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Mismatching Meanings in Brain and Behavior

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Abstract

Natural language interpretation is generally thought to be compositional, that is, the meanings of expressions are a function of the meanings of their parts and of the way the parts are syntactically combined. Theories of the syntax–semantics interface aim to articulate the details of this function. This article discusses a new research program in which psycholinguistic and neurolinguistic experiments on so-called syntax–semantics mismatches are used to elucidate the mechanisms that mediate between structure and meaning.

Compositionality

Natural language meanings are often mysterious. For example, why does piling the cushions high result in a high pile and not high cushions, whereas hammering the ring flat gives you a flat ring instead of a flat hammer? Or take the verb *begin*. Since it describes the beginnings of events, one would expect that it needs to combine with something that names an event of some sort, as in *begin writing a book* or *begin eating the pizza*. But actually it does not. Similar meanings are available even if the initiated activity is omitted: *begin a book* can mean 'begin writing a book' and *begin the pizza* can mean 'begin eating the pizza'. Why?

These are examples of questions that drive research on the syntax–semantics interface, the area of linguistics that investigates the relationship between the structural representations of linguistic expressions and their meanings. The contrast between *pile the cushions high* and *hammer the ring flat* was recently studied by Levinson (2007) and the *begin the book* type expressions have been discussed by Jackendoff (1997) and Pustejovsky (1995), among others. As regards the general architecture of the syntax–semantics interface, this much is clear: no matter how mysterious meanings may seem, the relationship between structure and meaning has to be transparent enough to account for our ability to comprehend and produce previously unencountered expressions. In other words, somehow, the lexical items themselves and their order are sufficient for interpretation, no matter how complex the meaning. This basic idea is the gist of the principle of compositionality:

Principle of Compositionality
The meaning of an expression is a function of the meanings of its parts and the way they are syntactically combined.

This principle dates back at least to Frege (1892) and its status in linguistic theorizing is usually that of a working hypothesis: researchers strive to develop compositional analyses, because compositionality explains humans' ability to comprehend and generate novel expressions. At the same time though, philosophers in particular often note that the principle is too vague to offer any serious constraints on possible theories (e.g., Janssen 1997; Pagin 2003; Szabó 2000, 2004). In particular, limiting the meanings of expressions to 'functions' of the meanings of their parts and their syntactic combinatorics is not to say much without a theory of exactly what those functions may look like. Thus, pretty much 'any meaning assignment can be compositionally imitated' (Szabó 2004: 341).

Consequently, in order for compositionality to constitute a useful hypothesis, one needs to define some rather specific interpretation of it. Furthermore, if we want linguistics to be part of the natural sciences, the interpretation should make testable, empirical predictions. So far, however, compositionality debates have not had a particularly empirical nature (for discussion, see in particular Dowty 2007). Instead, researchers have tended to use mostly conceptual arguments to decide what flavor of compositionality to endorse.

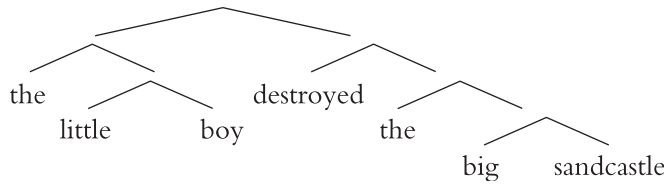
The aim of this article is to review an emergent body of psycho- and neurolinguistic research that promises a novel set of empirical tools for investigating the syntax–semantics interface. In order to keep the discussion manageable, I will primarily focus on a single type of expression, so-called complement coercion, exemplified by phrases such as *begin the book*, already mentioned above. I will first explain why this type of expression constitutes a 'syntax–semantic mismatch'. Then I will contrast two analyses of the mismatch, adhering to different versions of compositionality. I will first try to distinguish between them by examining well-formedness judgments in the way linguists traditionally do. I will show that this method leads to null results in the case of complement coercion, that is, we are not able to provide evidence for either of the competing analyses. In the second half of this article, I will then turn to the psycho- and neurolinguistic work on this construction, where positive results are obtained. The neurolinguistic work reveals that constructions such as complement coercion engage a somewhat surprising brain area, a region of the frontal lobe that is not generally considered a 'language area', but is instead heavily implicated for various types of non-linguistic higher cognition, including theory of mind. To conclude, I will speculate about the potential significance of this neurolinguistic finding for theories of the syntax–semantics interface.

Part I: Studying Syntax–Semantics Mismatch with the Traditional Tools of Linguistics

TRANSPARENT COMPOSITIONALITY VS. SYNTAX–SEMANTICS MISMATCH

Natural language expressions vary in the degree to which their meanings appear transparently predictable from the meanings of their constituents. For example, the sentence *the little boy destroyed the big sandcastle* has a highly transparent meaning and poses no major mysteries for theories of the syntax–semantics mapping. The syntax of this sentence is roughly as in (1) below. The semantic relationships between the different elements of the sentence are highly consistent with the syntactic structure. For example, the adjective *little* is sister to *boy*, and semantically, it modifies the same noun (i.e., the sentence has no readings where the *sandcastle* is *little* instead of the *boy*). Similarly, *big* modifies *sandcastle* and is syntactically sister to it. Finally, the syntactic subject of the sentence *the little boy* is interpreted as the agent of the sentence and the object *the big sandcastl*e as the affected argument (or patient), as is canonical in English.[1]

(1) The little boy destroyed the big sandcastle.



But it is easy to turn this sentence into an expression whose meaning is much harder to explain. For example, it is possible to add an adjective to the end of the sentence and have it describe a property of the sentence-initial subject, which in the linear string occurs nowhere near the adjective:

(2) The little boy destroyed the big sandcastle angry.

With the right intonation (accenting *angry*), *angry* contributes a mental state that holds of the little boy during the event described by the verb. This type of modification is called depictive modification and its semantic contribution is notoriously difficult to explain without some kind of a special rule, given that the adjective does not appear to form any type of constituent with the noun that it modifies (see, for example, Geuder 2000). In other words, the syntax seems to mismatch with the semantics.

Let us now turn to complement coercion. This construction involves verbs such as *begin*, *finish*, *start*, *complete*, *attempt*, *enjoy*, and *survive*. All these verbs semantically select for event-describing objects. *Begin*, for example, describes the beginnings of events or activities, and thus naturally combines

with VP-complements that describe activities, as in *the author began writing the book*. However, somewhat surprisingly, a very similar meaning can be obtained even if we omit the writing and have *begin* combine directly with a noun phrase, as in (3).

(3) The author began the book.

In (3), there is a conflict between the semantic requirements of the verb and the meaning of the object: the verb seeks to combine with an event-denoting complement but the object describes an entity. The situation exemplifies a so-called 'type mismatch'. A type mismatch often leads to ungrammaticality [as will be illustrated in (37) ahead], but not in this case. Instead, the sentence is interpreted as asserting that the author began some, contextually determined, activity involving the book. In other words, the grammar seems to have a mechanism for fixing the mismatch and inserting a silent event into the meaning of the sentence. Again, we have an apparent syntax–semantics mismatch: the meaning of the sentence involves some element that seems absent in the syntax.

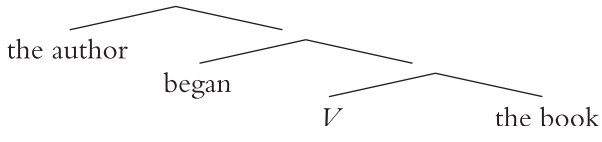
ANALYSES OF THE MISMATCH: SILENT HEADS VS. TYPE-SHIFTING

What possible sources could there be for meanings that seem part of an expression but do not map onto any its overtly pronounced elements, like the silent event sense in (3)? Linguistic theory generally offers two types of solutions:

i There is more to the syntax (and therefore the semantics) than what meets the eye/ear.
ii There is more to the semantics (but not the syntax) than what meets the eye/ear.

In the first type of solution, the mysterious meaning is introduced by a so-called silent head, that is, a syntactic head that lacks a pronunciation. This type of analysis could be executed in many ways, and in the space of this article it would be impossible to cover them all. However, one of the most intuitive versions of this approach would involve some type of silent verbal element mediating between the event-selecting verb (e.g., *begin*) and the entity-denoting object. Such an analysis is sketched in (4) for the sentence *the author began the book*.

(4) Silent head solution for *begin the book*

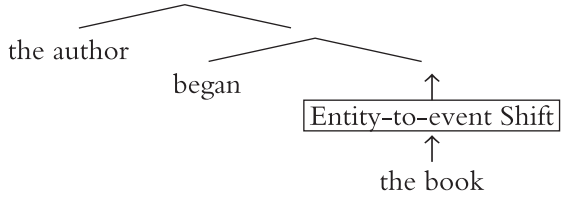


According to this analysis, English has a morpheme that behaves syntactically like a verb but is inaudible. In linguistics, silent syntactic elements are rather unexotic; they have been proposed in virtually every domain of the grammar, ranging from silent pronominal elements (Chomsky 1981) to covert verbal (e.g., Pesetsky 1994; Harley 1995) and prepositional heads (Hale and Keyser 1993; Pesetsky 1994), as well as various unpronounced projections in the so-called left periphery of the sentence, having to do with information structure notions such as topic and focus (e.g., Rizzi 1997). Typically, silent heads are assumed to have the standard properties of syntactic elements, although most linguists would probably agree that there must be some nontrivial constraints on what types of elements may be unpronounced. So far, however, there has been very little research explicitly addressing this question – see Kayne 2006 for the only extant proposal.

I will discuss the empirical predictions of (4) in the next two sections. At the conceptual level, a typical motivation for positing a silent head is that it allows one to solve the syntax–semantics mismatch while maintaining a maximally strong version of compositionality. In other words, the analysis in (4) allows for a complete homomorphism between the syntax and the semantics: each step in the semantic interpretation corresponds to a step in the syntactic composition. This view of the syntax–semantics interface was held in Montague grammar (Montague 1970), which is generally considered one of the main starting points for contemporary formal semantics (for a historical review, see, for example, Partee and Hendriks 1997).

In the second type of solution, where 'there is more to the semantics than what meets the eye,' the silent event sense is introduced by a purely semantic rule that affects the meaning but not the syntax. This is the type of solution that has uniformly been proposed for the *begin the book* type expressions. Specifically, the complement of the verb, that is, the entity-denoting object, has been hypothesized to 'coerce' into an event-meaning to satisfy the verb's semantic requirements (Pustejovsky 1995; Jackendoff 1997). Reflecting this analysis, this type of expression is usually called a 'complement coercion' construction. The tree in (5) gives the gist of the account, albeit without any formal detail. For accessibility's sake, I will refrain from formalizations throughout this article, but detailed treatments of the complement coercion rule can be found in Egg (2003); Jackendoff (1997); Pustejovsky (1995), and Pustejovsky and Bouillon (1995).

(5) Type-shifting solution for *begin the book*



Since complement coercion shifts the semantic type of the direct object from an entity (or individual) to an event predicate, it is an example of 'type-shifting'. Within linguistics, type-shifting was originally developed by Partee and Rooth (1983), who argued against Montague's uniform treatment of noun phrases as generalized quantifiers (Montague 1970) and in favor of an approach where a phrase such as *the teacher* denotes an individual as its basic meaning but lifts to a higher type in contexts such as *the teacher and every student*. In subsequent work, type-shifting has been exploited in the analysis of a wide variety of phenomena, including the interpretation of different kinds of noun phrases (Partee 1987), questions (Groenendijk and Stokhof 1989), nonconstituent coordination (Dowty 1988), topicalization (Steedman 1985), gapping (Steedman 1987, 1990), aspectual shifts (Moens and Steedman 1988), kind denoting noun phrases (Chierchia 1998), scope and binding (Jacobson 1999, 2000; Szabolcsi 2003; Shan and Barker 2006), quantification in questions (Chierchia 1993; Lahiri 2000; Krifka 2001), causative constructions (Bittner 1999), scrambled definites (De Hoop and Van der Does 1998), plurals (Winter 2001, 2002), and genitive constructions (Partee and Borschev 1998).

The important difference between silent heads and type-shifting is that type-shifting conforms to a weaker version of compositionality than silent heads. Since the type-shifting rule in (5) affects the semantics without affecting the syntax, the semantic composition involves a step that does not correspond to a syntactic step. In other words, theories with type-shifting have two mechanisms for introducing meaning, the syntax and type-shifting rules. Theories without type-shifting only have one: the syntax. Thus, the choice between silent heads and type-shifting is an important basic question about the architecture of the grammar. Natural language may have only one of them, or both of them, or perhaps neither. How can we find out?

HYPOTHESIS TESTING 101

In order to approach the silent head vs. type-shifting question as a standard scientific issue, I will first restate the hypotheses in somewhat more statistical terms. At the most basic level, both the silent head and the type-shifting approaches hypothesize that expressions such as *the author began the book* are not parallel to simple transitives that involve no hidden meaning (e.g., *the author liked/wrote the book*). Specifically, the silent head hypothesis predicts that complement coercion expressions differ from simple transitives both semantically and syntactically. Type-shifting, on the other hand, predicts that there should only be a contrast in semantics. To test these hypotheses, a so-called 'null hypothesis' needs to be defined. Null hypotheses either state that two or more sets of observations are not different from each other or that two or more variables are not associated with each other. In the present case, it is the former type of null hypothesis that is

relevant. In other words, the null hypothesis is that there are no differences between complement coercion expressions and simple transitives. Both the type-shifting and the silent head hypotheses then constitute so-called 'alternative hypotheses' to this null hypothesis.

If these are the hypotheses, then what constitutes a result? In science, one has a result if one is able to reject the null hypothesis. If the null hypothesis cannot be rejected, one has a so-called 'null result'. A null result is not proof of the null hypothesis; rather, it simply does not constitute evidence for the alternative. Null results may sometimes be informative, but in science they are not considered results per se; for example, they cannot by themselves be published in regular journals. Consequently, one always attempts to formulate hypotheses that predict differences between situations, as opposed to similarity, because showing that two situations do not differ is always a null result. Thus, from the point of view of hypothesis testing, the silent head hypothesis is stronger and more easily testable than type-shifting, because it predicts more contrast.

Now, an obvious difference between linguistics and the sciences is the use of statistics. To assess whether a null hypothesis can be rejected, statistical tests assess the probability of a given numerical outcome if the null hypothesis was in fact true. The lower the probability, the stronger the evidence against the null hypothesis. But in linguistics, we do not traditionally state the outcomes of our studies in numbers, so this definition of a result is not technically applicable. However, as discussed by Marantz (2005), the nonquantified data in linguistics can, and should, be viewed as 'meta-data', representing predicted outcomes of possible experiments. In other words, despite appearances, the contrasts reported by linguists are not qualitatively different from the results of standard cognitive psychology experiments. Thus, in the next two sections, I will assume the standard statistical definition of a 'result', even though the well-formedness observations under discussion are not quantified.

WELL-FORMEDNESS JUDGMENTS YIELD NULL RESULTS FOR THE SILENT HEAD HYPOTHESIS

The silent head hypothesis claims that despite appearances, complement coercion expressions involve two VPs instead of one. A common diagnostic for assessing whether a structure involves multiple VP-layers is adverbial modification. Two VPs offer two sites for VP-modification, as shown in (6), where the adverb modifies the embedded verb *read* in (a), and the matrix verb *like* in (b).

(6) Two VPs
    a. Low attachment: The boy liked reading the book page by page.
    b. High attachment: The boy liked reading the book immensely.

When the embedded verb is omitted and we only have one VP, the lower attachment becomes impossible, as shown in (7).

(7) One VP
a. Low attachment: #The boy liked the book page by page.
b. High attachment: The boy liked the book immensely.

The silent head hypothesis predicts that complement coercion should pattern with the 'two VPs' situation. But this prediction is not born out: adverbial modification of the hypothesized silent VP is impossible, as illustrated in (8).

(8) Complement coercion, low attachment:
#The boy began the book page by page.

Thus, we have a null result: the test does not distinguish between the coercion expression in (8) and the simple transitive in (7). Why? Perhaps because the null hypothesis is true or perhaps for some other reason. Since the cause is unknown, the result cannot be interpreted. Crucially, the null result is not evidence for type-shifting.

A second test that should be able to diagnose an unpronounced embedded VP involves so-called event anaphora. The example in (9) illustrates that the pronoun *it* can in general refer to events (Davidson 1967):

(9) Smith stabbed Jones. It happened at noon.

Thus, we can ask whether *it* can also refer to the silent event in complement coercion. As a control, (10) first verifies that event anaphora is possible of overt VP complements of coercion verbs. The example is constructed in such a way that the anaphor is only felicitous if it is interpreted as referring to the embedded event (since enjoyment cannot plausibly cause anyone to lose their eyesight):

(10) Overt VP-complement: Joe enjoyed reading these books but it ruined his eyes.

Now, if we construct the coerced version of (10), where the reading-event is left implicit, do we still have the same possibility of event anaphora? The answer is 'no'. In (11), the *it*-anaphor cannot refer to some unnamed activity involving books (such as reading).

(11) Complement coercion: #Joe enjoyed these books but it ruined his eyes.

Thus, we have another null result: the behavior of complement coercion is again indistinguishable from simple transitives, such as (12):

(12) One VP (simple transitive): #Joe liked these books but it ruined his eyes.

POSITIVE RESULTS ARE POSSIBLE: INTENSIONAL TRANSITIVES

At this point, a reasonable question to ask is whether the modification and anaphora tests ever yield positive results for an unpronounced event. They do. Consider the sentences in (13–14), involving so-called intensional transitive verbs. These are verbs such as *want*, *need*, *expect*, and *look for*, which semantically select for clausal complements, but are also well-formed with simple noun phrase objects, as shown by the (b) sentences.

(13) a. Bill wanted to have a beer.
b. Bill wanted a beer.
(14) a. Bill needed to get a haircut.
b. Bill needed a haircut.

Unlike complement coercion, which is usually assumed to involve type-shifting, intensional transitives have been argued to involve a silent head. Specifically, the 'short' (b) versions above have been argued to involve a covert syntax similar to the longer (a) versions (Larson et al. 1996; Harley 2003). Part of the core evidence for this is that the adverb modification and the event anaphora tests both successfully distinguish intensional transitives from simple transitives. The adverbial modification test is illustrated in (15). Here the adverb *quickly* cannot modify the matrix verbs *want* or *like* since mental states and desires do not have speeds. Consequently, the combination of *like* and *quickly* is ill-formed without a suitable embedded verb, as shown in (15b). But not so for the intensional transitive *want*. (15c) is well-formed and semantically parallel to the overtly spelled out version in (a). Thus, in this case we have evidence against the null hypothesis: intensional transitives do not pattern with simple transitives.

(15) Adverb modification
a. Two VPs: Joe wants to get results quickly.
Joe likes to get results quickly.
b. One VP: #Joe likes results quickly.
c. Intensional transitive: Joe wants results quickly.

The anaphora test yields the same result. Consider (16a), adapted from McCawley (1974).

(16) Event anaphora
a. Intensional transitive:
Joe wants some horses, but his mother won't allow it.

b. Two VPs:
Joe wants to get some horses, but his mother won't allow it.
c. One VP:
#Joe likes some horses, but his mother won't allow it.

In this example, the pronoun *it* cannot refer back to the mental state of wanting, since people's wants and desires are not something that can generally be allowed or disallowed by others. And *it* cannot refer back to *horses* either, because of the number conflict. Given that (16a) is nevertheless grammatical, there must be some unpronounced element that *it* is picking out. Indeed, the meaning of (16a) is parallel to that of (16b), where we have an overt *have* or *get*, and contrasts with the anomalous (16c), which involves a simple transitive use of *like*.

Thus, on the basis of intensional transitives, we can reject one explanation of the null results for complement coercion, namely, that the tests we used are in general incapable of detecting an unpronounced event.

Where does this leave us? We have seen some positive evidence for silent heads in the case of intensional transitives. This suggests that natural language in general does include phonologically null syntactic elements, which many researchers would take for granted anyway. But the predictions of the silent head hypothesis failed for complement coercion, yielding no positive evidence for a covert verb in this case. Of course, this does not mean that other tests might not yield a result; for example, Pylkkänen and McElree (2006) – as part of a longer exposition of this issue – show that in some cases, the distribution of complement coercion does resemble that of overt VPs. But overall, the evidence for a null verb in complement coercion is slim at best.

WHAT ARE THE PREDICTIONS OF TYPE-SHIFTING?

Earlier I said that linguistic theory, broadly speaking, has only two mechanisms for introducing unpronounced meanings, silent heads and type-shifting. Based on this, one might conclude that since the silent head hypothesis cannot be supported for complement coercion expressions, they must involve type-shifting. But recall that a null result is not a result and therefore does not entitle us to conclude anything. In other words, the failure of the silent head hypothesis is not evidence in favor of any other hypothesis.

Thus, in order to be able to endorse type-shifting, we need positive results predicted by it. In other words, we must assess whether the null hypothesis can be rejected on the basis of purely semantic contrasts between complement coercion expressions and simple transitives. But it turns out that this question is considerably harder to address than testing the silent head hypothesis.

Recall that the research project I am discussing is one that tries to explain why complement coercion expressions seem to have a hidden meaning, even though they syntactically look like simple transitives. At the outset of the investigation, this hidden meaning is a highly abstract entity, and we are trying to provide evidence that it in fact exists. The silent head hypothesis equates the abstract entity to a more concrete, better-understood entity, that is, a syntactic head. This allows us to perform various tests to assess whether the element introducing the hidden meaning in fact behaves like a syntactic head. In contrast, the type-shifting hypothesis does not equate the hidden meaning to some other phenomenon for which we might have a body of results to guide our investigation. Furthermore, it is an open question whether the various type-shifts proposed in the literature themselves represent a natural class of operations, as expressed in the following quote from Dowty (2007):

> The term 'type-shifting' (or 'type-lifting') covers a deceptive variety of kinds of analysis, ranging from homomorphic no-visible-effect category-changing rules with strictly determined compositional effects to free semantic rules which may or may not have a fully predictable effect (or maybe not a logically definable one). For this reason, trying to survey and compare the various proposals from the point of view of compositional transparency and syntactic economy would take us very far afield, even though these questions are important ones to address . . . (Dowty 2007: 37)

What the type-shifting analysis does is give a detailed description of what the hidden meaning is and then insert that meaning into the semantic representation via a rule. Describing the nature of the hidden meaning is a highly non-trivial research project on its own (and one that I am compressing the details of here). However, in order to have explanatory bite, the analysis would need to do more than describe and label the phenomenon. We need predictions beyond the very observation that a hidden event sense seems to be present in these expressions. It is exactly those predictions that are hard to spell out, since the basic gist of the type-shifting hypothesis is that it is relatively invisible to the grammar. So we are stuck: something like type-shifting seems to occur in these expressions (and in many others not discussed here), but we are lacking in methodology for showing that this is so.

This is where online measures of brain and behavior may help. In the rest of this article, I will review an emerging body of research showing that psycho- and neurolinguistic measures do successfully distinguish complement coercion from simple transitives in a way that the traditional methods discussed so far do not.

Part II: The Real-Time Processing of Syntax–Semantics Mismatch

PSYCHOLINGUISTIC STUDIES OF COMPLEMENT COERCION

Measuring the amount of time a person takes to read a sentence is a common method used in psycholinguistics to study sentence comprehension.

In an initial study on the processing of complement coercion, Brian McElree and colleagues discovered that a sentence involving complement coercion, such as (17), takes longer to read than simple transitives, such as (18) or (19) (McElree et al. 2001).

(17) The author was starting the book in his house. (coercion)
(18) The author was writing the book in his house.
(19) The author was reading the book in his house.

Example (18) uses the verb that is most commonly interpreted as the silent 'verb' in the coerced sentence, whereas (19) uses a less canonical activity. Even though (19) involves a verb that is not strongly associated with *author*, it is still easier to interpret than the coerced sentence.

This finding is exciting, because it is a positive result on a construction that is otherwise very difficult to distinguish from simple transitives, as discussed above. Of course, this result by itself does not yet tell us anything about what causes the reading time delay. But unlike the null results discussed above, it gives us something to study further: now we can imagine all sorts of experiments aimed at shedding light on the nature of this processing delay.

The first task is to assess whether the effect is actually an interesting one and not due to some factor unrelated to coercion. For example, perhaps verbs such as *start* are just harder to understand than *read* or *write*? Or perhaps the effect is due to a violation of a syntactic expectation for a VP after *start*, and not at all related to semantic mismatch? Both of these hypotheses have been eliminated by subsequent experiments. For example, the following result from Traxler et al. (2002) cannot be explained by either. Consider the contrast between (20) and (21):

(20) The boy started the puzzle. (coercion: event-selecting verb, entity-denoting NP)
(21) The boy started the fight. (no coercion: event-selecting verb, event-denoting NP)

These two sentences both involve the same verb *start* and they both have a simple noun phrase as the direct object. Consequently, hypotheses of the coercion effect that appeal to syntactic expectations set up by the verb or to the semantic properties of the verb would predict no processing difference between these two sentences, since the verb and the syntactic category of the object are held constant. However, even though both of these sentences have an NP object, in (21) that NP denotes an event, that is, the sort of thing that *start* wants as its complement, whereas in (20) the NP denotes an entity, the puzzle. This entity needs to be coerced into an event before we can make sense of it as something that can be started. If the semantic operation of shifting an entity to an event is what underlies the coercion

effect, then the mismatching (20) should take longer to process that (21) and this is exactly what the experiment revealed.[2]

In summary, reading time studies have shown that complement coercion expressions are more costly to process than various control expressions not involving type-mismatch. How does this result relate to the silent head and type-shifting hypotheses? It is compatible with both. For all we know, both silent heads and type-shifting might elicit a processing cost. In fact, there have been a few psycholinguistic studies reporting that verbs with complex events structures are more costly to process than semantically simpler verbs (McKoon and MacFarland 2000, 2002; Gennari and Poeppel 2003). If event structure is encoded syntactically, as hypothesized by many (for a review, see Ramchand 2007), this type of contrast would involve a manipulation of silent heads.

However, in the case of complement coercion, if all the unique predictions of the silent head hypothesis fail, that is, those predictions that not shared by type-shifting, then in this case type-shifting would seem to be more compatible with the data overall. The processing findings raise a multitude of questions about the details of the entity-to-event shift. For example, when encountering a sentence, such as *the boy started the book*, do we actually try to figure out what activity the boy started or do we just take the sentence to mean that the boy started some activity involving the book? On a more general level, do all meaning shifts affect reading time like complement coercion? If not, why not?

Answers to some of these questions exist, although mostly this research area is still an open playing field. For example, Frisson and McElree (2008) recently found that the coercion effect is equal for sentences such as (22), involving a single dominant interpretation for the implicit activity (i.e., writing), and sentences such as (23), where the implicit event could be interpreted as a number of activities, including shooting, reading, writing, editing, and reviewing.

(22) The student finished the essay.
(23) The director started the script.

If readers try to figure out the nature of the implicit activity, the latter sentence should take longer to process than the former, given that in a fill-in-the-blank test (*the student finished* _____ *the essay*) subjects showed a convergence of interpretations for (22) but not for (23). But instead, the two types of sentences elicited the same size coercion effect in reading time, suggesting that the shifted interpretation is underspecified with respect to the nature of the implicit activity. With respect to the question 'do all meaning shifts affect reading time like complement coercion does', the answer seems to be 'no', as the following section reveals.

TYPES VS. SORTS

There are numerous meaning shifts that could potentially be compared with the comprehension profile of complement coercion. One domain where processing measures could prove particularly valuable is the study of the differences between semantic types and so-called semantic 'sorts'.

Types are the categories on which the compositional system of semantics operates on (for a brief introduction to type-driven interpretation that assumes no formal background, see Pylkkänen and McElree 2006). For example, the reason why the sentence *the boy laughed* is semantically well-formed is because *the boy* is of the right semantic type to combine with *laugh*. The verb *laugh* is an event-description that needs to combine with an entity to form a sentence. *The boy* satisfies this requirement. In contrast, a sentence such as *the kick laughed* is unrescuable: *the kick* describes an event and simply cannot be the subject of *laugh*. This tells us that even though entities can be shifted into events, as witnessed by complement coercion, the reverse is not possible.

If types are the labels of the compositional system, then what are sorts? They are something more fine-grained, subtypes of types, so to speak. For example, there are many different sorts of entities in the world, animate and inanimate, abstract and concrete. These different sorts do not generally play a role in the compositional system, but they do matter for whether linguistic expressions make sense or not. *My desk laughed* is a grammatical sentence, but it describes a very implausible situation. It is an example of a sortal mismatch: the desk describes an inanimate entity but our knowledge of the world dictates that laughing is something that only some animate entities are capable of. Sorts are a fuzzy domain, as pointed out by Borschev and Partee (2004) in a recent discussion:

> Sorts are more fine-grained than types, and sorts need not form a taxonomic hierarchy; the sort food overlaps the sort plant, but neither subsumes the other. In a way all common noun and verbs can be considered as sorts, with a special partial order relation 'subsort' as well as an 'overlap' relation. But the structure of this system and its role in forming semantically well-formed constructions is not yet well understood. (Borschev and Partee 2004: 30)

Just as natural language seems to have productive ways to shift between types (as in complement coercion), sorts can shift, too. Consider the sentence in (24).

(24) The baby drank the bottle.

Since bottles cannot literally be drunk, it must be the case that we are able to shift the meaning of *the bottle* to a meaning such as 'liquid contained in the bottle'. Since liquids and bottles are both of the type 'entity', this would be an example of a sortal shift.

A few psycholinguistic studies have examined sortal shifts, often called 'metonymies'. These studies have focused either on expressions such as (25), where *Virginia Woolf* is interpreted to refer to works written by Virginia Woolf, or expressions such as (26), where Vietnam is interpreted as the war that occurred in Vietnam.

(25) The gentleman read Virginia Woolf.
(26) Americans protested during Vietnam.

So far results suggest that sortal mismatch does not engender the type of reading time delay that is elicited by type mismatch in complement coercion (Frisson and Pickering 1999; McElree et al. 2006). This holds even when the shift is novel: *the gentleman read Needham* is noncostly as long as the context establishes that Needham is a writer (Frisson and Pickering 2007). These results suggest that reading time measures could be used as a diagnostic of whether a construction involves a type mismatch or a sortal mismatch. Unfortunately though, the lack of reading time effects for these sortal mismatches is a null result. Consequently, these findings cannot help us discover anything more about sortal mismatch except that it is different from type mismatch. However, some initial results suggest that sortal mismatch might nevertheless be detectable in the brain. Let us now turn to this body of work.

SHIFTING BRAINS: COMPLEMENT COERCION AND THE ANTERIOR MIDLINE FIELD

As our discussion so far has hopefully demonstrated, studying the real-time processing of type mismatch can add a valuable new dimension to research on the syntax–semantics interface. The reading time delay associated with complement coercion shows that our brains indeed perform some extra work to fit mismatching meanings together. Via careful psycholinguistic experimentation, much can be revealed about the nature of this process. But today's neuroimaging techniques allow us to do even more: to directly measure the brain activity associated with the extra work.

Most cognitive neuroscience techniques are very good at one of two things: they either have a high accuracy in revealing 'where' in the brain a process occurs or they yield detailed information about the 'timing' of processing. In order to build models about how the brain computes language, both types of information are crucial. There is currently only one technique that exhibits an excellent combination of both spatial and temporal accuracy: magnetoencephalography (MEG). MEG measures the tiny magnetic fields that are generated by neuronal currents. MEG is as fast as the brain: the strength of the magnetic field can be measured millisecond by millisecond. From the distribution of the magnetic fields outside the scalp, we can also infer the locations of the neuronal currents generating the fields.

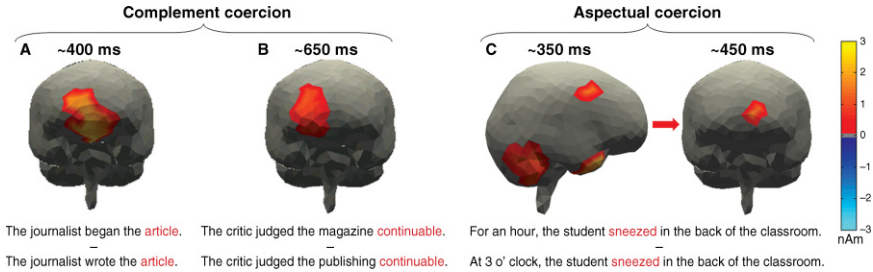


Fig. 1. Statistical maps of areas where complement coercion (A and B) and aspectual coercion (C) have elicited reliably increased brain activity. The maps plot the subtractions between the coerced and control expressions, as shown in the bottom panel, for those areas where the difference was reliable. Complement coercion, as measured both in the direct object position (A: Pylkkänen and McElree 2007) as well as on a deverbal adjective (B: Pylkkänen, Martin and McElree forthcoming), engaged overlapping ventromedial prefrontal areas. Aspectual coercion (C) elicited increased activity in a similar area, but only after a distributed right-hemisphere effect (Brennan and Pylkkänen forthcoming). If complement coercion exemplifies type mismatch and aspectual coercion sortal mismatch, then the currently available data would suggest similar neural mechanisms for the resolution of both types of mismatch (see text).

Despite a few decades of cognitive neuroscience research on language, it is still hard to point to results that are both solid and relate in some interesting way to representational and computational theories of language, the bread and butter of linguistics. This lack of progress has much to do with a longstanding disconnection between linguistics, psycholinguistics, and cognitive neuroscience: so far linguistic representation, language processing, and the neural bases of language have been studied by largely nonoverlapping communities (for discussion, see especially Marantz 2005 and Poeppel and Embick 2005). Fortunately, the situation is rapidly improving.

From the currently existing work on the neural bases of language, what seems to be clear though is that there is a network of left hemisphere areas, including almost all of the left temporal lobe, that are consistently activated during language processing in any modality. However, in an initial MEG study on complement coercion, Pylkkänen and McElree (2007) discovered that complement coercion elicits increased activity in an area very much outside this traditional 'language network'. Participants were presented with sentences such as (27) and (28) visually, word-by-word.

(27) The journalist began the **article** after his coffee break. (coerced)
(28) The journalist wrote the **article** after his coffee break. (control)

As shown in Figure 1A, approximately 400 ms after encountering the noun *article* in the coerced condition, activity reliably increased in an area of the frontal lobe, not in Broca's area but more medially and more anteriorly. The associated magnetic field was dubbed the anterior midline

field (AMF), reflecting its location. To test for the generality of this effect, Pylkkänen et al. (forthcoming) permuted the syntactic context of coercion by embedding the event-selecting verbs inside adjectives, as in (29–30) and changed the experimental task from an end-of-sentence well-formedness judgment to offline comprehension questions.

(29) The critic judged the magazine **continuable**. (coerced)
(30) The critic judged the publishing **continuable**. (control)

The MEG measurement was performed on the *able*-adjective, which needed to be interpreted as a property of the preceding noun. Since objects do not continue, only events do, successful interpretation of (29) required shifting *the mazagine* into an event denotation. Since the *able*-adjective is obviously more complex than the simple nouns used as targets in (27–28), one might expect the detection of the type mismatch to occur later than for (27) vs. (28). Indeed, results showed a coercion effect similar to the previous study in location but about 250 ms later (Figure 1B). This timing difference paralleled the results of a previous behavioral reading time study on the same materials (McElree et al. 2006).

Thus, we can find positive results for complement coercion not only in reading times but also in brain measurements. Recall that one of the challenges for the type-shifting hypothesis was that it does not equate type-shifting to any other phenomenon that might help us generate predictions about it. But having identified a neural effect of coercion, it becomes possible to ask what other types of processing occur in this region. I will first consider this question within the context of meaning mismatch, and then more broadly.

THE AMF AND SORTAL MISMATCH: ASPECTUAL COERCION

The initial finding that complement coercion elicits increased AMF amplitudes is obviously compatible with many functional interpretations. To narrow down the hypothesis space, we must investigate the generality of the effect. For example, how specifically is it related to type-mismatch? Two extant studies suggest that type-mismatch is neither sufficient nor necessary for AMF modulation. That type-mismatch is not necessary is suggested by recent results on so-called aspectual coercion (Brennan and Pylkkänen forthcoming), illustrated in (31), where the temporal properties of the verb and the adverb clash.

(31) The student sneezed for an hour.

Sneezes are naturally very short-lasting events. Thus, it is somewhat surprising that the verb *sneeze* can quite easily combine with an adverb such as *for an hour*, which describes an interval longer than what any individual

sneeze could possibly last. The temporal mismatch between the verb and the adverb seems to be resolved by taking *sneeze* to denote a repetitive activity of sneezing. In other words, the punctual verb is 'coerced' into a repetitive meaning involving multiple sneezes.

Aspectual coercion has been controversial from a variety of perspectives. Psycholinguistic studies have yielded mixed results on its processing correlates: while some studies have found expressions such as (31) to take longer to read than expressions involving no temporal mismatch (Piñango et al. 1999, 2006 Todorova et al. 2000, other studies have failed to find any such effect (Pickering et al. 2006). Theories of verb semantics also differ in whether a verb such as *sneeze* is actually represented as punctual (e.g., Jackendoff 1997) or simply as an activity with an underspecified duration (e.g., Moens and Steedman 1988).

There is one generalization that one can draw though: most theories in formal semantics do not consider the temporal difference between punctual activities such as *sneeze* and durative ones such as *laugh* to play any role in the type system.[3] The natural language ontology that is generally assumed to be encoded in types is much sparser; even the idea that events deserve a type of their own, separate from entities, has only recently become broadly accepted (see, for example, Parsons 1990 and Tenny and Pustejovsky 2000). With events in the ontology, *sneeze* and *laugh* would both be descriptions of events, although perhaps different sorts of events.

If the punctuality of *sneeze* is indeed invisible to the type system, then *sneeze* and the adverb *for an hour* would not mismatch in type. Consequently, a sentence such as *the student sneezed for an hour* should require no type-shifting and the compositional semantics should have no trouble in computing an interpretation for it. However, given our real world knowledge that sneezes are extremely brief events, the computed interpretation should describe an anomalous situation: one in which the student emitted a 1-h-long sneeze. Since this is clearly not the final interpretation, the theory would need to include a second stage of interpretation in which the meaning is shifted from a point action to a repetitive process. This last shift would occur somewhere outside the compositional system. That 'outside' is often called pragmatics. For a model of this type of two-stage interpretation, see in particular Johannes Dölling's work, where sortal mismatches are treated as presupposition failures (Dölling 1992, 1993, 1995, 1997, 2003; for further discussion, see also Borschev and Partee 2001; and Pylkkänen and McElree 2006).

If the AMF reflects meaning shift in general, whether semantic or pragmatic, then aspectual shifts should affect the AMF. Furthermore, if aspectual shifts are preceded by the computation of an anomalous meaning, then any potential AMF effect should be preceded by some activity reflecting the anomaly detection. This account was supported by Brennan and Pylkkänen's (forthcoming) MEG findings on temporally matching and mismatching verb–adverb combinations, such as (32)–(33).

(32) At 3 o'clock, the student **sneezed** in the back of the (match) classroom.
(33) For an hour, the student **sneezed** in the back of the (mismatch) classroom.

As shown in Figure 1C, at around 350 ms after the onset *sneeze*, a network of right hemisphere structures showed enhanced activity for the mismatching *sneeze*. This activity resembled an effect of semantic anomaly obtained in a previous MEG study (Halgren et al. 2002). About 100 ms later, another effect was observed, now in the AMF. Thus, this study showed that the AMF effect of coercion extended to aspectual shifts. Furthermore, the results indicate that type-mismatch may not be necessary for AMF modulation. Instead, these findings suggest the intriguing possibility that the brain might resolve sortal mismatch and type mismatch with the same mechanism.

THE ROLE OF 'MEANING' IN AMF MODULATION

If the AMF is modulated by meaning shift in general, should all kinds of type-mismatch engage the AMF? Potentially no. Many type-shifting rules do not affect meaning in the very intuitive way that complement coercion does. In fact, type-shifting rules originally had very little to do with meaning; rather, they were purely logical operations that changed the semantic type of an expression without affecting its content. Without introducing a large amount of formal apparatus, it is impossible to properly illustrate what this type of 'logical type-shifting' might look like, but (34) exemplifies a core case:

(34) The teacher saw every student.

Compared to complement coercion, this sentence seems like perfectly straightforward English; there is no obvious hidden meaning. The expression does, however, involve a type-mismatch. This is because quantified expressions such as *every student* are ill-suited to combine directly with a transitive verb such as *see*. The type-mismatch can be resolved by shifting either the type of the verb (Montague 1973) or the type of *every student* in such a way that the composition succeeds (for an introduction, see Heim and Kratzer 1998). Although this kind of type-shifting resolves the mismatch, it does not affect the meaning of the expression in any way; the shift is, in some sense, purely 'logical'.

Does type-mismatch in expressions such as (34) incur a processing cost? Recent work by Martin Hackl and colleagues suggests that it does (Varvoutis and Hackl 2006; Hackl et al. forthcoming). However, there is not yet any neurolinguistic work on type-mismatch in quantified expressions, so this phenomenon cannot at present inform our interpretation of the AMF.

But research does exist on another construction that intuitively falls into the category of non-meaning-adding type-shifting (Harris et al. 2007). This work examined so-called concealed questions (CQ), involving verbs such as *guess*, *determine*, and *explain*, all of which semantically select for proposition or question-denoting objects, as illustrated in (35):

(35) a. The announcer guessed who the winner of the contest was.
b. The salesman determined what the price of the convertible was.
c. The teacher explained what the consequence of the war was.

In their CQ uses, these verbs combine directly with a noun phrase, as shown in (36). The noun phrase has a question-like interpretation similar to the fully spelled out versions in (35), hence the term 'concealed question'.

(36) a. The announcer guessed the winner of the contest.
b. The salesman determined the price of the convertible.
c. The teacher explained the consequence of the war.

Concealed questions involve a type-mismatch between an NP-object and a question-selecting verb. The formal details of how the mismatch is resolved vary between theories but generally all accounts involve some operation that shifts either the type of the NP (Frana 2006; Romero 2006) or of the head of the NP (Nathan 2006). Interestingly, the mechanism that fixes the type-mismatch appears to be restricted to NPs headed by relational nouns (Nathan 2006; Caponigro and Heller 2007), as witnessed by the relative ill-formedness of the following examples:

(37) a. *The announcer guessed the contest.
b. *The salesman determined the convertible.
c. *The teacher explained the war.

Concealed questions and complement coercion are similar in that they both involve a type-mismatch between a verb and its object. In complement coercion expressions, the shifted meaning of the NP is clearly distinct from the unshifted one: anyone would agree that a book is something different from an activity involving a book. With CQs, however, it is unclear whether the shifted and the unshifted meanings differ in content. *The winner of the contest* denotes an unnamed individual who won a contest. The embedded question *who the winner of the contest was* differs from the noun phrase in syntactic and semantic category, but conveys no more information: the identity of the winner is not revealed. Thus, CQs involve type-shifting that affects the type of the direct object, but does not seem to impact its meaning.

To assess whether CQ interpretation is behaviorally costly and/or associated with an AMF effect, Harris et al. (2007) contrasted CQ expressions

such as (38a) with maximally similar expressions involving no type-mismatch, such as (38b). In this manipulation, the type-mismatch was revealed at the passive verb, which either selected for a proposition/question as in (a) or an entity as in (b):

(38) a. The costume of the famous actor was determined by the fashion stylist. (CQ)
b. The costume of the famous actor was delivered by the fashion stylist. (Control)

A reading-time experiment first showed that the CQ sentences were indeed more costly to process than the control expressions. However, in the brain measurements, this cost was not associated with increased amplitudes in the AMF. Instead, the manipulation affected activity in the left temporal lobe, a region that does count among the traditional 'language areas'.

Thus, data on two constructions, that is, CQs and object quantifiers, suggest that reading time delays can be elicited by type-mismatch even when its resolution does not require meaning-adding operations (Varvoutis and Hackl 2006; Harris et al. 2007; Hackl et al. forthcoming). The MEG data on CQs, however, indicate that there may be a qualitative difference between these kinds of cases and situations where the shift involves coercion into a new meaning. So far the theoretical semantics literature has been rather silent on whether type-shifting rules divide into distinct sub-classes – Yoad Winter's work on so-called internal vs. external mismatch represents one of the few examples (Winter 2007). The relative scarcity of research in this area may reflect a lack of empirical tools in linguistics for investigating whether type-shifting rules form distinguishable sub-classes. Thus, in this domain, brain measurements hold substantial promise in adding a rich new source data for elucidating the psychological mechanisms of type-mismatch resolution.

LANGUAGE AND ITS NEIGHBORS

Much recent discussion has emphasized the importance of studying language not in isolation but in the context of its neighboring non-linguistic cognitive abilities (e.g., Marcus 2006; Marcus and Rabagliati 2006). Language necessarily interfaces with the perceptual systems. Comprehending language would be impossible without working memory. And obviously, language is the primary form of human communication. Thus, it must somehow connect with social cognition.

The MEG studies discussed above have revealed that type-mismatch in complement coercion and hypothesized sortal mismatch in aspectual coercion both affect brain activity in inferior midline regions of the prefrontal cortex. Although this region is somewhat exotic from a neurolinguistic

point of view, it plays a major role in theories of the neural bases of social cognition – for a recent review, see Amodio and Frith (2006). For example, the medial prefrontal cortex is engaged in various theory of mind tasks, requiring reasoning about the mental states of others. In some ways, language comprehension is a type of a theory of mind task: for two individuals to interact, they must be able to infer from the vibrations of the air (i.e., sound) the message that the other person has in mind. One might then speculate that perhaps mismatching meanings are resolved via some mechanism that is shared with social cognition more generally.

If we discovered that type-mismatch is resolved somehow 'outside' the grammar, such a finding would have fundamental consequences for linguistic theory. This is because semantic theories differ drastically in whether type-shifting is at the very core of the interpretive system or essentially completely disallowed. In this short piece, focused on the empirical investigation of type mismatch, it would be impossible to do justice to the conceptual arguments that apply in this domain. As a crude simplification, type-shifting tends to be a core interpretive mechanism in frameworks that lack a so-called Logical Form (LF) as a representational level. LF is a syntactic structure that has been derived via covert movement operations that apply after any syntactic operations that might affect the phonological form of an expression (May 1985). For an introduction to a framework with an LF and no type-shifting, see Heim and Kratzer (1998). For models with type-shifting and no LF, see especially Jacobson (1999, 2002), Barker and Jacobson (2007), and Steedman (1996).

Clearly, for theories that disallow nonsyntactic semantic operations, a construction such as complement coercion is problematic since it really does not seem to involve covert syntactic structure. However, if the semantic mismatch of complement coercion and other such cases has to be resolved 'outside of language', as vague as that notion is, this just might mean that there is something very right about the view in which type-shifting is not part of the grammar. Furthermore, discovering that type-shifting is *like* something else that we can study, perhaps in the domain of social cognition, would be tremendously helpful in making progress on characterizing the nature of type-shifts as mental operations. Relating type mismatch to some other domain of cognition might also help us study what conditions the range of possible type-shifts, an important outstanding question of the syntax–semantics interface.

As of today, there is no evidence that any patch of cortex is dedicated to language. Thus, it is likely that one of the core goals for linguistics and the cognitive neuroscience of language will be to understand how mechanisms that operate in multiple domains of cognition are put to use in language. Elucidating the connections between language and its neighbors will obviously require a tremendous amount of effort and serious cross-disciplinary investigation. However, for semantic interpretation, the AMF response already constitutes a concrete brain measure that may link

semantic composition in an interesting way to nonlinguistic higher cognition. At this point, the connection is of course still highly elusive, but when it comes to studying the brain, the identification of some region of interest to study further is often half the battle.

Short Biography

Liina Pylkkänen obtained her PhD from the Massachusetts Institute of Technology in 2002. She is now an Assistant Professor of Linguistics and Psychology in New York University and the director of the NYU Neurolinguistics Laboratory. She has published experimental work on the neural bases of lexical, morphological, and semantic processing as well as theoretical work on argument structure and event semantics. Her research has appeared in journals such as *Cognition, Brain and Language, Trends in Cognitive Sciences* and the *Journal of Cognitive Neuroscience*. She is the author of *Introducing Arguments* (2008, MIT Press).

Notes

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[1] Why subjects tend to be interpreted as agents and objects as patients is obviously a serious research question, but the point is that this sentence follows a significant generalization about the semantic roles of subjects and objects, as opposed to forming an exception or a puzzle.

[2] One might still wonder whether the noun *puzzle* is just somehow harder to understand than the noun *fight*. This explanation was also eliminated by Traxler et al.'s study with additional controls such as *the boy saw the puzzle* vs. *the boy saw the fight*, involving verbs for which events and entities are equally good objects. These two sentences elicited no processing difference, as one would expect if the coercion effect of (20) was indeed due to the semantic mismatch between the verb *start* and the NP *the puzzle*.

[3] It should be mentioned though that much of the research that has focused on verb semantics has not been articulated using the kind of type-driven interpretation that this article assumes. This has to do with the fact that two somewhat separate traditions have developed in semantics: lexical semantics, focused on word meaning, and so-called 'formal' semantics, focused more on interpretation at the sentence level and the general mechanisms of composition. The separation is somewhat unproductive, since the two topics are clearly not distinct: sentence meaning depends on the meanings of the participating lexical items, as dictated by the principle of compositionality. Fortunately though, the two traditions are coming together more and more. For example, James Pustejovsky's influential work exemplified lexical semantic research that is couched within type-driven interpretation (e.g., Pustejovsky 1995). For more recent examples, see, for instance, Borschev and Partee (1998, 2001, 2004), Kratzer (2003, 2005), Levinson (2007), Lin (2004), and Pylkkänen (2002).

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