The Semantics of Complex Types

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Abstract

In this paper, I examine the behavior of several classes of lexical items exhibiting various degrees of systematic or logical polysemy. These words present an interesting challenge to conventional treatments of polysemy in natural language semantics. Extending the analysis of these classes presented in Pustejovsky (1994,1995), I elaborate the formal mechanisms responisible for capturing the syntactic and semantic behavior of nouns such as *lecture*, *prize*, *book*, and *lunch*, and verbs such as *read*, *rent*, and *break*. I argue that members of these classes must be represented as *complex types*, as they do not allow for simple conjunctive typing; furthermore, these nouns and verbs display a peculiar behavior regarding the quantificational force of the type which is absent from other nominal and verbal classes.

1 Simple and Complex Meanings

Over the past several years, there has been a resurgence of interest in questions relating to the "messiness" of word meaning. Inspired by a few early researchers who admitted of the complexity of sense determination and the fixing of reference (cf. Nunberg, 1979, Fauconnier, 1985, and Kayser, 1988), much of the work in semantics and computational linguistics is now expressly concerned with the representation and processing of polysemous lexical items and phrases.

I believe the reasons for this resurgence are two-fold. First, there is now an appreciation of the fact that systematic or logical polysemy is formally related to the problem of semantic selection and polyvalency, making the treatment of polysemy much more relevant to theoretical work on issues of syntactic form and polymorphic behavior. Second, formal mechanisms are now available for the analysis of these constructions, which allow them to be viewed as an integral component of the lexicon and the semantics, as opposed to off-line, non-compositional processes of sense extension or metaphorical interpretation.

In the discussion below, I will examine the syntactic and semantic behavior of several nominal types which have polysemous behavior. In particular, I will study one class of nominals which has been particularly difficult to model formally, namely, nouns such as *lecture*, *prize*, *book*, and *lunch*. Members of this class, I argue, must be represented as *complex types* rather than simple or *unified types*, as they do not allow for simple conjunctive typing. This class leads us to a consideration of verb classes which are themselves complex in nature. I provide an analysis of these concepts in terms of Cartesian types and explore their semantics in terms of operations within a relational algebra. Finally, I show how these nouns and verbs display some peculiar properties regarding quantification, which are absent from other nominal and verbal classes. I elaborate on the formal properties of these nouns first outlined in Pustejovsky (1994,1995), and explore the consequences of this analysis for discourse anaphora and general issues of reference.

Let us turn now to the behavior of logically polysemous nominals, in order to appreciate why they are intuitively interesting and formally problematic for conventional semantic treatments. The general characterization of some of these nouns has been widely studied (Apresjan, 1973, Atkins and Ostler, 1991, and Pustejovsky, 1991), and I will present only those data relevant to the present discussion. To begin, consider the semantic distinction underlying our conceptions of *food* and *lunch*. How are these nouns distinguished semantically? We obviously understand the concept of food as something paraphrasable by dictionary definitions such as "edible substance or material." What is food for one creature, of course, might be poison for another, giving the concept a slightly relational interpretation, but by no means formally establishing it as a relational noun, such as *brother* or *father*. All that seems to be required to minimally capture the meaning of the noun *food* is some characterization of the relation between the property of "substance" and that of "edible", relative to a class of certain individuals, e.g., humans. Our conception of *lunch*, however, seems more complex, since it makes reference to a specific period or event in the day as well. Unlike with *food*, it may refer to either the substance or event. For *food*, one might simply conjoin or unify these properties to give a specific intersective property of "edible substance." This assumes that modally subordinating properties such as "edible" have no internal structure, a tenable position only if one is willing to make liberal use of meaning postulates as off-line inferences in the compositional process of interpreting sentence meanings.

Unified Types

Contrary to the rather cavalier approach to representation briefly suggested above, I will assume a mechanism employing significantly more machinery for representing the analytic knowledge associated with words. On this view, the modal subordination of the predicate indicating the use of the substance is given an explicit representation, distinct from the material aspect of *food*. This is accomplished in the following manner. Assume that for a concept such as *food*, we can separate the characteristic property from the functional aspect. Let us call these components the FORMAL and TELIC roles, respectively. Minimally, then, the notion *food* is a concept making reference to distinct and orthogonal facets of knowledge, each expressing a different explanation of this concept. These two facets together with two other roles, CONSTITUTIVE and AGENTIVE, make up what I have referred to as the *qualia structure* for a lexical item (cf. Pustejovsky, 1995). A simple schematic description of a lexical item, α, using this representation is shown below:

(1) $$\begin{bmatrix} \alpha \\ \text{ARGSTR} = \begin{bmatrix} \text{ARG1} = x \\ \ldots \end{bmatrix} \\ \text{QUALIA} = \begin{bmatrix} \text{CONST} = \textbf{what } x \textbf{ is made of} \\ \text{FORMAL} = \textbf{what } x \textbf{ is} \\ \text{TELIC} = \textbf{function of } x \\ \text{AGENTIVE} = \textbf{how } x \textbf{ came into being} \end{bmatrix} \end{bmatrix}$$

As discussed in Pustejovsky (1995), the qualia constitute the necessary modes of explanation for understanding a word or phrase.[1] Continuing with the example above, we can imagine that *food* is a concept formed by conjoining or unifying orthogonal values from FORMAL and TELIC qualia roles, as illustrated somewhat schematically in (2) below.

(2) a. $\sigma = [_\sigma \ \ldots \ [Q_F = \mathit{substance}\ ]]$

b. $\tau = [_\tau \ \ldots \ [Q_T = \mathit{eat}\ ]]$

These two forms may unify, $\sigma \sqcap \tau$, to form a *unified type*, σ_τ, with the resulting qualia structure given in (3):

(3) $$\begin{bmatrix} \sigma\_\tau \\ \text{QUALIA} = \begin{bmatrix} \text{FORMAL} = \textbf{substance} \\ \text{TELIC} = \textbf{eat} \end{bmatrix} \end{bmatrix}$$

The TELIC relation, of course, carries its argument structure with it, hence a more proper statement of the semantics for a lexical item such as *food* would be that in (4).

(4) $$\begin{bmatrix} \textbf{food} \\ \text{ARGSTR} = \begin{bmatrix} \text{ARG1} = \texttt{x:physobj} \end{bmatrix} \\ \text{QUALIA} = \begin{bmatrix} \text{FORMAL} = \texttt{x} \\ \text{TELIC} = \texttt{eat(e}^P\texttt{,y,x)} \end{bmatrix} \end{bmatrix}$$

[1] These are grounded in the Aristotelian *aiatiae*, as argued in Moravcsik's study of Aristotle's notion of cause and explanation, cf. Moravcsik (1975).

We discuss the logical interpretation of qualia structures such as that above in Section 3.0 below. For now, let us simply view the orthogonal values of the qualia roles as logical conjunction, as in (5):

(5) a. $$\begin{bmatrix} \sigma\_\tau \\ \text{ARGSTR} = \begin{bmatrix} \text{ARG1} = x \end{bmatrix} \\ \text{QUALIA} = \begin{bmatrix} \text{FORMAL} = P(x) \\ \text{TELIC} = Q(x) \end{bmatrix} \end{bmatrix} \Longrightarrow$$

b. $\lambda x[P_F(x) \wedge Q_T(x)]$

For the interpretation of the noun *food*, this would give the expression in (6), ignoring some issues of quantification for now.

(6) $\lambda x \lambda e \exists y[food : substance_F(x) \wedge eat_T(e, y, x)]$

The qualia can, in fact, be structured by the conjunction of properties for many semantic classes of nominals. For example, we might view an artifact as something having an AGENTIVE quale value; that is, having been made:

(7) a. $$\begin{bmatrix} \textbf{artifact} \\ \text{ARGSTR} = \begin{bmatrix} \text{ARG1} = x \end{bmatrix} \\ \text{QUALIA} = \begin{bmatrix} \text{FORMAL} = \texttt{x} \\ \text{TELIC} = \texttt{make(e,y,x)} \end{bmatrix} \end{bmatrix} \Longrightarrow$$

b. $\lambda x \lambda e \exists y[artifact : F(x) \wedge make_A(e, y, x)]$

Putting the above concept together with a specific FORMAL value, e.g., a physical object, gives rise to the concept of a *physical artifact*, which can also be modeled as the conjunction of predicates (or unification of types):

(8) a. $$\begin{bmatrix} \textbf{artifact} \\ \text{ARGSTR} = \begin{bmatrix} \text{ARG1} = x \end{bmatrix} \\ \text{QUALIA} = \begin{bmatrix} \text{FORMAL} = \texttt{physical(x)} \\ \text{TELIC} = \texttt{make(e,y,x)} \end{bmatrix} \end{bmatrix} \Longrightarrow$$

b. $\lambda x \exists e \exists y[artifact : physical_F(x) \wedge make_A(e, y, x)]$

This method, in fact, permits us a general strategy for creating increasingly specific concepts with conjunctive properties. Such types, what I will call *unified types* (cf. Pustejovsky, 1995), can be seen as structured by orthogonal dimensions or perspectives, rather than as multiply inherited concepts. One would not want to allow the free structuring or combinatorics of conjunctive properties, however, since this would generate more nonsense than well-formed concepts. The question of what constitutes a well-formed concept is at the core of lexical semantic research, and it is necessary for any theory to address this issue directly in how representations are structures and generated.

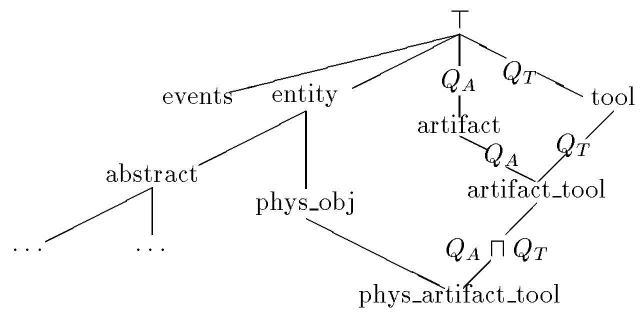
I will assume rather boldly that there is no multiple inheritance per se in natural language semantics. I will argue that what appear to be instances of concepts which inherit from multiple superordinates, are in fact either:

(a) *Typed orthogonal inheritance* structures; or

(b) *Complex types*, to be introduced below.

The qualia provide us with typed orthogonal information of the appropriate sort for the former class above. Let us assume that a concept is well-formed only if it inherits from a single parent within a given quale. Under this assumption, then, the only way to form more complex lexical or phrasal expressions would be by unifying predicates from distinct and orthogonal qualia. This is in fact what we proposed for the noun *food* above. The space of concepts generated by such a constraint is shown below in (9), where type unification generates new concepts. The unlabeled edges denote the FORMAL quale, Q_A denotes the AGENTIVE role, and Q_T denotes the TELIC.

(9)



By positing orthogonal modes of explanation for a concept, functional descriptions, for example, can be expressed without commitment to a specific material form. This view would appear to entail that all complex notions are derived by combining predicates (or types) from orthogonal qualia (or modes of explanation). For example, nothing can be both abstract and physical, or abstract and eventlike. The mode of "coming into being", i.e., AGENTIVE role, however, can annotate the description of a particular physical object to create a more complex concept along orthogonal descriptions.

Complex Types

As useful as this technique is for modeling concepts, it seems woefully inadequate to account for the many apparent counterexamples encountered in natural language. Notice in the sentences below, how the underlined nouns denote what would arguably be contradictory types, according to the concept construction algorithm given above.

(10) a. Mary doesn't believe <u>the book</u>.
Type(*book*) = `info`

b. John sold <u>his books</u> to Mary.
Type(*book*) = `physobj`

(11) a. Eno the cat is sitting on yesterday's <u>newspaper</u>.
Type(*newspaper*) = `physobj`

b. Yesterday's <u>newspaper</u> really got me upset.
Type(*newspaper*) = `info`

(12) a. Mary is in Harvard Square looking for the Bach <u>sonatas</u>.
Type(*sonata*) = `physobj`

b. We won't get to the concert until after the Bach <u>sonata</u>.
Type(*sonata*) = `event`

(13) a. I have my <u>lunch</u> in the backpack.
Type(*lunch*) = `food`

b. Your <u>lunch</u> was longer today than it was yesterday.
Type(*lunch*) = `event`

(14) a. The phone rang during my <u>appointment</u>.
Type(*appointment*) = `event`

b. My next <u>appointment</u> is John.
Type(*appointment*) = `human`

What is interesting about the above pairs is that the two senses are related to one another in a specific and non-arbitrary way. The apparently contradictory nature of the two senses for each pair actually reveals a deeper structure relating these senses, what I will call a *dot object*. For each sense pair, there is a relation which "connects" the senses in a well-defined way. I will characterize this structure as a Cartesian type product of n types, with a particularly retricted interpretation. The product $\tau_1 \times \tau_2$, of types τ_1 and τ_2, each denoting sets, is the ordered pair $<t_1, t_2>$, where $t_1 \in \tau_1$, $t_2 \in \tau_2$. Obvioiusly, the pairing alone does not adequately determine the semantics of the dot object; rather, there must exist a relation R which relates the elements of τ_1 and τ_2; i.e., $R(t_1, t_2)$. This relation must be seen as part of the definition of the semantics for the dot object $\tau_1 \cdot \tau_2$ to be well-formed.

The set of relations, $\{R_i\}$, can be seen as specialized type product operators, where the specific relation is built into the constructor itself:

(15) $\{R_i\} = \cdot_{R_1}, \cdot_{R_2}, \ldots, \cdot_{R_n}$

For nouns such as *book*, *disc*, and *record*, the relation R is a species of "containment," and shares grammatical behavior with other container-like concepts. For example, we speak of information *in* a book, articles *in* the newspaper, as well as songs *on* a disc. This containment relation is encoded directly into the semantics of a concept such as *book* —i.e., $hold(x, y)$— as the FORMAL quale value. For other dot object nominals such as *prize*, *sonata*, and *lunch*, different relations will structure the types in the Cartesian product, as we see below. Let us say that, for any dot object, α, defined as a Cartesian product, $\tau_1 \cdot \tau_2$, the following must hold:

(16) $\lambda x.y \exists R[\alpha(x : \tau_1.y : \tau_2) : R(x, y) \ldots]$

The lexical structure for *book* as a dot object can then be represented as in (17).

(17)
$$\begin{bmatrix} \textbf{book} & \\ \text{ARGSTR} = & \begin{bmatrix} \text{ARG1} = \texttt{y:information} \\ \text{ARG2} = \texttt{x:phys\_obj} \end{bmatrix} \\ \text{QUALIA} = & \begin{bmatrix} \texttt{information}\cdot\texttt{phys\_obj\_lcp} \\ \text{FORM} = \texttt{hold(x,y)} \\ \text{TELIC} = \texttt{read(e,w,x.y)} \\ \text{AGENT} = \texttt{write(e,v,x.y)} \end{bmatrix} \end{bmatrix}$$

This translates roughly to the following logical form:

(18) $\lambda x.y[book(x\text{: }\texttt{physobj}.y\text{: }\texttt{info}) : hold(x, y) \wedge \lambda w \lambda e[read(e, w, x.y)]$
$\wedge \exists e' \exists v[write(e', v, x.y)]]$

Nouns such as *sonata*, *lunch*, and *appointment*, on the other hand, are structured by entirely different relations, as explored below. What is important to note, however, is that the dot object construction (i.e., the type product) allows otherwise contradictory types to be combined into a single type. From a conceptual development point of view, this suggests that complex types are in fact learned later than simple or unified types (cf. Pustejovsky, 1995, for some discussion).

In order to make this clearer, I will distinguish two classes of complex type nominals, *endocentric* and *exocentric* dot objects. This distinction will reflect the manner in which the elements of the product are structured in the qualia, as defined below:

(19) **Dot Object Nominal Types:**

a. *Endocentric*: the entire dot object is made reference to in the qualia of the lexical structure;

$$\begin{bmatrix} \text{QUALIA} = \begin{bmatrix} Q_i = R(\ldots, x.y, \ldots) \end{bmatrix} \end{bmatrix}$$

b. *Exocentric*: the dot elements are split either within a single quale or between two qualia;

$$\left[\text{QUALIA} = \begin{bmatrix} Q_i = R(..., x, ...) \\ Q_j = R(..., y, ...) \end{bmatrix}\right] \text{ or}$$

$$\left[\text{QUALIA} = \left[\, Q_i = R(x, ..., y, ...) \,\right]\right]$$

This distinction has important consequences for quantification and reference. As we will see in the next section, endocentric dot objects such as *book* and *record* refer to both elements in the type product, whereas an exocentric dot object may refer to only one or both.

The notion of a complex type proves useful for explaining the polysemy associated with process-result nominalizations, such as *construction* and *examination* (cf. Grimshaw, 1990). Consider the senses of the noun *construction* in the three sentences below.

(20) a. The house's <u>construction</u> was finished in two months.
b. The <u>construction</u> was arduous and tedious.
c. The <u>construction</u> is standing on the next street.

In Pustejovsky (1995), it is suggested that a dot object actually allows us to capture all three senses of *construction* illustrated in (20) above. Informally, we can imagine this class of nominalizations as the type product of the two subevents constituting the transition event denoted by the verb.

(21) $\lambda e.e' \exists x \exists y[construction(e\colon \texttt{process}.e'\colon \texttt{state}) :<_{\propto} (e, e') \wedge Agentive(e, x, y)] \wedge Formal(e', y)]]$

In some sense, the only thing different about this dot object is the typing on the dot elements and the specific relation which structures them. Thus, whereas a book is a dot object composed of `information` and `physobj` and is structured by the relation of containment, *construction* is a dot object composed of `process` and `state`, related by the temporal relation in the event structure of precedence, namely, $<_{\propto}$. It should be pointed out that process-result nominals are exocentric in behavior.

Another example of an exocentric dot object is seen in the semantics of the noun *exam*. What is interesting about *exam* is that it can refer to the questions which compose the event of the examination, or the event of the examining itself. Questions, like any information objects, may also have physical manifestation, but need not (e.g., an oral exam). The ambiguity arises from the combination of the inherent polysemy possible in the type of information object of `question`, and the `event` of the examination. In this case, the relation which structures the two dot elements in the type product refers directly to the "asking" event, as illustrated below.

(22)
$$\begin{bmatrix} \textbf{exam} & \\ \text{ARGSTR} = & \begin{bmatrix} \text{ARG1} = \textbf{x:question} \end{bmatrix} \\ \text{EVENTSTR} = & \begin{bmatrix} \text{E}_1 = \textbf{e}_1\textbf{:process} \end{bmatrix} \\ \text{QUALIA} = & \begin{bmatrix} \textbf{question}\cdot\textbf{process\_lcp} \\ \text{FORMAL} = \textbf{ask(e}_1\textbf{,z,x)} \\ \text{AGENT} = \textbf{make(e}_2\textbf{,y,x)} \end{bmatrix} \end{bmatrix}$$

Thus far, we have encountered dot objects comprised of the following pairs of types:

(23) a. `physobj·info`: e.g., *book*, *record*;

b. `event·event`: e.g., *construction*, *examination*;

c. `event·question`: e.g., *exam*;

d. `event·food`: e.g., *lunch*, *dinner*;

e. `event·human`: e.g., *appointment*.

For each of the above type products, there is a unique relation, R_i, which structures the types. Cases that we have not examined here include nouns such as *prize*, *sonata*, and the more complicated concepts of *city* and *organization*. From our initial study, however, it appears that the theory of dot objects simplifies the model of complex meanings and the behavior of polysemous nominals. In this section, I have of course only scratched the surface of what the formal properties of these logical constructions are. Further considerations of the nature of dot objects are explored in Pustejovsky and Asher (forthcoming).

2 Complex Relations

In the previous section, we saw that certain classes of nominals, i.e., endocentric dot objects, have qualia values which are relations selecting for the dot objects directly. The examples we encountered above were the *read* and *write* relations as selected by the TELIC and AGENTIVE qualia, respectively, for a concept such as *book*. This is illustrated schematically below:

(24) a. $\lambda y.z\lambda x\lambda e[read(e,x,y.z)]$

b. $\lambda y.z\lambda x\lambda e[write(e,x,y.z)]$

What does it mean, however, for a verb to select a dot object as an argument and is there any way to distinguish such a relation from those that do not or cannot select a dot object? To answer this question, let us compare the selectional distribution of a lexical item typed as a dot object, with a word carrying the type of one of the dot elements; namely, *book* versus *story*.

(25) a. **Type**(*book*) = `physobj.info`

b. **Type**(*story*) = `info`

Given this distinction, there should be contexts in which one type is selected for and the other is prohibited. This is, in fact, what we observe. Notice that while the verb *read* permits direct selection of both types, the verb *tell* does not allow *book* as the head of its complement.

(26) a. Mary <u>read</u> a book.

b. Mary <u>read</u> a story.

(27) a. Mary <u>told</u> a story.

b. *Mary <u>told</u> a book.

While both books and stories are informational in nature, a story, unlike a book, need not be realized as a physical object. To illustrate this distinction, consider what the logical interpretations for the sentences in (26a) and (27a) are. For a type such as *book*, we will say that the dot elements of the type product are both extensional. Hence, for a dot object α, the following holds:

(28) EXISTENTIAL DISTRIBUTION:

$$\Box\forall\alpha\forall x.y[\alpha(x.y) \rightarrow \exists\alpha_1\exists\alpha_2[\alpha_1(x) \wedge \alpha_2(y)]]$$

This property holds for a complex type such as *book* because the FORMAL quale is an *extensional relation* between two individuals, viz. *hold*. The consequences of this are that both dot elements are existentially closed when existential force is given to the dot object. Hence (29c) follows as the interpretation of (29a).

(29) a. Mary <u>read</u> a book. $\Longrightarrow$

b. $\exists y.z\exists e[read(e,m,y.z) \wedge book(y.z)] \Longrightarrow$

c. $\exists y.z\exists e[read(e,m,y.z) \wedge book(y.z) \wedge physobj(y) \wedge info(z)]$

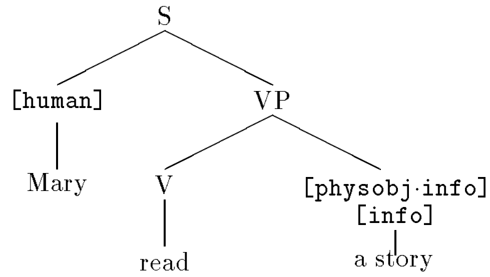
Because the noun *story* is a simple type, however, no such interpretation is possible, and all that is existentially asserted of (30a) is the story itself.

(30) a. Mary <u>told</u> a story. $\Longrightarrow$

b. $\exists x\exists e[tell(e,m,x) \wedge story(x)]$

Nevertheless, the verb *read* is able to coerce its complement in (26b) into both components of the complex type, `physobj.info`. The behavior of the verb *read* relative to the selection of a non-dot object complement illustrates the coercive nature of the predicate, as shown below (cf. Pustejovsky, 1995).

(31)



What is interesting about this example is that the type of the noun *story*, by virtue of the coercion, has been embedded within a complex type, which brings with it, a very different quantificational force than that seen when selected by the verb *tell* in (27a).

(32) a. Mary <u>read</u> a story. $\Longrightarrow$

b. $\exists y.z \exists w \exists e \exists P[read(e, m, y.z) \wedge P(y.z) \wedge story(w) \wedge w = z] \Longrightarrow$

c. $\exists y.z \exists w \exists y \exists e \exists P[read(e, m, y.z) \wedge P(y.z) \wedge physobj(y)$
$\wedge\, story(w) \wedge w = z]$

Thus, the NP *a story* appears to inherit additional existentially quantified properties by virtue of the semantic context within which it appears. Notice that the interpretation of the NP has not been type shifted in the sense of Partee and Rooth (1993), but rather embedded in a metonymic reconstruction, while preserving the underlying semantics of the NP, i.e., it is coerced.

It should be pointed out that verbs like *tell* do not appear to be able to coerce their complements in the same way that *believe* and *enjoy* are able to. Such considerations and other grammatical distinctions between coercing and non-coercing predicates lead us to distinguish between two types of selection, *active* and *passive*.

(33) a. *Active Selection*: Enables coercion, and allows accommodation to the required type.

b. *Passive Selection*: No coercion possibilities; requires direct selection of type by the complement.

I will have little more to say about this distinction here; this topic is taken up in the context of the theory of selection in Pustejovsky (1996).

Thus far we have explored the selectional distinctions between *read* and *tell*, and this has brought us a bit closer to understanding what it means for a predicate to select a dot object complement. It was observed that endocentric dot objects have the property of existential distribution, repeated below:

(34) Existential Distribution:

$$\Box\forall\alpha\forall x.y[\alpha(x.y) \rightarrow \exists\alpha_1\exists\alpha_2[\alpha_1(x) \wedge \alpha_2(y)]]$$

Now recall from our previous discussion how the verb *read* is able to impose an interpretation on a complement that it would otherwise not carry, as in (27), where **physobj** was imposed on an informational concept. Notice that a similar phenomenon occurs when the complement carries no intrinsic interpretation as an informational concept, as in (35).

(35) Mary read the subway wall.

Furthermore, observe that the subcategorization behavior for *read* permits the following structures.

(36) a. Mary read the book.

b. Mary read the book of articles.

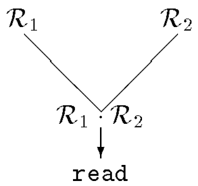
c. Mary read the articles in the book.

d. Mary read the articles.

The form in (36b) is, of course, not entirely due to the verb but also to the semantics of the head noun. Nevertheless, these considerations together with the coercive behavior of *read* strongly suggest that it is a complex relation, formed from relations which each take an element of the dot object as an argument.

A complex relation is one which decomposes into simpler component parts, each of which is itself a relation. For a relation such as *read*, which we modeled as selecting for a dot object in complement position, let us say that there are as many component relations as there are elements in the dot object selected for, in this case, two. This is illustrated schematically in (37) below.

(37)



If a *book* is a complex type, then the characteristic functions over this type must be decomposable and identifiable. Intuitively, we can separate the visual perception of the physical aspect of the dot object **physobj·info** from the understanding or comprehending of its informational aspect. Let us call these two relations $\mathcal{R}_1$ and $\mathcal{R}_2$, respectively. They are furthermore structured by a temporal precedence relation, $<_\propto$, since I must first see in order to comprehend the text. On this view, the verb *read* denotes a Cartesian type over relations, $\mathcal{R}_1.\mathcal{R}_2$, with a similar restriction to that mentioned in the previous section, that there must exist a relation structuring these relational elements. Hence, something like the following must hold for a complex relation which selects for a dot object:

(38) RELATION DECOMPOSITION:

a. $\lambda x.y\lambda z\lambda e[\mathcal{R}_1.\mathcal{R}_2(e,z,x.y)] \Longrightarrow$

b. $\lambda x\lambda y\lambda z\lambda e_1\lambda e_2[\mathcal{R}_1(e_1,z,x) \wedge \mathcal{R}_2(e_2,z,y) \wedge <_\propto (e_1,e_2)]$

In order to model the semantics of this complex relation more precisely, one might view such structures in terms of relational algebraic operations. Let us begin with our observation above that *read* might be viewed as a Cartesian product (where $\dot\cup$ denotes disjoint union):

(39) $\times : \mathcal{R}(\tau_1) \times \mathcal{R}(\tau_2) \rightarrow \mathcal{R}(\tau_1 \dot\cup \tau_2)$

But this is not quite right, for what is unique about a predicate such as *read* is that each relation in the product shares an *attribute* value. That is, the subject of R is the same as the subject of S. Therefore, let us call *read* the *join* of the two relations, R and S; more specifically, let us refer to it as a Θ-join operation over these relations (cf. Maier, 1983).

(40) $[X\Theta Y] : \mathcal{R}(\tau_1) \times \mathcal{R}(\tau_2) \rightarrow \mathcal{R}(\tau_1 \dot\cup \tau_2)$

Let Θ be a comparison operator on the common domain of X and Y, $W(X) = W(Y)$. We will say that a tuple from $R \times S$ satisfies the conditions defined by the filter $X\Theta Y$, if components with respect to the parameters X and Y stand in relation Θ. Hence, the Θ-join is defined according to this condition, for two relations R and S:

(41) $R[X\Theta Y]S \ := \ s_{X\Theta Y}(R \times S)$

A specific example of this that will be relevant to our discussion is a particular constraint on the relational product called an *equijoin*.

(42) $R[X = Y]S \ := \ s_{X=Y}(R \times S)$

Now, we can return to the sentence in (26a), and provide for the complete interpretation. Making use of both Existential Distribution and Relation Decomposition, we arrive at the following derivation:

(43) a. Mary <u>read</u> a book. $\Longrightarrow$

b. $\exists y.z \exists e[read(e,m,y.z) \wedge book(y.z)] \Longrightarrow$

c. $\exists y.z \exists e[read(e,m,y.z) \wedge book(y.z) \wedge physobj(y) \wedge info(z)] \Longrightarrow$

d. $\exists y \exists z \exists e_1 \exists e_2[read_1(e_1,m,y) \wedge physobj(y) \wedge read_2(e_2,m,z)$
$\wedge\, info(z) \wedge <_{\propto} (e_1,e_2)]$

The machinery creating complex relational types can also be used to explain some peculiar properties of certain "cooperative activity" predicates such as *rent* and *lease*, as well as "weakly symmetric" predicates, such as *meet*, *touch*, and *debate*. Consider briefly the behavior of *rent*. This verb is interesting because it allows for two subcategorizations, each corresponding to a distinct interpretation of the verb. Observe in (44) how the directionality of the relation is affected or dictated by the prepositional phrase selected for (cf. Bierwisch, 1983, Jackendoff, 1983).

(44) a. Mary <u>rented</u> the room from John.

b. Mary <u>rented</u> the room to John.

The interpretation given in one sentence entails the interpretation provided for in the other. The fact that the "renting event" entails two subparts or subevents suggests that the relation is itself complex in nature, where the relation actually refers to both perspectives on the transaction, i.e., the "giving" and the "taking" events.

This predicate can be modeled as a Θ-join complex relation, $R[X\Theta Y]S$, with the comparison operator constraining Y_R, the second parameter of R, to be identical to Y_S, the second parameter of S.

(45) $R[Y_R = Y_S]S \;:=\; s_{Y_R=Y_S}(R \times S)$

It is interesting to note that, in (46), the VP is semantically underspecified with respect to which subevent is being referred to. The semantics of the subject in each case acts to strongly bias the interpretation to one perspective or the other.

(46) a. The landlord <u>rented</u> the apartment.

b. The tenant <u>rented</u> the apartment.

If the verb with its complement are, in fact, underspecified, then the prepositional phrases in (44a) and (44b) are acting as filters on the interpretation of the complex relation. For example, in sentence (44a), the `to NP` phrase acts as a selector function over the relation, returning that relational element from the complex which satisfies its type (cf. Pustejovsky, 1996 for more details).

To conclude this section, let us briefly discuss why exocentric dot object nominals such as *meal* behave differently, with respect to quantification, from endocentric nouns such as *book*. Notice that the mention of *my meal* in (47a), while asserting the existence of the food, does not guarantee the existential closure of the event of eating the food. This remains intensional or irrealis in nature.

(47) a. I have my <u>meal</u> in the backpack.

b. Your <u>meal</u> was longer today than it was yesterday.

When asserting the occurrence of the event of eating in (47b), however, there is also existential closure of the food. What formal properties of the semantics of *meal* might account for this distinction?

In Section 1.0, I demonstrated how a concept such as *meal* could not be viewed as a conjunctive (or unified) type, and must be analyzed as a dot object, i.e., **event·food**. Looking more carefully at the semantics of this concept, we discover that the event is positioned within the TELIC role, which forces a modal subordination on the relation of eating.

$$(48)\quad \begin{bmatrix} \textbf{meal} & \\ \text{ARGSTR} = & \begin{bmatrix} \text{ARG1} = \texttt{x:food} \end{bmatrix} \\ \text{EVENSTR} = & \begin{bmatrix} \text{E1} = \texttt{e:process} \end{bmatrix} \\ \text{QUALIA} = & \begin{bmatrix} \texttt{event}\cdot\texttt{food} \\ \text{FORMAL} = \texttt{x} \\ \text{TELIC} = \texttt{eat(e,x,y)} \end{bmatrix} \end{bmatrix}$$

For our present purposes, this translates to the following logical interpretation:

(49) $\lambda x.e[meal : food(x) \wedge \Diamond\lambda y[eat(e, y, x)] \ldots]$

Closure on an exocentric dot object does not distribute to all dot elements, however, as illustrated in (50) with *Existential Blocking.*

(50) EXISTENTIAL BLOCKING:

$$\Box\forall\alpha\forall x.y[\alpha(x.y) \wedge Telic(..., y, ...) \rightarrow \exists\alpha_1[\alpha_1(x)]]$$

Rather, only when the intensional element in the dot object, i.e., the event, is asserted as in (47b), will both elements be existentially closed. The sentence in (47a) does not entail closure on the event in the dot object, while that in (47b) entails both closure on the food and on the event.

3 Conclusion

In this paper, I have attempted to clarify what the general properties of complex types in natural language are, and to characterize some of the formal aspects of these structures. I hope to have demonstrated that conventional typing models for lexical description are inadequate for explaining the logical and syntactic behavior of these objects. The machinery introduced to account for cases of nominal polysemy was extended to handle some cases of verbal semantics, and specifically for those verbs themselves selecting for dot objects.

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