The Iteration of Concept Combination in Sense Generation

Richard Cooper
Department of Psychology
Birkbeck College, London
Malet Street, London WC1E 7HX
R.Cooper@psyc.bbk.ac.uk

Bradley Franks
Department of Psychology
London School of Economics
Houghton Street, London WC2A 2AE
B.Franks@lse.ac.uk

Abstract
We report work in progress on the computational modelling of a theory of concepts and concept combination. The sense generation approach to concepts provides a perspicuous way of treating a range of recalcitrant concept combinations: privative combinations (e.g., fake gun, stone lion, apparent friend). We argue that a proper treatment of concept combination must respect important syntactic constraints on the combination process, the simplest being the priority of syntactic modiﬁer over the head in case of conﬂicts. We present a model of privative concept combinations based on the sense generation approach. The model was developed using COGENT, an object-oriented modelling environment designed to simplify and clarify the implementation process by minimising the ‘distance’ between the box/arrow ‘language’ of psychological theorising and the theory’s implementation. In addition to simple privatives (i.e., ones with a single modiﬁer, like fake gun) the model also handles iterated, or complex, privative combinations (i.e., ones with more than one modiﬁer, like fake stone lion), and reﬂects their associated modiﬁcation ambiguities. We suggest that the success of this model reﬂects both the utility of COGENT as a modelling framework and the adequacy of sense generation as a theory of concept combination.

Introduction
Concepts are usually taken to have three basic functions in mental life (see, e.g., Franks, 1992; Rips, 1995): a representation function (the representational contents over which thought and inference about the world takes place), a classiﬁcation (or referring) function (the contents accessed in determining whether objects fall under the denotation of a term), and a linguistic function (the contents accessed in understanding language and concatenated according to linguistically appropriate rules to comprise a mental representation of the meaning of a sentence or utterance). The ﬁrst two functions have been the primary concern of investigations of concepts in cognitive science.

It is widely accepted that insights about the representation and classiﬁcation functions of concepts can be obtained from an understanding of the way in which they combine to form complex concepts (e.g., Medin & Shoben, 1988; Smith, Osherson, Rips & Keane, 1988). We suggest that constraints on the process of combination itself should be forthcoming from an understanding of the linguistic function. Hence, accounts of concepts in general can be constrained by ascertaining the extent to which they respect critical factors concerning the linguistic function. In order to begin to make progress on this question, the work reported here focuses on the effects of aspects of the linguistic function on the representational function of concepts (since, arguably, the classiﬁcation function is parasitic on the representational function).

We present a computational model of concept combination from within the sense generation framework developed elsewhere (e.g., Franks, 1995), employing a computational framework developed in order to clarify the relationship between the speciﬁcation of theoretical commitments and their implementation (Cooper, Fox, Farringdon & Shallice, in press). This is an essentially symbolic framework for modelling cognitive phenomena: since our focus was on modelling the effect of syntactic relations on concept combination (rather than modelling those syntactic relations per se), the necessary perspicuity and clarity of the sequential ordering in the implementation of the syntax is more directly lent by a symbolic implementation than a connectionist one (such as Miikkulainen, 1993). We present a basic model of concept combinations ﬁrst (a head noun combining with a single modiﬁer), and then show how this can be extended to handle a simple form of syntactic inﬂuence on combination — the iteration of modiﬁers, with attendant scopng or modiﬁcation ambiguities that arise for their representation. The model presented is an aspect of work in progress. This work has a goal of locating a model of concept combination within a perspective gained from syntactic constraints on combination and from wider considerations of cognitive modelling.

Sense Generation and Concept Combination

Sense generation is an approach to concepts and concept combination that attempts to respect psychological evidence about classiﬁcation and representation in the context of pragmatic factors concerning communication. It postulates ‘quasi-classical’ lexical concept representations which express the default content for a concept, comprising attribute-value structures where each attribute takes only one value, and where those values can be overridden by contextual dictates (Franks & Braisby, 1990; Franks, 1995). These representations are quasi-classical in that, although they act as if they were necessary and sufﬁcient conditions for category membership within a single context, across different contexts their contents are defeasible and so are not classical deﬁnitions. A critical distinction between types of attributes is made on the basis of their relationship to category membership: ‘central’ attributes are ones that reﬂect deep, theoretical assumptions about the factors that are presumed essential for category membership (see Medin & Ortony, 1989; Braisby, Franks & Hampton, 1994, in press); by contrast, ‘diagnostic’ attributes are those aspects of
the surface appearance of objects that may be used for rough-
and-ready identification, but are not infallible guides. Sense

generation postulates a generative process that takes bottom-
up input from lexical concepts associated with the constituents
of a phrase, and outputs a sense for the phrase that provides a
closer fit to the pragmatic context than would the default
content of lexical concepts.

It can be argued (Franks, 1995) that a class of combinations
known as ‘privatives’ constitute a test-case for theories of con-
cept combination, in that they exhibit particularly strong, yet
predictable, forms of context-sensitivity. Privative adjectives
are analysed by Kamp (1975) as ones for which the following
inference is a logical truth: If \( x \) is a privative adjective-noun
then \( x \) is not a noun: for example, if \( x \) is a fake gun, then \( x \) is
not a gun.

Franks (1995) argues that this analysis should be extended
in three ways. First, the characteristic inference should be
weakened, to allow for the cognitively plausible classification,
if \( x \) is a fake gun, then \( x \) is a gun in some sense —
only with respect to appearance. Second, such an inference
is characteristic not only of the effect of a particular set of
adjectives on all nouns that they modify, but also of the in-
teraction of the contents of head nouns with modifiers that
are not themselves intrinsically privative. Third, ‘proper’
privatives, in which privative behaviour results from an intrin-

cis property of the adjective type, in fact come in two kinds
— ‘negating’ privatives (e.g., fake gun — where, intuitively,
the modifier negates the central attributes of the head), and
‘equivocating’ privatives (e.g., apparent friend — where the
modifier casts doubt on the head’s central attributes, but does
not completely negate them). In both cases, the diagnostic
attributes of the head noun concept are not denied in any way
— thus preserving the characteristic classification inference
based on appearances only, noted above. These types of pri-

vative have analogues in which privative behaviour results not
from the particular semantic type of the modifier, but from the
interaction of the contents of the concepts of head and mod-
ifier. Such ‘functional’ privatives include combinations like
stone lion or chocolate teapot (negating privative analogues of
fake gun), and wooden skillet or blue orange (equivocating
privative analogues of apparent friend). It is clear that, for
these cases, there is no intrinsic property of either the head
or modifier that produces the privative behaviour (e.g., when
stone modifies bridge, and when lion is modified by brown,
the resulting behaviour is not privative). Hence, privatives
embody a particularly strong form of context-sensitivity of
concept representations. Producing the sense for a privative
combination denies attributes of the head noun, requiring a
process that is not rigidly (i.e., monotonically) compositional
(for example, as in feature-addition; see Hampton, 1987).
This does not preclude a compositional account, however,
since the sense produced for a combination is still predictable
from the concepts of the parts and their mode of combination.

Despite their constituting a test case for theories of concepts
and concept combination, it is not clear that privatives can be
handled in, for example, prototype theory (Hampton, 1992),
schema theory (Murphy, 1988), or theories that assume that
combination operates by a process of either property mapping
or slot filling (cf., Wisniewski & Gentner, 1991). Moreover,
the requisite marked conflict between attributes of the head
and modifier may also be difficult to express in connectionist
terms. By contrast, a unified, compositional account of pri-

vatives within the sense generation framework is presented in
Franks (1995). The account employs unification-based opera-
tions to capture the various aspects of concept combination
(e.g., priority unification (Kaplan, 1987), in which the sense
for the combination inherits all of the attribute-value pairs of
the constituent lexical concept, with the exception that where
the two concepts conflict on one of the values of a common
attributes, the value of the priority constituent — the modi-
ifier — is inherited). The critical difference between negating
and equivocating privatives is expressed in terms of different
metonymic type coercion operators (cf., Klein & Sag, 1985;
Pustejovsky, 1991): for negators, the operator takes as input
the head noun’s lexical concept (comprising both central and
diagnostic attributes), and outputs a coerced representation
comprising the head’s diagnostic attributes and the negation
of its central attributes; for equivocators, the operator outputs
the diagnostic attributes of the head and neither the central at-
tributes nor their negation, but rather their being only possibly
true of the object being referred to. This corresponds to treat-
ing the attribute-value structures as potentially having three
truth-values — a value of an attribute may be true of a type of
object, false of it, or neither. For functional privatives, the
conflict between central attributes for stone and lion results in
those of the latter being negated, whilst the conflict between
diagnostic attributes for wood and skillet results in the cen-
tral attributes of the latter not being negated but being only
possibly true of the type of object described by the phrase.

This treatment captures defining semantic intuitions about
objects described by privatives, and hence their characteris-
tic classification inferences. For example, a stone lion pos-
sesses central attributes of stone objects, but only diagnostic
attributes of real lions. Similarly, fake guns do not possess
the central attributes of guns, but only their diagnostic at-
tributes. By contrast, an apparent friend performs diagnostic
behaviours of a friend, but this is consistent with only pos-
sibly possessing central motivational attributes of friendship;
similarly, a wooden skillet looks like a real skillet but may or
may not be able to support the central function of a skillet. In
all cases, the initial, bottom-up combination stage leaves the
elaboration and specification of the details of the combination
unspecified, producing schematic senses which are consistent
with a range of further possible specifications that depend on
informational and pragmatic context (e.g., resulting in the ad-
dition of the information that the stone lion is a statue, and
so has central attributes of a statue, or that an apparent friend
really is or is not a friend, with appropriate central attributes).

The model discussed here seeks to test this account in two
ways. First of all, to ascertain whether the account of simple
privative concept combinations (i.e., ones in which there is
a single modifier for the head) is coherent by modelling
it. Secondly, to ascertain whether the particular combination
operations are adequate for handling iterated or complex con-
cept combinations (in which there is more than one modifier).
This also provides a way of beginning to incorporate syntactic
constraints into concept combination.

Noun phrases often incorporate multiple modifiers of the
head noun. The multiplication of modifiers raises the possi-
bility of ambiguity in the scope of the modification, and this
problem is rendered especially complex when the multiplied
modifiers are privatives, and hence when a private combi-
nation is itself modified by a privative. For example, *fake
stone lion* could have two distinct readings, one in which the
first modifier has ‘wide’ scope over the second modifier and
the head (i.e., *fake (stone lion)*: a stone lion that is a fake),
and one in which the first modifier has ‘narrow’ scope over
the second modifier only, and they both modify the head (i.e.,
*(fake stone) lion*: a lion that is made of fake stone).

In essence, in order to arrive at an appropriate representation
for such complex combinations, the head-modifier relation-
ships — that is, the scope of the first modifier — must be
disambiguated. The disambiguation of such relationships is
taken to be provided by a syntax parser that provides input
to a conceptual interpreter. This does not imply, of course,
that no semantic or thematic lexical information is involved in
the process of syntactic disambiguation, merely that detailed
conceptual information is not (see, e.g., Trueswell, Tanenhaus
& Kello, 1993). The question of interest for our purposes is
then, given that the head-modifier relationships have been
disambiguated, does the sense generation account of simple
privative combinations generalise to complex privatives?

**The COGENT Modelling Environment**

Our model was constructed in COGENT (Cognitive Objects
within a Graphical EnviroNmenT), a developing cognitive
modelling tool. This system grew out of independent work
aimed at clarifying the relationship between psychological
theory and computational implementation within cognitive
modelling. In particular, it seeks to make explicit the range
of actual architectural commitments made by a psycholog-
cal theory, as distinct from mere implementation details (cf.
Cooper et al., in press; Cooper, 1995).

The COGENT modelling environment provides a set of con-
figurable cognitive ‘objects’ (such as rule-based processes,
and buffers with or without capacity limitations and content
decay). Central to the environment is a graphical interface
which allows the specification of executable models in the
box/arrow style. Different shaped boxes correspond to dif-
f erent types of object, and a complete executable model can
be developed by specifying appropriate properties and con-
 tents for all objects in the model. This minimises the distance
between the models traditionally developed by psychologists
and their implementations, simplifying the relation between
the two. At present, only symbolic objects are provided, but
anticipated future developments include extending the envi-
ronment by incorporating connectionist and network objects.
Extant uses include the implementation of production system
models (Cooper, 1996), models of decision making (that of
Fox, 1980), and models of prospective memory (Ellis, Shallice
and Cooper, in submission). Details of COGENT availability
and system requirements are available from the authors.

It is important to emphasise that COGENT is an environment,
not an architecture. As such the intention is that the system
should impose few (if any) constraints on the precise form of
a model’s implementation. In general, it is the particular the-
orist’s responsibility to provide such constraints. This is not
to say that architectures such as Soar (Newell, 1990) have no
role in computational work on cognition (though see Cooper
& Shallice (1995) for a discussion of some potential short-
comings of architecture-driven modelling), but to provide for
theorists who do not subscribe to all of the assumptions em-
bodyed in any extant architecture.

In spite of the above intention, one constraint which is im-
possed by COGENT, and which impacts on the current domain, is
the preclusion of recursive procedures (i.e., procedures which
call themselves). Most current programming languages allow
recursive procedures, and such procedures are of tremendous
utility when processing tree-structured data such as natural
language. However, true recursion requires a processing stack
to maintain the trace of execution throughout recursive calls
(in order to recover from the recursion once it bottoms out),
and associated dynamic memory allocation for independent
copies of local variables used within each recursive call.

While there is no prohibition on a COGENT process trigger-
ing itself, there is no processing stack within COGENT so there
is no possibility that, on completion, a process could return
control to the process that triggered it. (In fact, processing
within COGENT is based on a parallel model in which all boxes
are constantly potentially active: see Cooper (1995) for more
details.) Furthermore, COGENT’s assumed correspondence be-
tween cognitive objects (i.e., boxes) and functional cognitive
structures means that, for example, a process requiring local
variables will require an associated buffer in which to store
those variables. A truly recursive process would require a sepa-
rate copy of this buffer for each recursive call. Again, this
dynamic memory allocation is not available within COGENT.
Notice that the preclusion of recursion in COGENT arises not
from any prior prejudice against recursive procedures, but
from the directness of the mapping between functional units
and COGENT objects, and from the underlying (parallel) pro-
cessing model.

In light of the above, complex modified noun-phrases can-
not be processed in COGENT by recursively processing their
parts.

**Sense Generation in COGENT**

The model consists of a set of interconnected boxes (see Fig-
ure 1) of two principal kinds: buffers and rule-based pro-
cesses. A parsing process breaks input into a set of lo-
cal trees (i.e., binary branching nodes which disambiguate
head/modifier relationships) and adds its output to a tempo-
rary storage buffer (*Local Parse Trees*). We are not here
concerned with the internal details of this parsing process. A
second process, *Conceptual Access*, is triggered by elements
in the store, processing them (i.e., accessing the conceptual
content associated with their constituents) one at a time. These
contents comprise the single-valued attribute value structures
(with the major division between central and diagnostic at-
tributes) noted earlier. The order of this processing is con-
strained by the requirement that the conceptual content of the
constituents (i.e., head and modifier) is immediately available
(either from the Mental Lexicon or from a short term store to
which earlier processing may have written its results). As a
consequence, processing is bottom-up.

Once the initial content for both the head and modifier has
been obtained, the generation of the schematic sense for the
phrase proceeds via two further processes. These are also
controlled in a bottom-up manner, since they only depend
upon the type of operator or upon whether conflicts occur
at diagnostic or central levels. The particular detailed contents of lexical concepts are not critical to the generation of a schematic sense. Firstly, the content of the head is coerced in one of two ways (see above): either the head’s central attributes are negated (if the modifier is a negating privative adjective, or if the head and modifier conflict on central attributes), or the head’s central attributes are undercut or cast into doubt (if the modifier is an equivocating privative adjective, or if the head and modifier conflict on diagnostic attributes). Following this, the coerced central and diagnostic attributes of the head are priority unified with the corresponding attributes of the modifier, with the modifier’s attributes taking priority. This produces a schematic sense for the combination, which is temporarily stored in a conceptual store (cf., Potter, 1993). If this sense is associated with a constituent part of a complex noun phrase, then its arrival in the conceptual store will allow processing of its super-ordinate constituent to proceed: generating a sense for the complex noun phrase as a whole will then take inputs both from the Mental Lexicon (for lexical sub-constituents) and from the Short-term Conceptual Store (for non-lexical sub-constituents). The sense produced in this bottom-up manner is only schematic. Any post-combination specification or elaboration of this sense is viewed as involving an interaction between bottom-up and top-down influences and not modelled here.

The full specification of the model in COGENT consists of Figure 1 together with a specification of the configurable properties of each box in that figure. The theoretical differences between the Mental Lexicon and the Short-term Conceptual Store, for example, are reflected in different configurations of the corresponding boxes. In particular, the Mental Lexicon is modelled as a long term store with no decay and no capacity limitations, whereas the Short-term Conceptual Store is modelled as a temporary or working store with fixed decay and capacity limitations. Each process is fully specified in terms of a set of condition/action rules (one rule per process for this model) and some declarative Prolog conditions. The conditions of the rules either match elements from various buffers or perform logical operations (such as priority unification, specified in Prolog) on their data. The rules’ actions modify buffer contents or trigger further processes.

The three rules are presented in Figure 2. CH and DH represent the central and diagnostic attributes of the head (respectively). Similarly CM and DM represent the central and diagnostic attributes of the modifier. In Rule 1, the condition conceptual_lookup queries the Mental Lexicon and Short-term Conceptual Store to determine the content of the phrase’s head. The condition conflict_type serves a similar purpose for the modifier, but also takes account of adjectives which serve as operators (and so have no independent conceptual content — e.g., proper privatives like fake). If these conditions are met, the rule fires, deleting the local parse tree from its buffer, and triggering Coercion with the message coerce(Phrase, Type, CH, CM, DH, DM).

When Rule 2 is triggered, it coerces the type of the central attributes of the head according to that specified by the triggering process, producing CCH (i.e., coerced central head attributes). The process then triggers Priority Unification (Rule 3) with the message unify_content(Phrase, CCH, CM, DH, DM).

The triggering of Rule 3 priority unifies the central attributes of the coerced head and modifier, producing the central attributes of the combination (C), and the diagnostic attributes of the head and modifier, producing the diagnostic attributes of the combination (D). The conceptual content of the combination is then added to the Short-term Conceptual Store, where it may contribute to the construction of the conceptual content of a larger constituent (via the condition conceptual_lookup called by Conceptual Access (Rule 1)).

To illustrate, consider first a simple privative, such as stone lion. There is no syntactic ambiguity, and just one local tree. Processing therefore requires just one cycle through the diagram in Figure 1. Once the local tree appears in the Local Parse Trees store, Short-term Conceptual Access is triggered, thus accessing the lexical concepts for both stone and lion from the Mental Lexicon: both lexical concepts comprise central and diagnostic attributes. Conceptual Access also determines the nature of the combination in terms of any conflict of attributes (i.e., negating or equivocating privative for conflicts on central or diagnostic attributes respectively, or affirmative combination for no conflict). In the case of stone lion, a conflict of central attributes will be detected, fulfilling the requirements for a negating type coercion. Conceptual Access passes this information to the Correction process, which negates the central attributes of the head (lion). The output coerced representation then comprises the diagnostic attributes and the negated central attributes from the lexical concept for lion. The coerced representation of lion and the representation of the lexical concept for stone are then input to the Priority Unification process, which combines them (giving precedence to stone) to yield a representation of a type of object that possesses all of the central and diagnostic attributes of stone, and some of the coerced central and diagnostic attributes of lion, with the proviso that, where the values of attributes conflict, the values of stone take priority. The resulting representation
is of a type of object that has central attributes of stone (e.g., inorganic) and has negated central attributes of lion (e.g., inorganic, genetic structure not of a lion); it also has diagnostic attributes of stone (e.g., a grey colour, hard texture), and some, but not all, of lion (e.g., it has a lion shape, but not lion colour or lion habitat).

The case of complex noun phrases involving iterated modifiers is analogous, except that alternate possible syntactic structures (reflected in alternate local parse trees) lead to alternate possible senses. For fake stone lion, a sense of stone lion may be determined as above. The negating privative fake may then operate on this sense (temporarily available in the Short-term Conceptual Store) to yield a representation for a type of object that does not have the central attributes of stone lion (e.g., inorganic) but does have the diagnostic attributes of this combination. The second reading of fake stone lion corresponds to the case where the complex nominal fake stone modifies lion (corresponding to a lion which is made from some kind of fake stone, such as a hard plastic). In this case, the content of fake stone will first be determined. The relevant representation will have as central features the negation of the central features of stone (but the diagnostic features of stone). The result of combining this with the content of lion will depend on the precise form of central features of each. If the central features of fake stone do not conflict with those of lion, then an affirmative combination will be invoked, and all central attributes will be unified. The resulting sense allows that a fake stone lion is actually a real lion (perhaps pretending to be a statue). Equivocating or negating privative readings may also be licensed if there is conflict on diagnostic or central attributes respectively. In this way, the model demonstrates that the sense generation account of simple privatives can generalise to complex, iterated, concept combinations.

Future Developments

Future research will focus on four main areas. Firstly, although this work has shown that sense generation can provide an adequate account of iterated privative combinations, the model may also be used to assess the generality of the sense generation theory in terms of affirmative (i.e., non-privative) forms of combination (e.g., predicating adjectives like red and non-predicating adjectives like criminal).

The scoping ambiguities inherent in modifier iteration are, of course, just one of a range of syntactic phenomena that falls within the scope of the sense generation theory. A second strand of further work will therefore involve developing the model itself by addressing further syntactic phenomena. For example, combinations may involve syntactic form-class ambiguities. Thus, when interpreting, say, stone lion, a strictly bottom-up parser would initially interpret stone as a head noun, only to find that it is in fact a modifier. A fuller treatment of syntax would also incorporate the interaction between conceptual content and more coarse-grained content (such as thematic roles) relevant to resolving ambiguity.

A somewhat different area in which the model is underdeveloped concerns the classification and representational functions of concepts. The current model simply takes concept representations to comprise two different types of attribute. The combination operations are sensitive to these types of attributes but not to the particular attributes themselves. This allows a relatively schematic treatment of representation. However, in order to provide a full model of the representational and classification functions, more detail concerning the post-combination specification of the senses is necessary. This is addressed within the sense generation theory (see Franks (1995) for a full account), according to which any such specification is consistent with the results of the initial (schematic) combination stage. These developments will therefore augment (rather than negate) the current model.

Lastly, it is anticipated that developments in the COGENT software will allow further refinement of the model. More detailed modelling of the classification and representational functions of concepts may, for example, be better handled in a hybrid symbolic + connectionist model in which the Mental Lexicon (currently modeled as a static, symbolic, store), and its access, is handled by a connectionist component. Affir-
ative combinations in such a model might be handled by a purely connectionist “route”, but this route would be interrupted (in the sense of Cooper & Franks, 1993) in the case of privative combinations, where attribute conflicts would trigger type coercion prior to combination.

Conclusions

We have suggested that a plausible account of concept combination must be constrained by an understanding of the linguistic function of concepts, and that this can begin to be handled by modelling complex, iterated combinations. Given that simple privatives are themselves a complex set of combinations that can provide a test case for a theory of concepts, the ability to model complex privatives provides an even stronger criterion for any account’s adequacy. We suggest that the findings reported here indicate that sense generation can provide a framework for developing a plausible, generalisable account of concepts and concept combination.

The development of the model within the COGENT modelling environment has also demonstrated the utility of COGENT as a general modelling resource. We argue that the diagrammatic representation (Figure 1), together with the three rules which govern the behaviour of the three processes, clarifies the sense generation theory without obscuring essential aspects with implementation detail. In this sense, we aver, both sense generation and COGENT have profited (and will continue to profit) from their interaction in the development of this model.

References


