# Polysemy in Conceptual Combination: Testing the Constraint Theory of Combination

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**Abstract**

Most novel noun-noun combinations are polysemous in that they tend to suggest several possible meanings. A *finger cup* can be a cup in which fingers are washed, a cup shaped like a finger, a narrow cup and so on. In this paper, we present a new theory of concept combination, the constraint theory, that accounts for the polysemy of noun-noun combinations. Constraint theory, which uses three constraints (of inclusion, plausibility and informativeness) acting over a unitary mechanism that generates candidate interpretations, makes certain predictions about the polysemy of different combinations. In particular, it predicts that combinations involving artifact terms should be more polysemous than those involving natural kinds because the former have functional models that promote multiple interpretations. In a single experiment, this prediction is confirmed along with other predictions about the types of interpretation that tend to be produced.

## Introduction

Research on concept combination lies at the heart of our understanding of natural language and concepts (see Gleitman & Gleitman, 1970; Murphy & Medin, 1985; Osherson & Smith, 1981). Most previous research has concentrated on how people arrive at a single interpretation for a *modifier-head* combination like *car repair* or *plastic dog* (see Murphy, 1988, 1990; Wisniewski, 1995; but see Kay & Zimmer, 1976). This research has tended to underplay the creativity and inventiveness of conceptual combination. For concept combination can be viewed, like analogy, as a method for creating new knowledge from previous experience (see e.g., Keane, in press; Keane, Ledgeway & Duff, 1994). Taking this perspective, we look at the *polysemy* of conceptual combination, at the multiple interpretations an individual can produce to a single novel noun-noun combination [1]

[1] We assume that ambiguous words in combination will affect polysemy (e.g., bat ball); so, our concern is with how the conceptual representation of two normally unambiguous words affects polysemy (in Wisniewski & Gentner's, 1991, terms we examine the *relational ambiguity* not *lexical ambiguity* of combinations).

Table 1: Interpretations for *bed pencil*

(1) a pencil that you put beside your bed for writing some messages
(2) a pencil used to draw patterns on bed-clothes
(3) a bed made out of pencils
(4) a pencil shaped like a bed
(5) a thin bed
(6) a big, flat pencil that is a bed for a doll
(7) a pencil case

So, typically, we present subjects with novel noun-noun concept combinations and note the frequency and variety of interpretations they produce to each combination. Table 1 shows just some of the interpretations produced to the novel combination *bed pencil*.

The present research is motivated by several aims. First, to examine several little-investigated factors that affect polysemy. Second, to determine whether the results from single-interpretation paradigms extend to this multiple-interpretation one. Third, to learn about the structure of our conceptual systems. Fourth, to determine the baseline ambiguity in combinations that is resolved by context (see e.g., Murphy, 1990). In the following sections, we review some of the empirical and theoretical work in this area before presenting a new theory of combination and a test of this theory.

### Some Empirical Findings in Concept Combination

Single-interpretation research has established several regularities about the content of interpretations (see e.g., Hampton, 1987; Murphy, 1988; Smith, Osherson, Rips & Keane, 1988; Wisniewski & Gentner, 1991). Three main categories of interpretation have been studied (typical percentages based on single-interpretation studies by Wisniewski and colleagues are indicated):

- *Relational interpretations* (30%-50%) establish some relationship between the modifier concept and the head concept (e.g., 1, 2 and 3 in Table 1)

- *Property-mapping interpretations* (30%-50%) assert a property of one concept as true of the other concept (e.g., 4 and 5 in Table 1)

- *Hybrid interpretations* (0-10%) which are *both* the modifier-concept and the head-concept (e.g., "a colorful fish that is kept as a pet" for *pet fish.*; closest example in Table 1 is 6)

To these we add a fourth category that has not been closely examined before:

- *Known-concept interpretations* (?%) where the interpretation is a known concept (e.g., 7 in Table 1)

The second main empirical regularity is that the *referent* of the interpretation (what it is about) is typically the 2nd noun or *linguistic-head* of the combination, following the pragmatics of English noun-noun phrases (Gleitman & Gleitman, 1970; e.g., see 1, 2, 4 and 6 in Table 1). However, in some cases, *reversals* occur in which the 1st noun or *linguistic-modifier* is the referent (e.g., 3 and 5 in Table 1). Wisniewski and Gentner (1991) found such reversals in substance-count phases (e.g., a *plastic dog* is a piece of plastic shaped like a dog). Finally, some interpretations (termed *exocentric* in linguistics; Cannon, 1987) can have as referent a concept other than those mentioned in the combination (e.g., 7 in Table 1). It remains to be seen whether these empirical regularities hold when we consider the multiple interpretations produced by a single individual to a given combination.

### Some Theories of Combination

Two main theories have concerned themselves with the above empirical regularities; concept-specialisation theory (e.g., Cohen & Murphy, 1984; Murphy, 1988) and alignment theory (e.g., Wisniewski & Markman, 1993; Markman & Wisniewski, in press).

*Concept-specialisation theory* maintains that the combination process specialises a slot of the head concept with the modifier concept. So, "a pencil used in bed" specialises the function-slot of *bed* with *pencil* (see Table 1). This theory expects relational interpretations with linguistic-head referents. However, it does not easily predict the other interpretation-types or reversals (i.e., it is not clear whether they could emerge from the theory's ill-specified elaboration process).

*Alignment theory* maintains that combination involves an alignment process, in which the concepts' slots are aligned to find commonalties (matching slot-value pairs) and alignable differences (matching slots with different values). These alignable differences are then used to identify properties to map (e.g., in *elephant bird* the size-slot matches but the values differ, allowing BIG to be mapped from *elephant* onto *bird*). On its own, this theory expects property-mapping and hybrid interpretations to be produced and seems to allow some types of reversals to occur (in substance-count phrases; see Wisniewski & Gentner, 1991). However, it is silent on known-concept interpretations and requires a specialisation mechanism to deal with relational interpretations.

Both of these theories concentrate on explaining how a single, acceptable meaning for a compound is produced. In contrast, a theory of polysemy must account for the variety of meanings that are produced to a given compound and how these interpretations might vary in their relative acceptability. We propose a new *constraint theory* of concept combination that explicitly deals with polysemy using a unitary mechanism to explain all the interpretation-types, which makes specific predictions about the nature of reversals.

## Constraint Theory of Concept Combination

Constraint theory has three components: (i) three constraints -- inclusion, plausibility and informativeness -- that decide the acceptability of interpretations (ii) a generative mechanism that produces interpretations which satisfy those constraints (iii) a set of knowledge assumptions about the types of concepts used in the combination.

### The Three Constraints

At the heart of the theory, three constraints of inclusion, plausibility and informativeness decide the acceptability of compound phrase interpretations. These constraints can reject some interpretations and/or promote some as being more acceptable than others; hence, dealing directly with the issue of relative acceptability. The choice of the constraints is motivated by the pragmatics of compound interpretation and use. There are a number of pragmatic requirements which a compound phrase interpretation should meet: each constraint implements one of these general requirements in a specific way. The first requirement is that an interpretation should in some way include both constituent concepts of the phrase being interpreted: any interpretation of a novel compound such as "bed pencil" should involve both the concept *bed* and the concept *pencil*. This requirement is carried in our theory by the constraint of *inclusion*, which specifies a particular way in which concepts are included in interpretations: through the presence of their *diagnostic* properties.

A second requirement is that compound interpretations should describe something which is consistent with background knowledge: interpreting *bed pencil* as "a bed you can pick up and write with" would be unacceptable in most contexts. In constraint theory this requirement is carried by the constraint of *plausibility*, which states that consistent interpretations are those which contain elements which are aready known to *co-occur* in background knowledge.

Finally, a third requirement is that compound phrase interpretations should convey some new information (e.g., Grice, 1975). Interpreting *bed pencil* as "just an ordinary pencil; you could use it in bed if you wanted" is clearly incorrect: the speaker chose the modifier *bed* to specify a particular type of pencil and a good interpretation should take that into account. In constraint theory this requirement is carried by the constraint of *informativeness*, which states that a good interpretation will contain properties which could not be conveyed by either the modifier or the head concept alone.

The *inclusion* constraint requires interpretations to contain diagnostic predicates of both concepts. In our terms, a diagnostic predicate is one that strongly distinguishes the concept from other known, related concepts (similar to Rosch's, 1978, *cue validity* idea). Inclusion makes the second interpretation more acceptable than the first:

- a cactus fish is a green fish
- a cactus fish is a prickly fish

because PRICKLY is more diagnostic of cactus than GREEN. The inclusion constraint also requires that *the referent of the interpretation possess diagnostic predicates of the linguistic-head* (i.e., the 2nd noun). This does not disallow reversals but requires these linguistic-modifier referents to have the diagnostic predicates of the linguistic-head. Usually, this will mean that diagnostic properties of the linguistic-head will be asserted of the linguistic-modifier. For example, Wisniewski & Gentner (1991) report a reversal interpretation for *chair ladder* of "a chair that is by necessity used as a ladder" where the diagnostic function of *ladder* is asserted of the *chair*. Thus, the theory makes the novel prediction that reversals should tend to be property-mapping interpretations (a prediction we test later).

The *plausibility* constraint requires that interpretations describe an object (or collection of objects) which could plausibly exist. Plausibility makes the second interpretation more acceptable than the first:

- an angel pig is a pig with wings on its tail
- an angel pig is a pig with wings on its torso

because prior experience dictates that wings are typically attached to the centre of gravity of an object (excepting Hermes). Plausibility is computed from the degree to which the semantic elements of an interpretation have occurred together in known concepts. Plausibility predicts that known-concept interpretations should occur because, being known concepts, they have the highest possible plausibility score.

The *informativeness* constraint requires interpretations to communicate something new (satisfying Grice's Maxim of Quantity; Grice, 1975,). Informativeness excludes feasible interpretations that do not communicate anything new relative to either constituent concept. So, it would predict that people should not produce the following:

- A bed pencil is a pencil made of wood

because MADE-OF-WOOD does not convey any new information about either *beds* or *pencils*. It also accounts for Downing's (1977) finding that people find combinations with *redundant modifiers* unacceptable; for example, pig pork. Informativeness plays an important role in deciding between interpretations which tie on inclusion and plausibility.

### The Generative Mechanism

The generative mechanism constructs compound phrase interpretations incrementally under guidance from the constraints proposed by theory. For a given phrase this mechanism forms interpretations by selecting subsets of diagnostic and plausibly co-occuring predicates. In its search for the best interpretation for a given phrase the mechanism iteratively builds multiple interpretations, stopping when better interpretations can no longer be constructed (see Costello, 1996 for a detailed description). This unitary mechanism can generate a wide range of interpretations of different types, having a variety of referents. Note that even though this mechanism can produce relational and property-mapping interpretations, it does so without using specialisation or alignment mechanisms.

### Types of Knowledge

Constraint theory also has assumptions about the types of concepts used in combinations. As in the above theories, we assume that concepts have complex representational, predicate structure (consisting of attributes, objects and relations). In this paper, we examine an assumption about the basic ontological distinction between artifacts and natural kinds (see e.g., Keil, 1986).

Artifact concepts (*guns, buildings,* and *cups*) differ in several ways from natural kinds (*birds*, *trees*, and *snails*); predominantly, in that artifacts are functionally-related to other concepts. These functional models should facilitate polysemy because they typically have several possible roles (e.g., agent, object, recipient, instrument). For example, an *elephant gun* can be a gun used by an elephant to shoot things (agent role) or a gun used to shoot elephants (object role). Natural kinds do not normally have associated functional models and therefore should support less polysemy. Furthermore, the relational roles in artifacts tend to have a wider scope than those of natural kinds, in the sense that a wide range of objects can be used to fill them (see Wisniewski & Gentner, 1991). A gun can be used to *shoot* almost anything but a snail can only *eat* vegetative matter.

Both of these factors, along with the inclusion constraint's requirement that the referent of an interpretation possess diagnostic properties of the linguistic-head, suggest that combinations with an artifact head should manifest significantly more polysemy than those with a natural-kind head.

## Concept-Type & Polysemy

This experiment tested three main predictions of constraint theory. First, the prediction that all four types of interpretations should occur (notably the known-concept interpretations predicted by plausibility). Second, that when reversals occur they should tend to be property-mappings (based on inclusion). Third, that concept-type should affect the polysemy of combinations; specifically, that artifact-head combinations should generate more interpretations than natural-kind head ones (based on more functional interpretations).

Subjects were given four sets of six combinations from the following categories: artifact~artifact (e.g., "pencil bed"), natural-kind~artifact (e.g., "river chair"), artifact~natural-kind (e.g., "chair river") or natural-kind~natural-kind combinations (e.g., "oak dog").

## Method

**Subjects & Design**. Twenty undergraduates at Trinity College Dublin took part voluntarily in the experiment (one was excluded prior to data analysis). The design was a 2 (head-category) x 2 (modifier-category) one, both being within-subjects variables. Combinations were counterbalanced for the order of the specific words used (e.g., each subject got *bed pencil* and *pencil bed*). This variable which is not reported here does not change the effects found (see Costello, 1996, for details).

**Materials**. Twenty-four basic-level words (12 artifact words and 12 natural-kind words) were used to construct the 24 combinations (see Appendix). Frequency of occurrence of the words in each set determined using the Oxford Psycholinguistic Database (Quinlan, 1992). A t-test comparing artifact and natural-kind word frequency showed no reliable difference between the categories ($t(22) = .84$, $p > .4$).

**Procedure**. The instructions asked subjects to say "what the phrase could plausibly mean and if you can think of more than one possible meaning for a phrase then report them in the order in which they occur to you", for the novel combinations they were shown. The combinations were presented individually on cards and subjects' responses were audio recorded. Subjects were tested individually.

**Scoring**. Subjects' interpretations were classified by both experimenters into the four interpretation-types[2]: relational, property-mapping, hybrid and known-concept. They were also classified by referent: head, reversal or other. Finally, the frequency of functional interpretations were noted. Differences were resolved by discussion (agreement was 97%).

## Results & Discussion

The results confirmed the main predictions of the constraint theory in finding that head-artifact combinations were more polysemous than head-natural kind ones, based on increased numbers of functional interpretations being produced in the former. The results also confirmed the predicted tendency for reversals to be property-mapping interpretations, with property-mappings dominating the reversals category while relational interpretations dominated the head- and other-referent categories.

**Types of Interpretation**. Each of the four types of interpretation were found among the 1019 produced: relational 46% (468), property-mapping 33% (337), hybrid 0.3% (3), and known-concept 15% (157), with 6% (57) in the other category. These results are in line with previous findings on the first three categories and confirm that known-concept interpretations are a commonly produced type. The findings support the flexible generative mechanism used in the constraint theory and its proposed constraints.

**Polysemy**. On average each subject produced about two interpretations per combination ($M = 2.24$), although the frequency ranged from 1 to 6. The 2 head-category (artifact or natural-kind) x 2 modifier-category (artifact or natural-kind) repeated-measures ANOVA revealed a main effect of head-category; with artifact-head combinations producing reliably more interpretations ($M = 2.36$) than natural-kind-head ones ($M = 2.12$,; $F(1,17) = 7.89$, $p = .01$, $MSe = .78$). No other reliable effects or interactions were found. An item analysis revealed similar effects of head-category ($F(1,22) = 5.71$, $p < .05$, $MSe = 1.12$).

An analysis of the proportion of functional interpretations produced to a given phrase showed that there was a higher proportion of functional interpretations produced to artifact-head ($M = .40$) than to natural-kind-head combinations ($M = .12$; $F(1,17) = 72.96$, $MSe = .122$, $p < .0001$). A similar, but lesser, difference was found between artifact-modifier ($M = .33$) and natural-kind-modifier combinations ($M = .19$; $F(1,17) = 18.23$, MSe = .115, $p < .0005$).

Both of these results support the core assumptions of the constraint theory. In particular, they show that artifacts are much more polysemous than natural kinds, especially when they are in the head position. Furthermore, it shows that this extra polysemy is based on their associated functional models.

**Referents & Reversals**. As expected, most of the referents of interpretations were to the linguistic-head of the combination (68%), but reversals using the linguistic-modifier as the referent were relatively common (9%), with the remainder having some other concept as the referent (23%). This result confirms that such reversals are not limited to combinations of a substance-object form but occur more generally, albeit not as frequently (Wisniewski & Gentner, 1991, found rates as high as 38%).

The inclusion constraint predicts that when reversals occur they should tend to be property mappings (of the head's diagnostic predicates) rather than another interpretation-type. This prediction is confirmed by an analysis of interpretation types in the different referent categories. In the head-referent category, the interpretations produced tend to be relational (51%) rather then property-mappings (36%; a similar pattern is found in the other-referent category). In contrast, in the reversals category interpretations tend to be property mappings (54%) rather than relational ones (31%). All these differences are statistically reliable.

**Significance of Findings**. With any new paradigm the issue of the relevance of the findings always arises. Does the process by which people produce multiple interpretations have anything to do with people's normal comprehension of novel compounds? In particular, do contextual influences normally banish the possibility of polysemy in novel combinations? We would like to argue that the combination process used to produce multiple interpretations is the same as that which produces a single

[2] Operational definitions of the first three of these categories were similar to Wisniewski's (1996).

interpretation, with contextual influences acting to highlight the single interpretation selected.

In support of this position it may be noted that the types of interpretations produced in the present study and the relative frequencies of these interpretation-types closely parallel those found in traditional, single-interpretation studies. This is strong evidence for the proposition that the same process is being tapped in this and previous studies.

Granted, people may not normally entertain all the possible meanings reported by our subjects when a novel combination is presented in context (Murphy, 1990). For example, a *pencil bed* could be a narrow bed, a container for pencils, a bed that is pencil-shaped and so on. If you are told that "the pencil bed is in the bedroom upstairs" you are likely to assume that a narrow bed is upstairs, whereas if you are told that "the pencil bed is in the middle of the exam hall" you are more likely to think that it is some receptacle for pencils. However, not all contexts will necessarily disambiguate a novel combination; if you are told "he moved the pencil bed last week" either of the above two meanings could still hold (Mulligan, 1997). So, context will not necessarily banish all ambiguity.

Indeed, we believe that polysemy should be studied to tell us more about contextual influences in normal comprehension. At present we have little knowledge about the baseline ambiguity of novel combinations, and thus do not know what problems of ambiguity are resolved by context (see Mulligan, 1997).

## General Discussion

The present paper reports a new theory of conceptual combination that aims to explain specific aspects of the multiple interpretations produced by people to novel noun-noun combinations. Using this theory, we have shown that different types of concepts differentially affect polysemy; that combinations with artifact heads are more polysemous than those with natural-kind heads (similar results have been found for the superordinate/basic-level distinction). Furthermore, we have confirmed the generality of these findings in other experiments using several hundred different combinations (see Costello, 1996). We have also simulated these results in a model of the theory called $C^3$ (the Constraint Model of Concept Combination).

In constraint theory, we have tried to deal with the creative contents of interpretations produced by people to a single combination. At present, we have not concerned ourselves with more traditional concerns like typicality ratings (although ultimately we plan to extend the theory in this direction). In doing this we have tried to open up a new area of research on the factors that affect polysemy that appears to be very fruitful. In the course of this we have confirmed several ideas about the structure of the human conceptual system. Theoretically, we have been driven by parsimony to develop a single unitary mechanism and a few simple explanatory constraints to account for these effects.

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## Appendix: Combinations Used in the Experiment

| | **artifact head** | **natural-kind head** |
|---|---|---|
| **artifact modifier** | Bed Pencil | Chair River |
| | Train Hat | Knife Apple |
| | Bus Shirt | Hammer Rose |
| | Shirt Bus | Horse Gun |
| | Pencil Bed | Shoe Herring |
| | Hat Train | Ball Potato |
| **natural-kind modifier** | Apple Knife | Boulder Grass |
| | Potato Ball | Tulip Eagle |
| | Rose Hammer | Oak Dog |
| | River Chair | Grass Boulder |
| | Herring Shoe | Eagle Tulip |
| | Gun Horse | Dog Oak |