Conceptual Combination as Theory Formation

Dietmar Janetzko
dietmar@cognition.iig.uni-freiburg.de
Institute of Computer Science and Social Research
Center of Cognitive Science
University of Freiburg i. Br.
D-79098 Freiburg

Abstract

Conceptual combination is an instance of synthetic problem solving comparable to design or planning. This work reviews evidence supporting the view that the result of such a synthesis has much in common with theory formation. Similar to theory formation inference in conceptual combination can be modeled by using abduction as the principal mechanism to generate hypotheses. However, abduction in itself provides no answer to questions regarding the explanation and selection of hypotheses. Results of two experiments address these issues and provide converging evidence to the view that conceptual combination is a form of theory formation. The results are interpreted within a framework of constraint satisfaction which is assumed to take place on a micro-level (compounding relations) and on a macro-level (principle of parsimony).

Introduction

What is the "glue" between words like *house* and *boat* that allows us to make sense out of the resulting conceptual combination *house boat*? There is a number of indications suggesting that conceptual combination is an instance of synthetic problem solving (like design or planning) that may be qualified as theory formation *en miniature*: First, most of the researchers in the field agree that conceptual combination can be best described in terms of knowledge structures, viz., two or more concepts that are reconstructed locally once they are involved in conceptual combination. Simple concepts in itself are often viewed as condensed theories (e.g., Murphy & Medin, 1985). Second, in many cases conceptual combinations can be paraphrased by a relative clause (e.g., *a house boat is a boat that ...*). In this way it becomes evident that conceptual combinations may add a more fine-grained conceptual schema to the conceptual classification system we already have. This is an example of *taxonomy revision* that is often related to theory formation (e.g., Shrager & Langley, 1990). Third, conceptual combinations provide support in description, explanation and prediction of phenomena, all of which are often taken to be the defining functions of theories (e.g., Brown & Ghiselli, 1955). The descriptive function is perhaps the most obvious one since conceptual combination is one of the major linguistic mechanisms for word formation (Olsen, 2000). The explanatory function is actually at the heart of conceptual combination: whenever we are confronted with a combination of concepts, we cannot but start searching for a coherent explanation that integrates the concepts usually by relation linking or carry over of an attribute. Finally, the predictive function is supported by the fact that selective inheritance of attributes is made possible in conceptual combination (Hampton, 1987). Hence, new phenomena or artifacts are often labeled by making use of it (Costello & Keane, 2000). While work in theory formation has traditionally focused on respectable scientific theories that have become hallmarks in the history of science, theory formation in conceptual combination is of a more mundane type. Usually, its basic function is to set up micro theories that help explaining simple compounds like, e.g., *turpentine jar* and the phenomena they are referring to. However, there are striking parallels between both types of theory formation.

Though most of the work on conceptual combination relies on comparable schemas of knowledge representation, the procedural assumptions may differ considerably. Upon closer inspection it becomes evident that some of the variance in the field is due to the fact that different problems of conceptual combination are focused. These aspects can be sorted by recasting them in terms of a model of theory formation. In so doing, constraint satisfaction needs to be recognized as a major aspect of processing in synthetic problem solving (Smith & Brown, 1993). As in many instances of synthetic problem solving, in conceptual combination there is a huge number of possibilities to integrate entities (e.g., nouns). This is evidenced by the high number of interpretations obtained especially from novel compounds (Costello & Keane, 1997).

However, many of the investigations of conceptual combination rely exclusively on interpretation and rating tasks. These methods can only tap time-consuming processes. Clearly, we all know that conceptual combination can proceed both slowly and controlled. But there is also evidence from the few reaction time studies on conceptual combination that this process can also be very fast and and carried out automatically (e.g., Gagné & Shoben, 1997). The fact that processing of conceptual combinations may be accomplished either very fast or slowly needs to be accounted for. For this reason, I will suggest a schema that addresses the issue of constraint satisfaction in conceptual combination on two levels, which classify problems of conceptual combination according to two tasks:

I. The interface-selection task. A open question in conceptual combination is whether or not conceptual combinations are represented as a whole or in parts (*full listing hypothesis* vs. *decomposition hypothesis*, Butterworth, 1983). This issue clearly has consequences for models of processing of compounds and thus for the interface-selection task in conceptual combination. Usually, however, in work on conceptual combination it is the *decomposition hypothesis*, which is implicitly adopted. In so doing, a number of rationales has been hypothesized for the selection of the part(s) of the knowledge structures involved (e.g., slots, relations) that are taken to establish the linkage between combining concepts. Investigations and models that address the interface-selection task have been put forth: Wisniewski (2000) suggested that an alignment process, viz., similarity assessment, between modifier and head guides this task, while Estes & Glucksberg (2000) found evidence that salience of attributes is underlying interface-selection. Finally, investigations by Gagné & Shoben (1997) supported the view that there is a fixed set of compounding relations and selection of a relation is done according to the frequency of its usage. Construction of interpretations of conceptual combinations proceeds by rendering the reconstructed knowledge of the concepts involved into the natural language. This task is accomplished if one or many interpretations of candidate conceptual combinatations are found.

II. The interpretation-selection task. Even if the selection problem is solved successfully, there is usually a great number of possible interpretations remaining. Hence, a second step has to take over that consists of evaluating the candidate interpretations. Work along these lines has been carried out by Costello & Keane (2000) who provide empirical evidence that search of an appropriate interpretation is narrowed down by the constraints of diagnosticity, plausibility and informativeness.

Basically, the two task of this schema boil down to a generate-and-test approach, which is adjusted to issues of conceptual combination. While there are a number of investigations that address either the first or the second task, there is no organizing framework that integrates work in the field and provides empirical evidence supporting this framework. Only in a few investigations the generative nature of conceptual combination that leads to synthesis of knowledge structures has been spelled out in a sound way. The goal of this paper is to identify and investigate mechanisms of theory formation in conceptual combination. In so doing the schema outlined above provides some methodological assistance by guiding the investigations to both a micro-level and a macro-level.

The paper is organized as follows: First, I am describing the type of conceptual combination that has been investigated in this work. Second, the role of theories in conceptual combination is discussed. Third, following the work of Stickl (1989) and Hobbs, Stickel, Appelt & Martin (1990), I give an outline of abduction, which is assumed to be the generative mechanism that drives theory formation in conceptual combination. While the work on abduction mentioned provides a sound foundation of processing conceptual combinations, there are some empirical questions relating to the generation and selection of hypotheses that are not addressed by this approach. Fourth, according to the two-step schema introduced above, I am presenting two experiments on these issues. The first experiment highlights mechanisms of linking modifier and head in conceptual combination. The structure of preferred theories is investigated in the second experiment. The final discussion places the results into the framework presented initially and considers open questions related to theory formation in conceptual combination.

Conceptual Combinations

The first part of a nominal or noun-noun compound is usually called the *modifier* and the second part is referred to as the *head*. There are various schemata for classifying interpretations of this type of compound, but the one most widely accepted schema seems to be the one introduced by Wisniewski (e.g., Wisniewski, 2000). He distinguishes three types of interpretations: In *relation-linking* interpretations, people explicitly use a relation to explain a compound (e.g., robin snake = a snake that eats robins). *Property* interpretations involve one or a few properties of the *modifier* that are applied to the *head* (e.g., robin snake = a snake that has a red underbelly). *Hybrid interpretations* are not precisely characterized since this category might apply to a conjunction of the constituents or a cross between them (robin canary = a bird that is half canary and half robin). The work on conceptual combination described in this paper is focusing on noun-noun compounds that have a relational interpretation.

The Role of Theories

The seminal paper of Murphy & Medin (1985) is often taken to be the beginning of a line of research that views concepts as condensed theories. In many investigations of conceptual combination that follow this approach, knowledge or theories have not been described very precisely. Still, ample evidence has been collected that background or domain knowledge feeds into conceptual combination (e.g., Hampton, 1997).

In the work presented here, theories may be defined on two levels: On a functional level, theories are conceived as knowledge structures subjects may use for description, explanation and prediction of phenomena of interest. On a representational level, I am adopting a schema for describing both the nominal compounds, background knowledge and for deriving thematic or compounding relations that has been suggested by Hobbs et al. (1990, p. 24f):

$$(\exists x, y) turpentine(y) \wedge jar(x) \wedge nn(y, x)$$

The three propositions of this logical form are meant to signify a juxtaposition of two nominals, and *nn* is a placeholder for the compounding relation to be found. The background theory might take the following logical form

$$(\forall y) liquid(y) \wedge etc_1(y) \supset turpentine(y)$$

which denotes that being liquid is among other attributes a feature of turpentine and

$$(\forall e_1, x, y) function(e_1 x) \wedge contain'(e_1, x, y) \wedge liquid(y) \wedge etc_2(e_1, x, y) \supset jar(x)$$

meaning that if the function of something (x) is – among other things – to contain liquid, then it may be a jar.[1]

Abduction in Conceptual Combination

The view on conceptual combination outlined in this work follows a rationale of inference called *abduction* that can be described as explanatory hypothesis generation (Stickel, 1989; Hobbs et al, 1990). More precisely, the proper place of (the generative part of) abduction in the schema described above is within the first task: By abductive inference hypotheses are generated on the basis of domain or background knowledge that provide a means for interface selection. Evaluation of the hypothesis is part of the second task.

Abduction is a mechanism used frequently in models of theory formation. Contrary to deductive reasoning there is no guarantee for correctness in abductive reasoning. Cast in a more concise formal lingo, abduction can be described as follows:

$\mathcal{D}$ is a collection of data (facts, observations, givens);
(1.) $\mathcal{H}$ explains $\mathcal{D}$ ($\mathcal{H}$ would, if true, imply $\mathcal{D}$);
(2.) No other hypothesis explains $\mathcal{D}$ as well as $\mathcal{H}$;
Therefore, $\mathcal{H}$ is correct.
(cf. Falkenhaimer, 1990, p. 160, numbers added).

Applied to the analysis of conceptual combination $\mathcal{D}$ refers to a noun-noun juxtaposition. $\mathcal{D}$ is really just a juxtaposition and does not provide any hints concerning its potential coherence or fitting together. However, it motivates processes that seek to find evidence in favor or against coherence in $\mathcal{D}$ (cf. Thagard, 1997). $\mathcal{H}$ signifies one or many compounding relation(s). They slip into the role of hypotheses that have the potential of specifying in which way the concepts of $\mathcal{D}$ cohere. Note that hypotheses are derived from domain or background theories. In our example introduced in the preceding section we may infer abductively

$$(\forall e_1 x, y) contain'(e_1, x, y) \supset nn(x, y)$$

meaning that the placeholder *nn* might be identified with the relation or hypothesis *contains*.

If there are more hypotheses that may explain $\mathcal{D}$, the best of them is selected. Clearly the criteria of what "best" means in the field of conceptual combination are not specified in this fairly general definition.

Two things should be noted in the definition of abduction as provided by Falkenhainer (1990): First, abduction is a two-step process that bears strong commonalities to the two tasks in conceptual combination described above. Second, to find out whether or not the definition – and thus abduction – holds in conceptual combination, this definition needs to be applied to the field and also further specified. But what does "true" (1.) and what does "well" mean" (2.) in the definition above?

Both issues are essentially empirical questions. Concerning the first of them I am making the conjecture that the hypothesis $\mathcal{H}$ is said to be true iff the relation can be successfully instantiated by the concepts of $\mathcal{D}$. Whether and to which degree instantiation is modified by similarity on the level of attributes is also an open issue. Concerning the second issue I assume that a hypothesis is said to explain $\mathcal{D}$ well if it is parsimonious and sound, which is equivalent to the heuristic of Occam's razor.

Experiment 1: Constraints on the Micro-Level

Experiment 1 examines the effect of activation of thematic relations on the process of conceptual combination. Patterns of the compounding relations were varied as the independent variable. This variable was chosen for two reasons: First, by using this variable it could be investigated whether the *full listing hypothesis* or the *decomposition hypothesis* holds in conceptual combination. Second, by using this variable groups of items could be set up that differed in the degree of similarity. Hence, a comparison of different accounts to conceptual combination could be carried out. These are approaches that rely primarily on similarity (e.g., Wisniewski, 2000) vs. approaches in which compounding relations hold the key to conceptual combination (e.g., Gagné & Shoben, 1997). With regard to the schema introduced above, experiment 1 addressed the interface-selection task, viz., the mechanisms leading to the linkage between modifier an head.

Method

A semantic decision task was used to assess conceptual combination in nominal compounds. Subjects were instructed to read both prime and target and were requested to decide as quickly and as correctly as possible whether the target was a concept that refers to a material entity (e.g., rubberball).

Participants. The subjects were 39 students (18 male and 21 female) of Freiburg University who either participated for course credit or payment. The age of the subjects ranged between 18 and 29.

Materials and Procedure. The experimental stimuli were prime-target pairs. Both prime and target were common compounds that were based on simple German

[1] The primed predicate $contain'(e_1, x, y)$ together with its arguments signify that e_1 is the eventuality of *contain* being true for *x* and *y*.

nouns[2]. Compounds based on metaphors, names or associated words were excluded. Since novel compounds are known to elicit a variety of interpretations, I used common compounds that have a standard interpretation. In this way, fixation of the number of interpretations was achieved, and thus the effect of the independent variable, viz., the pattern of the compounding relation, could be investigated more precisely. Investigations of the effects of the independent variable led to the selection of 4 groups of items (cf. Table 1).

	CoI	CI	NCI	DI
Prime	lipstick	snowball	tennisball	summertime
Target	rubberball	rubberball	rubberball	speedlimit

Table 1: Groups of Items used in Experiment 1

18 *Control items (CoI)*, which were made of pairs of compounds each of which used a different thematic relation. Moreover, the words in each pair were different (e.g., tennisball - snowball - thematic relations: “x is made of y”, “x is used for y”). All items used (both prime and target) were made up of concrete concepts (e.g., lipstick).
18 *Concordant items (CI)*, which were made of pairs of compounds both of which shared the same thematic relation. Moreover, the head concept was identical in prime and target (e.g., snowball - rubberball, common thematic relation: “x is made of y”). To achieve a balance between concrete and abstract relations, 9 of the items of CI used the relation “x is made of y”, and 9 employed the relation “x is used for y”. All CI used concepts (both prime and target) referring to concrete words.
18 *Non-concordant items (NCI)*, which were made of pairs of compounds each of which used a different thematic relation. Still, 9 target compounds used a concrete thematic relation (”x is part of y”), while 9 used an abstract thematic relation (”x is used for y”). The head concept was identical in prime and target (e.g., tennisball - snowball, thematic relations: “x is made of y”, “x is used for y”). All NCI used concepts (both prime and target) referring to material entities.
18 *Distractor items (DI)*, which were made of pairs of compounds each of which used a different thematic relation. In contrast to items of all other groups all distractor items (both prime and target) used abstract concepts (e.g., speed record).

Note that prime and target of CI, NCI and CoI (each of which was presented together with the items from DI) were becoming increasingly dissimilar: In CI there was an identity of thematic relation and modifier, in NCI only the heads were overlapping. Finally, in CoI there was neither on the level of words nor on the level of the thematic or compounding relations any overlap. While all words in CI, NCI and CoI were concrete, all words in DI were abstract.

[2]Note that the experiment was carried out in German where all compounds are written as one word.

The items were used in a between subjects design with three groups. Subjects of each group was presented with the 36 Items of (CI & DI; NCI & DI, CoI & DI). Thus, in each group there was the same number of abstract and concrete targets (18:18). The SOA was 300 msec and the ISI was 100 msec (cf. Zwitserlood, 1994). Subjects worked first through a series of 24 training items that included a mixture of all types of items mentioned above. After that subjects were requested to decide as quickly and as correctly as possible whether the 36 items used were concrete or abstract words.

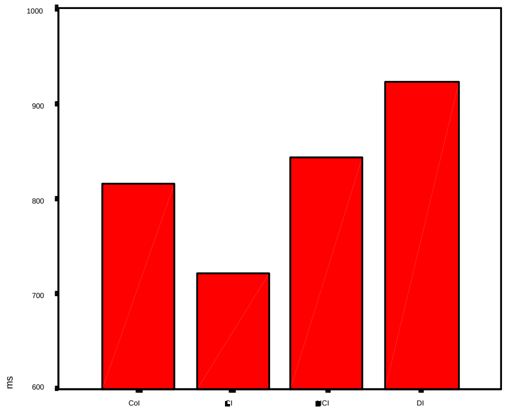

Figure 1: Results of Experiment 1

Results and Discussion

Fig. 1 presents an overall view of the results of experiment 1. Pairwise analyses of the results were carried out via Mann-Whitney-U-tests and via the Wilcoxon-test in the case of the dependent samples involved in the comparison of CI and DI. Scores of CI were significantly lower than the scores of the groups NCI (z=-7,37 , $p < .001$), CoI (z=-3,41 , $p < .001$), and DI (z=-6,45 , $p < .001$). Interestingly, the difference between scores of CoI and scores of NCI was not statistically reliable. Beyond that the difference does not point into the direction expected on the basis of a similarity approach (cf. Figure 1). This suggests that similarity (on the level of attributes) between heads of prime and target had no facilitating effect.

The results indicate two things: First, processing of the compounding thematic relation plays indeed an important role in conceptual combination. Throughout the investigation the thematic relation has never been expressed explicity. Given the fast mode of the task we may safely conclude that the compounding relation is processed unconsciously. This is especially striking since common compounds were used. These concepts are often believed to be processed as one unit without considering the constituents. This can be taken as a conservative test of the *decomposition hypothesis*, which was clearly better supported by the data than the *full listing hypothesis*.

Second, having addressed the more basic question whether the *decomposition hypothesis* or *full listing hy-*

pothesis gives a better account of the data, I will now turn to the question whether similarity (on the level of attributes) or relations hold the key for the interface-selection task. It is worth pointing out that NCI scored quite low although there was an identity of heads in both prime and target. If attributes had played at least a minor role, then the increasing similarity on the side of the stimuli (*sim* CI $>$ NCI $>$ CoI) would have induced corresponding effects on the side of the dependent variable (*rt* CI $>$ NCI $>$ CoI). However, this is not the case. Taken together, the data do not support the view that similarity (as specified on the level of attributes) provides the rationale of addressing the selection problem.

It is tempting to assume that by priming a particular (misfitting) relation in NCI, this relation may block or reduce the salience of the most suitable thematic roles of the constituents. Hence, the subject has to make an effort to retrieve a more appropriate relation from the domain knowledge. This may be due to a time-consuming derivation process. A possible model of this process is provided by the abductive rationale spelled out by Hobbs et al. (1990).

Experiment 2: Constraints on the Macro-Level

The goal of experiment 2 was to examine aspects of compound interpretation that affect its acceptance. With respect to the schema introduced above, experiment 2 addressed the interpretation selection task, viz., the choice between competing interpretations of a conceptual combination. If conceptual combination is indeed a form of theory formation, then features like “concise” and “plausible” often considered to be aspects of a good theory should also characterize an appropriate interpretation of a conceptual combination.

Method

In experiment 2 judgments of interpretations of novel compounds were elicited. The type of interpretation was used as the independent variable. The interpretations employed in the experiment had been generated and assessed in two preparation studies conducted before experiment 2 with independent samples of subjects.

Participants. 121 subjects (57 male, 64 female) between 16 and 42 years old participated in experiment 2.

Materials and Procedure. 4 $\times$ 20 pairs of novel compounds along with group specific interpretations were used in experiment 2. The material consisted of novel compounds since common compounds have a standard interpretation. Thus, a variety of different possible and in principle equally appropriate interpretations could not be generated on the basis of common compounds.

The interpretations investigated in experiment 2 had been set up in two preparation studies carried out with different subjects: First, in an in-between study a sample of subjects (20 subjects, 12 female, 8 male, between 18 and 41 years old) was requested to generate interpretations of 20 novel German compounds (e.g., “curtain hotel”) according to 4 conditions: *detailed and creative* (dc), *detailed and plausible* (dp), *concise and creative* (cc), and *concise and plausible* (cp). Second, in a subsequent in-between rating study a new sample of subjects (32 subjects, 21 female, 11 male, between 18 and 47 years old) assessed each group of interpretations on a five-point scale according to its aptness or inaptness. For each of the 20 novel compounds that have been used, 4 interpretations with the highest aptness ratings were selected and were subsequently employed in experiment 2.

The final outcome of the two preparation studies were 80 pairs of conceptual combination + interpretation all of which were on a high level of aptness. The pool of 80 pairs of conceptual combination + interpretation was divided into 4 groups of 20 items. Each group consisted of an equal share of items from all 4 conditions (dc, dp, cc, cp). In experiment 2, subjects of each group were presented with 20 pairs of novel compounds + interpretations that should be assessed on a five point rating scale (1 excellent – 5 unappropriate) concerning their aptness as an explanation of the compound.

Results and Discussion

Fig. 2 presents an overall view of the results of experiment 2. Pairwise comparisons of the results were conducted via Mann-Whitney-U-Tests. Scores of cp turned out to be significantly lower than the score of the groups dc (z=-16,29 , $p < .001$), dp (z=-3,54 , $p < .001$), and cc (z=-18,05 , $p < .001$).

The results of experiment 2 show that criteria that are usually applied to sound theories also apply to interpretations of conceptual combinations. These results are consistent with the more general hypothesis of this paper that conceptual combination is a form of theory formation.

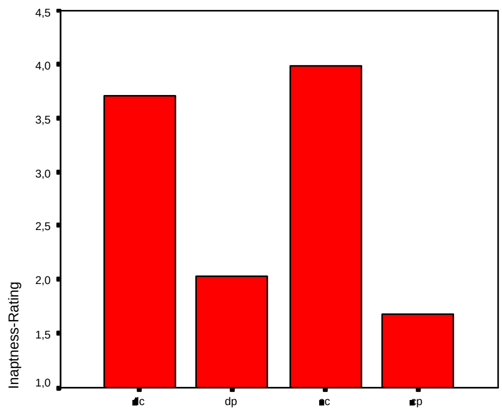

Figure 2: Results of Experiment 2

General Discussion

Research on conceptual combination can be characterized by two more general issues: First, empirical work in the field has mostly been conducted isolated from considerable formal work on conceptual combination. The formal work on abduction outlined briefly in this paper provides valuable insights for conceptual combination, e.g., concerning knowledge representation and abduction. Second, within the camp of empirical researchers the two basic tasks in conceptual combination have usually not been distinguished properly. The work presented in this paper reacts to these problems both by setting up an account of conceptual combination as theory formation that integrates many aspects of the field and by providing empirical data that is consistent with this framework. Clearly, more empirical work is necessary that fleshes out the framework presented in this work and elucidate the role of domain or background knowledge which has also been found influencial in conceptual combination. In fact, work on abduction coming mostly from computational linguistics offers some guidance for knowledge representation (Hobbs et al., 1990, p. 24), which is almost absent in more psychological work on this topic. Taken together, both issues stress the role of abduction in conceptual combination. This pattern of reasoning might help to explain conceptual combination in terms of theory formation.

Viewing conceptual combination as an example of theory formation holds the promise of a crossfertilisation between two hitherto almost uncombined research tradition: Research on conceptual combination could became more aware than hitherto that the phenomenon under study is a generative process details of which can be captured in terms of explicit schemas of knowledge representation. On the other hand, work in theory formation that has been focusing on theory formation in the natural science (an excellent survey is given by Darden, 1997) could broaden this perspective and consider theory formation *en miniature* in conceptual combination. Investigations based on this research strategy could be fruitfully applied in psychology, anthropology and ethnology.

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