color red. Thus, in order to appear as perception, the perception must do so according to the rule that when this sort of event occurs, it appears as the perception of red. It is the rule governing the appearance that constitutes Thirdness. It tells us in what respect the appearance as event reveals the 'possible' elements of Thirdness.

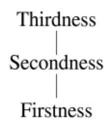

Figure 2. Peirce's categories and their involvement relation.
A lower category is involved in a higher one.

The most original feature of Peirce's analysis is that it shows that in everything cognizable all three categories are involved: respectively an aspect of reality which is not related to anything but itself (Firstness), an aspect of contrast (Secondness), and an aspect of mediation (of gluing together) (Thirdness)**.** The dynamic version of the doctrine is that every event (which is the element of Secondness) involves some possible qualities (Firstness) and some aspect of order (Thirdness). On the basis of the above dependency and subservience relations, the three categories can be arranged in a structure. See fig.2.

Sign aspects and interpretant aspects

Every phenomenon, as far as it can be cognized, is of the nature of a sign. According to Peirce, a sign always consists of a complexus of the three categories. By recursively applying his categorical schema, this time to the three categories of signs, Peirce concluded that signs can be analyzed in nine sign aspects. Peirce writes:

> *A Sign, or Representamen, is a First which stands in such a genuine triadic*

relation to a Second, called its Object, as to be capable of determining a Third, called its Interpretant, to assume the same triadic relation to its Object in which it stands itself to the same Object.

As a First, a sign can be a quality (qualisign), an event (sinsign), or a rule-like habit (legisign). As a Second, it can represent its object through a relation of similarity (icon), by pointing in the direction of the object (index) or, by expressing a conventional property involved in it (symbol). As a Third, it can mediate its object to an interpreting agent through expressing the sign's object as a possible (rheme), an actually existent (dicent) or, a proposition (argument, proposition interpreted as in 'something proposed'). On the basis of the dependencies and subservience relations, between them, the nine sign aspects can be arranged in a structure. See fig.2. Note the difference between interpretant, for instance, a thought sign, and interpreter, which is an interpreting system.

A sign only functions as a sign if it is interpreted. Following our assumption that for each sign aspect there must exist a corresponding interpretant aspect, in (Breemen & Sarbo, 2009) we have shown that Peirce's theory of interpretants can be completed in a structure consisting in nine interpretant aspects. See also fig.3. We skip details and directly illustrate the nine interpretant aspects with an example.

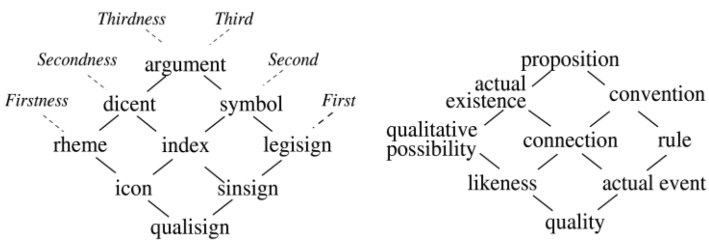

Figure 3. Peirce's sign aspects (left) and their mundane terms (right). Firstness, Secondness and Thirdness are categories; First, Second and Third are categorical aspects.

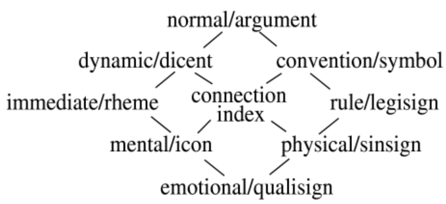

Figure 4. Peirce's interpretant aspects and associated sign aspects

An example of the nine interpretant aspects

We leave our earlier example of the appearing red light and proceed with the running example of the first experiment described later in this paper. Assume the sign to be the diagram, as shown in fig.5, perceived as a collection of impressions (perceived qualities). In addition, assume that the interpreter is primed with the question: "area(A)=2*area(B); $x=?$". The nine interpretant aspects can be explained as follows.

(1) The impressions get sorted out as a form (mental energetic interpretant; icon) and

settle as a singularity (physical energetic interpretant; sinsign).

(2) Since it is a familiar *iconic* singularity the form is recognized as an instance of a typical geometrical problem (rule; legisign). Since it is a *singular* icon out of any context at this stage, all kinds of interpretations become possible such as the form as a sign of an affine transformation, a computation of area, and so on (immediate interpretant; rheme).

(3) As the interpretation of the diagram is embedded in the specific context of the mathematical question, a conventional meaning of the legisign is developed (convention; symbol). Through the connection with knowledge contained in the interpreting system about known geometrical operations, the conventional meaning gets embedded in an understanding of the diagram as a sign of a certain geometrical operation to be applied on this occasion (dynamical interpretant; dicent). For instance, "the pair of diagonals of *A* divides it in four equal triangles (dicent), "a pair of equal triangles can be combined in a quadrangle through rotation" (symbol). Here, "diagonal" refers to background knowledge about quadrangles (index).

(4) This dynamical interpretant is, again through a connection with what is contained in the interpreting system, placed under a rule of habit that covers this kind of case and a response is generated ("*A* contains two pairs of equal triangles; by means of rotation a pair of equal triangles of *A* can be combined in a quadrangle satisfying the desired goal; therefore we should apply this operation" (normal interpretant; argument).

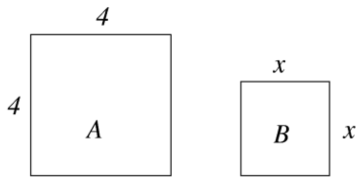

Figure 5. A geometrical problem

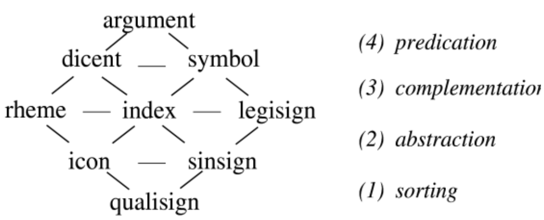

Figure 6. Peirce's sign aspects as an interpretation process (horizontal lines represent interactions between interpretation moments)

Process model revisited

The model of information processing introduced earlier in sect. "Process model" can be shown to be conform to the above classification of interpretant aspects. An important difference between the two models lies in the assumption, taken on behalf of the process model, that intermediate representations (cf. interpretation moments) arise via interactions between a state and an effect, in the context of background state and effect qualities. Through the interaction between state and effect, a change/contrast arises. That change is eventually interpreted as an event. In this chapter we merge the two models in a single one (see fig.6). Interpretation proceeds in four stages. Below we refer to positions in the process model (cf.

interpretation moments) by their Peircean sign aspects given in quotation marks, e.g. 'icon'.

(1) In *sorting*, 'raw' qualities of an interaction ('qualisign') perceived by the interpreting system are sorted out in a state ('icon') and effect ('sinsign'), which are in focus, and background or context qualities ('index'), which are complementary (i.e. not in focus).

(2) In the subsequent operation, *abstraction*, comprising the interaction between 'icon' and 'sinsign', the input qualities are abstracted into types, through matching with existing prototype concepts. This obtains a representation of the input in the 'rheme' (abstract state) and 'legisign' positions (abstract effect) (Smith, Osherson, Rips & Keans, 1988).

(3) In *complementation*, the interaction between 'rheme' and 'index', and between 'index' and 'legisign' are represented by expressions in the 'dicent' and 'symbol' positions, respectively. This operation could be called contextualization, by virtue of the use of prototypical information provided by the 'index'. Contextualization is comparable to lexical access and semantic interpretation (Margolis & Laurence, 1999).

(4) Finally, in *predication*, the interaction of 'dicent' and 'symbol' is represented by a hypothetical proposition ('argument') about the relation between the co-occurring state and effect qualities of the input interaction. If the hypothesis drawn does not fit or even is disconfirmed, either new complementation is searched for in the context or another focus is taken on the input qualities ('qualisign').

Note the correspondence between the above four stages, the four steps of interpretation, and the four levels of the model of information processing introduced in previous section**s**. As conceptualization is expressible as sign interpretation, in fig.6 we have in front of us the blueprints of a procedure underlying conceptualization as a process. Through its relation with the Peircean sign aspects, this procedure can be called a meaningful model of information processing.

In the experiments described later in this chapter the input consists in natural language utterances. How such utterances can be mapped to sign aspects that eventually yield the output, is illustrated in the next section with the analysis of a sample text. A full scale linguistic interpretation of the utterances is beyond our current goal. A formal definition of our process model as a syntactic parser may be found in (Sarbo & Farkas, 2002).

Cognitive theoretical background

Besides being grounded in Peircean semiotics, our process model is informed by cognitive theories of conceptualization as well. According to Piaget, learning and cognitive processes are adaptive 'tools' aiding man in its interaction with its environment. Focusing on cognitive development, Piaget defined four different stages in child development (Rigter, 1996):

(1) *Sensory-motor phase.* Objects and object characteristics are learned and recognized through perception and motor manipulation; this knowledge is stored as concepts or abstract representations of object characteristics (e.g., sweet).
(2) *Pre-operational phase.* Percepts are explained through reasoning. It is assumed that the most salient concept properties are included into interpretations.
(3) *Concrete operational phase*. Learning that different points of view are possible.
(4) *Formal operational phase*. Reasoning without preceding perception, development of abstract reasoning and hypothesizing.

A similar definition of conceptualization is due to Mead (1934, 1974), distinguishing cognitive activity in four phases: (1) impulse, (2) perception, (3) manipulation, (4) consummation. We assume that a ‘fully developed’ cognitive system amalgamates the processes and operations specified above and that these are effective in concept formation. Our model extends these notions and builds a bridge towards Intelligence Augmentation.

Sample conceptualization process

The running example of this section is a text found in (Huibers, 1996). In this fragment (see fig.7), the author explains his conception of ‘Information Retrieval Systems’ as given in fig.7 and depicted in fig.8. The utterances in fig.7 can be analyzed in sign aspects, as follows. Below, utterances are referred to by their sequence number and abbreviations, as shown in fig.7. Sign aspects are assigned to utterances on the basis of their contribution to the desired result ('argument'). The results of the analysis are recapitulated in fig.9.

nr.	string	abbreviation
1.	*There are several document-bases.*	*sev-docb*
2.	*Each document-base contains*	*each-docb*
	different types of information.	*dt-of-info*
3.	*There are various types of users and*	*vt-of-users*
	there are vast differences between	
	their information needs	*vdiff-ineeds*
4.	*There are various kinds of search-tasks,*	*vk-of-st*
	or stated differently,	
	there are several ways in which	*sev-ways*
5.	*a user can be satisfied with*	*canb-satf*
	the returned information.	*ret-info*

Figure 7. A sample text defining the concept 'Information Retrieval Systems'

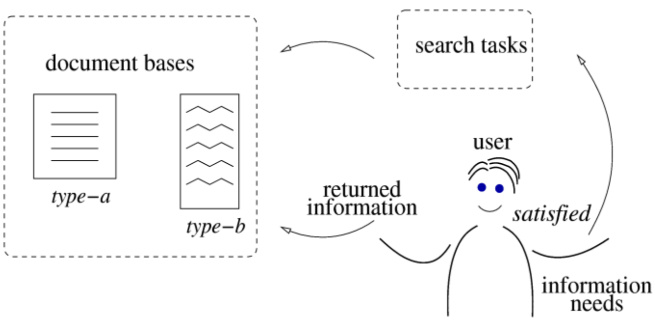

Figure 8. An illustration of the underlying phenomenon

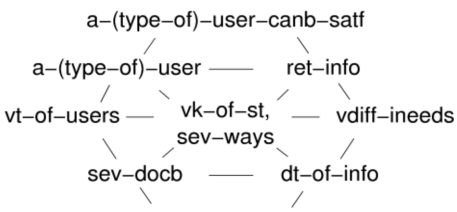

Figure 9. Interpretation moments as sign aspects

(1) *there are several document-bases (sev-docb)*:='icon'.

The postulation (*are*) of *sev-docb* as constituent entities, not as qualitatively possible ones (rheme), nor as such entities in context (dicent). The hypothesis immediately above can be justified by the fact that, besides (2), *sev-docb* has no later references in the text.

(2) *different types of information (dt-of-info)*:='sinsign'.
An expression of *dt-of-info* as an appearing new property of *docb* (cf. actual event). By means of the adjective *different*, this sinsign lays the ground for an interpretation of its relative difference with *each* (icon), as a legisign.

(3) *there are various types of users (vt-of-users)*:='rheme'.
An expression of existent entities (*are*). The later anaphoric reference to *users*, by *their*, in *vdiff-ineeds*, enables *vt-of-users* to be interpreted as an expression of a range of possibilities (‘of what type can users be’). Following the dependencies between the Peircean sign aspects, the interpretation of *vt-of-users* in the rheme position implies a representation of *users* in the icon position, enabling *users* and *docb* to be synonymously interpreted as constituents of ‘Information Retrieval Systems’ (their synonymous meaning is represented by *sev-docb*).

(3) *there are vast differences between their information needs (vdiff-ineeds)*:='legisign'.
A generalization of the single event, *dt-of-info*, in the rule governing this type of events, represented by *information-needs*. This is made possible by the relative difference between the icon and sinsign, marked by *each* and *several* on the one hand, and *different-types-of* on the other. The hypothesis immediately above is confirmed by the rule-like compatibility of *vast differences* (as an effect) and *information needs* (as its object), expressed by *vdiff-ineeds*. Due to the dependencies between the Peircean sign aspects, the interpretation of *vdiff-ineeds* as a legisign implies the interpretation of *vast differences* and *between* in the sinsign position. Note that this interpretation of the expressions is already involved in the interpretation of *dt-of-info*.

(4) t*here are various kinds of search-tasks (vk-of-st)*:='index'.
As there is no reference to *vk-of-st* later in text, this symbol may not represent information which is in focus. For this reason, *vk-of-st* cannot be interpreted as a rheme or dicent expression of the input either. According to the preferred interpretation, *vk-of-st* is representing an event, not by explaining it in any way, but only pointing in its direction. Due to the dependencies between the Peircean sign aspects, an interpretation of *vk-of-st* as an index expression implies the existence of complementary qualities (qualisign position). Hence these qualities must be involved in the rheme and legisign expressions as well.

(4) *there are several ways (sev-ways)*:='index'.
By virtue of the coordinator, *or stated differently*, and the complementation by *in which...*, also the above symbol can be interpreted as an indexical expression of complementary qualities. Note the complementary perspectives conveyed by the expressions *vk-of-st* and *sev-ways*. This is typical for the index position.

(5) *a user (a-user)*:='dicent'.
An expression of *vt-of-users* in context (more precisely, *a-(type-of)-users*), representing users demanding *various-kinds-of-search-tasks*.

(5) *returned information (ret-info)*:='symbol'.
From a syntactic point of view, the predicate (symbol position) is defined by the phrase

can be satisfied with the returned information. The complement (*ret-info*) can be interpreted as a representation of the nested phenomenon, 'information returning'. Following this line of thinking, *can be satisfied with (canb-satf)* is interpreted as a representation of an interaction between *ret-info* and *a-(type-of)-user*, hypothetically expressing the goal of 'Information Retrieval Systems' (argument position). Note that *ret-info* can be a representation of the conventional meaning of *vdiff-ineeds* in context, expressed by a combination of different *information needs* and *search tasks*, that may correctly be called 'information returning'.

Qualisigns can appear only when they are involved. Following this assumption of Peircean semiotics, expression in the qualisign position are omitted.

In order to test our hypothesis that conceptualization proceeds along the lines of our model, we conducted a couple of experiments. In the experiments the input is defined in natural language. By lack of space, an analysis of the utterances in sign aspects cannot be given in full extent. A more detailed account of this mapping may be found in (Couwenberg, 2007) and (Klomp, 2008).

FIRST EXPERIMENT: PROBLEM SOLVING

In the first experiment we focused on individual conceptualization. Twenty-eight pupils from a primary school in Nuland, The Netherlands, took part in this test. The age range was 11-12 years. The pupils were asked to solve a mathematical problem, as described by Plato (427-347 BC). See also fig.5. In his dialog the *Meno*, he raises the question how to determine the length of the sides of a square which is half as large as a given square (Plato, 1871). We chose this problem because its solution is straight forward, as outlined in (Magnani, 2001). At the same time the problem is complex enough to furnish the experimenters with data. Although the pupils already learned to compute squares, they rated the problem as difficult. According to the teachers, the participating pupils were not familiar with the problem since it was not a part of their Math course. Regarding their cognitive development in this domain, 8th graders are similar to adults (Delfos, 2000). The sample problem was chosen because many IA applications are targeting the respective population.

It is plausible to assume that with complex problems the outlined conceptualization process is recursively used whereby the propositions formed at the end of one process serve as input for the next run. Per run, one proposition is generated. Each run is delimited by the identification (naming) of a relation (e.g. "Square *A* is larger than square *B*").

The process is driven by the goal to formulate a fitting proposition. In solving a problem, the number of embedded analyses (cf. recursion) can be affected by three parameters:

- What is in focus (always a contiguous segment of input qualities).
- Input complexity (number of propositions used for describing the phenomenon in focus).
- Internal context (relevant knowledge of the world).

These are the sources of inter- and intra variability in interpretation. By the given problem, with a generally accepted solution, it is possible to determine in advance the goal governing the entire conceptualization process. Exploiting the thinking-out-loud method in the process of solving a complex mathematical problem, it is possible to gather verbal reports containing utterances reflecting the interpretation process. Utterances can be coded and ordered as sign aspects. The degree of match with the dependency structure specified by our model can be statistically determined. But do note that the same utterance very well may function as another sign aspect if the goal of conceptualization is different.

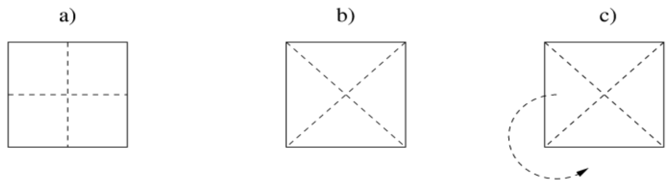

Figure 10. Additional material used in the experiments

Method

The test is supervised. If the hypothesis by the participants is disconfirmed by the experimenter, the experimenter may help shifting focus by the participant, from seeing the diagram as a problem to seeing it more as a solution, for instance, by drawing the participant's attention to the existence of diagonals in a quadrangle. To this end, the experimenter can make use of additional material. Background knowledge about diagonals is assumed to be available by the pupils. Note that by shifting focus, the instructor is not providing extra information with respect to the original problem.

In the experiment, verbalizations by the participants were recorded and transcribed during problem solving. Subsequently, verbal utterances were coded into the nine sign aspects. The use and the order of the stages of sign interpretation were determined on the basis of the prevailing sign aspects. This way, we were able to determine whether the observed conceptualization unfolds according to the stages specified by our model. This method is rather coarse in that verbalizations need not be entirely synchronous with the actual cognitive processing. We assume that the nine types of sign aspects are 'tied' to the respective operations of the model (e.g. 'icon', 'sinsign', 'index' - *sorting*, 'rheme', 'legisign' - *abstraction*, etc.).

Procedure and materials

The experiment was conducted using a standard protocol. All sessions were videotaped. The time intervals needed to solve the problem were registered by the experimenter using a stop watch. The setting was an empty classroom; a familiar work surrounding for 8th graders. The experiment was conducted individually. The experimenter was seated in an L-setting with respect to the pupil in order to avoid a suggestion of a 'leadership role' to the experimenter since this may affect the pupils' level of commitment to solving the problem. The experiment was conducted during regular school time. The experimenter was instructed not to interfere with the process of solving the problem unless this is indicated in the protocol. Each session started with the experimenter giving an instruction about the task and the procedure. The recordings contained on average 75 verbal utterances. Instruction: "First of all, you will receive a card with a drawing on it. The drawing expresses a geometrical problem. Your task is to uncover the problem and to find its solution. While doing this I would like you to say everything you are thinking about this problem."

This is called ‘thinking-out-loud’ method. Subsequently, the participants were handed over the drawing (see fig.5) and the session started. It was determined in advance in which situations the experimenter would interfere and how: If a participant was stuck with (part of) the problem (operationalized as inactive for 20 seconds) or if he/she made a mistake, the experimenter prompted him/her to try again and solve the problem or to try and correct the error. Some types of errors were anticipated upon which were already described in Plato’s Meno. They indeed occurred in the pilot study. Additional material used in the experiments is displayed in fig.10. This material was provided, if needed, in different orders assigned randomly.

Coding procedure

All transcribed verbal utterances were first assessed for their contribution to the solution of the input problem. Two kinds of codes were assigned: (1) contributes to the solution of the problem; (2) ‘side-tracking’ or ‘errors’ like wrong perception/representation/interpretation of the problem, wrong assumptions, and logical errors. For the former kind of utterances a coding system was developed with sign aspects and examples specified. In order to validate the coding system two experts independently coded a sample of verbal protocols. The degree in which the interpretation process in solving the problem is congruent with the conceptualization process as specified by our model was determined on the basis of prevalence of ‘correctly’ formed output argument aspects, i.e. 'arguments' preceded by conceptualizations (cf. interpretation moments) from any of the preceding processing stages in the order specified by our model.

Analyses

The inter-rater reliability of the coding system was determined using Cohen’s Kappa, and means and standard deviations (SD) were computed using Statistical Package for the Social Sciences, version 14 (SPSS 14).

Results

The inter-rater reliability for the coding criteria was high (Cohen’s Kappa = 0,924). In total, 1690 verbal utterances were coded. Average percentage of task related utterances was M=79% (SD=17.07). Average percentage of utterances classifiable into sign aspects was 84 (SD=10.5). Average percentage of congruent 'arguments' was 42 (SD=37.81).

Discussion

Our preliminary results show a high level of congruence of concepts comprising verbal reports with the concept types specified in our model. Moreover, also the order of concept formation as inferred from verbal reports is congruent with the order of processing stages specified in our model.

Human conceptualization can be fast. In order to get hold of the unfolding interpretation process we introduced a task that, by virtue of its complexity, forces problem solving to be split into stages. In the first stage, subjects are typically stuck at a trivial interpretation of their input (e.g. "There is a mathematical problem"). In this stage, conceptualizations from the lower part of the process model (see fig.6) are dominantly produced. The subsequent stages are more difficult and often re-focusing is needed in order to proceed in solving the problem. At the same time, conceptualizations of higher level sign aspects are generated (see fig.6). The findings suggest that solving the problem is effective if the interpretation process proceeds as suggested in our model.

SECOND EXPERIMENT: PROBLEM ELICITATION

In the second experiment we concentrated on team-wise conceptualization. To this end we analyzed an actual elicitation process at the Dutch software firm Sogeti Nederland B.V. In this process, three clients assisted by a professional elicitator were involved in the specification of a problem with the clients' database system. The entire elicitation process, that took 4 hours, was recorded and transcribed. Since in this experiment we had access to data from a single process, statistical analysis was not possible. However, the elicitation process was complex and we could test our hypothesis, that conceptualization, if successful, proceeds along the lines of our process model, by considering an analysis of a number of nested sub-processes of conceptualization. An example is provided in the next section.

Individual conceptualization differs from co-operative conceptualization in two aspects. One of them is the use of the context ('index'). In individual conceptualization the context consists in prototypical information possessed by the interpreter about objects in the world. This is opposed to conceptualization processes by teams, in which a context comprising shared information about the common input problem is gradually developed by the participants. Another difference is the assumption of a shared, uniform representation of knowledge (a use of identical sign aspects) by the participants. As conceptualization is necessarily individual, establishing a common conceptualization of the input problem assumes that concepts generated by individual processes can be merged through coordination.

Sample problem elicitation

A problem with the clients' application software, '*myAssignment'*, instigated the elicitation process. The goal of *myAssignment* is to provide adequate information to employees, managers and client(s), about assignments and, most importantly, about communication between the participants of a project. The elicitation process was conducted in a separate room, in a usual setting, without intervention by the observer whose only task was to operate the fixed camera.

A sample elicitation session is displayed in fig.11. The goal of this session is the disclosure of missing functionalities in *myAssignment*. Utterances of the sample text are interpreted from the perspective of *this* goal. In the analysis below, interjections are omitted. Note that interjections do have functions such as expressing doubt, agreement and alike. The results of the analysis are recapitulated in fig.12-13.

1. *(Pe) What, what I miss, ehh, in the current application ... is that ehh ... that I*

have an overview, ehh ... of the steps that I find most logical.
(Ca) Hmm, hmm (with approval)
2. *(Pe) What already happened.*
(Ca) Yes.
(Pe) And ehh ... what turned out to be the result.
3. *(Ca) History.*
4. *(Pe) Yes, history ...*
(Ca) Yes.
(Pe) ... went that, that, ehh, that description of the assignment to the ehh... employee?
5. *(Pe) For, I think I see a check mark of that application ...*
(Ca) Yes.
6. *(Pe) But I do not get a confirmation of anything, of ehh ...*
(Ca) No.
(Pe) whether it, ... it has been sent.
7. *(Pe) And I also do not know if it has been worked out by the employee.*
(Ro) Hmm, hmm.
(Pe) Do you, ehh...?
8. *(Ca) No, no I only know it because they tell me, like "Hi, I consulted and reached agreement and ehh ... that ehh ..."*
9. *(Ca) Yes of course, in the end you can read it off from the date of the last update, but you do not get ...*
(Pe) O.K.
10. *(Ca) ... an automatic mail or, or a mutation. For it is impossible to see what has been changed in the brief.*
(Pe) OK.
11. *(Ca) So, I also miss the history, like ehh ... what was the initial assignment.*

Figure 11. A sample elicitation session (Peter (Pe) and Caroline (Ca) are clients, Robert (Ro) is elicitator)

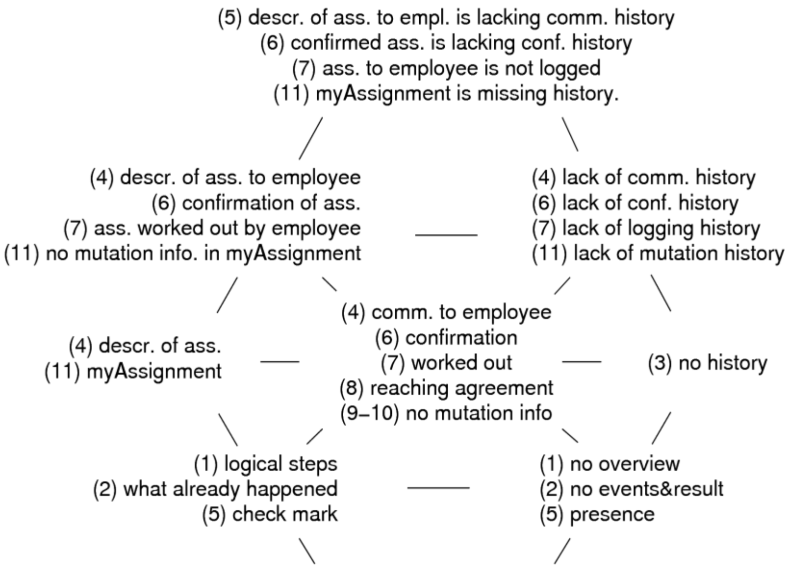

Figure 12. Elicitation by a team of participants (utterances are labelled by their sequence number as shown in fig.11)

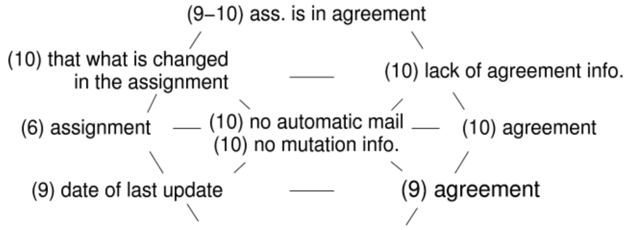

Figure 13. Nested conceptualization process

(1) *logical steps*:='icon', *no overview*:='sinsign'.
Peter admits that in the current application he is missing (cf. event) steps that he finds logical (cf. state).

(2) *what already happened*:='icon', *no events and result*:='sinsign'.
Peter refines his judgment, by paraphrasing his earlier concepts.

(3) *no history*:='legisign'.
Finally, Caroline recognizes the habitual concept of '*no history*', in the instance ('*no overview*') and corresponding form ('*logical steps'*) suggested by Peter.

(4) *description of assignment*:='rheme'; c*ommunication to employee*:='index'.
Similarly so, Peter recognizes an abstract concept involved in the input problem: 'description of the assignment'. He also refers to 'communication' towards the '*employee*'. As that concept is not further explained in this session (nor in the encompassing text), it must refer to background information. From the fact that Peter is expressing his 'doubt' in a proposition about the input problem (*description of assignment to employee is lacking communication history*:= 'argument') we conclude that all less developed sign aspects must be generated as well, such as the 'lack of a communication history': *lack of communication history*:= 'symbol' and, the 'description of the assignment' communicated to the employee: *description of assignment to employee*:= 'dicent'.

(5) *check mark*:='icon'; *presence*:='sinsign'.
Peter is justifying his conclusion, by referring to a possible 'presence' (cf. effect) of 'check marks' (cf. state), in *myAssignment.*

(6) *confirmation*:='index'.
Peter's doubt is related to his question about the existence of a conventional logging of 'confirmations' and, corresponding 'confirmed assignments': *confirmation of assignment*:= 'dicent'; *lack of confirmation history*:= symbol'.

(7) *working out*:='index'.
Peter doubts, if logging is actually 'worked out' by the employee. The appearance of this background information enables a re-evaluation of all more developed interpretation moments: *assignment worked out by employee*:= 'dicent'; *lack of logging history*:= 'symbol'.

(8) *reaching agreement*:='index'.
Caroline admits having the same doubts as Peter has. She points out that the employee, not the application software is providing her with information about reaching agreement with the client. According to her, a lack of logging is what is meant by 'missing communication history'. Hereby she is referring to 'reaching agreement' as a

nested process: *assignment is in agreement*:= 'argument', degenerately represented by a pointer: *reaching agreement*:= 'index', in the encompassing conceptualization process. By introducing a new 'index' expression, Caroline shows her interpretation of a common term involved in the generation of Peter's conclusion (note that a generation of the 'dicent' and 'symbol' positions is coordinated by the context ('index'), in the interpretation process).

In (9) and (10), Caroline is further elaborating on her conceptualization of the nested process. In (9) she pinpoints: *date of last update*:= 'icon'; *agreement*:= 'sinsign'. In (10) she introduces: *no automatic mail, no mutation information*:= 'index'; *lack of agreement information*:= 'symbol'. By making use of dependencies between the sign aspects and, the assumption that ‘agreement’ (cf. effect) must be related to an ‘assignment’, enables the nested conceptualization process to be completed: *assignment*:= 'rheme'; *agreement*:= 'legisign'; *that what is changed in the assignment*:= 'dicent'.

(11) *changing*:='index'.

Through a proposition of the nested process, the element of a ‘no mutation information’ is inherited in the index position of the encompassing conceptualization process. The appearance of this information as an index expression, this time not as a sign of doubt, but as one of a hypothesis, triggers a re-evaluation of all more developed input sign aspects. Assuming (11) is providing a conclusion of the conceptualization process so far, it follows that the subject of the process Caroline is referring to (although not explicitly mentioning) must be the application program itself: *myAssignment*:= 'rheme'; *no mutation information in myAssignment*:= 'dicent'; *lack of mutation history*:= 'symbol'. She concludes: *myAssignment is missing history*:= 'argument'.

By introducing new conceptualizations for already existing ones that have identical sign aspects, the participants of the process make an attempt to coordinate their individual conceptualization processes with such processes by the others.

Discussion

The above example illustrates that conceptualization by a team of participants is congruent with our model. A preliminary analysis of the entire recorded text shows the possibility for a similar result (Klomp, 2008).

A practical conclusion that can be drawn from this experiment is the following. If the participant(s) of an elicitation process are all aware of the stages that their conceptualization process has to go through, then meta-level information about the process (what is the current stage and which stages do follow) can be used to control the process on object-level. In other words, the dependency structure of sign aspects can be used as pigeon-holes during the generation of a solution for a problem.

A rough analysis of the second experiment reveals that approximately 63% of the entire text is effectively contributing to concepts generated by the elicitation process. The remaining text is either redundant or not relevant for the problem in focus. In a workshop following the experiment the participants of the elicitation process have been instructed about the nine sign aspects. After a 15-20 minute introduction they were able to use the new information and comprehend their elicitation process from a higher-level perspective. This gives hope that efficiency on object-level could be improved by making use of meta-level information about the process. Further research is needed to unveil the effects of such a combined use of information in elicitation processes.

FUTURE RESEARCH DIRECTIONS

Our future research aims at the further development of our applied as well as of our theoretical results. This involves a more refined analysis of the data obtained by the Meno-experiment. We are in particular interested in the role played by goals and subgoals during problem solving and in the question how hierarchies of (sub)goals can be modeled and eventually used for a characterization of different conceptualization strategies. We also plan a new experiment that capitalizes on the use of object- and meta-level information in co-operative problem elicitation projects. The goal of this line of research is to validate our conjecture that a combined use of the two kinds of information can improve the efficiency of conceptualization.

In our theoretical research we try to expand our computational model to Peirce's most expanded, but unfinished sign classification. This classification is better known as the *Welby classification* because the ideas are made public mainly by Peirce's correspondence with lady Welby, a member of the Signific circle. The main difference between Peirce's 1903 classification, the classification we work with, and the Welby classification concerns the attention paid to quantification and modality in the latter. As a result the three sign relations, yielding nine sign aspects and ten sign types is expanded to ten relations, yielding thirty sign aspects and 66 possible sign types. Following the conclusion of Morand (2004) that the small classification is the kernel of the Welby classification, we try to show that on the basis of Peirce's nine sign aspects a computational model can be defined for the expanded classification as well.

CONCLUSION

We have shown that our model can be used to analyze concept formation in human problem solving, either individually or in teams. This means that the model is highly congruent with human information processing. This suggests that individual and team-wise conceptualization are in principle the same. Being a formal model, it can be used in a wide range of IA-applications such as computer supported tutoring and human-computer interfacing. A typical way to proceed would be to determine the goal that must be served and fill the sign aspects positions with what is needed to realize that goal. Note that in most cases, subordinate processes are needed. Such nested processes always appear through the index position that, by coordinating the interpretation moments, ties together the whole process of interpretation. However, more experiments are needed in order to explore the features of the model more extensively.

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KEY TERMS & DEFINITIONS

Intelligence Augmentation is a field of research aiming at increasing the capability of a man to approach a complex problem situation, to gain comprehension to suit his particular needs, and to derive solutions to problems.

Interpretation is a translation of input to an informed response, by an (interpreting) agent.

Ontology is the study of being qua being (philosophy). In computer science, ontology refers to (i) an inventory of all types of entities in a domain, (ii) an inventory of the mode of being of the representational primitives.

Problem elicitation is a process that tries to control co-operative interpretation in complex situations.

Process can be characterized by three conditions: (i) one event initiates a sequence and another terminates it, (ii) every event that contributes to the sequences yielding the terminating event is regarded as part of the process and (iii) the terminating event governs which events make up the sequence.

Semiotics is a general theory of all possible kinds of signs, their modes of signification, of denotation, and of information; and their whole behavior and properties, so far as these are not accidental.

Sign is traditionally equated with what we know as the sign vehicle (the sign as an object). In Peircean semiotics the concept of sign is much more encompassing since the relation of the 'vehicle' with its object(s) and interpretant(s) are included.

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[i] See: http://tomgruber.org/writing/ontology-definition-2007.htm

[ii] We obtained the association of the category Firstness with being, Secondness with existence and Thirdness with reality from C. Schuyt (personal communication, 1991)