Eye-Tracking and Conceptual Combination

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Abstract

Processing conceptual combinations has been shown to be based on interactive activation of the concepts involved (Coolen, van Jaarsveld, & Schreuder, 1993). In this paper an approach for investigating conceptual combinations of nouns in an online way by using eye-tracking data is described. Words fixated in a compound-production task form a sequence of symbolic data that can be analyzed by a psychometric method called knowledge tracking (KT) that is based on Markov processes. Empirical evidence has been found that conceptual combinations assessed as medium acceptable attract eye movements more frequently than other ones (especially clearly acceptable or clearly unacceptable conceptual combinations).

Introduction

Understanding compounds is an ubiquitous cognitive process. Many languages are rich in compounds, and conceptual combination is one of the most important ways of forming new concepts. Currently there are five major theories of concepts: the classical approach, the prototype theory, the exemplar approach, the theory-based model, and the theory of psychological essentialism (Hampton, 1998). It is, however, well known in the literature on concepts that none of these theories provides a convincing explanation to a key issue encountered when processing concepts: conceptual combination. Regarding prototype theory of concepts, for instance, Osherson & Smith (1981, 1984) made evident that there is no generally applicable function that maps the prototypes of PET and FISH to the prototype of the resulting compound PET FISH. However, in many languages – including, e.g., German – conceptual combination is a basic mechanism in both generation and understanding of natural language. In a word: while previous work on concepts had a narrow focus on simple concepts, it is now generally accepted that a theory of concepts can not do without a theory of compounding and methods to carry out empirical investigations accordingly.

There are two general strands of theories that react to the failure of the major theories of concepts. One of these strands has a clear semantic orientation. Theories in this tradition seek to explain conceptual combination by referring to the meaning of compounds. A case in point is the concept-specialization theory (Murphy, 1988), which regards conceptual combination like HOUSE BOAT as a refinement or specialization of the more general concept BOAT. The other strand of theories on compounds has a more syntactic orientation and is rooted in linguistics, in particular in the syntax of words (Selkirk, 1982). Work on compounds in this tradition is based upon the observation that there are striking parallels to fundamental phenomena well known in sentence processing: First, we can generate and understand an unlimited number of compounds on the basis of a small number of simple concepts. Second, we can assess the well-formedness of compounds indicating that there is a "grammar of concepts" with some classes of concepts being more prone to form combinations with others. Recent work on conceptual combination tries to link both approaches, e.g., by analyzing semantic constraints to the compounding process (Keane & Costello, 1997) or by trying to establish a catalogue of semantic relations that link concepts together (Gagné & Shoben, 1997). The methods applied, however, can hardly capture the process of compounding, which has been shown to be highly interactive with the concepts involved in a compound activating each other mutually (Coolen, van Jaarsveld, & Schreuder, 1993).

While rating studies, analysis of thinking aloud protocols and reaction time studies clearly provide valuable insights into conceptual combinations they have difficulties to capture the interactive nature of processing conceptual combinations. We take the view that investigations of conceptual combinations could profit very much from methods that take the interactive nature of processing conceptual combinations into account. Information of this type establishes constraints concerning theories about conceptual combination.

The goal of this paper is to present a method that allows for an approach to online-investigation of conceptual combinations. The paper is organized as follows: First, we briefly report on previous work on Markov processes in cognitive science. Second, an overview of *knowledge tracking* (Janetzko, 1996; 1998; in press) is given. Knowledge tracking is a method that is based on Markov processes and tailored to analyzing sequential symbolic data so that underlying cognitive structures become explicit. Third is an outline of an empirical validation study that shows more specifically how this approach can be brought to bear in empirical research. In particular, it is described in which way eye-tracking protocols are recorded while subjects build conceptual combinations. Finally, we discuss possible consequences for investigating concepts.

Eye-Tracking and Markov Processes

The method used to analyze eye-tracking protocols rests on Markov processes, which are usually explained by referring to stochastic processes. A stochastic process is defined by a random variable X_n, a state space (potential values of the random variable), and transition probabilities between the states. Processes with every state depending on one or many preceding states are called Markov processes. Models based on Markov processes are quite common in fields like pattern recogntion – in particular speech recognition – or DNA sequencing. In speech recognition, hidden Markov models (HMMs), viz., a special type of Markov process, are widely used. In HMMs, the states are unknown. Markov processes have also been used and adopted to the analysis of sequential data in cognitive science, in particular eye-tracking data (Suppes, 1990; Salvucci & Anderson, 1998). Here, fixations form a sequence of states, and the outcome of analysis is the identification of a model that accounts best for some observed sequence of states. When using a method based on Markov processes like knowledge tracking for analyzing cognition it is important to remember some of their defining features. In particular, the fact that this technique derives prediction in a strict history-based way has to be considered. For this reason, modelling controlled cognitive processes (e.g., goal-directed cognition like some types of planning or problem solving) via Markov processes raises severe problems . In this case, the phenomenon analyzed clearly conflicts with features of the formal model used. By the same token, modelling cognitive processes that underlie conceptual combination by analyzing eye-tracking protocols appears to be a suitable field for applying this type of models. The reason for this is that processing conceptual combination is (even for novel compounds) often extremly fast (e.g., Zwitserlood, 1994) and thus apparently not a goal-driven process.

Knowledge Tracking

Knowledge tracking (KT) is a psychometric method that carries out a diagnosis of cognitive representations. Knowledge tracking can be used in confirmative or in a generative mode. The former provides a rationale to decide which of some candidate theories (concept structures) explains a sequence of data best.[1] The latter may be taken to generate a concept structure on the basis of some start-up structures such that the newly generated structure fits to the data best (Janetzko, in press). We will, however present only the confirmative mode of knowledge tracking. Knowledge tracking rests on Markov processes models (Gardinger, 1990), but it is tailored to analyzing cognition. For instance, knowledge tracking provides more flexibility when calculating goodness of fit scores between empirical data and models. The models may be parametrized such that spreading activation in models is realized (Janetzko, in press). Furthermore, models set up within knowledge tracking are empirically testable, which is not the case in standard HMMs (Dijkstra & de Smedt, 1996).

The Data: Sequence of Concepts

The input of data required by knowledge tracking is a sequence of symbolic data or concepts (e.g., the sequence of the concepts CAT, DOG, FISH, MOUSE etc.) that refer to the sequence of states in a Markov process. This kind of data may be obtained in eye-tracking studies, thinking aloud studies or studies of HCI (human computer interaction).

The Theory: Relations and Structures

Knowledge tracking needs a theory to analyze sequences of symbolic data. To specify a theory we have to select one or many relations (e.g., `x is-a y`, `x eats y`). On the basis of a relation we may then add a set of concepts that are taken to instantiate the relations. We end up with concept structures. A very simple concept structure can be described in a Lisp-like notation as (is-a (MOUSE MAMMAL) (HORSE MAMMAL) (SHARK FISH) (HERRING FISH) (FISH VERTEBRATE) (MAMMAL VERTEBRATE)) (cf. Fig. 1). Every network (e.g., hierarchies ontologies, partonomies, semantic networks) of concepts, be it a cyclic or an acyclic graph, can be called a concept structure. Other formalisms of knowledge representation like, e.g., schemas or scripts may also be redescribed as concept structures (Janetzko, 1996).

Calculating Scores for Goodness of Fit

In KT, the theory, viz., one or many concept structures, is taken to calculate goodness of fit scores on the basis of sequences of symbolic data. The goodness of fit scores describe how well a sequence of symbolic data can be explained by a concept structure. Usually, a number of concept structures is brought to bear, all of which are competing as far as the explanation of the data is concerned. The structure that yields the best goodness of fit score will then be taken as the most suitable model for the cognitive structure explaining the

[1] By explanation we refer to the theory-based prediction of data.

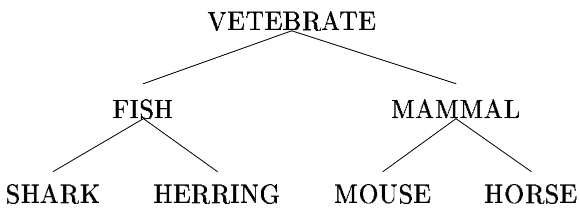

Figure 1: Simple Concept Structure organized by the Relation is-a

empirical data. To compute scores for goodness of fit we have to transform all concept structures into transition probabilities. The technical details behind the calculation of the goodness of fit scores are described in Janetzko (1996; in press).

Knowledge Tracking in five Steps

In sum, analyzing cognitive structures via knowledge tracking involves five steps:

- eliciting concepts and relations in the domain under study and setting up concept structures,
- recording empirical data (sequences of concepts), e.g., in eye-tracking studies,
- expressing the concept structures by transition probabilities; this is essentially the transformation of knowledge-based models into probabilistic models,
- explaining empirical data by using concept structures and calculation of goodness of fit scores
- selecting the structure that produces the best goodness of fit score.

Empirical validation studies carried out with data collected in human-computer interaction support the claim that the structure that gives the best account of the empirical data is in fact the structure that has dominated cognition while producing the data under study (Janetzko, 1996).

Eye-Tracking and Conceptual Combination

We used a simple production task to record eye-tracking data while subjects were engaged in conceptual combinations. Subjects were presented with a computer screen where randomly simple German nouns were displayed in circular way (cf. Fig. 2).[2] Presenting the stimuli (nouns) in a circular way does not lead to one big path of overlapping eye-tracks. Nilly-willy, this would have been the consequence, if we had presented the stimuli in a list-form. Thus, a circular arrangement of the stimuli allows us to analyze the eye tracking more conveniently (cf. Fig. 2).

Figure 2: Arrangement of Concepts in Study 2

The subjects were requested to form noun-noun-compounds by using the concepts presented on the screen. In so doing, subjects had to rely on their eye-movements in order to combine concepts. In preliminary studies, it became obvious that some subjects throw one glance on the screen and rely then heavily on their working memory. Clearly then, in theses cases the eye-tracking data are not indicative for the compounding process. To impede this memory-based strategy we introduced a secondary task: Subjects were requested to count backwards from 10 to 0. Whenever they were able to produce a compound they could pause during counting backwards, state the compound and start again counting backwards. Eye-tracking was recorded while the subjects were producing compounds. The fact that our subjects could combine concepts while doing a second task provides supporting evidence to our initial assumption that conceptual combination is not a goal-directed process. Every indication to the contrary would have raised problems concerning the application of a technique based on Markov processes. To balance out sequence effects, we set up a computer programm that arranged the items randomly in a circular way for each trial. The presentation of items was never in one line (cf. Fig. 3). In this way, a possible bias towards reading from one item to the next one to the right was minimized. The whole procedure of recording the eye-traces is presented in Zugenmaier and Janetzko (1998). By presenting the stimuli in the way described we are in a position to record the eye-movements while subjects were carrying out the task of conceptual combination (cf. Fig. 4). Note that the sequence of eye-movements can easily be conceived as a sequence of symbolic data. Knowledge tracking allows us to analyze these data by calculating goodness of fit scores with respect to con-

[2]Translation (in clockwise order beginning with the concept at the 12 o clock position): Way, Fence, Castle, Garden, Guest, King

cept structures.

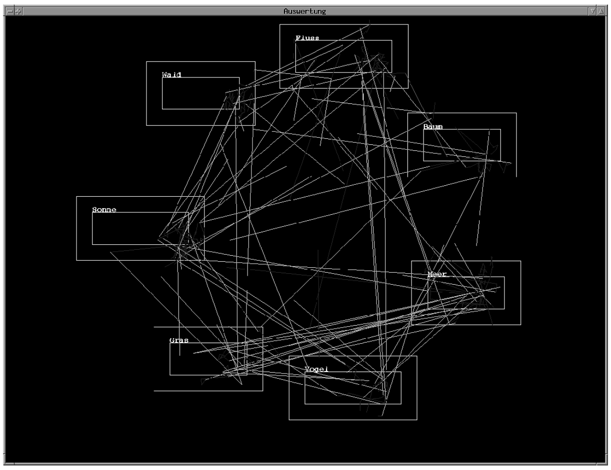

Figure 3: Eye Movements recorded in Conceptual Combination

Empirical Validation Study

The goal of the empirical validation study was to test the sensitivity of analyzing eye-tracking data with respect to underlying structures by using knowledge tracking. The general steps when applying this approach are as follows:

- Setting up concept structures that slip into the role of hypotheses used to analyze sequential symbolic data via knowledge tracking.
- Administering a compound-production task and recording the eye-tracking protocols.
- Converting the sequence of eye-movements into a sequence of symbolic data.
- Analyzing the sequence of symbolic data via knowledge tracking.

In the following sections we present the steps of this examination in more detail

Study 1: Specification of Concept Structures

The purpose of this study was to elicit acceptability scores for compounds that could possibly be of predictive value for eye-tracking behavior as examined in the next study. We used compounds built by the concepts that were also used in the following study.

Participants

Participants were 12 subjects (6 male, 6 female). According to a simple questionnaire administered before the investigation all subjects spoke German as their first language.

Materials

Subjects had to assess the acceptability of 49 nominal compounds that were systematically produced by using the words AUTO, HAUS, PARK, TÜR, SCHIFF, STUHL, ZAUN (Translation: car, house, park, door, ship, chair, fence). All words used for conceptual combinations can be considered as simple German words that are very common according to word frequency indexes like CELEX.

Procedure

On the basis of the seven concepts stated above all possible noun-noun compounds were produced (AUTOHAUS, AUTOPARK, AUTOSCHIFF etc.[3]) Some of these concepts are true lexicalized compounds that are in everyday usage of German speakers (e.g., HAUSTÜR, engl: housedoor) while other compounds sound rather odd for German speakers (e.g., ZAUNSCHIFF, engl: fenceship). Still other compounds are with respect to their acceptability between these extremes. The subjects assessed the acceptability of each compound on a 5-point rating-scale.

Results

The results of study 1 was a simple classification into 5 classes of compounds that differed with regard to their level of acceptance. Moreover, each of these classes had an internal structure (Fig. 4) , which was employed in the following study. For ease of presentation, we will just give an outline of the summary scores obtained in this rating study (cf. Tab. 1).

Discussion

The acceptability ratings were transformed into concept structures that could easily be used by knowledge tracking as hypotheses required to analyze symbolic sequential data. If, for instance, we transform the class of highly acceptable compounds into a concept structure, we obtain a structure like (class-1 (AUTO HAUS) (AUTO TÜR) (HAUS TÜR) (PARK HAUS)). The meaning of this structure is simply that by using the nouns listed in pairwise brackets highly acceptable nominal compounds can be built. Similar concept structures can be constructed by the data that lead us to establish the other classes of compounds (Tab. 1).

Study 2: Compound-Production Task

In study 2 we collected eye-movement protocols (sequences of symbolic data) that reflect cognitive processes in a compound-production task. Before specifying details of study 2, it is important to see the linkage between both studies. By using the results of study 1 we have established concept structures that express the acceptability of compounds. In study 2 data

[3]In an agglutinative language like German compounds usually form a single compound word.

Table 1: Stimuli and results of study 1

Class	Compound	Rating
1	AUTOHAUS, AUTOTÜR, HAUSTÜR, PARKHAUS	$\bar{x} = 1$
2	AUTOPARK, HAUSSCHIFF, HAUSZAUN, PARKTÜR, PARKZAUN, ZAUNTÜR	$1 < \bar{x} \leq 2$
3	AUTOSCHIFF, HAUSPARK, PARKSTUHL, SCHIFFPARK, STUHLPARK	$2 < \bar{x} \leq 3$
4	AUTOSTUHL, HAUSAUTO, HAUSSTUHL, SCHIFFSHAUS, TÜRZAUN	$3 < \bar{x} \leq 4$
5	PARKSCHIFF, STUHLAUTO, STUHLSCHIFF, TÜRHAUS, TÜRPARK, TÜRSCHIFF, TÜRSTUHL, ZAUNAUTO, ZAUNSCHIFF	$4 < \bar{x} \leq 5$

are collected that will be analyzed by using these concept structures. In so doing, we can address the question whether or not acceptability of compounds is important for the eye-movement behavior. We hold the hypothesis that subjects will fixate more often compounds that are at a medium level of acceptability. This should be so since compounds considered very high or very low in acceptability should be analyzed more quickly. Hence they should lead to less pair-wise fixations. In contrast, compounds on a medium level of acceptability should be considered more intensively. Here, we expect a high rate of "jumping" back and forth between the concepts involved.

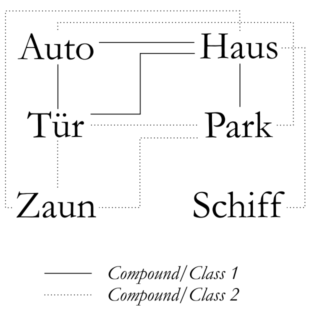

Figure 4: Concept Structures based on Study 1

The types of arrows indicate different levels of acceptance for compounds. Note that only the compounds of classes 1 and 2 are presented (Park=parc, Haus=house, Tür=door, Schiff=ship, Zaun=fence, Auto=car).

Participants

Participants of study 2 were 5 subjects of whom 2 were female. According to a simple questionnaire administered before the investigation, all subjects spoke German as their first language.

Materials

The 7 German words, the compounds of which have already been described in study 1, were also used in study 2.

Procedure

Subjects had to produce compounds according to the procedure described above. Eye-tracking data were recorded by IVIEW, a video-based tool for eye-tracking by Sensomotoric Instruments that uses the corneal reflection technique. The analysis software allowed us to specify rectangular areas laid over the concepts to decide whether or not a word has been fixated.

Results

The eye-movements were automatically recorded and transformed into a sequence of symbolic concepts (trace). This trace has been analyzed by using the five concept structures that were obtained as a result of study 1 (cf. Table 1). We carried out a descriptive analysis of the data. Figure 5 shows the results of our analysis (goodness of fit scores) on the on the y-axis. These were obtained by analyzing the eye-tracking data of five subjects across five classes of compounds that are lined up on the x-axis (cf. Fig. 5). The results provide supporting evidence to our hypothesis that highly acceptable (class 1) and also highly inacceptable (class 5) compounds do not lead to intensive processing while compounds that are on a mediate level of acceptability do. Clearly, we need further data to establish a firm empirical ground. However, the tendency of the data testifies to the usefulness of this method.

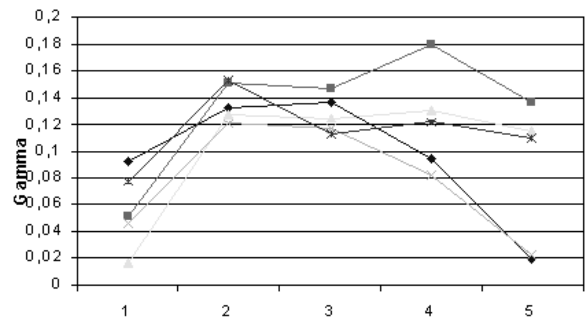

Figure 5: Analysis of Eye-Tracking Protocols via Knowledge Tracking

General Discussion

The purpose of this study was to show the feasibility of knowledge tracking as a method to analyze eye-tracking in compounding. Knowledge tracking is a general method that can be taken to analyze each type of sequence of symbolic data on the basis of some concept structures (cf. Janetzko, 1998; 1999; in press). In our analysis of eye-movement protocols via knowledge tracking three aspects became apparent: First, the method employed gives a good indication of cognitive processes in conceptual combination. In particular, it is an online-method, and it thus provides insights into conceptual combination by measuring the effort put into this task. However, eye-tracking protocols especially when recorded in exploratory tasks like ours suffer from a bad signal-noise ratio. This is due to the fact, that subjects very often generate and test compounds. Second, we only applied concept structures that essentially express whether or not a compound is or is not acceptable. If knowledge tracking is used to investigate the knowledge used in compounding the concept structures applied have also to represent knowledge. This can be done, if we take compounding relations like `x is_made_of y` or `x causes y` (Gagné & Shoben, 1997) to analyze the conceptual combination. Third, we may assume that vast amounts of knowledge are applied in a task like the compound-production task introduced in this paper: Possible relations are tested, and analogues to well-known similar compounds are generated. For a more complete analysis of the knowledge involved in a task like this, a method is required that can tap the theories applied by a problem-solver once he or she forms a compound. To meet this requirement, we have developed a version of knowledge tracking that is no longer restricted to be a confirmative method. This type of knowledge tracking specifies the plausible bridging inferences that may be drawn between pairs of concepts in a symbolic trace. Then, it adds up these inferences to a theory underlying the production of the symbolic trace (Janetzko, in press).

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The Role of Mental Imagery in Understanding Unknown Idioms

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Abstract

In studies of the cognitive processing of idioms, the role of mental imagery in understanding idioms remains a controversial issue. Cacciari and Glucksberg (1995) conducted an experimental study to investigate whether generating mental images of idioms can facilitate their comprehension. Their results appeared to reject both the possible connection between the literal mental image of an idiom and the figurative meaning of the idiom, and the facilitatory effect of mental imagery on comprehension. Our study aims at exploring the facilitatory role of mental images in understanding unknown idioms. We used a paraphrase verification task for transparent and opaque unknown idioms translated from foreign languages into Bulgarian. The results demonstrate that literal mental images of transparent unknown idioms can facilitate their comprehension in terms of error scores in a simple paraphrase verification task. No facilitation effect for opaque unknown idioms was obtained. This points towards a link between the literal mental images of transparent idioms and their figurative meanings.

Introduction

The bulk of cognitive research on idioms is devoted to comprehension processes. Some have investigated the contribution of the literal and figurative meanings of idioms in the comprehension process, and whether both meanings are computed serially or in parallel (Needham, 1990; Estill&Kemper, 1982; Glass, 1982; Swinney&Cutler, 1979); other studies have shown that at some recognition point literal processing stops and the figurative interpretation becomes available (Cacciari&Tabossi, 1988; Tabossi&Zardon, 1993; Titone&Connine, 1994). Another research area explores the tenet that conceptual metaphors constrain or mediate our understanding of idioms (Gibbs&O'Brien, 1990; Nayak&Gibbs, 1990; Gibbs, 1992). Finally, researchers have also studied the strategies that people use to understand tropes and idioms, for example, using the semantics of the constituent words, analogies, metaphorical extensions, etc. (Cacciari, 1993; Flores d'Arcais, 1993). However, relatively little attention has been paid to the role of mental imagery in the process of understanding figurative language. In some theoretical frameworks, imagery is regarded as an important component in discovering the figurative meaning of tropes and idioms (Lakoff, 1994; Paivio&Walsh, 1998), although experimental studies have produced contradictory results (Gibbs&O'Brien, 1990; Cacciari&Glucksberg, 1995).

Following Lakoff and Johnson's framework (1980), Gibbs and O'Brien (1990) argue that the meanings of idioms are motivated by conceptual metaphors. For example, the idiom *spill the beans* is motivated by the CONDUIT metaphor which specifies the conceptual mapping that THE MIND IS A CONTAINER and IDEAS ARE ENTITIES. Their claim is that people have conventional images and knowledge for the meanings of idioms. To test this, in Gibbs and O'Brien's experiment, subjects were asked to form a mental image of an idiom and describe it verbally. The results suggest that these images have a dynamic nature and people are able to determine the causes and consequences of the actions in them. The data obtained also confirm the expectation of a high degree of consistency in mental images for idioms with similar figurative meanings. Thus, Gibbs and O'Brien (1990) emphasize that conventional images are "unconscious, automatic, and independent of modularity" (p. 39). They do not propose any algorithm of constructing mental images for idioms but they investigate "the *products* of speakers' mental images for idioms as a way of discovering the knowledge and information that potentially motivate the figurative meaning of idiomatic phrases in English" (ibid.). Finally, they do not claim that people use mental imagery during 'normal' idiom comprehension given that idioms are processed very rapidly. It is children and non-native speakers of a language but not experienced speakers that may form mental images as a way of understanding idioms.

Contrary to the findings of Gibbs and O'Brien (1990), Cacciari and Glucksberg (1995) claim that the images associated with idioms do not reflect their meanings, moreover, forming mental images does not facilitate the comprehension of idioms. They argue that people cannot bypass the literal meaning when processing idioms and forming a mental image, and that it is much easier to form a literal image of an idiom than a figurative abstract one. In this case the images that reflect the literal meaning of an idiom could not refer to the underlying conceptual