Type Theory and Lexical Decomposition*

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Abstract

In this paper, I explore the relation between methods of lexical representation involving decomposition and the theory of types as used in linguistics and programming semantics. I identify two major approaches to lexical decomposition in grammar, what I call *parametric* and *predicative* strategies. I demonstrate how expressions formed with one technique can be translated into expressions of the other. I then discuss argument selection within a type theoretic approach to semantics, and show how the predicative approach to decomposition can be modeled within a type theory with richer selectional mechanisms. In particular, I show how classic Generative Lexicon representations and operations can be viewed in terms of types and selection.

1 Introduction

In this paper, I examine the relation between the type of an argument as selected by a predicate, and the role this argument subsequently plays in the computation of the sentence meaning. The thesis that I will put forth

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is that there is an important connection between the nature of the type that a predicate selects for as its argument, and the subsequent interpretation of the predicate in the model. In order to understand this connection, I explore the logical structure of decomposition as used in linguistic theory. Two basic models of word meaning are discussed, *parametric* and *predicative* decomposition. These are then compared to selection within a rich type theory.

Type theoretic selection can be viewed as *partial decomposition*. The advantage over a full decomposition model such as predicative is that, in defining a predicate, one is not forced to identify the distinguishing features (as in Katz and Fodor) in the model. However, the types used as assignments to the arguments of the predicate are a recognizable and distinguished subset of possible predications over individuals.

In the first two sections, I explore the relation between methods of lexical representation involving decomposition and the theory of types as used in linguistic semantics and programming semantics. I first distinguish two approaches to lexical decomposition in language, *parametric* and *predicative* decomposition. I demonstrate how expressions formed with one technique can be translated into expressions of the other. I then discuss argument selection within a type theoretic approach to semantics, and show how type theory can be mapped to the predicative approach of lexical decomposition. I argue that a type theoretic framework results in an interpretative mechanism that is computationally more tractable than with either atomic expressions or simple parametric decomposition. In the final three sections, Generative Lexicon (GL) is illustrated as a constrained model of type selection and predicative decomposition. I outline three basic mechanisms of argument selection for semantic composition, and demonstrate how these mechanisms interact with the type system in GL.

2 Methods of Lexical Decomposition

Typically, linguistically sensitive theories of lexical structure tend to focus on how verb meanings relate to syntactic forms within a sentence; that is, linking lexical-semantic form to syntax (van Valin, 2005, Levin and Rappaport, 2005, Jackendoff, 2002, Davis and Koenig, 2000). To accomplish this, much of the work on the structure of lexical items in language over the past ten years has focused on the development of type structures and typed feature structures. The selectional behavior of verbal predicates, on this view, follows from the type associated with the verb's arguments. There is, however, a distinction in the way that verbs select their arguments that has not been noticed, or if it has, has not been exploited formally within linguistic theories; namely, argument structure and decomposition are intimately connected and typically inversely related to one another.

Before we examine the various models of lexical decomposition, we need to address the more general question of what selection in the grammar is, and what exactly the formal nature of an argument is. We begin by reviewing informally what characteristics may comprise the predicative complex that makes up a verb's meaning. These include, but are not limited to:

(1) a. Specific properties of the participants of the event;
b. Change of being, state, location, relation;
c. Causation and agency;
d. Manner and means of an activity;
e. Temporal and spatial constraints;
f. Intentionality of the actor;
g. Instrumental information;
h. Psychological state of the participants;

The question that I wish to address in this paper is the following: which of these aspects can be abstracted as selectional restrictions to arguments, and which of these can be abstracted as arguments in their own right? To answer this question, I will first examine the role that lexical decomposition plays in the theory of grammar. I will characterize four approaches to decomposition that have been adopted in the field, and illustrate what assumptions each approach makes regarding selectional restrictions on the arguments to a verb.

Linguists who do adopt some form of lexical decomposition do not typically concern themselves with the philosophical consequences of their enterprise. Still, it is hard to ignore the criticism leveled against the field by Fodor and LePore (1998), who claim that any model of semantics involving decomposition is without support and leads to the anarchy of conceptual holism. In fact, however, most linguists assume some kind of decompositional structure for the semantic representations associated with lexical items, including, as it happens, Fodor and LePore themselves.[1]

How do we decompose the meaning of a verb? In order to categorize the various techniques of decomposition, I will assume that a predicative expression such as a verb has both a *argument list* and a *body*. This is schematically illustrated in (2) below.

(2)

$$\overbrace{\lambda x_i}^{Args}\overbrace{[\Phi]}^{Body}$$

Intuitively, the question is the following: if the semantics of a predicate can convey any or all of the components of meaning mentioned above in (1), then how are they represented, if at all, in the semantic form adopted for the lexical representation of this predicate? How explicit is the predicative decomposition over Φ, and how many arguments does the predicate carry underlyingly? What I hope to demonstrate here is the way in which the *args-body* structure is modified by different approaches to lexical decomposition in order to account for these separate components of a predicate's meaning.

We will consider four possible strategies for reconfiguring the *args-body* structure of a predicate.[2] We begin first with the null hypothesis, what I refer to as *atomic predication*. In this approach, the parameter structure of the underlying semantic representation of an expression α is mirrored directly by the realization of the verb's arguments in the surface syntax.

(3) ATOMIC DECOMPOSITION: The expression α has a simple atomic body, Φ, and a parameter list matching the arguments in syntax.
$\lambda x_n \ldots \lambda x_1[\Phi] \implies \text{Verb}(\text{Arg}_1, \ldots, \text{Arg}_n)$

This is illustrated in the sentences in (4)-(5), where each argument in the semantic form is expressed syntactically.

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[1] The admission that mentalese appears to be a first order language is already an acceptance that some sort of decomposition is desirable or necessary for describing language. But beyond this, we will see that the vocabulary accepted as standard to discuss verb behavior is a further commitment to types or categories as part of lexical descriptions.

[2] Each of these strategies has been thoroughly explored in the literature. What I hope to illustrate here is the organization of these approaches according to the above classification. The focus in the discussion below will be on verbs and their projection to syntactic form.

(4) a. $\lambda x[\text{die}(x)]$
b. The flower died.

(5) a. $\lambda y \lambda x[\text{hit}(x, y)]$
b. The car hit the wall.

To ensure the correct mapping to syntax from the lexical representation of the predicate, a mechanism of *argument identification* must be assumed.[3]

From the basic representation in (3), four distinct strategies for the decomposition of lexical information have been proposed in the literature.[4]

(6) a. PARAMETRIC DECOMPOSITION: The expression α has a simple atomic body, Φ, but the parameter list adds additional arguments for interpretation in the model:

$$\lambda x_m \ldots \lambda x_{n+1} \lambda x_n \ldots \lambda x_1[\Phi]$$

b. SIMPLE PREDICATIVE DECOMPOSITION: The expression α has a complex expression of subpredicates, $\Phi_1, \ldots \Phi_k$, over the parameter list:

$$\lambda x[\Phi_1, \ldots \Phi_k]$$

c. FULL PREDICATIVE DECOMPOSITION: The expression α has a complex expression of subpredicates, $\Phi_1, \ldots \Phi_k$, while also adding additional arguments to the parameter list, binding into the subpredicates:

$$\lambda x_m \ldots \lambda x_{n+1} \lambda x_n \ldots \lambda x_1[\Phi_1, \ldots \Phi_k]$$

d. SUPRALEXICAL DECOMPOSITION: The expression α does not change, but the parameter structure is enriched through mechanisms of additional operators such as $\mathcal{R}$ (associated with functional categories); the interpretation of α is enriched by an extra compositional operation:

$$\lambda f_\sigma \lambda x_1[\mathcal{R}(f)(x_1)](\lambda x[\Phi_1, \ldots \Phi_k])_\sigma$$

[3]This is the θ-theory in varieties of Chomsky's framework from the 1980s, and the Functional Uniqueness Principle from LFG.

[4]For the present discussion, I assume that the subpredicates in the expressions below are related by means of standard first order logical connectives.

For each of these approaches, the representation adopted for the predicate meaning will have consequences for the subsequent mapping of its parameters to syntax, namely, the problem of argument realization. To better illustrate the nature of these strategies, let us consider some examples of each approach, beginning with parametric decomposition. Within this approach, the intuitive idea is to motivate additional parameters over which a relation is evaluated in the model. These can be contextual variables, parameters identifying properties of the speaker, hearer, presuppositional information, and other pragmatic or domain specific variables. Perhaps the most widely adopted case of parametric decomposition is Davidson's proposed addition of the event variable to action predicates in language (Davidson, 1967). Under this proposal, two-place predicates such as *eat* and three-place predicates such as *give* contain an additional argument, the event variable, e, as depicted below.

(7) a. $\lambda y \lambda x \lambda e[\text{eat}(e)(y)(x)]$
    b. $\lambda z \lambda y \lambda x \lambda e[\text{give}(e)(z)(y)(x)]$

In this manner, Davidson is able to capture the appropriate entailments between propositions involving action and event expressions through the conventional mechanisms of logical entailment. For example, to capture the entailments between (8b-d) and (8a) below,

(8) a. Mary ate the soup.
    b. Mary ate the soup with a spoon.
    c. Mary ate the soup with a spoon in the kitchen.
    d. Mary ate the soup with a spoon in the kitchen at 3:00pm.

In this example, each more specifically described event entails the one above it by virtue of and-elimination (conjunctive generalization) on the expression.

(9) a. $\exists e[\text{eat}(e, m, \text{the-soup})]$
    b. $\exists e[\text{eat}(e, m, \text{the-soup}) \wedge with(e, \text{a\_spoon})]$
    c. $\exists e[\text{eat}(e, m, \text{the-soup}) \wedge with(e, \text{a\_spoon}) \wedge in(e, \text{the\_kitchen})]$
    d. $\exists e[\text{eat}(e, m, \text{the-soup}) \wedge with(e, \text{a\_spoon}) \wedge in(e, \text{the\_kitchen}) \wedge at(e, \text{3:00pm})]$

There are of course many variants of the introduction of events into predicative forms, including the identification of arguments with specific named roles (or partial functions, cf. Dowty, 1989, Chierchia, 1989) such as thematic relations over the event. Such a move is made in Parsons (1980).[5]

Within AI and computational linguistics, parameter decomposition has involved not only the addition of event variables, but of conventional adjunct arguments as well. Hobbs et al. (1993), for example, working within a framework of first-order abductive inference, models verbs of change-of-location such as *come* and *go* as directly selecting for the "source" and "goal" location arguments. As a result, directional movement verbs such as *follow* will also incorporate the locations as direction arguments.

(10) a. $\lambda z \lambda y \lambda x \lambda e[\text{go}(e, x, y, z)]$
b. $\lambda z \lambda y \lambda x \lambda e[\text{follow}(e, x, y, z)]$

Generalizing this approach, we see that parametric decomposition involves the addition of logical parameters to the body of the expression without enriching the "descriptive content" of the predicate itself. Furthermore, on this strategy, the one-to-one correspondence from the semantic representation to syntactic expression of an argument is not explicitly maintained.

(11) PARAMETRIC DECOMPOSITION:
$$\lambda x_m \ldots \lambda x_{n+1} \lambda x_n \ldots \lambda x_1[\Phi] \implies \text{Verb}(\text{Arg}_1, \ldots, \text{Arg}_n)$$

Because some parameters are not always expressed, such a theory must take into consideration the conditions under which the additional parameters are expressed. For this reason, we can think of parametric decomposition as requiring both argument identification and *argument reduction* (or Skolemization) in the mapping to syntax. That is, something has to ensure that an argument may be elided or must be expressed.

We turn next to *simple predicative decomposition*. Perhaps the best known examples of lexical decomposition in the linguistics literature are the componential analysis expressions proposed in Katz and Fodor (1963). Under this strategy, concepts such as *bachelor* are seen as conjunctions of more "primitive" features:[6]

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[5]The neo-Davidsonian position adopted by Kratzer (1994) does not fall into this category, but rather in the supralexical decomposition category below. Reasons for this will become clear in the discussion that follows.

[6]Whether the concept of *married* is any less complex than that of the definiendum *bachelor* has, of course, been a matter of some dispute. Cf. Weinreich (1972).

(12) $\forall x[\text{bachelor}(x) \Longrightarrow [\text{male}(x) \wedge \text{adult}(x) \wedge \neg\text{married}(x)]]$

Independent of the syntactic or semantic motivations for such a definition, it is clear that (12) is an instance of the simple predicative decomposition. For the present discussion, notice that neither the argument structure nor the type of the variable has changed in the expression in (12) for *bachelor*; only the body of the expression has been effected.

Verbs have also been expressed as simple predicative decompositions in the literature; for example, the representation for the verb *die*, as (13) illustrates (cf. Lakoff, 1965, Dowty, 1979).

(13) $\forall x[\text{die}(x) \Longrightarrow [\text{Become}(\neg\text{alive}(x))]$

Again, using our simple *args-body* description of the expression, the predicative content in the *body* of (13) has become more complex, while leaving the arguments unaffected, both in number and type. The mapping to syntax from a simple predicative decomposition structure can be summarized as the following relation:

(14) SIMPLE PREDICATIVE DECOMPOSITION:
$\lambda x_n \ldots \lambda x_1[\Phi_1, \ldots \Phi_k] \quad \Longrightarrow \quad \text{Verb}(\text{Arg}_1, \ldots, \text{Arg}_n)$

In addition to argument identification, this strategy requires that the subpredicates, $\Phi_1, \ldots \Phi_k$, get collapsed into one syntactically realized verbal element.[7]

When the predicative and parametric approaches to decomposition are combined we arrive at what I will refer to as *full predicative decomposition*. This is generally the approach taken in Generative Lexicon Theory (Pustejovsky and Boguraev, 1993, Pustejovsky, 1995), Jackendoff's Conceptual Structure (Jackendoff, 2002), Pinker (1989), and Levin and Rappaport's work on predicate decomposition (Levin and Rappoport, 1995, 2005).

For example, ignoring aspects of named functional roles (e.g., qualia structure or thematic relations), the decomposition for a causal predicate such as *kill* includes reference to the subevent involving the activity proper (Moens and Steedman's (1988) preparatory phase) and the culminating state. This is represented in (15).

[7] Recall that such collapsing operations were an important process prior to lexical insertion in Generative Semantics, cf. McCawley, 1972, Dowty, 1979.

(15) a. **kill**:
$\lambda y \lambda x \lambda e_1 \lambda e_2[\text{act}(e_1, x, y) \wedge \neg\text{dead}(e_1, y) \wedge \text{dead}(e_2, x) \wedge e_1 < e_2]$:
b. The gardener killed the flower.

The correspondence between lexical structure and syntactic realization for this strategy can be schematically represented as follows:

(16) FULL PREDICATIVE DECOMPOSITION:
$$\lambda x_m \ldots \lambda x_{n+1} \lambda x_n \ldots \lambda x_1[\Phi_1, \ldots \Phi_k] \implies \text{Verb}(\text{Arg}_1, \ldots, \text{Arg}_n)$$

Note that, as with parametric decomposition, both argument identification and argument reduction are required for the mapping to syntax. As with the simple predicative strategy, a condition is required to ensure that the subpredicative structure is adequately expressed in the syntax.

Finally, it should be noted that the effects of decomposition can be reconstructed through composition in a more abstract syntax, as proposed, for example, by Kratzer (1996). Following Marantz's (1984) analysis of verbs as lacking external arguments in their lexical encoding of argument structure, Kratzer proposes that the external argument is introduced through a functional category of *voice*, which adds the argument that was otherwise missing from the verbal structure. The event associated with the agent and that of the main predicate are composed through an operation she terms *Event Identification* (Kratzer, 1996).

(17) SUPRALEXICAL DECOMPOSITION:
a. $\lambda x_n \ldots \lambda x_1[\Phi] \implies \text{Verb}(\text{Arg}_1, \ldots, \text{Arg}_n)$
b. $v \implies \lambda f_\sigma \lambda x_1[\mathcal{R}(f)(x_1)]$
c. $\lambda f_\sigma \lambda x_1[\mathcal{R}(f)(x_1)](\lambda x[\Phi])_\sigma$

Thus, in the sentence in (18), the external argument along with the semantics of agency and causation are external to the meaning of the verb *build*.

(18) John built a house.

This view has broad consequences for the theory of selection, but I will not discuss these issues here as they are peripheral to the current discussion.

3 Types and the Selection of Arguments

Having introduced the basic strategies for semantic decomposition in predicates, we now examine the problem of argument selection. We will discuss the relation between selection and the elements that are assumed as part of the type inventory of the compositional semantic system.

In the untyped entity domain of classical type theory as conventionally adopted in linguistics (e.g., Montague Grammar), determining the conditions under which arguments to a relation or function can "be satisfied" is part of the interpretation function over the entire expression being evaluated. The only constraint or test performed prior to interpretation in the model is the *basic typing* carried by a function. For example, to determine the interpretations of both sentence (19a) and (19b), the interpretation function, $[\![.]\!]^{M,g}$ tests all assignments according to g within the model M.

(19) a. A rock fell.
$\exists x \exists e[\text{fall}(e, x) \wedge \text{rock}(x)]$
b. A rock died.
$\exists x \exists e[\text{die}(e, x) \wedge \text{rock}(x)]$

Hence, our assignment and model will determine the correct valuation for the proposition in (19a). As it happens, however, there will be no assignment that satisfies (19b) in the model. We, of course, as speakers of language, intuit this result. The model does not express this intuition, but does evaluate to the same answer. The valuation may always be correct (the correct truth-value universally assigned), but the computation required to arrive at this result might be costly and unnecessary: costly because we must evaluate every world within the model with the appropriate assignment function; and unnecessary because the computation could effectively be avoided if our system were designed differently.

This can be accomplished by introducing a larger inventory of types and imposing strict conditions under which these types are accepted in a computation. A richer system of types works to effectively introduce the test of "possible satisfaction" of an argument to a predicate. The types in the entity domain encode the possible satisfaction of the argument. We can think of argument typing as a *pre-test*. If an expression fails to past the pretest imposed by the type, it will not even get interpreted by the interpretation function.[8] This is what we will call a “fail early” selection strategy. Hence, the domain of interpretation for the expression is reduced by the type restriction.

In the discussion above, we distinguished the argument list from the body of the predicate. To better understand what I mean by a “fail early” strategy of selection, let us examine the computation involved in the interpretation of a set of related propositions. Consider the following sentences.

(20) a. The woman slept soundly.
b. The soldier died in the street.
c. The child dreamt of Christmas.

Imagine *tracing* the interpretation of each sentence above into our model. Given a domain, for each sentence, the assignment function, g, and interpretation function, I results in a valuation of each sentence. What is notable about the sentences in (20), is that the trace for each sentence will share certain computations towards their respective interpretations. Namely, the argument bound to the subject position in each sentence is *animate*. How is this common trace in the interpretation of these predicates represented, if at all, in the grammar? [9]

Consider the λ-expression for a two-place predicate, Φ, which consists of the subpredicates $\Phi_1, \ldots, \Phi_k$. The variables are typed as individuals, i.e., e, and the entire expression is therefore a typical first-order relation, typed as $e \rightarrow (e \rightarrow t)$.

(21)

$$\overbrace{\lambda x_2 \lambda x_1}^{Args} \overbrace{[\Phi_1, \ldots \Phi_k]}^{Body}$$

[8]In programming languages, the operation of semantic analysis verifies that the typing assignments associated with expressions are valid. This is essentially done in compilation time, as a pre-test, filtering out arguments that would otherwise have the wrong type. In a model that does not perform predicate decomposition to incorporate typing constraints, sentences like (19b) are just false.

[9]Regarding argument selection, there are two possible strategies for how the argument accommodates to the typing requirement. Given that the type requirement is a pretest, the argument expression can fail (strict monomorphic typing), or coerce to the appropriate type (polymorphic typing). We will not discuss coercion in the context of the fail early strategy in this paper.

A richer typing structure for the arguments would accomplish three things: (1) it acts to identify specific predicates in the body of the expression that are characteristic functions of a given argument;

(22)

$$\lambda x_2 \lambda x_1 [\Phi_1, \ldots \overbrace{\Phi_{x_1}}^{\tau}, \ldots \overbrace{\Phi_{x_2}}^{\sigma}, \ldots, \Phi_k]$$

(2) it pulls this subset of predicates out of the body;

(23)

$$\lambda x_2 \; \lambda x_1 [\Phi_1, \ldots, \Phi_k - \{\Phi_{x_1}, \Phi_{x_2}\}]$$

and (3) it takes the set of predicates associated with each argument and *reifies* them as type restrictions on the λ-expression, i.e., as the types τ and σ.

(24)

$$\lambda x_2 : \sigma \; \lambda x_1 : \tau [\Phi_1, \ldots, \Phi_k - \{\Phi_{x_1}, \Phi_{x_2}\}]$$

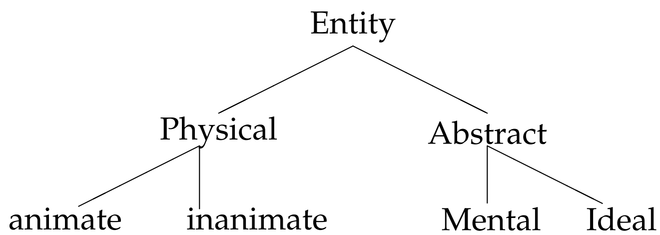
The typing restriction on the arguments can be seen as a *pretest* on the λ-expression, where they act as restricted quantification over a domain of sorts, denoted by that set of predicates. So, in terms of the computation, we see that the test for each argument is performed before the predicate is considered for evaluation.

Returning to the examples in (20), we can identify one distinguishing predicate over each subject argument as *animate*. This suggests that the verbs *sleep*, *die*, and *dream* are members of the natural class of predicates taking an animate argument as logical subject. This aspect of the computation that the sentences share can be captured within the model by means of a structure such as a semi-lattice. Hence, if $anim \sqsubseteq e$, then, *sleep* and the related predicates from (20) are typed as in (25a):

(25) a. *sleep*: $anim \rightarrow t$
b. $\lambda x : anim[sleep(x)]$

Under such an interpretation, the expression makes reference to a type lattice of expanded types, such as that shown in (26) below (cf. Copestake and Briscoe, 1992, Pustejovsky and Boguraev, 1993).

(26)



Thus, instead of representing the verb *sleep* as the λ-expression

(27) $\lambda x[animate(x) \wedge sleep(x)]$

we can interpret predication of animacy over the subject directly as a *pre-test condition* on the typing of that argument, $\vdash x\colon anim$. This will be denotationally equivalent to the previous expression in (27), but would be operationally distinct. Namely, the computation performed to determine whether the subject satisfies the condition on animacy is done before the λ-reduction is even computed.[10]

What this correspondence suggests more generally is that a semantic expression in one decomposition strategy may be translated (and perhaps equivalent) to an expression in another strategy. Of particular interest is the relation between predicate decomposition and strategies involving richer inventories of types. There is an obvious trade-off in expressiveness between these two strategies. Where decomposition posits specific predications over its argument, an enriched typing strategy will make many of those predications part of the typing assignment to the argument itself, cf. below.

(28) Types for the verb *sleep*:

[10]This brings up the issue of how a pre-test is related to the presuppositional interpretation of argument selection. Although an important question, I will defer discussion to a forthcoming treatment of selection mechanisms, Pustejovsky (2006).

APPROACH	Type	Expression
atomic	$e \rightarrow t$	$\lambda x[sleep(x)]$
predicative	$e \rightarrow t$	$\lambda x[animate(x) \wedge sleep(x)]$
enriched typing	$anim \rightarrow t$	$\lambda x : anim[sleep(x)]$

Similar remarks hold for the semantics of nouns, and in particular, the predicative decomposition of relational nouns (cf. Borschev and Partee, 2001) and agentive nouns (Busa, 1996).

In the remainder of this paper, I will examine in more detail the consequences of enriching the inventory of types. First, however, we examine what linguistic motivations exist for such a move.

4 Enriching the Type System

4.1 Semantic Transparency

Researchers in linguistics typically assume that language meaning is compositional, and that a theory of semantics for language should model this property. There appear to be, however, many phenomena in language that are non-compositional and which are not directly accounted for by conventional models of compositionality (Partee, 1992, Kamp and Partee, 1995). This gap in descriptive power has motivated several views of richer representation and semantic operations, one of which is Generative Lexicon Theory (Pustejovsky, 1995). Generative Lexicon (GL) is concerned in part with explaining the creative use of language. On this view, our ability to categorize and structure the world is an operation of generative categorization and compositional thought, and the lexicon is seen as a dynamic component, responsible for much of the information underlying this phenomenon. Language, therefore, is the natural manifestation of our generative construction of the world through the categories it employs. This has been an implicit guiding principle within much of linguistic semantic research, from Chomsky (1986) to Ginzburg and Sag (2000) and Jackendoff (2002).

In Pustejovsky (2005) I refer to this informally as the *Principle of Semantic Transparency*. From a GL perspective, this states that the syntactic realization of an argument is directly dependent on: (a) the semantic type imposed by the selecting predicate; and (b) the coercion transformations available to that type in the grammar. What this says is that there is a direct mapping from semantic representations and their types to specific syntactic effects. Specifically, it states that such a mapping must be a property of semantic categories generally, and not merely selectively. The thesis as stated may in fact be too strong, and indeed there appear to be areas of grammar where direct semantic transparency seems to fail (such as the syntactic realization of mass and count terms cross-linguistically). Nevertheless, I will adopt semantic transparency to help structure our intuitions regarding the linguistic modeling of types for selection in grammar.

The standard theory of selection in grammar can be viewed as follows. There is some inventory of types, $\mathcal{T}$, associated with the entities in the domain, along with t, a Boolean type. Verbs are analyzed as functional types, meaning that they are functions from this set of types to t (i.e., employing a functional type constructor such as $\rightarrow$). The selectional constraints imposed on the arguments to a verb are inherited from the type associated with that argument in the functional type that the verb carries. This is generally quite weak and if any further constraints are seen as being imposed on the semantics of an argument, then they would be through some notion of selectional constraints construed as a presupposition during interpretation.

The approach taken here differs from the standard theory in two respects. First, we will aim to make the selectional constraints imposed on a verb's arguments transparently part of the typing of the verb itself. This entails enriching the system of types manipulated by the compositional rules of the grammar. Following Pustejovsky (2001), I will assume the theory of type levels, where a distinction is maintained between *natural*, *artifactual*, and *complex* types for all major categories in the language. Secondly, the mechanisms of selection available to the grammar are not simply the application of a function to its argument (function application, argument identification, θ-discharge), but involve three type-sensitive operations: type *matching*, *coercion*, and *accommodation*. These will be introduced in subsequent sections.

4.2 The Notion of Natural Type

There has been a great deal of research that depends on the concept of *natural kind*, much of it in developmental psychology (Rosch, 1975, Keil, 1989), presupposing the discussion of the problem as presented in Putnam (1975) and Kripke (1980). Although the problem emerges in a superficial manner in the semantics and knowledge representation literature (Fellbaum, 1998), there is surprisingly little discussion of the conceptual underpinnings of natural kinds and how this impacts the linguistic expression of our concepts. This section addresses the linguistic and conceptual consequences of the notion of natural kind. Particularly, I will examine what it means, from the perspective of linguistic modeling, for the grammar to make reference to a natural or unnatural kind in the conceptual system.

The world of entities inherited from Montague's theory of semantics is, in many respects, a very restricted one. In that model, there is no principled type-theoretic distinction made between the kinds of things that exist within the domain of entities. Similarly, the only distinctions made in the domain of relations pertains mostly to the number of arguments a relation takes, or the intensional force introduced over an argument (cf. Dowty et al, 1981, Heim and Kratzer, 1998). Many enrichments and modifications have been made to this model over the past thirty years, including the addition of stages and kinds (cf. Carlson, 1977), but interestingly enough, no extensions have ever been made for modeling natural kinds.

From a linguistic point of view, this might not seem surprising, since the grammatical behavior of natural kind terms doesn't noticeably distinguish itself from that of other nominal classes. In fact, there has never been sufficient evidence presented for making such a grammatical distinction. Consider, for example, the sentences in (29) below. The natural kind terms *dog*, *man*, and *bird* behave no differently as nominal heads than the artifactual nouns *pet*, *doctor*, and *plane*.

(29) a. Mary saw every *dog/pet*.
b. John visited a *man/doctor*.
c. *Birds/planes* can fly.

Similarly, no discernible difference between nominal classes is present with the adjectival constructions below.

(30) a. a sick *dog/pet*
b. an American *man/doctor*
c. white *birds/planes*

In this section, however, I discuss three linguistic diagnostics which appear to motivate a fundamental distinction between natural and unnatural kinds. These diagnostics are:

(31) a. *Nominal Predication*: How the common noun behaves predicatively;
b. *Adjectival Predication*: How adjectives modifying the the common noun can be interpreted;
c. *Interpretation in Coercive Contexts*: How NPs with the common noun are interpreted in coercive environments.

Let us first consider the nominal predicative construction, illustrated in (32) with natural kind terms.

(32) a. Otis is a dog.
b. Otis is a poodle.
c. Eno is a cat.

As is apparent, natural kind terms permit singular predication: what is interesting, however, is that they appear to require predicative uniqueness. Note that the nominal co-predication in (33a) is odd, while that in (33b) is ill-formed ('!' here indicates semantic anomaly).

(33) a. ?Otis is a dog and an animal.
b. !That is a dog and a cat.
c. Otis is a dog and therefore an animal.

While (32a) identifies the individual, Otis, as belonging to a particular natural kind, *dog*, the predication in (33a) would apparently violate a pragmatic principle on redundant typing (Gricean informativeness). The predication in (33b), on the other hand, is contradictory.

Observe that the *and-therefore*-construction in (33c) is acceptable with the nominal sortal terms *dog* and *animal*. This construction is valid when the first nominal term is a subtype of the second nominal term; hence, since dogs are a subtype of animals, the construction is valid.

The property of predicative uniqueness does not hold for adjectives, however. Something can obviously be both "big and red", "long and thin", or "flat and smooth". Note, however, that co-predications from the same domain are ill-formed, as shown in (34).

(34) a. !This box is large and small.
b. !Your gift is round and square.

Such examples illustrate the inherent complementarity of the predicative space being alluded to in each example; *size* in (34a) and *shape* in (34b). The restriction on co-predication suggests that natural kind terms are structured in a taxonomy, somehow obeying a complementary partitioning of the conceptual space, in a similar manner to the adjectival cases in (34).

The question that immediately arises is how prevalent the restriction on nominal predication is. The fact is that most co-predication with nominals is acceptable, and natural kind terms are the exception. Observe the sentences in (35), with nominals from the class of artifacts.

(35) a. This is both a pen and a knife.
b. The substance is a stimulant and an anti-inflammatory.

Occupational terms and agentive nominals also easily co-predicate, as seen in (36).

(36) a. Mary is a housewife and a doctor.
b. Bernstein was a composer and a conductor.

Not surprisingly, the *and-therefore*-construction is acceptable with both artifacts and human agentive nominals.

(37) a. This object is a knife and therefore a weapon.
b. Emanuel Ax is a pianist and therefore a musician.

Knives are a subtype of weapon, and pianists are a subtype of musician. Notice, however, that the *and-therefore*-construction in (38) is also acceptable.

(38) Emanuel Ax is a pianist and therefore a human.

While it is true that pianists are humans, this subtyping relation is different from that with musicians in (37b). We return to this distinction below in the next section.

While natural kinds terms seem to distinguish themselves from other sortal terms with nominal predicative constructions, the same holds for certain adjectival predications as well. Consider the adjectival modifications in (39), with natural kind terms as head.

(39) a. very old gold
b. a new tree
c. a young tiger
d. such a beautiful flower

The adjectives in (39) behave in a conventional subsective manner and are unambiguous in their modification of the nominal head. That is, there is one distinct semantic aspect of the head that they modify. Compare these examples to those in (40) and (41), with artifacts and agentive nominals as head, respectively.[11]

(40) a. a blue/Swiss pen
b. a bright/expensive bulb
c. a long/shiny CD

(41) a. a very old friend
b. a good professor
c. such a beautiful dancer

With the NPs in (40), observe that the adjectives can modify aspects of the nominal head other than the physical object: *blue* in (40a) can refer to the color of the object or the color of the ink; *bright* in (40b) most likely refers to the bulb when illuminated; and *long* in (40c) can refer only to the length of time a CD will play.[12]

Turning to the agentive nominal heads in (41), a similar possibility of dual adjectival modification exists. The adjective *old* in (41a) can refer to the individual as a human or the friendship; *good* in (41b) can refer to teaching skills or humanity; and *beautiful* in (41c) can refer to dance technique or physical attributes.

From this brief examination of the data, it is clear that not all kind terms are treated equally in nominal predication and adjectival modification. As a final diagnostic illustrating grammatical distinctions between natural and unnatural kind terms, let us consider the selection of NPs in

[11] This class of adjectives has been studied extensively. Bouillon (1997) analyzes such constructions as subselective predication of a qualia role in the head. Larson and Cho (2003) provide a more conventional interpretation without the need for decompositional representations.

[12] In both (40b) and (40c), interpretations are possible with modification over the object, but they are semantically marked with *bright* and contradictory with *long*.

type coercive contexts. Verbs that select for multiple syntactic frames for the same argument can be viewed as polymorphic predicates. In Pustejovsky (1993, 1995), it is argued that predicates such as *believe* and *enjoy*, as well as aspectual verbs such as *begin* and *finish* can *coerce* their arguments to the type they require. For example, consider the verb-object pairs in (42)-(43):

(42) a. Mary enjoyed drinking her beer.
b. Mary enjoyed her beer.

(43) a. John began to write his thesis.
b. John began writing his thesis.
c. John began his thesis.

Although the syntactic form for each sentence is distinct, the semantic type selected for by *enjoy* and *begin*, respectively, remains the same. For the readings in (42b) and (43c), following Pustejovsky (1995), we assume that the NP has undergone a type coercion operation to the type selected by the verb. For example, in (43c), the coercion "wraps" the meaning of the NP "his thesis" with a controlled event predicate, in this case defaulting to "writing".

What is interesting to note is that artifactual nouns seem to carry their own default interpretation in coercive contexts. This property is completely absent with natural kind terms, however, as shown below.

(44) a. !John finished the tree.
b. !Mary began a tiger.

There are, of course, legitimate readings for each of these sentences, but the interpretations are completely dependent on a specific context. Unlike in the coercions above, natural kinds such as *tree* and *tiger* carry no prior information to suggest how they would be "wrapped" in such a context.

In sum, we have discovered three grammatical diagnostics distinguishing natural kind terms from non-natural kind terms. They are:

(45) a. *Nominal Predication*: How the common noun behaves predicatively;
b. *Adjectival Predication*: How adjectives modifying the the common noun can be interpreted;
c. *Interpretation in Coercive Contexts*: How NPs with the common noun are interpreted in coercive environments.

Given this evidence, it would appear that natural kinds should be typed distinctly from the class of non-naturals in language. The latter, however, is itself heterogeneous, and deserves further examination. As explored in Pustejovsky (2001), there are specific and identifiable diagnostics indicating that the class of non-natural entities divides broadly into two classes, what I call *artifactual types* and *complex types*. Because this distinction largely mirrors that made in Pustejovsky (1995) between unified and complex types, I will not review the linguistic motivations in this paper.

In the next section, I show how the representations and mechanisms of Generative Lexicon (GL) theory can account for these distinctions. These facts can be accounted for by establishing a fundamental distinction between natural types and non-natural types within our model. We first review the basics of GL and then present our analysis.

5 Types in Generative Lexicon

Generative Lexicon introduces a knowledge representation framework which offers a rich and expressive vocabulary for lexical information. The motivations for this are twofold. Overall, GL is concerned with explaining the creative use of language; we consider the lexicon to be the key repository holding much of the information underlying this phenomenon. More specifically, however, it is the notion of a constantly evolving lexicon that GL attempts to emulate; this is in contrast to currently prevalent views of static lexicon design, where the set of contexts licensing the use of words is determined in advance, and there are no formal mechanisms offered for expanding this set.

One of the most difficult problems facing theoretical and computational semantics is defining the representational interface between linguistic and non-linguistic knowledge. GL was initially developed as a theoretical framework for encoding selectional knowledge in natural language. This in turn required making some changes in the formal rules of representation and composition. Perhaps the most controversial aspect of GL has been the manner in which lexically encoded knowledge is exploited in the construction of interpretations for linguistic utterances. Following standard assumptions in GL, the computational resources available to a lexical item consist of the following four levels:

(46) a. LEXICAL TYPING STRUCTURE: giving an explicit type for a word positioned within a type system for the language;
b. ARGUMENT STRUCTURE: specifying the number and nature of the arguments to a predicate;
c. EVENT STRUCTURE: defining the event type of the expression and any subeventual structure it may have; with subevents;
d. QUALIA STRUCTURE: a structural differentiation of the predicative force for a lexical item.

The qualia structure, inspired by Moravcsik's (1975) interpretation of the *aitia* of Aristotle, are defined as the modes of explanation associated with a word or phrase in the language, and are defined as follows (Pustejovsky, 1991):

(47) a. FORMAL: the basic category of which distinguishes the meaning of a word within a larger domain;
b. CONSTITUTIVE: the relation between an object and its constituent parts;
c. TELIC: the purpose or function of the object, if there is one;
d. AGENTIVE: the factors involved in the object's origins or "coming into being".

Conventional interpretations of the GL semantic representation have been as feature structures (cf. Bouillon, 1993, Pustejovsky, 1995). The feature representation shown below gives the basic template of argument and event variables, and the specification of the qualia structure.

$$\left[\begin{array}{l} \alpha \\ \text{ARGSTR} = \left[\begin{array}{l} \text{ARG1} = x \\ \ldots \end{array}\right] \\ \text{EVENTSTR} = \left[\begin{array}{l} \text{E1} = e_1 \\ \ldots \end{array}\right] \\ \text{QUALIA} = \left[\begin{array}{l} \text{CONST} = \textbf{what } x \textbf{ is made of} \\ \text{FORMAL} = \textbf{what } x \textbf{ is} \\ \text{TELIC} = \textbf{function of } x \\ \text{AGENTIVE} = \textbf{how } x \textbf{ came into being} \end{array}\right] \end{array}\right]$$

It is perhaps useful to analyze the above data structure in terms of the *args-body* schema discussed in previous sections. The *argument structure (AS)* captures the participants in the predicate, while the *event structure (ES)* captures the predicate as an event or event complex of a particular sort (Pustejovsky, 2001). The body is composed primarily of the *qualia structure* together with temporal constraints on the interpretation of the qualia values, imposed by event structure. This is illustrated schematically below, where $\mathcal{QS}$ denotes the qualia structure, and C denotes the constraints imposed from event structure.

(48)

$$\overbrace{\overbrace{\lambda x_n \ldots \lambda x_1}^{AS}\overbrace{\lambda e_m \ldots \lambda e_1}^{ES}}^{Args} \quad \overbrace{[Q_1 \wedge Q_2 \wedge Q_3 \wedge Q_4;\ C]}^{Body:\ QS \cup C}$$

Given this brief introduction to GL, let us return to the problem of argument selection. I propose that the selection phenomena can be accounted for by both enriching the system of types and the mechanisms of composition. I will propose three mechanisms at work in the selection of an argument by a predicative expression. These are:

(49) a. PURE SELECTION (Type Matching): the type a function requires is directly satisfied by the argument;
b. ACCOMMODATION: the type a function requires is inherited by the argument;
c. TYPE COERCION: the type a function requires is imposed on the argument type. This is accomplished by either:
i. *Exploitation*: taking a part of the argument's type to satisfy the function;
ii. *Introduction*: wrapping the argument with the type required by the function.

Following Pustejovsky (2001), we will separate the domain of individuals into three distinct type levels:

(50) a. NATURAL TYPES: Natural kind concepts consisting of reference only to Formal and Const qualia roles;
b. ARTIFACTUAL TYPES: Concepts making reference to purpose or function.
c. COMPLEX TYPES: Concepts making reference to an inherent relation between types.

The level of a type will be modeled by its structure, following Asher and Pustejovsky's (2001, 2005) *Type Composition Logic*. The set of types is defined in (51) below.

(51) a. e the general type of entities; t the type of truth values.
(σ, τ range over all simple types, and subtypes of e; cf. the semi-lattice in (26) above).

b. If σ and τ are types, then so is $\sigma \rightarrow \tau$.

c. If σ and τ are types, then so is $\sigma \otimes_R \tau$, where R can range over $Agentive$ or $Telic$.

d. If σ and τ are types, then so is $\sigma \bullet \tau$.

In addition to the conventional operator creating functional types ($\rightarrow$), we introduce a type constructor $\bullet$ ("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 Pustejovsky (1995). We also introduce a type constructor $\otimes$ ("tensor") which can be seen as introducing qualia relations to a base type.

To illustrate how the type system here is a natural extension of that in Pustejovsky (1995), consider a classic GL type feature structure for a term α, ignoring CONST for now:

(52)
$$\begin{bmatrix} \alpha \\ \text{QUALIA} = \begin{bmatrix} \text{FORMAL} : \beta \\ \text{TELIC} : \tau \\ \text{AGENTIVE} : \sigma \end{bmatrix} \end{bmatrix}$$

In Pustejovsky (1995), the type specification for an expression α, (i.e., the FORMAL qualia value β) is distinct from the other qualia values in the semantic representation for α. The qualia structure, on this view, is the entire feature structure associated with the expression.

What we will do here, is conceptually not that different but has some interesting consequences for how compositionality is modeled. We will identify the entire qualia structure as the typing assignment for the expression itself. That is, we integrate the FORMAL type specification 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; that is, [FORMAL $= \beta$] is simply written β.

The additional qualia values can be seen as structural complementation to the head type. Each quale value will be introduced by a tensor operator, $\otimes$. To differentiate the qualia roles, we will subscript the operator accordingly; e.g., $[\text{TELIC} = \tau]$ can be expressed as $\otimes_T \tau$, $[\text{AGENTIVE} = \sigma]$ can be expressed as $\otimes_A \sigma$.

Now the feature structure for the expression α from (52) can be represented as a single composite type, as in (53), or written linearly, as $\beta \otimes_T \tau \otimes_A \sigma$.

(53) $$\begin{bmatrix} \alpha: & \beta \\ & \otimes_T \tau \\ & \otimes_A \sigma \end{bmatrix}$$

Given these assumptions for how qualia structures can be interpreted as types, let us return to our previous discussion of natural versus non-natural types. We can see the expression of natural typing throughout the major linguistic categories in the language:

(54) a. **Nouns**: rock, water, woman, tiger, tree
b. **Verbs**: fall, walk, rain, put, have
c. **Adjectives**: red, large, flat, big

These will be our atomic types, from which we will construct our $\otimes$-types and $\bullet$-types (artifactual and complex types, respectively).

We will assume that the natural entity types, $\mathcal{N}$, are just those entities formed from the Formal qualia value i.e., atomic types. The natural types are formally structured as a join semi-lattice (Pustejovsky, 2001), $\langle \mathcal{N}, \sqsubseteq \rangle$ (cf. the structure in (26)).

Now consider the predicates that select for just these 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 sub-domain of natural types follows conventional functional typing assumptions: for any type τ in the sub-domain of natural types, $\tau \in \mathcal{N}$, $\tau \rightarrow t$ is a *natural functional type*.

First, let us review some notation. I assume a *typing judgment*, $g \vdash \alpha : \tau$, with respect to a grammar to be an assignment, g, an expression, α, and a type, τ, such that under assignment g, the expression α has type τ. In the case of the natural types, I will also assume the following equivalence:

(55) $g \vdash x : \tau \in \mathcal{N} \ =_{df} \ g \vdash x : e_n$

Hence, all of the predicates below are considered *natural predicates*, since each is a functional type created over the sub-domain of natural entities.[13]

(56) a. *die*: $e_N \rightarrow t$
b. *touch*: $e_N \rightarrow (e_N \rightarrow t)$
c. *be under*: $e_N \rightarrow (e_N \rightarrow t)$

These predicates can be expressed as λ-expressions with typed arguments as in (57):

(57) a. λx:e_N[*die*(x)]
b. λy:$e_N \lambda x$: e_N[*touch*(x,y)]
c. λy:$e_N \lambda x$: e_N[*be-under*(x,y)]

Before we look at how natural types are exploited in composition in the language, we will illustrate how non-natural types are constructed in GL's Type Composition Logic.

5.1 Artifacts and Artifactual Types

One of the innovations introduced by GL is the idea that conceptual differences in the mental lexicon are reflected in the qualia structures for the lexical items associated with those concepts. Hence, the nouns *person*,

[13]It is worth noting that the propositions formed by the composition of a natural predicate with natural type entities have a special status, since they form the basis of what we will call *natural propositions*. Examples of such propositions are given below:

1. The rabbit died.
2. The rock touches the water.
3. The ants are under the tree.

It is interesting to compare this to Anscombe's (1958) discussion and Searle's (1995) extension regarding "brute facts" as opposed to "institutional facts.". The natural predication of a property over a natural entity is a judgment requiring no institutional context or background. Facts (or at least judgments) can be classified according to the kinds of participant they contain; in fact, as we shall see, the qualia and the principle of type ordering will allow us to enrich this "fact classification" even further.

typist, *water*, and *wine*, all have distinct qualia structures reflecting their conceptual distinctions. This has always been at the core of GL's view of lexical organization. What I wish to do here is demonstrate how these differences are accounted for directly in terms of the structural typing introduced above.

In the previous section, natural entities and natural functions were defined as the atomic types, involving no $\otimes$- or $\bullet$-constructor syntax. Artifactual objects, that is, entities with some function, purpose, or identified origin, can now be constructed from the tensor constructor and a specific value for the TELIC or AGENTIVE role. I will adopt the term *artifact*, in a broad sense, to refer to artifactually constructed objects, or natural objects that have been assigned or assume some function or use.[14] Following the discussion above, then, composing a natural entity type, e_N, with a Telic value by use of the $\otimes$-constructor results in what we will call an *artifactual type*.[15]

(58) ARTIFACTUAL TYPE (Version I): For an expression α, whose head type, $\beta \in \mathcal{N}$, then for any functional type γ, the $\otimes_R$-construction type, $\beta \otimes_R \gamma$, is in the sub-domain of *artifactual types*, $\mathcal{A}$.

To illustrate how the qualia structure of artifacts can be modeled in this fashion, observe the type structures for a selection of artifactual entity types:

(59) a. *beer*: $liquid \otimes_T drink$

b. *knife*: $phys \otimes_T cut$

c. *house*: $phys \otimes_T live\_in$

As it stands, the definition in (58) is not general enough to model the set of all artifacts and concepts with function or purpose. As argued in Pustejovsky (1995), the head type (the FORMAL quale role) need not be an atomic type (natural), but can be arbitrarily complex itself. As a result, we will broaden the type for the head to include artifactual types as well:

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[14]Dipert makes a similar move in his 1993 book *Artifacts, Art Works, and Agency*.

[15]The judgments expressed by the predication of an artifactual predicate of an artifactual subject results in an artifactual proposition. This is formally similar to Searle's notion of institutional fact.

(60) ARTIFACTUAL TYPE (Final Version): For an expression α, whose head type, $\beta \in \mathcal{N} \cup \mathcal{A}$, and any functional type γ, the $\otimes_R$-construction type, $\beta \otimes_R \gamma$, is in the sub-domain of *artifactual types*, $\mathcal{A}$.

As with the naturals, the creation of functions over the sub-domain of artifactual types is straightforward: for any type τ in the sub-domain of artifactual entity types, $\tau \in \mathcal{A}$, $\tau \rightarrow t$ is a *artifactual functional type*. Below are some examples of such functional types, expressed as λ-expressions with typed arguments:

(61) a. λx:e_A[*spoil*(x)]

b. λy:$e_A \lambda x$:e_N[*fix*(x,y)]

Before we examine the specific mechanisms of selection accounting for strong (enriched) compositionality in the grammar, we review the final level of types generated by the Type Construction Logic, that of the Complex Types (Dot objects).

5.2 Dots and Complex Types

Because the behavior of complex types has been studied in a number of works (Pustejovsky, 1995, 1998), I will concentrate on how they are constructed in GL's Type Construction Logic. To account for the inherent polysemy in nouns such as *book*, where distinct ((62a) and (62b)) and contradictory (62c) selectional environments are possible, GL introduces a type constructor, $\bullet$, which reifies the two elements into a new type.

(62) a. Mary doesn't believe the book.

b. John bought his book from Mary.

c. The police burnt a controversial book.

(63) COMPLEX TYPE: For any entity types $\alpha, \beta \in \mathcal{N} \cup \mathcal{A}$, the $\bullet$-construction type, $\alpha \bullet \beta$, is in the sub-domain of *complex types*, $\mathcal{C}$.

Creating functions over the sub-domain of complex types is similarly straightforward: for any type τ in the sub-domain of complex entity types, $\tau \in \mathcal{C}$, $\tau \rightarrow t$ is a *complex functional type*. Below is an example of the verb *read*, a complex functional type, since it selects a complex type as its direct object.

(64) a. *read*: $phys \bullet info \rightarrow (e_N \rightarrow t)$
b. λy:$phys \bullet info$ λx: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 $phys \bullet info$. In a selective context such as (65), the predicate directly selects for a complex type, *a magazine*.

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

How exactly this is accomplished we will explain below. In the next section, we turn finally to the mechanisms of selection at work in ensuring that predicates and their arguments are compatible in semantic composition.

6 Mechanisms of Selection

In this section, we examine the compositional processes at work in communicating the selectional specification of a predicate to its arguments. In particular, we analyze domain-preserving selection between a predicate and its arguments. As a result, we will not discuss type-shifting rules across domains, such as the classic type coercion rules invoked in aspectual and experiencer verb complementation contexts (e.g., *enjoy the beer*, *finish the coffee*). How these operations are analyzed in terms of the compositional mechanisms presented here is described elsewhere (cf. Pustejovsky, 2006).

There are three basic mechanisms available in the grammar for mediating the information required by a predicate, F, and that presented by the predicate's argument. For a predicate selecting an argument of type σ, $[\_\_\_]_\sigma\ F$, the following operations are possible:

(66) a. PURE SELECTION: The type a function requires of its argument, A, is directly satisfied by that argument's typing:

$$[\ A_{\alpha}\ ]_{\alpha}\ \ F$$

b. ACCOMMODATION: The type a function requires is inherited through the type of the argument:

$$[\ A_{\beta}\ ]_{\alpha}\ \ F,\ \ \alpha \sqcap \beta \neq \bot$$

c. COERCION: The type a function requires is imposed on the argument type. This is accomplished by either (where $\odot$ represents the disjunction of the two constructors, $\otimes$ and $\bullet$):

i. *Exploitation*: selecting part of the argument's type structure to satisfy the function's typing:

$$[\ A_{\alpha\odot\tau}\ ]_{\beta}\ \ F,\ \ \alpha \sqsubseteq \beta$$

ii. *Introduction*: wrapping the argument with the type the function requires:

$$[\ A_{\alpha}\ ]_{\beta\odot\sigma}\ \ F,\ \ \alpha \sqsubseteq \beta$$

The table below illustrates what operations are available in which selectional contexts. Obviously, *pure selection* is only possible when both the type selected and the argument type match exactly. Also, *accommodation* is operative only within the same type domain.

The remaining cases are varieties of coercion: *exploitation* is present when a subcomponent of the argument's type is accessed; and *introduction* is operative when the selecting type is richer than the type of its argument.[16]

[16]It might be possible to view pure selection as incorporating the accommodation rule as well, which would result in a more symmetric distribution of behavior in the table. Whether this is computationally desirable, however, is still unclear.

(67)

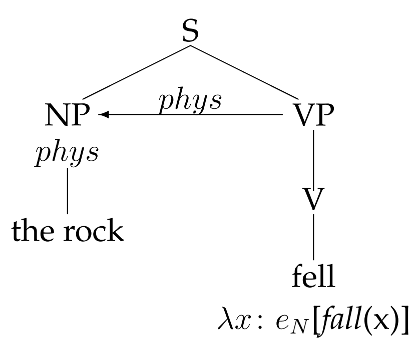
		Type Selected	
Argument Type	Natural	artifactual	Complex
Natural	Sel/Acc	Intro	Intro
artifactual	Exploit	Sel/Acc	Intro
Complex	Exploit	Exploit	Sel/Acc

To better understand the interactions between these operations, let us walk through some examples illustrating each of these selectional operations. We start with the set of predicates selecting for a natural type argument. Consider the intransitive verb *fall*, as it appears with natural, artifactual, and complex arguments, respectively. The typing on the head noun for each example is given in parentheses.

(68) a. $\mathcal{N}$: The rock fell to the floor. ($phys$)
b. $\mathcal{A}$: The knife fell to the floor. ($phys \otimes_T cut$)
c. $\mathcal{C}$: The book fell to the floor. ($phys \bullet info \otimes_T read \otimes_A write$)

The mechanism at work in (68a) is pure selection, as illustrated below in (69).

(69)



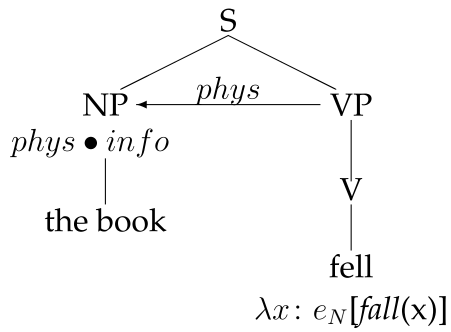
For the second and third examples, exploitation applies to provide access to the physical manifestation of the type appearing in the argument position. Below is the derivation for (68c); the exploitation in (68b) is similarly derived.[17]

[17]Exploitation on the $info$ element of the dot object for *book* occurs in examples such as (i) below:

(i) I don't believe this book at all.

Here the verb is selecting for propositional content, which is present by exploitation in the dot object of the direct object.

(70)

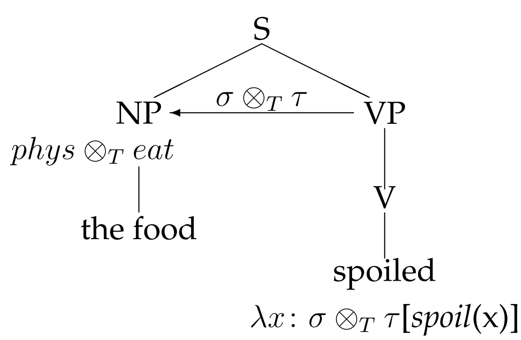


Now let us consider artifactual type selecting predicates. We take the verb *spoil* as an example. Again, we look at each type possibility in argument position. The selected type of the complement is in parentheses.[18]

(71) a. $\mathcal{N}$: The water spoiled. ($phys$)
b. $\mathcal{A}$: The food spoiled. ($phys \otimes_T eat$)

Consider first the case of pure selection in (71b). Here the predicate is selecting for an artifactual entity as subject, and the NP present is typed as one. Hence, the typing requirement is satisfied.

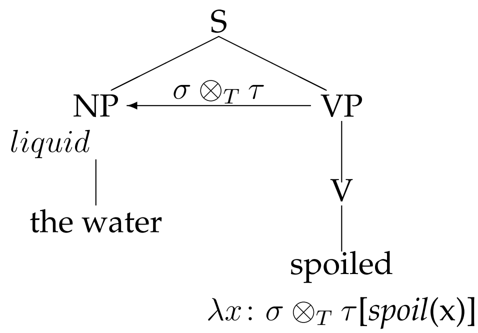
(72)



Now consider the presence of a natural entity in a subject position selecting for an artifactual type. This is the case in (71a); to satisfy the typing requirements on the predicate, the coercion rule of *Introduction* is required to wrap the natural type with a functional interpretation; that is, this water was going to be used for something, it had some function intended for it. The derivation is shown below.

[18]For the present discussion, we ignore selection of a dot object in an artifactual type context. In general, the analysis will follow the introduction rule seen in (71a) below, but there are complications in some cases. These are discussed in Pustejovsky (2006).

(73)

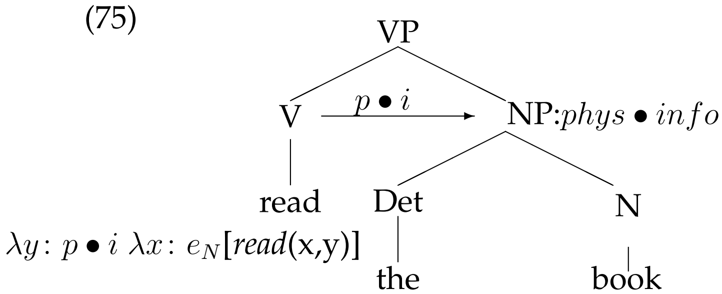


Finally, let us examine the selectional mechanisms at work when the predicate selects for a complex type. As discussed in Pustejovsky (1998, 2001), these include verbs such as *read*.

(74) a. $\mathcal{N}$: Mary read a rumor about John. ($info$)
a′. $\mathcal{N}$: The bathers read the sand on the beach. ($phys$)
b. $\mathcal{A}$: The passengers read the walls of the subway. ($phys \otimes_T \tau$)
c. $\mathcal{C}$: Mary read the book. ($phys \bullet info \otimes_T read \otimes_A write$)

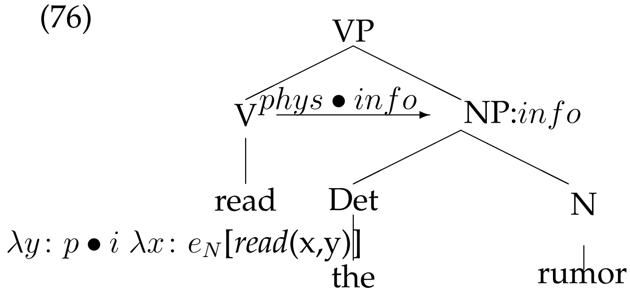
In this case, sentence (74c) is the example of pure selection. The predicate *read* requires a dot object of type $phys \bullet info$ as its direct object, and the NP present, *the book*, satisfies this typing directly. This is shown in (75) below, where $p \bullet i$ abbreviates the type $phys \bullet info$.

(75)



For all of the other cases, (74a), (74a′), and (74b), the NP in direct object position is wrapped with the intended type by the rule of Introduction, as shown below for sentence (74a).

(76)



The consequences of this type shifting, as argued in Pustejovsky (1998), is that this information object (*the rumor*) must have a physical manifestation, in order for it to be read. This follows directly from the mechanism of Introduction in this case.

7 Conclusion

In this paper, I have examined the relationship between decomposition and argument typing in semantics. What emerges from the interplay of these two formal strategies is a clearer understanding of some of the mechanisms of compositionality in language. I outlined a model of argument selection for natural language involving two major components: a three-level type system consisting of natural, artifactual, and complex types; and three compositional mechanisms for mediating the type required by a predicate and the type present in the argument. These are: pure selection (matching), accommodation, and coercion. There are two kinds of coercion, exploitation and introduction, and we illustrated each of these operations at work in the syntax.

8 References

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