

The Composition of Compounds: A resource logic account

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1 Introduction

Noun-noun compounding remains a challenging, yet for this reason intriguing, component of natural language grammar, in part because of its quasi-grammatical nature. The basic reason for this is that noun-noun compounds are semantically incomplete relative to their surface forms. They require the instantiation of a missing, relation between the two nouns making up the compound in order to be fully interpreted. This fact has received different treatments within various theories. In an early transformational account, Lees (1960) proposed that compounds were obtained from base sentence representations via transformations. The complete spelling out of a compound like *population growth* is therefore something like *The population grows* Hacken (2009). In this conception, the productivity of compounds is essentially equivalent to the productivity the language as a whole; virtually any sentence derivable by the grammar which contains the constituent nouns of a compound can be nominalized into it via a transformation. This is essentially the view propounded by Downing (1977, pg. 840), who writes that “the constraints on N+N compounds in English cannot be characterized in terms of absolute limitations on the semantic or syntactic structures from which they are derived.”

Conversely, there are accounts that attempt to narrow the range of acceptable relations to a finite, or enumerable, number. For example, Levi (1975) constrains the number of deletable predicates in transformational derivation of compounds, proposing twelve core relations that are deletable in compound formation, and accounting for the semantics of compounds containing nominalizations of verbal roots in terms of the argument structures of the root verbs. Jackendoff (2010) proposes a set of compounding relations that render the set of viable relational interpretations enumerable through a system that, while generative, is more constrained than that of Lees, which allows any sentence to instantiate the relation. A major question in the literature is the degree to which compound interpretations must be derived and stored directly in the lexicon, appearing essentially atomically in sentential derivations (Giegerich, 2009, Jackendoff, 1975). The position carved out here is that compounding requires a lexical input into the derivation of compound meanings that is richer than is often supposed, and that this lexical input is manipulated in a derivation to output the semantics for the entire compound. The syntax also has to be augmented with rules specific to noun-noun compounding constructions. After a discussion of the prerequisites for such an account of compounding, a precise proposal of the required derivational rules is expounded in section 5–7. The technical exposition presupposes the concepts and notation of LFG, paired with the linear logic formalism that has become standard in LFG semantics. The essential portions of this framework are summarized in the Appendix.

2 Semantics of compounding

Noun compounds are syntactically incomplete relative to their semantics in that they require a relational component, which is unspecified at the level of syntax, to complete their meaning. Given a pair of nouns N_1 and N_2 , the interpretation of their concatenation $N_1 N_2$ is given by (1).¹

$$(1) \quad \llbracket N_1 N_2 \rrbracket = \lambda R. \lambda x. \exists y. \llbracket N_2 \rrbracket(x) \wedge \llbracket N_1 \rrbracket(y) \wedge R(x, y) \mid R := e \rightarrow (e \rightarrow t)$$

where $:=$ relates an object of the meaning language to its lambda type.² There are several things to notice about this formula. The first is that the relation R is lambda-abstracted from the formula, so that the formula has type $(e \rightarrow (e \rightarrow t)) \rightarrow (e \rightarrow t)$. This leads to a problem for assigning a meaning to a noun-noun compound, in that the denotation of the compound is the wrong type for a noun phrase. Recall that a noun-noun compound is syntactically substitutable for a common noun. Hence, a compound is expected to have the same semantic type as a noun, $e \rightarrow t$. The fact that it does not signals some semantic incompleteness. The second thing to note is that the variable x is lambda-bound, while y is bound by an existential operator. This means that, once a relation R is given, the entire phrase has the type of a common noun, or $e \rightarrow t$. This fact is unsurprising, given that common nouns and noun-noun compounds are part of the same syntactic substitution class. The two therefore have the same kind of denotation; namely, they are both properties. The third important fact is the subsectivity of N_1 considered as a modifier of N_2 . An $x \in \llbracket N_1 N_2 \rrbracket$ is in $\llbracket N_2 \rrbracket$, but not necessarily in $\llbracket N_1 \rrbracket$. This corresponds to the inference

$$(2) \quad x \text{ is an } N_1 N_2 \rightarrow x \text{ is an } N_2$$

which holds almost universally of noun-noun compounds in English. Conversely, the corresponding inference from $N_1 N_2$ to N_2 does not generally hold.

There are notable exceptions among other types of compounds (notably, among adjectival modifiers, including non-subsective and privative adjectives like *possible* and *fake*). Examples from other compound types include:

- (3) Verb-Noun
- a. cutthroat
 - b. pickpocket
 - c. scarecrow
 - d. daredevil

¹The denotational semantics given in (1) is similar to that provided by Jackendoff (2009, pg. 122) under the name of the *Modifier Schema*: $\llbracket N_1 N_2 \rrbracket = [\mathcal{Y}_2^2; [F(\dots, X, \dots, \alpha, \dots)]]$, paraphrased as *an N_2 such that F is true of N_1 and N_2* . In Jackendoff's account, F is an n -place relation that takes N_1 and N_2 as arguments. The main difference here is that I explicitly give denotational semantics using lambda-notation in a higher-order meaning language. This is in keeping with the Glue semantics literature. Also, the use of a lambda-abstracted relation R also gives a more dynamic picture of how the missing relation becomes instantiated in compound semantics.

²Although this point does not bear discussing at much length, it should be noted that there is some ambiguity about the denotation of N_1 , postulated here as a property, when N_1 is instantiated as a proper name. Consider, for example, the compound *Canada beaver*, which refers to beavers that are in some unspecified relation to Canada and where Canada denotes an individual in the model. In this case, the logical meaning of the compound is best rendered as something like:

$$(i) \quad \llbracket \text{Canada beaver} \rrbracket = \lambda R. \lambda x. \llbracket \text{beaver} \rrbracket(x) \wedge R(c, x)$$

where $c = \llbracket \text{Canada} \rrbracket$ and is of type e . Alternately, depending on one's theory of proper names, $\llbracket \text{Canada} \rrbracket$ could be viewed as a property that is a singleton set, in which case the schematic interpretation (1) is exactly right. In any case, the extension of (1) to cover cases like (i) is trivial, and the approach described here is general enough to be adapted to it easily.

- (4) Adjective-Noun
- a. redhead
 - b. longlegs
 - c. hardback
 - d. dimwit
- (Selkirk, 1982)

Among noun-noun compounds, such cases are apparently rarer. There do exist some examples, but they are highly idiomatic.

- (5)
- a. egg head (intellectual)
 - b. skin head (person with a shaved head)
 - c. paperback (book with a paper binding)
 - d. birdbrain (idiot)
- (Bauer, 2008)

However, it is likely that these uncommon examples are simply conventionalized and thus lexically encoded as idiomatic synonyms of their real meanings. If so, $\llbracket N_1 \rrbracket$ and $\llbracket N_2 \rrbracket$ do not appear at all in the denotation of the compound. Instead, the semantics for the compound are assigned directly in the lexicon. In the worst case, the meaning is entirely atomic, in the sense that there is no apparent contribution by the two constituent nouns to the meaning of the compound. Cases like *egg head* are probably of this type—one will be hard pressed to find a relation between eggs and heads that picks out people who are intellectuals. In any case, there is an important difference between the context of coinage and the context of current usage; while such a correspondence may have existed in the former, it does not exist in the latter. For less degenerate cases, a variant of (1) can be provided that does not postulate the subsectivity of N_1 :

$$(6) \quad \llbracket N_1 N_2 \rrbracket = \lambda Q. \lambda x. \exists y. \exists z. \llbracket N_1 \rrbracket(z) \wedge \llbracket N_2 \rrbracket(y) \wedge Q(x, y, z)$$

where Q is a three-place relation. (6) only requires that x be related somehow to N_1 's and N_2 's, and not that it be an N_2 itself. This is in keeping with the meaning of an exocentric compound like *paperback*, which is a book whose back is made of paper. In the case a *paperback*, we can give a rough semantics like $\lambda x. \exists y. \exists z. \textit{paper}(y) \wedge \textit{back}(z) \wedge [\textit{made.of}(z, y) \wedge \textit{back.of}(x, z)]$. Assuming x is a book, then the last conjunct, a three-place relation, picks out the set of paperbacks, and is therefore a good instantiation of Q .

According to Selkirk (1982), the property that the deduction (2) holds corresponds to the right-headedness of compounds. The (left) nonhead constituent of a noun-noun compound, in Selkirk's account, is a further definition of the head constituent, such that the nonhead narrows the meaning furnished by the head. Put another way, the nonhead noun is a subsective modifier of the head noun. This property, which holds quite widely, follows immediately from (1).

Finally, notice that no stipulation is made about the identity of R beyond a statement of its type, $e \rightarrow (e \rightarrow t)$. In particular, it is not required that R be the denotation of a lexical item; R is free to be virtually any relation, including phrasally constructed ones. Perhaps the simplest relation is equality, which is attested in compounds like *singer-songwriter* which denote the intersection of the two compounded nouns. If the relation $=$ is inserted in (1), the resulting formula is

$$(7) \quad \lambda x. \exists y. \llbracket N_2 \rrbracket(x) \wedge \llbracket N_1 \rrbracket(y) \wedge x = y$$

which is extensionally equivalent to the intersection of $\llbracket N_1 \rrbracket$ and $\llbracket N_2 \rrbracket$. So intersective cases like these are easily dealt with by (1).

At the other end of the spectrum, R may be instantiated as a complex predicate requiring a lengthy paraphrase to express. For instance, (Downing, 1977, p. 818) discusses the compound

apple-juice seat, which, in the context in which it arose, was interpreted as “the seat in front of which a glass of apple-juice had been placed”. While the relation of being “in front of a glass of apple juice” is internally complex, it is appropriately interpreted in (1) by instantiating R as something akin to $in.front.of(x, y) \wedge in(y, r)$ where r denotes the contextually salient room where the apple-juice seat is to be found. However, one can imagine circumstances in which a different interpretation would be favored. For instance, it could refer to a seat on which apple-juice has been spilled. The role of the contextual parameter for determining the relation that completes the compound signals that primarily pragmatic principles are in play in such cases. An in-depth discussion of such principles is outside the scope of this paper. I will instead focus on the constraints on the interpretation of several types of compounds, and explain how these constraints can be satisfied within a compositional account of compound semantics. I assume that, except in some cases of interest, the semantics of compounds are largely free to interface with pragmatics in order to instantiate R .

The schematic interpretation of noun-noun compounds provided in (1) is best thought of as providing a fairly rigid constraint on the interpretation of compounds. It is not claimed that this denotation captures the semantics of all compounds, although it is difficult to produce novel compounds that do not satisfy (1). The case of exocentric compounds has already been discussed, where it was concluded that these cases are probably best approached as lexical entries with no compositional structure.

3 Interactions of compounding and nominal argument structure

Beyond the basic asymmetry between the N_2 head of a compound and its modifier N_1 , the nouns of a noun-noun compound are also asymmetrical in their ability to take one another as arguments. As noted by Selkirk, the left-hand noun in an English noun-noun compound, even when there is evidence that it possesses argument structure, cannot have its argument positions satisfied by the left-hand head. For instance, the deverbal *bomber* in *plane bomber* can denote something that bombs planes. However, when the nouns are reversed in *bomber plane*, this reading is not available; *plane* cannot be the object/Theme of *bomber* (Selkirk, 1982, p. 24).

I assume that *bomber* has a denotation like *an x such that x bombs something*, which is a relational denotation. Moreover, I assume that deverbal nouns like *bomber* are semantically related to their verbal roots. This is justified by the inference that a *bomber* has something that it bombs, which becomes even clearer if an *of*-complement is specified. A *bomber of cities* is an x such that *x bombs cities*. This connection between the verbal noun and its root can be expressed purely in terms of the denotation of the noun by assuming that the underlying relation expressed in the verb and the derived nominal are the same.

Note that the goal here is not to give completely worked out theory of word formation. However, I do follow Asudeh (2005) in assuming that relational nouns like *neighbor* have a denotation of type $e \rightarrow (e \rightarrow t)$ of the form $\lambda y. \lambda x. neighbor(x, y)$, where *neighbor*(x, y) is a binary relation that expresses *x is a neighbor of y* . Similarly, deverbal nouns have relational interpretations, but ones in which the underlying relation can generally be identified with the one contributed by the verbal root. Hence *bomber* has the denotation $\llbracket bomber \rrbracket = \lambda y. \lambda x. bomb(x, y)$, expressing the relation *x bombs y* . This characterization of the semantics of relational nouns captures everything essential about their argument structure; they are capable of taking complements that specify the argument of the underlying relation, and even when no explicit argument appears, the presence of *some* argument is implied. The Agent of bomb is actually the x that is abstracted out from *bomber*; the bomber is the one who bombs.

It should be noted that not all nouns exhibiting deverbal morphology are linked semantically to an underlying verbal form—at least not directly. Jackendoff (1975, pg. 647ff) cites examples like *aggression-aggressor-aggressive*, *retribution-retributive*, and *perdition*, which do not have verbal roots in English, as evidence that derived nominal forms are stored individually and in full in the lexicon, without being linked to to an underlying verbal form. For instance, there is no English word *aggress* from which the argument structure of *aggression* can be derived. There is additional merit to this view in the fact that even the meanings of genuine deverbal nouns are not always linked straightforwardly with those of the roots. Consider a military aircraft constructed at the tail end of a war and immediately retired before it has ever been deployed. Such an aircraft would rightly be judged a *bomber*, even though it has never bombed anything. The meaning of *bomber* in such cases is something more like *an x such that the characteristic/intended function of x is to bomb something*, a relation different from that of $\llbracket \text{bomb} \rrbracket = \lambda y. \lambda x. \text{bomb}(x, y)$. Conversely, a commercial airliner retro-fitted to deliver an explosive payload by a cash-strapped military organization might not be considered a bomber plane. However, it is clear that words like *aggression* by themselves possess an argument structure, which can be realized explicitly as an *against*-complement. No matter how the argument structure for such nouns is obtained, it can be represented semantically as a relation, such as $\lambda y. \lambda x. \text{aggression}(x, y)$ (e.g. *x's aggression against y*), without an assumed link to an underlying relation *aggress*. Similarly, *bomber* expresses a relation, even if it is not the relation of bombing something. (Jackendoff, 2010, pg. 436-42) proposes a small inventory of sixteen “basic functions” that can instantiate the missing relation in a compound, among them two-place *proper function* and *characteristic function* predicates. While Jackendoff does not use these to give the semantics of deverbal nouns, preferring instead a semantics derived from the verbal meaning, these proposed *function* relations are quite close to the meaning of *bomber plane* in the example above, and might better capture the semantics of *bomber* than the relation $\text{bomb}(x, y)$ corresponding to the denotation of its verbal root. If so, the relevant relation should be encoded lexically, as part of the semantics of *bomber*. To the extent that the semantics of deverbal nouns captures a *proper/characteristic function* relation, this can be encoded in a semantic rule to the effect of

$$(8) \quad \llbracket V\text{-er} \rrbracket = \lambda x. \exists y. \text{char}[x, \llbracket V \rrbracket(x, y)]$$

where *char* is a relation between individuals and one-place predicates expressing *the proper function of x is to do P*. This is also similar to the *telic function* of Pustejovsky (1991, 2013), which is part of the lexical specification of word meaning that can be exploited in the construction of interpretations through compositional procedures. The import of such examples is that a semantics of compounding requires access to lexically encoded relational resources. The point here is not to give a theory of word formation, or a full account of the semantics of deverbals, only to explain how relational nouns behave in compounding, and model this behavior in a compositional system.

Relational nouns, despite having extra argument positions, generally appear in syntactic contexts where these arguments are left unsaturated. For instance, *I asked the cab company to send a driver* is grammatical, even though it is not indicated what it is that the driver drives. This is easily explained by a lexical rule allowing optional existential closure over the unsaturated argument(s) of a relational noun as proposed in (Asudeh, 2005). Following Dalrymple (2001), I assume that nouns have the Glue type $\text{VAR}_\sigma \multimap \text{RESTR}_\sigma$, abbreviated as $v \multimap r$. Relational nouns have the modified type $\text{ARG}_\sigma \multimap (\text{VAR}_\sigma \multimap \text{RESTR}_\sigma)$, since they possess an extra argument ARG_σ that is either supplied as a premise or disposed of via existential closure. A rule of existential closure can be expressed as in (9), where the outermost parentheses indicate optional invocation.

$$(9) \quad (\lambda R. \lambda x. \exists y. R(x, y) : (a \multimap (v \multimap r)) \multimap (v \multimap r))$$

Introducing (9) reduces the arity of the relation by quantifying over the outermost variable. The effect of applying (9) in a derivation is shown below.

$$\frac{\lambda y. \lambda x. driver(x, y) : a \multimap (v \multimap r) \quad \lambda R. \lambda x. \exists y. R(x, y) : (a \multimap (v \multimap r)) \multimap (v \multimap r)}{\lambda x. \exists y. driver(x, y) : v \multimap r} \multimap \varepsilon$$

The meaning of is the result $\lambda x. \exists y. driver(x, y)$ is the property of being a driver of something. This result can be used subsequently in the derivation of a complete sentence, without having the argument y filled by anything.

Existential closure operations will become significant later in dealing with the interactions between N_1 and N_2 argument structure in compounding. The essential phenomenon is that N_1 's and N_2 's differ in their ability to take one another as arguments. Moreover, constraints on argument saturation differ depending on the class of relational noun considered. For instance, the examples in (10) exhibit the difference between *-er* deverbals and morphologically unmarked relational nouns.

- (10) a. bomber plane
 b. neighbor hater
 c. painting cat

In (10-b), it is permissible for the indicated neighbor to be the hater's neighbor. Similarly, the cat in (10-c) may be interpreted as *a cat x such that there is a painting of x* . Conversely, it is not permissible for the plane in *bomber plane* to be the thing that is bombed—though it is permissible for it to be the bomber. Indeed, this is the preferred interpretation, and it is given by existentially quantifying over the bombed y and instantiating R as equality.

4 Problems with a lexicalist account

Given that a lexicalist account of compounding is a natural approach to take in accounting for the semantics of compounds, it is important to discuss in detail why such an account is not tenable. I have argued that, in most cases, noun-noun compounds have denotations like (11),

- (11) a. $\lambda R. \lambda x. \exists y. \llbracket N_1 \rrbracket(y) \wedge \llbracket N_2 \rrbracket(x) \wedge R(y, x)$ (*best-case*)
 b. $\lambda Q. \lambda x. \exists y. \exists z. \llbracket N_1 \rrbracket(z) \wedge \llbracket N_2 \rrbracket(y) \wedge Q(z, y, x)$ (*almost-worst-case*)

A simple alternative analysis would simply hold the meanings of compounds to be atomic properties in which the denotations of N_1 and N_2 do not have to figure in the semantic representation at all. The interactions discussed above between compound semantics and nominal argument structure indicate that the argument structure of nouns is indeed crucial to characterizing the semantics of compounds, so this extreme hypothesis can be put aside. A weaker version of this hypothesis states that compound semantics are largely stored in the lexicon, rather than being composed in a syntactic process. This is, for instance, the view propounded in Jackendoff (1975), where it is argued that the best way to handle compound semantics is to encode the semantics for each compound directly in the lexicon. Besides the fact that compound denotations are often provided in contexts, by instantiating R *in medias res* of sentential derivation, I see two main arguments against this view of things.

First, the sheer productivity of compounds, as well as their recursive syntactic construction, suggests that a lexical encoding of compound meanings would be overly burdensome. Consider the following examples.

- (12) a. [campaign finance] indictment
 b. [screen door] [key hole]
 c. [winter weather] [skin troubles] (Jackendoff, 2010, p.414)

These examples illustrate the folly of any theory maintaining that all compounds are stored in the lexicon. A lexicon that included entries for novel compounds like *Sunday school teachers welcome committee meeting* would be much too large to be psychologically realistic.³ And in any case, the meanings of such compounds are often contextually determined (Bauer, 1979). So a speaker’s ability to produce and comprehend them has to be accounted for by some compositional procedure.

Second, the (left-hand) heads of noun-noun compounds are generally open to binding by elliptical constructions, which implies that the semantic resources they contribute to a formula are retrievable separately from the entire compound. *One*-ellipsis within compounds has historically been considered a diagnostic of compoundhood (Lieber and Stekauer, 2009), with compounds expected to prohibit substitution of N_2 by *one*. An ostensive prohibition against *one*-ellipsis out of a compound is often assumed by scholars as canonical, and sometimes employed to justify a sharp relegation of compounding to the lexicon—e.g (Giegerich, 2009).

Recently, assumptions about the behavior of *one* in English have been put to the test and found wanting. Payne et al. (2013), for instance, find through corpus studies that *one*-anaphora is much less syntactically constrained than is generally believed. The prohibition against *one*-ellipsis in compounds, too, has a thin evidential basis. In fact, except in the case of highly conventionalized compounds, the *one*-substitution operation is not problematic, and is in fact attested in written texts. Since the availability of *one*-substitution has consequences for an account of compound semantics in a Glue framework, I will consider a few examples of the phenomenon and discuss its implications. In general, an N_2 in a noun-noun compound may be substituted for the elliptical *one* without producing ungrammaticality, as in the examples of (13).

- (13) a. Fred employs a dog groomer_{*i*} every month, and a cat one_{*i*} every two weeks.
 b. Every programming textbook_{*i*} is inferior to an algorithms one_{*i*}.
 c. Considering the different scales, experimental techniques_{*i*} are diffraction ones_{*i*}, mainly light scattering techniques. (Wikipedia, 2015)

The subscript indexes *i* in (13) do not indicate coreference, only antecedence. The meaning of (13-a) is that Fred employs a dog groomer and a cat groomer every month; the elliptical *one* has the same semantic type, and the same content, as its antecedent, *groomer*. The found example

³There are no known grammatical proscriptions against particular noun-noun combinations, though many such combinations might seem semantically problematic. However, assuming that compounding is an unrestricted process, the size of the sublexicon required to store all noun-noun pairs is the square of the size of the sublexicon containing nouns, which is a very large lexicon to store. And this just includes two-noun compounds—things get much worse when we consider compounds with more than two constituent nouns, since distinct bracketings must be considered for strings of three or more nouns. To be precise, if the language allows compounds of n nouns and $|N|$ is the size of the sublexicon containing nouns, then there are (using the Catalan number $\frac{1}{n+1} \binom{2n}{n}$) to calculate the number of distinct bracketings)

$$\sum_{i=1}^n |N|^i \frac{1}{i} \frac{(2(i-1))!}{(i-1)!^2} \quad (1)$$

compounds admissible in the language, which represents an upper bound on the size of the nominal sublexicon when there is some finite bound on the length of admissible compounds. The nominal sublexicon thus grows polynomially with the size of the sublexicon for nouns, and factorially with the length of admissible compounds. In the case where the language allows truly recursive compound construction, then under the strong lexicalist conception, the nominal sublexicon is simply infinite. So a strong lexicalist position about noun-noun compounds, in which the means of all such compounds is stored in the lexicon, is unlikely to result in a lexicon of a psychologically realistic size.

(13-c) is interesting because it exhibits noun phrase nonparallelism. The antecedent occurs in an adjective-noun compound, but the elliptical *one* occurs in a noun-noun compound. This does not detract from the fact that the elliptical phrase occurs within a noun-noun compound. The examples in (13) involve intra-sentential ellipsis, but *one* may also find its antecedent in the discourse context.

- (14)
- a. Jerry only likes adventure books_{*i*}. That’s why he throws out the romance ones_{*i*} he gets as gifts.
 - b. When you go to the supermarket, please pick up the olive oil_{*i*}. I also need the sunflower one_{*i*} for the chicken.
 - c. *When you go to the supermarket, please pick up the olive oil_{*i*}. I also need the baby one_{*i*} for my skin.

In these examples, *one* behaves largely like a regular pronoun, except that it binds a nominal rather than an NP constituent. The crucial point is that *one* is bound by an N-type constituent occurring earlier. One should also note the contrast between (14-c) and (14-b), which illustrates how *one*-ellipsis is conditioned on the antecedent and the elided element having the same semantic content, which makes sense if the input to compounding is a semantic resource—rather than a syntactic object where *R* necessarily remains unpronounced—introduced into the context.

An in-depth discussion of ellipsis is not possible here, but I will briefly indicate how such examples lead directly to the need for a compositional procedure for building compound meanings from subconstituent meanings. The simplest account of *one*-anaphora in these cases is that *one* simply duplicates the semantic resource of its antecedent, and makes it available for consumption by other semantic resources. This is generally the course taken by accounts of anaphora within Glue semantics, which are largely inspired by the treatment of pronouns in Categorical Grammar (CG) (Steedman, 2000). In such accounts, pronouns mainly function at the semantic level, duplicating resources occurring elsewhere and making them available for derivations (Asudeh, 2004, Dalrymple et al., 1999). For instance, to handle cases of intra-sentential anaphora, (Asudeh, 2005, p.396) proposes a pronoun resource of the form

- (15) himself
 $\lambda z.z \times z : (\uparrow_{\sigma} \text{ANTECEDENT})_e \multimap ((\uparrow_{\sigma} \text{ANTECEDENT})_e \otimes \uparrow_{\sigma_e})$

(15) takes the pronoun’s antecedent as an argument and returns, on the Glue language side, a multiplicative conjunction of the antecedent resource and a pronoun resource. On the meaning language side, it returns a duplicated pair of the *e*-type denotation of the antecedent. Intra-sentential anaphora must be dealt with differently, since there is no resource provided elsewhere in the sentence to consume the antecedent. However, the generalization is that anaphors duplicate resources occurring elsewhere—either in the derivation of the sentence in which the anaphor occurs, or in that of some other sentence.

While pronouns duplicate entity-denoting resources, *one* duplicates a resource of the form:

- (16) $\lambda x.P(x) : v \multimap r$

where *P* is a property. This means that, in the cases of *one*-ellipsis discussed above, the semantic resource contributed by *one* is identical to that contributed by the antecedent. The antecedent, in these cases, occurs within a noun-noun compound. Assuming that semantic resource duplication is the correct way to handle *one*-anaphora—which seems like the correct choice for maintaining a consistent and uniform approach to anaphors—it is difficult to explain how lexicalized compounds can have their individual components retrieved and redeployed. Moreover, *one*-anaphora with antecedents in compounds is syntactically flexible, in that the antecedent resource may be

consumed by a different type of modifier than the *one*-resource. For instance, the examples in (17) involve *one*-ellipsis into and out of compounds of different kinds.

- (17) a. Jim doesn't like adventure books_{*i*} anymore. He wants to read harder ones_{*i*}.
(*Noun-Noun to Adjective-Noun*)
b. I don't want to read difficult books_{*i*} anymore. Please just get me a romance one_{*i*} this time.
(*Adjective-Noun to Noun-Noun*)

In example (17), *one* introduces a copy of its antecedent into a compound construction, but the antecedents occurs in an differently-modified noun phrase. It is generally assumed that the denotation of a noun in an adjective-noun compound is its usual property denotation, with the adjective modifying the meaning contributed by the noun. Again, assuming the basic pattern that *one*-ellipsis duplicates semantic resources, a lexicalist account of compound semantics would need to explain the identity of semantic resources across different compound types. How does a resource contributed by the adjective-noun compound come to differ from that contributed by meaning invoked via ellipsis within the noun-noun compound?

5 Compositional semantics of noun-noun compounding

The reader is hopefully convinced that, apart from a small number of cases, compounding can be given a compositional account in terms of the denotations of its constituent nouns. Following from the discussion above, a compositional theory of noun-noun compounding should satisfy a number of conditions.

- (18) **Desiderata of a theory of compounding**
- a. Recursiveness, with reduction to a final result of type $e \rightarrow t$
 - b. A relational interpretation of the form (1)
 - c. (Right) Semantic endocentricity (excluding lexicalized exocentric compounds)—the denotation of the compound is a subset of the denotation of the head
 - d. Access to relational content of the modified head noun, and constrained access to relational content of the modifier
 - e. Access to discourse, world knowledge, and other pragmatic resources to instantiate R

Item (18-a)—recursiveness—is essentially the requirement that the grammar be able to construct interpretations for embedded compounds like $[[vampire\ rat]\ hunter]$ whose interpretations are properties. Desideratum (18-e) is something of a negative condition requiring that certain degrees of freedom be available in the semantics of compounds—the relation R may be instantiated from a variety of sources. This is appropriate, given that the relations provided by head nouns, though highly favored in compounds like *truck driver*, have—albeit somewhat extraordinary—contexts in which they are defeasible. Hence, the semantics of compounding must guarantee that such interpretations are optional.

Confining our attention to the semantic contributions of the two nouns *qua* nouns, and disregarding for the moment the fact that they occur in a compounding construction, we are left with the following denotations:

- (19) a. $[[N_1]] = \lambda y.P(y) : v_1 \multimap r_1$
b. $[[N_2]] = \lambda y.Q(y) : v_2 \multimap r_2$

where P and Q are properties. However, recall that the target denotation for the compound is given schematically by:

$$(20) \quad \llbracket N_1 N_2 \rrbracket = \lambda R. \lambda x. \exists y. \llbracket N_1 \rrbracket(y) \wedge \llbracket N_2 \rrbracket(x) \wedge R(x, y) : (a_{r_1} \multimap (v_{r_2} \multimap r_r)) \multimap (v \multimap r)$$

This denotation is motivated by the empirically observed semantics of noun-noun compounds, and captures the semantic asymmetry of N_1 and N_2 in the usual case where N_2 is the semantic head. As discussed, N_2 must be available for elliptical binding, and examples like (14-c) show that it must “carry” the relation with it in ellipsis. It is therefore N_2 that must have its type lifted to modify N_1 .

This lifting of N_2 can be performed, and the above desiderata can be satisfied, by the introduction of semantic resources that carry out the required composition. For the simplest case of an endocentric compound with two nonrelational noun arguments, an appropriate resource is given as C_σ below.

$$(21) \quad \textbf{Definition: Compounding resource } C^\sigma \\ C^\sigma = \lambda R. \lambda Q. \lambda P. \lambda x. \exists y. Q(y) \wedge P(x) \wedge R(x, y) : \\ \uparrow_\sigma \text{ REL} \multimap ((v_1 \multimap r_1) \multimap ((v_2 \multimap r_2) \multimap (v \multimap r)))$$

($\uparrow_\sigma \text{ REL}$) is an abbreviation for a relational resource with Glue type $a_1 \multimap (a_2 \multimap r)$. C^σ consumes a relation and two resources contributed by nouns N_1 and N_2 , returning a noun-type resource with a property denotation. It is clear that C^σ satisfies the recursion property. When two nominal resources and a binary relational resource are supplied, C^σ reduces to a resource with Glue type $v \multimap r$, the type of a noun. Supplying an additional noun resource and another instance of C^σ allows the compound to be embedded in yet another compound, in either the N_1 or N_2 position.

Earlier, the case of relational nouns was discussed. It was found that the relation supplied by a relational N_2 could, but need not, instantiate R . This optional instantiation can be handled by including an optional lexical entry that specifies the semantic feature REL. Every deverbal is linked with its root verb form V, so we can simply identify REL with the denotation of V.⁴

$$(22) \quad (\uparrow_\sigma \text{ REL} = \llbracket V \rrbracket)$$

This specification of REL produces the right resources for a valid Glue proof of the appropriate relational denotation for a compound with a relational N_2 that directly supplies the relation. The proof crucially relies on the use of the existential closure operation over the argument of *driver* defined in (9). In the derivation, REL is set to $\lambda y. \lambda x. \text{drive}(x, y)$ by (22). The two optional lexical resources from *driver* are the closure operator and the verbal resource associated with *driver*.

$$(23) \quad \textbf{Premises for } \textit{car driver} \\ \begin{array}{lll} 1 & \lambda z. \textit{car}(z) : v_1 \multimap r_1 & \text{Lex. } \mathbf{car} \\ 2 & \lambda y. \lambda x. \textit{driver}(x, y) : a_2 \multimap (v_2 \multimap r_2) & \text{Lex. } \mathbf{driver} \\ 3 & \lambda S. \lambda x. \exists z. S(x, z) : (a_2 \multimap (v_2 \multimap r_2)) \multimap (v_2 \multimap r_2) & \text{opt (Lex. } \mathbf{driver}) \\ 4 & \lambda y. \lambda x. \textit{drive}(x, y) : \text{REL} & \text{opt (Lex. } \mathbf{driver}) \\ 5 & \lambda R. \lambda P. \lambda Q. \lambda x. \exists y. Q(y) \wedge P(x) \wedge R(x, y) : \text{REL} \multimap ((v_2 \multimap r_2) \multimap ((v_1 \multimap r_1) \multimap (v \multimap r))) & C^\sigma \end{array}$$

⁴Depending on the semantics chosen for deverbals, this could alternatively be some derived predicate systematically built from V, as in (8)

(24)

$$\begin{array}{c}
\frac{\lambda R.\lambda P.\lambda Q.\lambda x.\exists y.Q(y) \wedge}{P(x) \wedge R(x, y) :} \text{opt. (Lex. driver)} \\
\frac{REL \rightarrow ((v_2 \rightarrow r_2) \rightarrow ((v_1 \rightarrow r_1) \rightarrow (v \rightarrow r)))}{\lambda P.\lambda Q.\lambda x.\exists y.Q(y) \wedge P(x) \wedge} \text{Lex. driver} \\
\frac{drive(x, y) : (v_2 \rightarrow r_2) \rightarrow ((v_1 \rightarrow r_1) \rightarrow (v \rightarrow r))}{\lambda y.\lambda x.drive(x, y) : a_2 \rightarrow} \text{opt. (Lex. driver)} \\
\frac{\lambda S.\lambda x.\exists z.S(x, z) : (a_2 \rightarrow (v_2 \rightarrow r_2)) \rightarrow (v_2 \rightarrow r_2)}{\lambda x.\exists z.driver(x, z) : v_2 \rightarrow r_2} \text{Lex. driver} \\
\frac{\lambda Q.\lambda x.\exists y.Q(y) \wedge \exists x.driver(x, z) \wedge drive(x, y) : (v_1 \rightarrow r_1) \rightarrow (v \rightarrow r)}{\lambda x.\exists y.car(y) \wedge \exists z.driver(x, z) \wedge drive(x, y) : (v \rightarrow r)} \text{Lex. car} \\
\frac{}{\lambda z.car(z) : v_1 \rightarrow r_1} \text{Lex. car} \\
\frac{}{\rightarrow \mathcal{E}}
\end{array}$$

(25)

$$\begin{array}{c}
\frac{\lambda R.\lambda P.\lambda Q.\lambda x.\exists y.Q(y) \wedge}{P(x) \wedge R(x, y) :} \text{opt. (Lex. driver)} \\
\frac{REL \rightarrow ((v_2 \rightarrow r_2) \rightarrow ((v_1 \rightarrow r_1) \rightarrow (v \rightarrow r)))}{\lambda P.\lambda Q.\lambda x.\exists y.Q(y) \wedge P(x) \wedge} \text{Lex. driver} \\
\frac{R(x, y) : (v_2 \rightarrow r_2) \rightarrow ((v_1 \rightarrow r_1) \rightarrow (v \rightarrow r))}{\lambda y.\lambda x.drive(x, y) : a_2 \rightarrow} \text{Lex. driver} \\
\frac{\lambda S.\lambda x.\exists z.S(x, z) : (a_2 \rightarrow (v_2 \rightarrow r_2)) \rightarrow (v_2 \rightarrow r_2)}{\lambda x.\exists z.driver(x, z) : v_2 \rightarrow r_2} \text{opt. (Lex. driver)} \\
\frac{\lambda Q.\lambda x.\exists y.Q(y) \wedge \exists x.driver(x, z) \wedge R(x, y) : (v_1 \rightarrow r_1) \rightarrow (v \rightarrow r)}{\lambda x.\exists y.car(y) \wedge \exists z.driver(x, z) \wedge R(x, y) : (v \rightarrow r)} \text{Lex. car} \\
\frac{\lambda R.\lambda x.\exists y.car(y) \wedge \exists z.driver(x, z) \wedge R(x, y) : REL \rightarrow (v \rightarrow r)}{\rightarrow \mathcal{I}, 1} \text{Lex. car} \\
\frac{}{\rightarrow \mathcal{E}}
\end{array}$$

Observe that, due to applications of (9) and (22), *driver* contributes three resources: its own denotation, a duplicate of that denotation with Glue type REL, and the existential closure operator. The proof results in a denotation for the compound of a noun in which the y satisfying *car* is related to x by *driver*, as desired.

What about the case where the relation R remains unspecified? That is, where R is not provided by either noun in the compound, but is supplied by world knowledge, contextual information, or some other mechanism? This case is shown in (25) for the case of *car driver*. It differs from (24) in the first and final steps, where the relation R is abstracted out of the compound. In such cases, the derivation of a compound—and, by transitivity, of a sentence—will not reduce to a propositional resource. Rather, it reduces to a function from relations into propositions. A sentence containing a single compound will depend on the provision of one relation. It will therefore have the lambda-type $(e \rightarrow (e \rightarrow t)) \rightarrow t$. One containing two compounds will depend on two relations—and so on. This is similar to the case in the variable-free binding theory presented by Jacobson (1999), where calculating the denotation of a sentence depends on the provision of an e -type antecedent to a sentence of type $e \rightarrow t$ (Asudeh, 2005). This should not be viewed as a problem—rather it is precisely our means of satisfying desideratum (18-e), namely, that an appropriate relation for completing the meaning of a compound can be supplied by pragmatically-specified resources.

6 N_1 argument-reduction

We have seen that relational N_2 resources can be obtained from the lexical entries of such nouns, and duplicated by a few simple Glue operations. We now turn our attention to the asymmetry between N_1 and N_2 nouns in their argument-taking properties within compound noun constructions. How this asymmetry can be syntactically specified so that compound resources are introduced at the appropriate moment will be discussed in the next section. For now, we will focus on the semantic side: what derivational resources are necessary to derive obligatory N_1 argument reductions.

Recall the essential fact that deverbal N_1 's, though not ordinary relational N_1 's, are prohibited from having their argument positions satisfied by the denotation of the N_2 they accompany. I will refer to this phenomenon as *N_1 argument reduction*. It can be handled by setting the introduction of the existential closure resource defined in (9) from optional to obligatory, resulting in a lexical rule:

$$(26) \quad \lambda R. \lambda x. \exists y. R(x, y) : (a \multimap (v \multimap r)) \multimap (v \multimap r)$$

The removal of the parentheses around (26) indicates that the insertion of a closure resource is no longer optional. In N_1 compounding contexts, the specification of this resource is given in the lexical entry for the introduced N_1 if it is relational. As discussed, certain broad classes of nouns, especially deverbals, exhibit this property compounds, so the lexical insertion of (9) need not be specified on a case-by-case basis, but can be inherited as a function of the syntactic class it belongs to, based on lexically-specified class features such as DEVERB for deverbal nouns. We go on to discuss how this can be encoded within an LFG grammar.

7 Specification of compounding resources at the syntax- semantics interface

The syntax of noun-noun compounds appears straightforward, but this appearance is only superficial. In reality, some work is required to create a syntactic account that captures the semantics of compounds. An elementary phrase structure rule proposed by Selkirk (1982) captures the recursiveness of compounding.

$$(27) \quad N \rightarrow N N \quad (\text{Selkirk, 1982})$$

However, the two Ns in (27) are syntactically symmetrical; neither appears as a syntactic head. This contrasts with the semantic asymmetry between the two nouns in a compound, whose left hand member functions more like a modifier on the left hand member. Accounting for this semantic asymmetry between heads and nominal modifiers of heads, requires some work, since the constituent structure described in (27) provides no indication of the semantic prominence of N_2 , or of the role of N_1 as a modifier.

The asymmetry between the (left) modifier noun and the (right) head noun can be expressed in a revised rewrite rule

$$(28) \quad N \rightarrow \begin{array}{c} N \\ @NNMOD \end{array} \begin{array}{c} N \\ @NNHEAD \end{array}$$

The expressions prefixed by @ are LFG *templates*. Templates were introduced by Dalrymple et al. (2004) to encode generalizations about word classes that shared several properties. The goal there was to facilitate and shorten grammar writing by referring to bundles of features all at once. Such templates may be referenced in the grammar to state conditions on the structure of the constituents for which they are invoked. Asudeh et al. (2013) employ templates to introduce meaning constructors into derivations. An invocation of a template containing a semantic resource simply adds that semantic resource to the semantic resources already introduced by the constituent for which the template is invoked.

The need to invoke additional resources in compounding motivates the use of templates in this case to introduce meaning constructors specific to noun-noun compounds. The template definitions for NNMOD and NNHEAD given below are simply lists of f-structure functional equations and meaning constructors introduced by the nonhead and the head respectively.

$$(29) \quad \text{NNHEAD} = \downarrow = \uparrow \text{PRED} \\ C^\sigma$$

$$(30) \quad \text{NNMOD} = \downarrow = \uparrow \text{NMOD}$$

The template definition for NNHEAD simply passes up the f-structure of the head to the PRED of the compound. Crucially, NNHEAD introduces the C^σ meaning constructor defined in (21), which performs the required compounding operation. The template for the NNMOD template states that the f-structure of the modifier is added as an NMOD feature to the compound constituent.

An additional template accounts for the argument-reduction of deverbal modifiers, which come with an invocation of the template DVB in their lexical entries. The DVB template refers back to the NNMOD template to perform the required argument reduction in these cases.

$$(31) \quad \text{DVB} = @NNMOD \Rightarrow \lambda R. \lambda x. \exists y. R(y, x) : (a \multimap (v \multimap r) \multimap (v \multimap r))$$

An invocation of @DVB introduces the implicational condition indicated in its definition. If the template NNMOD is invoked in a DVB, argument-reduction is required to take-place. This accounts for the special semantics of deverbal N_1 's.

An interesting series of questions arises about the nature of the semantic operation performed by C^σ , which converts N_1 to an operator over the meaning constructor of N_2 . The questions that arise have to do with the ordering of the application of C^σ in relation to the compilation of contexts for future elliptical reference. Given that *one*-ellipsis consists of a duplication of a noun-type resource, the data suggest that the determination of a relation R must precede the compilation of contexts eligible for future anaphoric reference. The relevant data come from *one*-ellipsis, in a contrast noted above and repeated here.

- (32) a. When you go to the supermarket, please pick up the olive oil_{*i*}. I also need the sunflower one_{*i*} for the chicken.
 b. *When you go to the supermarket, please pick up the olive oil_{*i*}. I also need the baby one_{*i*} for my skin.

The difference between (32-b) and (32-a) is that the relation between the antecedent and its N_1 is not reproduced in the elliptical sentence. This suggests a lexical process wherein N_2 is converted into a modifier and “carries” R during ellipsis, such that the application of $C^\sigma(R)$ to $[[N_2]]$ precedes the collection of admissible *one*-antecedents. However, contradictory evidence comes from ellipsis into and out of adjective-noun compounds, in which N_2 certainly does not “carry” or accept a hidden R , as well as consideration of compounds of length $n > 2$.

- (33) a. *Jerry is picky about what format he reads in. That’s why he reads adventure_{*i*} ebooks but throws out one_{*i*} hardcovers.
 b. ?Jerry is picky when it comes to fiction genres. That’s why he has an [adventure books_{*i*}] pedestal, and a [romance ones_{*i*}] shredder.

While (33-a) is completely unacceptable, (33-b) is slightly questionable, but substantially better. A reasonable conclusion is that the antecedent of *one* must occur as *an* N_2 in *some* compound, but not necessarily the base one that is the semantic core of the entire noun phrase. This complicates things, since if all applications of C^σ must be exhausted prior to the collection of antecedents for *one*, *books* would never appear among the candidates in (33-b). This seems to provide evidence against framing C^σ as some variety of “lexical rule” that transforms the semantic contribution of N_1 directly, and introduces the possibility that a model of incremental derivation, with elliptical context collection occurring at a number of stages, is needed to handle these cases in a Glue framework. For now, these are live questions requiring further investigation.

8 Conclusion

This paper has provided the first, to my knowledge, formal account of the semantics of noun-noun compounds within a Glue framework, arguing that the semantics of such compounds can be dealt with using primarily materials encoded in the lexical entries for individual nouns, often with supplemental inputs from pragmatic knowledge. The semantics of compounds are shown to be inappropriately dealt with by a strong lexicalist position to the effect that compounds separately recorded as individual lexical entries, without a clear combinatorial relation to their constituent nouns. In addition, it is shown that the facts about ellipsis out of noun-noun compounds provide evidence in favor a compositional procedure for compounding that is not reducible to lexical compound-formation rules. The compositional proposal developed here speaks to the debate about whether compounding is a productive syntactic process, as argued by many early

researchers, or more of a lexical operation, as has more recently been held. As argued here, the facts seem to favor a rich lexical semantic input to recursive compositional operations, where idiosyncratic behavior is specified at the lexical level.

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A Appendix: Glue Semantics with Linear Logic

In Glue semantics, lexical entries contribute semantic resources that are employed in proofs of output meanings. Readings of sentences are generated through proofs utilizing these input premises. The inputs to a Glue proof are *meaning constructors* of the form

$$(34) \quad \mathcal{M} : G$$

where \mathcal{M} is a term of the meaning language (here, a typed higher-order logic with lambda abstraction) and G is a term from the Glue logic that specifies how terms are to be combined. Importantly, derivation in Glue semantics is *resource sensitive*, in that resources are “consumed” by proof steps, and cannot be reintroduced later on.

According to the Curry-Howard correspondence, there is a one-to-one correspondence between proofs in implicational logic and computation of functions, here expressed in the lambda calculus (Curry et al., 1972, Howard, 1995). The proof rules for the Implicative fragment of linear logic (ILL) employed here are given below, with their canonical connection to meaning language operations on left hand side.

(35) Implication Elimination

$$\frac{\begin{array}{c} \vdots \\ a : A \end{array} \quad \begin{array}{c} \vdots \\ f : A \multimap B \end{array}}{f(a) : B} \multimap \varepsilon$$

(36) **Implication Introduction**

$$\frac{\begin{array}{c} [a : A]^i \\ \vdots \\ f : B \end{array}}{\lambda x.f[x/a] : A \multimap B} \multimap \mathcal{I}, i$$

How these rules are employed in meaning derivations will become clear in section 5. Readers desiring a more thorough account of the Glue semantics and linear logic are referred to Crouch and Genabith (2000).