Coercion in a general theory of argument selection*

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Abstract

In this article, I address the general mechanisms of argument selection in language, and specifically the role played by type coercion operations in linguistic theory. The view presented here is that compositional mechanisms must be open to more information than just the base type of an expression. Such "compositional flexibility" in the type that accommodates to the one selected by the verb has been the topic of considerable research recently. In this article, I position how such coercion mechanisms operate in the larger context of general selectional strategies in the grammar. I first outline my assumptions regarding the general theory of type selection, adopting a model of Generative Lexicon Theory (GL). I distinguish between two strategies at work in language, type matching and type coercion, both treated as strong compositional mechanisms. A library of possible coercion operations is defined, as well as apparent constraints on their application in language. I conclude with a discussion of corpus-based experiments based on the formal models of coercion and selection presented here.

1. The significance of compositionality

Coercion has emerged in recent years as an extremely powerful mechanism for describing many diverse selectional mismatches in language (Partee and Rooth 1983; Moens and Steedman 1988; Pustejovsky 1991; Dölling 1992; Jackendoff 1997; Egg 2005). In many respects, this mirrors some of the power and expressiveness of structural transformations from early generative linguistic models. As with the subsequent retreat from unconstrained transformational operations in syntax (Peters and Ritchie 1973; Chomsky 1973; Pullum and Gazdar 1982; Lappin et al. 2001), there have likewise been proposals for constraining the application of coercion and type-shifting mechanisms in the

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grammar (Pustejovsky 1995b; Saint-Dizier and Viegas 1995; Carlson 1977; Hendriks 1993; Egg 2005).

Nevertheless, it is clear that coercion is a pervasive and dynamic component of language, and as such, must be modeled integrally in the theory of selection adopted by the grammar. In this article, I discuss how this should be achieved in the context of a compositional view of language. After presenting a range of data illustrating type selection violations, I outline the general principles of selection and coercion that will be used to systematically account for these data, while maintaining a compositional framework. I then discuss the major coercion classes, providing example derivations for each in turn. I conclude with a discussion of how a general theory of selection and coercion relations can be used for annotating a large corpus of verb-argument relations, and subsequent experimentation on compositional mechanisms in language as found in corpora.

There has traditionally been an assumption in theoretical linguistics that, as speakers of language, we understand utterances by understanding their component parts (Janssen 1983; Thomason 1974). The "principle of compositionality", as this view is generally known, characterizes how smaller units of meaning are put together to form larger, more meaningful expressions in language. Perhaps the most famous formulation of this notion comes from Frege, paraphrased here by Partee:

> The meaning of an expression is a function of the meanings of its parts and the way they are syntactically combined. (Partee 1984: 153)

This perspective has been extremely influential in semantics research over the past forty years, and the theoretical foundations for compositional operations within the sentence have been developed in considerable detail (Partee 1986; Chierchia 1995; Janssen 1997; Jacobson 2002; Werning 2004). If one assumes a compositional approach to the study of meaning, then two things immediately follow: (1) one must specify the meanings of the basic elements of the language; and (2) one must formulate the rules of combination for how these elements go together to make more complex expressions. The first aspect includes determining what words and morphemes mean, that is, the *lexical semantics* of the expression. The second aspect entails defining a calculus for how these elements compose to form larger expressions, i.e., *argument selection*, *modification*, and *combination*. Needless to say, in both of these areas, there is much divergence of opinion, but most linguists generally agree on the basic assumptions inherent in compositionality: namely, the combinatorics of meaning are dependent on the compositional possibilities of the component parts of utterances in language.[1]

While there might be general agreement that compositionality is a desirable and perhaps necessary property of language, there appear to be many linguistic phenomena that do not overtly exhibit compositional behavior. One of the most interesting challenges involves the phenomena of contextual modulations referred to collectively as *systematic polysemy* (Apresjan 1973). Recently, there has emerged an appreciation of how complex this problem is (Nerlich 2003), as well as a new understanding of the parameters at play in the interpretation of polysemous expressions (Cruse 1995; Croft and Cruse 2004; Evans 2009). Within Generative Lexicon Theory (GL), two factors have been identified as contributing to the interpretation of polysemous terms: the nature of the expression's lexical semantic representation; and the mechanisms for exploiting this information in context compositionally. In recent work, this distinction has been identified with *inherent* versus *selectional* polysemy (Pustejovsky 2006; Pustejovsky and Ježek 2008). Indeed, as many studies have concluded (Dirven 2002; Jackendoff 2002), polysemy cannot adequately be modeled without enriching the various compositional mechanisms available to the language. In particular, lexically driven operations of coercion and type selection provide for contextualized interpretations of expressions, which would otherwise not exhibit polysemy.

To illustrate this distinction, consider some well known contextual modulations, shown in (1)–(3), where the noun exhibiting inherent polysemy has been underlined and the projected sense of the noun is in parentheses.

(1) a. *John bought the new <u>book</u> by Obama*. (physical object)
    b. *John doesn't agree with the new <u>book</u> by Obama*. (information)
(2) a. *Mary left school after <u>lunch</u>*. (event)
    b. *Mary brought <u>lunch</u> to school*. (food)
(3) a. *The guards stood on top of the gate*. (physical object)
    b. *The truck drove through the gate*. (aperture)

Inherent polysemy is seen where multiple interpretations of an expression (the nominal head) are available by virtue of the semantics inherent in the expression itself. That is, the nouns *book*, *lunch*, and *gate*, inherently denote both concepts expressed in the examples. We return to such examples in Section 4.

These examples contrast with the more common form of contextual modulation called *selectional polysemy*, illustrated in the sentences below, where the selecting expression has been underlined.

(4) a. *Mary left <u>after</u> her coffee*.
    b. *Mary left <u>after</u> drinking her coffee*.
    c. *Mary left <u>after</u> she drank her coffee*.

Selectional polysemy is seen where a novel interpretation of an expression is available due to contextual influences, namely, the type of the selecting expression. In (4), for example, the selectional force of the temporal preposition/connective *after* is satisfied through three distinct syntactic strategies. In fact, many syntactic selectional mismatches now can be viewed through the licensing of coercion mechanisms: from aspectual predicates (5); concealed questions (6); attitude verbs (7); factives (8); and control verbs (9) (Godard and Jayez 1993; Heim 1979; Kartunnen 1971; Pustejovsky 1993).

(5) a. *Mary began her thesis last month*.
b. *John finished his coffee*.
(6) a. *Mary knows the time*.
b. *John told me his weight*.
(7) a. *John believes every politician he hears*.
b. *They denied the brutal conditions of the prison.*
(8) a. *The graduate student regrets his last homework assignment*.
b. *The hacker acknowledged the break-in.*
(9) a. *Mary tried the apple pie, but found it too sweet*.
b. *John wants a car for two days*.

In each case above, the selecting predicate takes as its argument an expression that is typed differently from the type conventionally selected by that predicate. For example, the verb *deny* is typically modeled as selecting for a propositional complement (i.e., *t*), but in (7b), it selects for a stative denoting nominal, *conditions*, as head of a definite NP.

As discussed in Pustejovsky (1995a), compositionality might be maintained in such cases by an enumeration of distinct word senses for the predicates. This results in a grammar drawing on a lexicon with multiple senses for each lexeme (viz., sense enumeration), with new word senses for every novel context in the language encountered by a speaker. Such a model is characterized as "weakly compositional", and fails to capture the apparent fact that the predicate typing remains constant in these contexts, while it is the complement which is shifting its sense to accommodate to the verb. Capturing this information in the grammar would result in a system that is "strongly compositional" in nature. Jackendoff (1997), adopts this distinction employing coercion, and refers to the resulting system as "enriched composition", the term we use in the present discussion.

Type coercion operations have been recognized as playing an important role in explaining these modulations, in order to maintain strong compositionality (cf. Partee and Rooth 1983; Groenendijk and Stokhof 1989; Egg 2005; Pinkal 1999; Bouillon and Busa 2001; Egg et al. 2001). The identification of coercion as a factor in a particular linguistic construction has direct consequences on the characterization of the lexemes and phrases as polysemous. If we accept that strong (enriched) compositionality is a property of language, then we accept as well that coercion phenomena are quite pervasive in language, and the mechanisms for such shifts must be integrated into the basic compositional operations in the grammar.

2. Mechanisms of coercion

In this section, I examine the modes of composition necessary to maintain a compositional model of selection, given the assumptions and challenges presented in the previous section. I begin with the selectional properties of ambiguous verbs, in order to better differentiate type selection from coercion, before distinguishing the methods of coercion.

It is pointless to ask how many meanings we have for a particular word in language without reference to the mechanisms with which we determine the specific sense of a word or phrase in context. Processes of contextual modulation allow us to adopt our finite lexical resources to countably infinite situations, and linguists differ considerably in assigning responsibility for whether meaning shifts occur at all and, if so, how. As a result of this divide, the role that compositionality plays in structuring not only the grammar but also the lexicon is significant. In most linguistic frameworks, for example, lexical ambiguity is represented by reference to distinct entries and word senses for the expression. For multiple verb senses, each entry acts on its arguments in a compositional manner. This means that the semantics of the result of application of the verbal function to its argument is determined by the semantics of the function itself, i.e., function application. Consider, for example, the way in which the verb *kill* has at least three distinct senses.

(10) a. *John killed the plant.*
b. *Mary killed the conversation.*
c. *John killed the evening watching TV.*

Each of these senses has a regular and productive distribution in the language. Let us assume that these verb senses are distinct semantic units, perhaps related to each other, but stored separately in the mental lexicon. Support for this view draws on the fact that they have distinct subcategorization and type selection frames, and if they are distinct senses, then the semantic computation involving these senses in the syntax can be performed compositionally. As such, they can be modeled adequately by a sense enumerative lexical (SEL) model (cf. Pustejovsky 1995a for discussion). In such a model, each sense of a word, as in (10), would be strongly typed, illustrated in (11) below, where the intended sense is glossed as a relation with its appropriate argument types.

(11) a. kill_1: CAUSE-TO-DIE(THING, ANIMATE)
b. kill_2: TERMINATE(HUMAN, EVENT)
c. kill_3: SPEND(HUMAN, TIME, EVENT)

Given distinct lexical types for these three senses of *kill*, compositional mechanisms in the semantics can compute the sentences in (10) as cases of function application, shown in (12) below.

(12) Function Application (FA):
If α is of type a, and β is of type a → b, then β(α) is of type b.

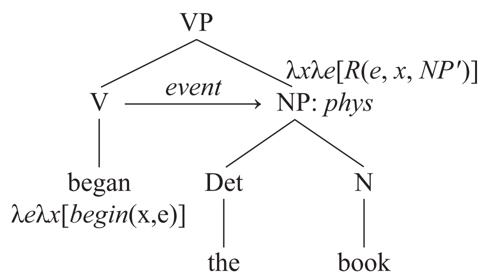
Hence, the derivation in (10c) has a successful computation if verb sense kill_3 is selected. If we had tried using the type associated with kill_2, the sentence would not have an interpretation. Irrespective of the cognitive merits of (or lack thereof) the sense enumerative approach to ambiguity, this does demonstrate that compositional operations reflect the lexical and conceptual commitments in the grammar. Namely, by enumerating separate senses for ambiguous predicates, we can ensure strong (unique) typing on the arguments expected by a verb (function), and thereby maintain compositionality within these constructions.

Clearly, if function application as described above were inviolable, then we would not expect to encounter examples of type mismatch between verb and argument. But, of course, as we saw in the previous section, such data are ubiquitous in language, and can be modeled with a mechanism known as *type coercion* (Pustejovsky 1995a; Copestake and Briscoe 1995; Partee and Rooth 1983). This is an operation that allows an argument to change its type, if it does not match the type requested by the verb. A classic GL example of this operation can be seen in the coercion employed in (14), mirroring the underlying type seen in (13), where the aspectual verb *begin* selects for an event as its complement type:

(13) Mary began [reading the book]$_{event}$.
(14) Mary began [the book]$_{event}$.

In such configurations, the verb is said to "coerce" the NP argument into an event interpretation. Under such an analysis, the NP may denote a salient event that involves the book in some way, e.g., reading it, writing it, and so on. This is schematically represented below, where the NP *the book* has been reinterpreted through coercion, as embedded within a relation, *R*, involving the book.

(15)



How much of the predicative content of this event is reconstructed is a matter of some discussion (Nunberg 1995; Lapata and Lascarides 2003). Within GL and some other frameworks (Van Valin and LaPolla 1998; Jackendoff 2002), such knowledge can be lexically encoded through the use of semantic templates called *Qualia Structure,* hence providing a mechanism for preserving compositionality in the construction above. The qualia are taken as representing an essential component of word meaning, capturing how language speakers understand objects and relations in the world and provide the minimal explanation for the linguistic behavior of lexical items. These are: the *Formal* role: the basic category that distinguishes the object within a larger domain; the *constitutive* role: the relation between an object and its constituent parts; the *Telic* role: its purpose and function; and the *Agentive* role: factors involved in the object's origin or "coming into being". Qualia structure is at the core of the generative properties of the lexicon, since it provides a general strategy for creating new types.[2] In classical GL treatments, the qualia act as type shifting operators, allowing an expression to satisfy new typing environments. On this view, every expression, α, has some set of operators available to it, Σ_α, that provide the resources for such type shifting behavior. Coercion can then be characterized as follows (Pustejovsky 1993):

(16) Function Application with Coercion (FA_c):
If α is of type c, and β is of type $a \rightarrow b$, then,
(i) if type c = a then $\beta(\alpha)$ is of type b.
(ii) if there is a $\sigma \in \Sigma_\alpha$ such that $\sigma(\alpha)$ results in an expression of type a, then $\beta(\sigma(\alpha))$ is of type b.
(iii) otherwise, a type error is produced.

Locally governed type coercion operations have been integral to the basic architecture of GL, as they allow us to maintain a compositional treatment of argument selection in the grammar, while enabling contextual modulation in lexical meanings.

Nevertheless, constraining the power of coercion has been both a theoretical and a practical concern, both within GL as well as other models addressing such phenomena. Unconstrained coercion, as embodied in (16), is both too powerful and too limiting a mechanism. It is too powerful because it is not uniformly or universally applicable to all function application contexts. It is also too weak, in that there are type-shifting data that fall outside this definition.

More recent work has identified distinct mechanisms of coercion, operating under distinct licensing conditions, with different domains of application. In the remainder of this section, I develop this integrative view of "coercion as selection". In order to account for the selection phenomena discussed above, two innovations are proposed: (a) enriching the type system; and (b) enriching the compositional mechanisms. Specifically, I define four distinct mechanisms at work in the selection of an argument by a predicative expression: (i) pure selection (type matching); (ii) accommodation subtyping; (iii) coercion by introduction; and (iv) coercion by exploitation. These will be introduced in detail below.

Following Pustejovsky (2001, 2006), we will assume that the domain of individuals can be structured into three, increasingly complex, conceptual types:[3]

(17) a. *Natural types*: Natural kind concepts making reference only to Formal and Constitutive qualia roles;
b. *Artifactual types*: Concepts making reference to Telic (purpose or function), or Agentive (origin).
c. *Complex types*: Concepts making reference to a relation between at least two types from the other levels.

For the present discussion, I will interpret the feature-based representation of Qualia Structure from GL as more conventionally structured types, using the *Type Composition Logic (TCL)*, introduced first in Asher and Pustejovsky (2006), explored in Pustejovsky (2006), and developed more recently in Asher (2011). The levels above will be differentiated in terms of their type structure. The set of types is defined in (18) below.

(18) a. e the general type of entities; t the type of truth values.
If σ and τ are types, then so is $\sigma \rightarrow \tau$.
If σ and τ are types, then so is $\sigma \otimes_Q \tau$, for qualia relation, Q.
If σ and τ are types, then so is $\sigma \bullet \tau$.

In addition to the standard operator creating functional types in (18b), TCL introduces a type constructor • ("dot"), which creates dot objects from any types σ and τ, deriving $\sigma \bullet \tau$. This is essentially identical with the construction of complex types in classic GL. The language also introduces a type constructor $\otimes_Q$ ("tensor"), which can be seen as adding qualia relations to a *head* type.

To illustrate how the type system here is a natural extension of that in classic GL, consider a type feature structure for a term α, with values specified for qualia roles Formal, Telic, and Agentive.

(19)
$$\begin{bmatrix} \alpha \\ \text{QS} = \begin{bmatrix} \text{FORMAL} = \beta \\ \text{TELIC} = \tau \\ \text{AGENTIVE} = \sigma \end{bmatrix} \end{bmatrix}$$

If the entire qualia structure is identified as the typing assignment for the expression, α, then we can integrate the Formal type with the qualia values to create a richer typing structure. Assume that the Formal role is always present in the qualia, and hence will be considered the *head* type of the assignment[4];

that is, [FORMAL = β] is simply written β. The additional qualia values can be seen as structural complementation to the head type, where each qualia value is introduced by a tensor operator, $\otimes_Q$. To differentiate the qualia roles, we will subscript the operator accordingly; e.g., [TELIC = τ] can be expressed as $\otimes_T \tau$, and [AGENTIVE = σ] can be expressed as $\otimes_A \sigma$. Hence, now the feature structure for the expression α from (19) can be represented as a single composite type, as $\alpha : (\beta \otimes_A \sigma) \otimes_T \tau$.

Now let us return to the three levels of types from (17). The first two classes in (17) are defined in terms of qualia. For example, a natural physical object is simply a head type with no complement typing. For example, *lion*, *rock*, and *water* would all satisfy the type *phys*. These are the *natural types*, N[5]. The natural entity types are just those entities formed from the FORMAL quale and are formally structured as a join semi-lattice, $\langle N, \sqsubseteq \rangle$. We can see the expression of natural typing throughout the major linguistic categories in the language: nouns such as *rock*, *water*, *woman*, *tree*; verbs such as *die*, *walk*, *fall*; and adjectives such as *large*, *red*, and *flat*. These will be our atomic types, from which we will construct our ⊗-types and •-types (artifactual and complex types, respectively).

Consider the typing for the predicates that select for natural types. Once natural type entities have been defined, we are in a position to define the natural predicates and relations that correspond to these types. The creation of functions over the subdomain of natural types follows conventional functional typing assumptions: for any type τ in the subdomain of natural types, $\tau \in N$, $\tau \rightarrow t$ is a *natural type* function, i.e., verb or modifier to a natural type.

Let us refer to the type of a natural or any subtype as e_N, and the predicates selecting natural types in functional form as: $e_N \rightarrow t$. Consider, for example, a natural predicate such as *die* or *touch*. These verbs select for arguments with a specific atomic subtype from the domain of natural individuals, regardless of how complex the selected type might be.

(20) a. $\lambda x{:}e_N\,[die(x)]$
b. $\lambda y{:}\, e_N\, \lambda x{:}\, e_N\,[touch(x,y)]$

The consequences of this typing will become clear in the next section, when the different compositional mechanisms are explored in detail.

Natural types can be seen as atomic elements while the qualia structure can be viewed as a calculus allowing for the construction of richer semantic structures. For example, we can enrich our conceptualization of *water*, a natural type, by giving it a function (i.e., a Telic value), thereby changing its status to that of an *artifactual type*, $e_A \in A$. The resulting type is given as, $phys \otimes_T \tau$. If we identify the value of the TELIC as, e.g., "drinking", and further specify the subtype for this concept as liquid ($liquid \sqsubseteq phys$), then we have the concept of "drinking water": *liquid* $\otimes_T$ *drink*. Following the same strategy over classic GL qualia structure, we can also identify a specific origin (Agentive role) for an artifact, such as for *bread*, as the following type: (*phys* $\otimes_A$ *bake*) $\otimes_T$ *eat*.

As with the naturals, the creation of functional types over the domain of artifactual types is straightforward: for any type τ in the domain of artifactual entity types, $\tau \in A$, $\tau \rightarrow t$ is an *artifactual type* function, as shown below, for example.

(21) a. $\lambda x{:}e_A[$*spoil*$(x)]$
b. $\lambda y{:}e_A\lambda x{:}e_N\,[$*fix*$(x,y)]$

This is an innovation in the way a predicate selects its arguments, and one that has formal consequences for compositional processes, as we shall see in the next section. Lastly, let us consider the *complex types*, which are reifications of at least two types, bound by a "coherent relation" (cf. Pustejovsky 1994). They are constructed through a type-construction operation (the dot, •) over the domain of Naturals, Artifactuals, and Complex Types. For example, *book* is a complex type denoting both the informational content and the physical manifestation of that content, i.e., *phys•info*. The coherent relation, in this case, is the *manifestation* of the information through the physical form. Other examples include the nouns *gate*, *school*, *lunch*, and *promise*. Dot objects are to be interpreted as objects with a complex type, but are not necessarily complex objects. The constituents of a dot type identify distinct and seemingly incompatible types; for example, the noun, *lunch*, identifies both an eventuality of eating and the physical manifestation of food: *event•food*; *speech* identifies both the speech act and the information conveyed through that act, event • info, and so forth. One of the key properties of complex types is that they allow copredication. In co-predication, two distinct senses of a lexical item are simultaneously accessed, for instance by applying apparent incompatible types of predicates to a single type of object, as in *The book I'm reading is heavy*, and, *The lecture was long but interesting*, etc. (cf., Nunberg 1979, 1995; Copestake and Briscoe 1995; Pustejovsky 1995a, 1998; Asher and Pustejovsky 2006; Asher 2011).

As with artifactual predicates, creating functions over the subdomain of complex types is similarly straightforward: for any type τ in the domain of complex entity types, $\tau \in C$, $\tau \rightarrow t$ is a *complex functional type* function. Below is an example of the verb *read*, a complex functional type, since it selects a complex type as its direct object.

(22) a. *read*: *phys•info* $\rightarrow (e_N \rightarrow t)$
b. $\lambda y{:}$*phys•info* $\lambda x{:}e_N\,[$*read*$(x,y)]$

The concept of *reading* is *sui generis* to an entity that is defined as "informational print matter"; that is, a complex type such as *phys•info*. In a selective context such as (23), the predicate directly selects for a complex type, *a magazine*.

(23) Mary read *a magazine* on the plane.

There are many things in everyday discourse, however, that do not satisfy this typing *inherently*, but which we happily read: a wall, the side of a bus, a rumor, and so forth. These will be viewed as "coercions by introduction" in the next section.

As mentioned above, there are two grammatical innovations necessary for enriching the model of selection. The first is a richer lexical representation, presented above. The second is a more expressive theory of selection. Here we introduce four mechanisms at work in the selection of an argument by a predicative expression. We then examine the compositional possibilities available to predicates for how they select their arguments, in order to model how polysemy arises in grammar. For a predicate, *F*, selecting an argument of type σ, namely $F(\_\_)_{\sigma}$, the following operations are possible:

(24) a. SELECTION (Type Matching): The target type for a predicate, *F*, is directly satisfied by the source type of its argument, *A*:
$F(A_{\alpha})_{\alpha}$
b. ACCOMMODATION SUBTYPING: The target type a function requires is inherited through the type of the argument:
$F(A_{\beta})_{\alpha}$, $\beta \sqsubseteq \alpha$
c. COERCION BY INTRODUCTION: the type a function requires is imposed on the argument type. This is accomplished by wrapping the argument with the type required by the function:
$F(A_{\alpha})_{\beta \odot \sigma}$, $\alpha \sqsubseteq \beta$ (domain-preserving)
$F(A_{\alpha})_{\beta}$, $\alpha \rightarrow \beta$ (domain-shifting)
d. COERCION BY EXPLOITATION: the type a function requires is imposed on the argument type. This is accomplished by taking a part of the argument's type to satisfy the function:
$F(A_{\alpha \odot \tau})_{\beta}$, $\tau \sqsubseteq \beta$

The selection mechanisms introduced in (24) allow for modulation of types during semantic composition. Selection or *Type Matching (TM)* takes place when the type call of the verb is directly satisfied by the argument. In this case, no type adjustment occurs. *Accommodation subtyping (AS)* occurs when the target type is a supertype of the type of the argument (and hence, the resulting function application accommodates to the type present in the argument. In *Coercion by Introduction (CI)*, the selecting target type is richer than the argument type and can be seen as wrapping the argument with the target type required by the function. As we will see, this can result in the type shifting to a new domain (domain-shifting) or staying within the same domain (domain-preserving). Finally, *Coercion by Exploitation (CE)* takes place when the target type required by the function is not satisfied by the source type, but is accessed and exploited from substructure in the source type. This may involve any manner of subtype, either through exploiting the qualia type or a dot object type. All but the first selection strategy above are type adjustment operations, but we will model them as distinct mechanisms, since they operate under different conditions and constraints, as we shall see in the next section.

3. Compositionality at work

The specification of argument-hood by a predicate can be viewed as the encoding of pretests or conditions for the correct computation by the predicate in function application. Hence, formally, there are two ways to proceed if these conditions are not satisfied during the computation of a function applying to its argument:

(25) If the argument condition (i.e., the test for the target type) is not satisfied, the predicate either:
  (i) fails to be interpreted (strict selectional typing);
  (ii) changes the argument source type according to one or more licensed coercion mechanisms (strong/enriched composition).

In the context of this condition, we will examine the strategies introduced in the previous section, to better articulate the modes of composition at work in a diverse sampling of linguistic constructions.[6] We will explore all four compositional mechanisms as they apply within each of the three type levels introduced earlier: namely, natural, artifactual, and complex types. We examine the selection process from the perspective of the functional element dictating the target type, focusing on three predicates as illustrative of the behavior in their class: *fall*, *spoil*, and *read*.

(26) a. Natural predicate ($e_N \rightarrow t$), *fall*: takes argument, x, of type, phys $\sqsubseteq$ e_N; λx:phys[*fall*(x)]
  b. Artifactual predicate ($e_A \rightarrow t$): *spoil*[7]: takes argument, x, of type *phys* $\otimes_T$ τ, or e_A; λx:e_A[*spoil*(x)]

c. Complex predicate: $(e_C \rightarrow (e_N \rightarrow t))$, *read*: takes internal argument, y, of type phys•info $\sqsubseteq e_C$; λy:phys•info $\lambda x:e_N$ [*read*(x,y)]

For each of these predicates and their respective *target types*, we now consider examples where the arguments vary by their *source type*, as illustrated below.

(27) Target = Natural
   a. *The rock fell*. (Source = Natural)
   b. *The beer fell*. (Source = Artifactual)
   c. *The book fell*. (Source = Complex)

(28) Target = Artifactual
   a. *The water spoiled*. (Source = Natural)
   b. *The beer spoiled*. (Source = Artifactual)
   c. *The bottle spoiled*. (Source = Complex)

(29) Target = Complex
   a. *Mary read the proposition*. (Source = Natural)
   b. *Mary read the rumor*. (Source = Artifactual)
   c. *Mary read the book*. (Source = Complex)

3.1. *Type matching and accommodation*

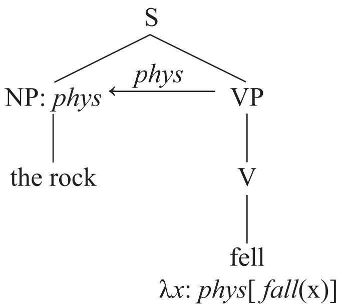
We begin with those contexts where the type restrictions imposed by the functional element are satisfied by the argument, namely selection or type matching cases. These are the sentences comprising the diagonal in the table shown below.

Table 1. *Composition Table of Type Matching Predicates*

Source Type	Target Type		
	Natural	Artifactual	Complex
Natural	(27a)		
Artifactual		(28b)	
Complex			(29c)

Consider first the selection *Natural Types* in (27a). For illustration purposes, I assume that the noun *rock* is a natural type, e_N, subtyped as phys.[8] The composition proceeds with no additional computational devices needed besides function application, as illustrated in (30).

(30)



Hence the derivation of (27a) in (30) is straightforward, through the application of Type Matching (TM), represented schematically in (31):

(31) a. "fall" is of type phys → t;
b. "the rock" is of type material (modulo GQ type shifting);
c. Accommodation Subtyping applies, material ⊑ phys:
⟹ "the rock" is of type phys:
d. Function Application (TM) applies; ⟹ fall(the-rock)

Notice that if the argument type is identified as a proper subtype of the target type, then *accommodation subtyping* allows the computation to proceed. For example, in (32), the noun *water*, typed as liquid, where liquid ⊑ phys ⊑ e_N, will satisfy the target type requirements from the predicate *fall*.

(32) *Some water fell on the floor*.

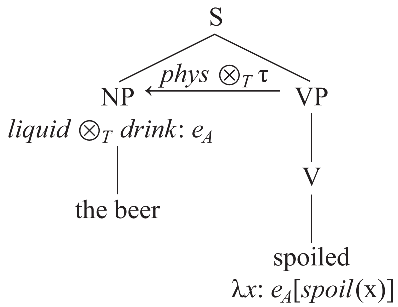
This results in the derivation shown in (33):

(33) a. "fall" is of type phys → t;
b. "some water" is of type liquid (modulo GQ type shifting);
c. Accommodation Subtyping applies, liquid ⊑ phys:
⟹"some water" is of type phys:
d. Function Application (TM) applies;
⟹ fall(some-water)

When both target and source types are *Artifactual Types*, then type matching is also in effect. We see this in sentence (34) (= (28b)), where the predicate *spoil* requires an argument that is defined as functional in nature (cf. Pustejovsky 2006), and this is indeed provided by the artifactual NP, *the beer*.

(34) *The beer spoiled*.

(35)



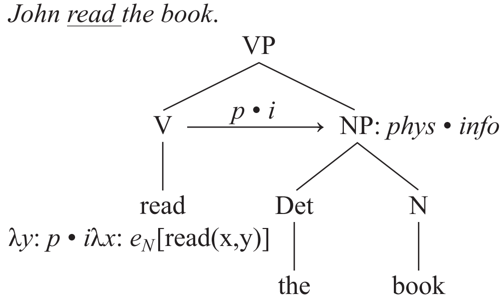
There are two things to notice about this derivation. Matching is accomplished only through accommodation subtyping on both the head type, and the value specified in the TELIC role: that is, over the head type, liquid $\sqsubseteq$ phys; and over the TELIC value, drink $\sqsubseteq$ τ. This is shown in the accompanying derivation in (36):

(36) a. "spoil" is of type *phys* $\otimes_T \tau \rightarrow$ t;
b. "the beer" is of type liquid ⊗T drink (modulo GQ type shifting);
c. Accommodation Subtyping applies to the head, liquid $\sqsubseteq$ phys:
$\Longrightarrow$ "the beer" has head type phys:
d. Accommodation Subtyping applies to the TELIC, drink $\sqsubseteq$ τ:
$\Longrightarrow$ "the beer" has TELIC type τ
e. "the beer" has type phys $\otimes_T \tau$;
f. Function Application (TM) applies;
$\Longrightarrow$ spoil(the-beer)

Finally, observe how type matching selection of *Complex Types* proceeds without complication for the example above in (29c), where the predicate *read* combines with the dot object headed NP, *the book*.

(37) *John read the book.*

(38)



The derivation of this example is fairly direct, and is shown in (39).

(39) a. "read" is of type $p{\bullet}i \rightarrow (e_N \rightarrow t)$;
b. "the book" is of type $p{\bullet}i$ (modulo GQ type shifting);

c. Function Application (TM) applies;
$\Longrightarrow \lambda x$ [read(x,the-book)]

There are many other examples of type matching that I will not discuss here, due to space limitations, including: collective/distributive readings, count/mass distinction, and event type and Aktionsarten selection, among others.

3.2. *Coercion by introduction*

In this section we now look systematically at how new typing information is introduced to the source type of the argument by the selecting predicate. Following Pustejovsky (2006), we distinguish between *domain-shifting* and *domain-preserving* coercions. The former involves the type-shifting across domains mentioned in the previous section, with complement coercing predicates such as *enjoy* and *begin*. Domain-preserving coercions involve the modulation of the type structure of a phrase while staying within the same domain in the model, e.g., the domain of individuals, or the domain of relations between individuals. Hence, the following type shifting rules are all domain-preserving: Individuals ⇒ Mass, Mass ⇒ Individuals, Natural ⇒ Artifactual, Artifactual ⇒ Complex, Complex ⇒ Natural, and so forth. Here we consider domain-preserving coercions first.

Recall the composition table introduced above, in Table 1, where the diagonal indicated type matching (TM) by a predicate over the three type levels. *Coercion by Introduction* (CI) is easily identified as applying to all cells in the composition table above this diagonal, as illustrated in Table 2.

Table 2. *Composition table of TM and CI predicates*

Source Type	Target Type		
	Natural	Artifactual	Complex
Natural	(27a)	(28a)	(29a)
Artifactual		(28b)	(29b)
Complex			(29c)

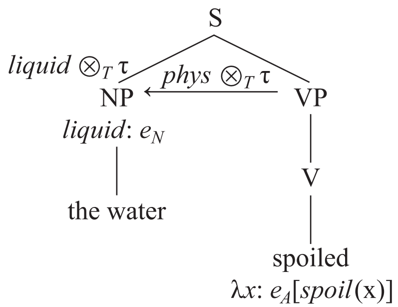
The relevant examples are repeated below in (40).

(40) a. *The water spoiled*.
b. *Mary read the proposition*.
c. *Mary read the rumor*.

When examining the behavior of domain-preserving coercions, it should be noted that there are just as many strategies for enriching typing information as there are transitions (or jumps) from distinct type levels in the semantics. For the type model presented in this article, there are two possible strategies: (i) qualia introduction, which introduces additional qualia-based typing; or (ii) dot introduction, which introduces a dot object to a non-complex type argument. We look at each of these in our discussion below.

Consider the sentence in (40a) and the alleged mismatch in typing. The verb *spoil*, as discussed above, is an artifactual predicate, and as such, imposes artifactual typing on its argument.[9] The source type of the argument "the water", however, is from the subdomain of natural entities, liquid. The resulting composition involves *qualia introduction* to the subject, as shown below in (41).

(41)

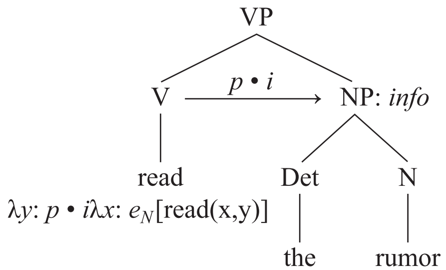


When a verb selecting for an artifactual type, such as *spoil*, combines with a natural type, Qualia Introduction applies and coerces it to a certain function or purpose. The interpretation of this sentence suggests that the water has a purpose or use in the context of utterance; e.g., for baking, for an experiment. The computation is shown in (42).

(42) a. "spoil" is of type *phys* $\otimes_T \tau \rightarrow t$;
b. "the water" is of type liquid (modulo GQ type shifting);
c. Accommodation Subtyping applies to the head, liquid $\sqsubseteq$ phys:
$\Longrightarrow$ "the water" has type phys;
d. Coercion by Qualia Introduction (CI-Q) applies to the type phys, adding a TELIC value τ:
$\Longrightarrow$ "the water" has type phys $\otimes_T \tau$;
e. Function Application applies;
$\Longrightarrow$ spoil(the-water)

Similarly, when a complex type-selecting predicate, such as *read* and *write*, combines with an argument which is not a dot object, *dot introduction* introduces the additional typing information to the source type, in order to facilitate the function application.[10] For example, as discussed above, the verb *read* selects for the dot object, *phys•info*, as its internal argument. Frequently, however, the collocating object is not a complex type, but naturals or artifactuals, as indicated in (40b)–(40c). We illustrate this operation of Coercion by Dot Introduction (CI-•) for (40c) below in (43).

(43)



The intended interpretation is that there is a physical manifestation of the propositional content of the rumor that is introduced by the predicate *read*, by virtue of its type; e.g., it was in the newspaper, on the web, etc. The derivation for this structure is as follows:

(44) a. "read" is of type $p \bullet i \rightarrow (e_N \rightarrow t)$;
b. "the rumor" is of type i, $i \sqsubseteq t$ (modulo GQ type shifting);
c. Coercion by Dot Introduction (CI-•) applies to the type i, adding the missing type value, p, and the relation associated with the •:
$\Longrightarrow$ "the rumor" has type $p \bullet i$;
d. Function Application applies; $\Longrightarrow \lambda x[\text{read}(x,\text{the-rumor})]$

We will defer from discussing the more traditional cases of aspectual type coercion (involving *begin*, etc.) until after exploitation has been presented.

3.3. *Coercion by exploitation*

In this section, we explore those mechanisms that access typing information that is already present in the source type, namely, coercion by exploitation (CE). Referring to our examples from above, when remaining within a domain, these refer to everything below the diagonal in our table. CE consists of exploiting part of the internal structure of a given type. For example, artifactual types and complex types have an internal structure and can hence be exploited. Since Naturals are atomic types with no internal structure, they cannot be exploited by this operation. However, Accommodation Subtyping acts to exploit the hierarchical typing available in such cases, as we saw above.

Table 3. *Composition table of TM, CI, and CE predicates*

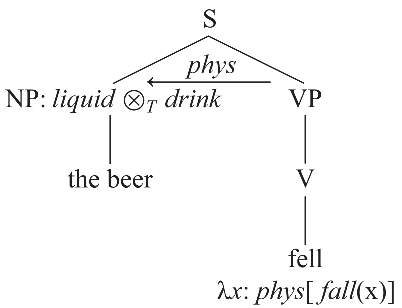
Source Type	Target Type		
	Natural	Artifactual	Complex
Natural	(27a)	(28a)	(29a)
Artifactual	(27b)	(28b)	(29b)
Complex	(27c)	(28c)	(29c)

The relevant cases of coercion by exploitation (CE) from our examples above are repeated below in (45).

(45) a. *The beer fell.*
b. *The bottle spoiled.*
c. *The book fell.* (c′. *Mary bought a book.*)

The sentence in (45c′) illustrates the same mechanisms as those at work in (45c), and makes for a useful comparison to the CI cases from the previous section. For (45a), CE operates over the source type and exploits the head type that is present. We illustrate the structure of this coercion for the former case.

(46)

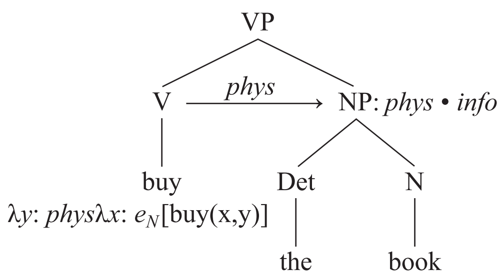


In this example, it is the physical manifestation of the NP meaning that is selected for by the predicate, regardless of any additional type complexity. The accompanying derivation is illustrated below in (47).

(47) a. "fall" is of type phys $\rightarrow$ t;
b. "the beer" is of type phys $\otimes_T \tau$ (modulo GQ type shifting);
c. Coercion by Exploitation (CE) applies to *liquid* $\otimes_T \tau$:
$\Longrightarrow$ "the beer" has type liquid;
d. Accommodation Subtyping (AS) applies to head, liquid $\sqsubseteq$ phys:
$\Longrightarrow$ "the beer" has type phys:
e. Function Application applies;
$\Longrightarrow$ fall(the-beer)

Now consider what we Now consider what we call *Coercion by Dot Exploitation* (CE-•). When an expression is typed as a dot object, such as *book* (*phys•info*), *house*, (*phys•loc*), *speech* (*event•info*) and *exit* (*event•loc*), it is disambiguated in context by the selecting predicative phrase, an operation we refer to as Coercion by Dot Exploitation. It consists of exploiting one aspect of the complexity of a dot type (namely, its inherent polysemy) by way of predicating over that element only. Dot exploitation can act on either element, depending on which type within the dot object is exploited: since in principle we assume that dot objects are commutative, from the point of view of their *modus operandi* the two operations are similar (but see additional remarks in Asher and Pustejovsky 2006; Asher 2011). An example of coercion by dot exploitation with the noun *book* in object position is shown below.

(48)



The derivation for this structure is as follows, ignoring the benefactive argument of *buy* for discussion.

(49) a. "buy" is of type phys → (e_N → t);
b. "the book" is of type phys • info, (modulo GQ type shifting);
c. Coercion by Dot Exploitation (CE-•) applies to the type phys•info, returning phys:[11]
⟹ "the book" has type phys;
d. Function Application applies;
e. ⟹ λx[buy(x,the-book)]

In this example, the type resulting from exploitation (CE-•) immediately satisfies the selection requirements of the predicate, *buy*. The other dot element of *book* (info) is exploited when selected by a predicate such as *believe*, as in *John believed the book*.

The example in (45b) involves a more complicated derivation, however.

(50) *The bottle spoiled*.

Rather, we see a case of CE-• followed by a qualia introduction, CI-Q.

(51) a. "spoil" is of type *phys* $\otimes_T$ τ → t;
b. "the bottle" is of type *phys•liquid*, (modulo GQ type shifting);

c. Coercion by Dot Exploitation (CE-•) applies to the type *phys•liquid*, returning liquid:
   ⟹ "the bottle" has type liquid;
d. Coercion by Qualia Introduction (CI-Q) applies to the type liquid, adding a TELIC value τ:
   ⟹ "the bottle" has type *liquid* $\otimes_T$ τ;
e. Function Application applies;
   ⟹ spoil(the-bottle)

Here we have a complex type, *phys•liquid*, where one of the readings is exploited, i.e., liquid, and then wrapped with an interpretation from CI-Q, where the liquid is typed as having a TELIC value by virtue of the governing predicate's target type. This is an example of multiple coercions where the resulting type remains within a single domain.

In this section we have discussed all four compositional mechanisms in the context of domain-preserving shifts. The table below identifies the compositional mechanisms operative for every situation that can arise within one domain.

Table 4. *Full composition table within a fixed domain*

Argument Type is:	Verb selects for:		
	Natural	Artifactual	Complex
Natural	TM/AS	Qualia-CI	Dot-CI
Artifactual	Qualia-CE	TM/AS	Dot-CI
Complex	Dot-CE	Dot-CE	TM/AS

Thus far, our discussion has focused on the exploitation of the *head* type or one of the dot elements in a complex type, where both elements are heads. In the next section, we see how qualia information is exploited in domain-shifting coercions.

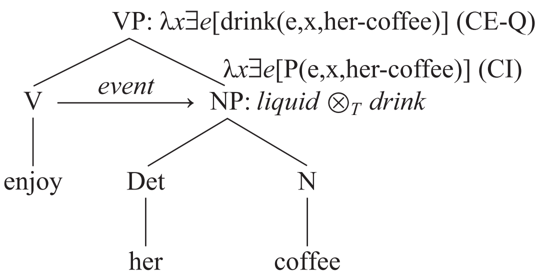
3.4. *Domain-shifting coercions*

Within the type structure associated with the domain of individuals, there is an inherent distinction between the head type and the possible type values associated with the Telic and Agentive qualia. For example, the artifactual typing of the nouns *beer* and *wine* is *liquid* $\otimes_T$ *drink*, where the Telic value *drink* is typed as a relation. It is because of this embedded type structure that GL has analyzed the classic complement type coercion cases as making reference to “hidden predicative information” associated with a nominal concept, as in (52) above and (53) below (cf. Briscoe et al. 1990; Pustejovsky and Boguraev 1993).

(52) Mary began [the book]$_{event}$.
(53) Mary enjoyed [her coffee]$_{event}$.

These are domain-shifting coercions, which are always identified as coercions by type introduction (Pustejovsky 2006). Consider the coercion in (53). Because these have been studied so extensively in the literature, I will gloss over some of the technical details in the computation involved.

(54)



Notice that a predicate such as *enjoy* selects for and introduces an event type to the NP complement in (53). Coercion by Qualia Exploitation (CE-Q) optionally applies to the typing of the NP, to provide a potential (default) interpretation for the predicate associated with the event. In this case, that predicate is *drink*.[12]

(55) a. “enjoy” is of type event → (e_N → t);
b. “her coffee” is of type *liquid* $\otimes_T$ *drink*, (modulo GQ type shifting);
c. Coercion by Introduction (CI) applies to the type liquid ⊗T drink, returning event:
⟹ “her coffee” has type event;
d. Coercion by Qualia Introduction (CI-Q) applies to the type event, adding a value drink to the predicate, *P*:
⟹ “her coffee” has type event, with P bound to drink;
e. Function Application applies;
⟹ λy[enjoy(y,λx∃e[drink(e,x,her-coffee)]]

Extensive examples from corpora of CI followed by CE-Q are discussed in Pustejovsky and Ježek (2008).

3.5. *Functional coercion*

As a final example of how the proposed mechanisms of coercion account for sense modulation phenomena, consider the selectional behavior of the verb *hear*, illustrated in (56) below.

(56) a. *The children* heard *a sound outside*.
b. *The villagers* heard *the bell | alarm*.
c. *John* heard *the neighbor's dog last night*.

What is interesting about these three examples is how the selectional requirements for the target type are satisfied (cf. Ibarretxe-Antunano 1999; Willems and Defrancq 2000). If we assume that *hear* selects for sound as its internal argument type, then (56a) involves Type Matching (TM) over its internal argument.

(57) a. "hear" is of type sound $\rightarrow (e_N \rightarrow t)$;
b. "a sound" is of type sound (modulo GQ type shifting);
c. Function Application (TM) applies;
$\Longrightarrow \lambda x[\text{hear}(x,(\text{a-sound})]$

As argued in Pustejovsky and Ježek (2008), perception verbs like *hear* may exploit the Qualia values of their internal arguments, where those entities have a Telic role which involves the production of a sound (*bell*, *whistle*, *siren*, *alarm clock*, and so forth). Hence, the sentence in (56b) can be analyzed in terms of Coercion by Qualia Exploitation (CE-Q), where the type for the noun *bell* is phys $\otimes_T$ ring. This provides the appropriate noise-making activity which is then heard, but it does not, by itself, result in the target type required by the predicate, i.e., sound. We are also left without a solution to how the source type in (56c) matches the target type, since there is no qualia structure to exploit from the natural typing for the noun *dog*.

To solve both these problems, we turn to a related selection phenomenon involving types that can be both *nominal* and *attributive* in nature. That is, they can denote a value (nominally) or be an attribute of something else (attributively). For example, the type *name* can denote a value, e.g., Mary, or be an attribute of an individual, e.g., *name(x)*. Consider the two types, *loc* and *time* (for typing locations and temporal intervals, respectively), as demonstrated in (58). The verb *leave* selects for an internal argument typed as *loc*, while the object of the temporal preposition *after* is typed as *time*.

(58) a. John left Boston.
b. Mary taught before noon.

Notice, however, that neither predicative context in (59) is satisfied by the source type of the NP, *the party*, i.e., event.

(59) a. *John* left *the party*.
b. *Mary taught* before *the party*.

While we might analyze (59b) as involving some sort of temporal trace of the event, this won't provide a solution for the example in (59a). In fact, they are both instances of a more general mechanism called *attribute functional coercion* (Pustejovsky and Rumshisky 2010). This mechanism operates over types that have both nominal and attributive realizations in the grammar. As it happens, both *loc* and *time* can be seen as denoting nominal elements (from the domain of regions for the former, and the domain intervals and points, for the latter), but also an attributive function: e.g., the *location* of something, the *time* of something, etc. We define this coercion as follows:

(60) Attribute Functional Coercion (AFC):
 a. Given an expression α, typed as: $\tau \rightarrow \beta$
 b. the type τ shifts to $e \rightarrow \tau$
 c. α is now typed as: $(e \rightarrow \tau) \rightarrow \beta$

To see how this applies in the examples above, consider how the verb *leave* accommodates to the mismatched typing from the NP, *the party*, in (59a), where an informal logical form for this sentence is given in (61b).

(61) a. *leave*: $\lambda y{:}loc\ \lambda x{:}e_N\ [leave(x, y)]$
 Functional Coercion: $loc \Rightarrow e \rightarrow loc$
 leave: $\lambda y{:}e \rightarrow loc\ \lambda x{:}e_N\ [leave(x, y)]$
 $(= \lambda y{:}e\ \lambda x{:}e_N\ [leave(x, loc(y))])$
 b. $\exists e \exists y[leave(j, y) \wedge party(e) \wedge loc(e) = y]$

Now we return to our problems of type mismatch with the verb *hear*, as encountered above in (56b)–(56c). Assume that *hear* is typed as in (62).

(62) *hear*: $\lambda y{:}sound\ \lambda x{:}e_N\ [hear(x, y)]$
 Functional Coercion: $sound \Rightarrow e \rightarrow sound$
 hear: $\lambda y{:}e \rightarrow sound\ \lambda x{:}e_N\ [hear(x, y)]$
 $(= \lambda y{:}e\ \lambda x{:}e_N\ [hear(x, sound(y))])$

(63) a. "hear" is of type $sound \rightarrow (e_N \rightarrow t)$;
 b. "the bell" is of type $phys \otimes_T ring$ (modulo GQ type shifting);
 c. Functional Coercion applies to sound: $sound \Rightarrow e \rightarrow sound$
 d. Function Application (TM) applies; $\Longrightarrow \lambda x[hear(x,(sound(the\text{-}bell))]$
 e. CE-Q applies to $phys \otimes_T ring$, returning ring: $\Longrightarrow \lambda x[hear(x,(ring(the\text{-}bell))]$

A similar derivation results in the licensed computation for (56c), where sound(the-dog) does not necessarily return a specific sound-making activity associated with the dog. Optionally, however, we might imagine the application of a Coercion by Exploitation (CE) rule accessing the *conventionalized attributes* associated with that object. For example, this might de-feasibly accommodate to "barking" for how one might hear a dog. This topic is beyond the scope of the present discussion, but is explored in some depth in Pustejovsky and Ježek (forthcoming).

4. Conclusion and recent developments

In this article I have discussed the mechanisms of coercion in the context of a general theory of selection in the grammar. The focus has been to examine the contexts where argument selection fails, and some type adjustment or accommodation is necessary to satisfy the conditions on the computation expected by the predicate. One topic we have only touched on only briefly is the connection between lexical decomposition and the type theory used for selection and coercion. Sentence meaning and lexical meaning are connected through the types employed in composition. But the types that the expressions carry are themselves determined by mechanisms of lexical decomposition[13]. Hence, the continued articulation and development of a calculus of lexical decomposition is an important area for further exploration.

The increasing role that coercion is beginning to play in grammatical descriptions within linguistics is witnessed by a growing acceptance that sense modulations, grammatical polymorphisms, and lexical polysemy may involve the application of lexically or constructionally driven coercion strategies. For example, coercion has become a central component within the theory of Construction Grammar (CxG), as articulated in Goldberg (2006) and Michaelis (2003a, 2004a). Many researchers within the CxG literature employ coercion in conjunction with constructional templates for analyzing a broad array of linguistic phenomena (Michaelis 2003b; Ruiz de Mendoza Ibáñez and Mairal Usón 2008).

The role of coercion in morphosyntactic processes has also recently been explored. Im and Lee (in press), for example, explore how the "light verb" meaning within the *ha*-construction in Korean can be accounted for using coercion of the complement. Similarly, Huang and Ahrens (2003) propose that nominal classifiers in Mandarin do not simply agree with the noun but actually coerce them to particular kind and event interpretations.

A further extension to the model of coercion presented here is to view type shifts as a result of updating processes within a discourse context. While this is the goal of Asher and Pustejovsky (2006), in recent work Asher (2011) has developed the Type Composition Logic (TCL) into a fully dynamic logic. This can be seen as a way of formalizing the contextualized updates that occur in selectional polysemy, where information is added to an argument from contextual factors. This is an important direction in the study of coercion, as it focuses on the dynamic processes involved when argument selection fails in a predication: namely, the accommodation of the argument to a particular interpretation required by the predicate. This approach does not, however, adequately account for the role of decomposition in argument selection, and how this relates to the typing of the predicate, as described earlier.

In order to present characteristic or "casebook" examples of coercion as exploited throughout the grammar, the examples used in this article have been introspective or phenomenological in origin, per standard practice in theoretical linguistics. But proper justification for theoretical claims comes from empirical coverage of larger datasets, and it is becoming increasingly clear that corpus-based research should be acknowledged within theoretical work[14]. In fact, recent integrative works have begun to demonstrate both the theoretical significance of analyzing larger datasets as well as the empirical significance of theory as it constrains data analysis. As many researchers have pointed out, not all theoretically predicted contexts for coercion and sense modulation interpretations are grammatically acceptable. For this and other reasons, there is considerable interest in using a corpus-based approach to test theoretical claims as they pertain to argument selection and coercion. What one sees is that, while theory predicts behavior that is not attested, linguistic behavior exists that is not predicted by theory. The methodology involves taking these data to inform and update the theory, and in some cases modify or drop theoretical assumptions.[15] Preliminary results of this effort suggest that there is considerable lexical variation in coercion occurrence (acceptability), even with classic constructions.[16] With larger and larger datasets, such studies will provide empirical evidence for testing different hypotheses regarding coercion phenomena, just as psycholinguistic data have proved so useful in substantiating as well as challenging various claims within the coercion literature (Baggio et al. 2010; Pinango et al. 2006; Pylkkanen and McElree 2006).

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Notes

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1. There is growing disagreement over the exact nature of the calculus of relations between constituent parts, however. Recent theoretical and experimental work in corpus-based linguistics suggests that the "relations between constituents" may be: (a) more numerous than

first believed; (b) weaker in semantic content; and (c) may involve aspects and indexes into the context of usage that formal approaches had not considered before (Hanks 2006; Hanks and Pustejovsky 2005). These considerations are beyond the more limited discussion intended for the present article, but see Church and Hanks (1989), Lin (1998), and Merlo and Stevenson (2001) for further debate.

2. The qualia are inspired in part by Moravcsik's (1975) interpretation of Aristotelian *aitia*. See Pustejovsky (1995a) and Moravcsik (1990) for further discussion.
3. These are typed refinements of the simple, unified, and complex types formed from qualia structure.
4. The intention here is to make an analogy to the head/complement distinction from syntactic constructions.
5. The linguistic motivations for establishing a fundamental distinction between natural and non-natural types and the conceptual underpinning of naturals are discussed in detail in Pustejovsky (2006).
6. There are numerous coercion mechanisms we will not discuss here, due to limitations on space. These include: grinding and packaging operations, distributive/collective type shifts, and aspectual coercions and reinterpretations in discourse (Moens and Steedman 1988; Krifka 1992; Landman 1995).
7. Natural types that are conceptualized as having a function or purpose may possibly spoil as well, of course, as with milk, meat, etc.
8. Formally, the common noun, *rock* would be typed $e_N \rightarrow t$, or subtyped as phys → t. The simplification is for expository purposes, and does not affect the resulting compositional distinctions. Further, I assume Montague's conventional type shifting rules are applicable, accommodating shifts from individual type e to generalized quantifier types, (e → t) → t, where appropriate (Montague 1973; Thomason 1974; Partee 1984).
9. There are obviously other constraints at play with the selecting predicate, but they do not factor into our discussion of coercion by introduction here.
10. This is first introduced as an introduction rule in Pustejovsky (1998). In the present treatment, we follow the specific analysis in Asher and Pustejovsky (2006).
11. This is essentially the *Type Pumping* operation from Pustejovsky (1995a) and *Dot Exploitation Left* from Asher and Pustejovsky (2006). Similar remarks hold for exploiting the right element as well.
12. I ignore the specifics of the type for *enjoy* for purposes of presentation. Formally, however, it selects for an event description, e → E. See Pustejovsky (1995a) for discussion.
13. For more information on how decomposition strategies impact the resulting type theories, cf. Pustejovsky (2006).
14. As this relates to sense modulation and coercion phenomena, some relevant works include: Hanks (2006), De Clerck et al. (2011), Hanks and Pustejovsky (2005), Ježek and Lenci (2007), Pustejovsky and Rumshisky (2008, 2010), Pustejovsky and Ježek (2008).
15. This work is part of a larger effort to annotate a large corpus with compositional operations (Pustejovsky et al. 2009).
16. For example, cf. Lapata and Lascarides (2003) and Pustejovsky and Rumshisky (2010).

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