Logical Form *vs.* Logical Form: How does the Difference Matter for Semantic Computationality?

Abstract. Logical form in logic and logical form (LF) in the *Minimalist* architecture of language are two different forms of representational models of semantic facts. They are distinct in their form and in how they represent some natural language phenomena. This paper aims to argue that the differences between logical form and LF have profound implications for the question about the nature of semantic interpretation. First, this can tell us whether semantic interpretation is computational and if so, in what sense. Second, this can also shed light on the ontology of semantic interpretation in the sense that the forms (that is, logical form and LF) in which semantic facts are expressed may also uncover where in the world semantic interpretation as such can be located. This can have surprising repercussions for reasoning in natural language as well.

Keywords: Logical form; Minimalist architecture; LF; semantic interpretation; semantic facts; reasoning.

Introduction

The exact nature of semantic interpretation is still faintly understood or grasped despite the fact that we use language everyday and understand an enormous number of linguistic expressions with no *a priori* bound. This paper aims to make sense of the nature and form of semantic interpretation by tracking the differences between logical form, which is used in logic and Logical Form (LF), which is a part of the *Minimalist* architecture of language within Generative Grammar. Throughout the entire paper, the phrase ‘logical form’ will be used to signify the logical representation and LF will denote the syntactic component in Generative Grammar. Both logical form and LF *represent* aspects of semantic structures of natural language. But what is it about semantic structures that they can be represented as such by logical form or LF? Note that logical form is a metalanguage that can be employed to express properties of semantic interpretation, while LF is a syntactic component within the architecture of the language faculty. When we say that LF represents aspects of meaning, we mean that LF is a syntactic system which is interpreted semantically. Within Generative Grammar, the model that interprets LF objects is a mental organization called ‘Conceptual-Intentional (C-I) system’, which interfaces with LF, while the model for logic is an abstract model in which interpretations of logical forms are couched. On another view, LF represents what may be called structured meanings in the sense of Cresswell (1985). Structured meanings derive from the meanings of the component expressions *and* from the meaning of the whole structure the component expressions are components of. Suffice it to say, these formal representations express properties of natural language meaning, and so they can uncover, one many believe, much about the form of semantic representation. There are well-known differences between logical form and LF many of which have already been noted (Bach, 1989; Heim & Kratzer, 2002).The significant question for us is whether semantics or meaning in language can be computational in its character, given that syntax is generally believed to be computational in Generative Grammar, and that descriptive generalizations about semantic facts can be made with reference to both logical form and LF. The important proviso to be made is that the aim is certainly not to merely zoom in on differences between logical and LF. Rather, the aim is to understand how and in what ways logical and LF can tell us something about the ontological status of semantic interpretation. Given this goal, much of what will follow derives from Mondal (2013).

While exploring the ontology of semantic interretation, Steedman & Stone (2006) have defended a realist interpretation of semantics within which semantics can be conceived of in computational terms, though they think it is better to keep semantics from aspects of processing. Such concerns raise deeper issues regarding the terms in which semantics can be computationally realized in the mind/brain because semantics can be represented in realist terms without any computational baggage, but at the same time, semantics can also be instantiated in human brains in being amenable to operations in cognitive computations. The quandaries this gives rise to are much deeper than is generally appreciated. And this is what the present paper will delve into.

Against this backdrop, first an introductory sketch of what logical form and LF are will be drawn up. Then some parallels between them will be pointed out. The differences laid out against a stratified pattern of linguistic phenomena can have significant implications and ramifications for the nature of semantic interpretation as well as for the issue on semantic realization in the mind/brain and reasoning in natural language. But before we proceed, we may first get an idea of the sense in which the notion of computationality will be cashed out since much of the discussion will hinge on the notion of how semantics is or can be computational.

Semantics and Computation

In the absence of a better understanding and grasp of what meaning is, it is certainly difficult, if not outright impossible, to understand the notion of semantic computationality. This is more so because computation per se is also one of the most confounded and unclear notions used in cognitive science (Piccinini & Scarantino, 2011; Fresco, 2011). Questions on whether semantics is or can be computational rests on whether or not the right concept of computation is employed in order to have it applied to the phenomenon which we are concerned about. There are reasons to believe that the notion of semantic computationality may be used in the classical sense of computation within which inputs are mapped to outputs according to some well-defined rules by means of symbolic manipulation of digital vehicles in the form of linguistic strings. This notion of computation is the narrowest in the hierarchy of notions of digital computation (Piccinini & Scarantino, 2011). One of these reasons has to do with the fact that it is this notion of computation that has been appealed to in much of Generative Linguistics, where syntax is thought to be computational. But whether semantics is computational in the analog sense of computation, or in the *generic sense*, in Piccinini & Scarantino's words, which covers both digital and analog computation is something which is beyond the scope of the current paper. We may, however, note that this question can be best understood if and only if the minimal sense of semantic computationality in terms of the specification of computable functions on semantic structures is figured out. The notion of computable functions can be approached in the following sense. When we talk about computation, we require (i) a function that is computed, (ii) a system which computes the function, and also (iii) an effective procedure (also called an *algorithm*). This comes out clearly from the *Church-Turing Thesis*, which states that anything that can be computed with an effective procedure in the physical world can be computed in Turing machines. So let's now have an overview of logical form in logic and LF.

On Logical Form

Logical form of natural language sentences determines their logical properties and logical relations. Logical form of natural language sentences is constructed relative to a theory of logical form in the language of a theory of logic (say, first order logic) (Menzel, 1998). In fact, this idea can be traced to the Davidsonain system of logical forms. Plus Quine (1970) has always insisted on a pluralism of different logical forms. Logical form in logic can be schematized in the following way:

$$\begin{gathered} T = \{\mathrm{T}_1 \ldots \mathrm{T}_n\} \\ L = \{\mathrm{L}_1 \ldots \mathrm{L}_m\} \\ \mathcal{L} = \{\mathcal{L}_1 \ldots \mathcal{L}_k\} \\ \mathrm{A} = \{\mathrm{A}_1 \ldots \mathrm{A}_j\},\ \mathrm{B} = \{\mathrm{B}_1 \ldots \mathrm{B}_i\} \end{gathered} \qquad \textbf{(1)}$$

The formulation in (1) specifies a few things: T is the set of theories of logical form; L is the set of all possible logical forms; $\mathcal{L}$ is the set of theories of logic. $L\mathcal{L}_k{}^{Tm}$ in (2) below is the set of logical forms relative to a theory of logical form Tm, which is a member of T, and in the formulas of a theory of logic $\mathcal{L}_k$. A theory of logic may be, for example, first-order logic or higher-order logic.

$$L\mathcal{L}_k{}^{Tm} \subseteq L \quad \& \quad \Psi : L\mathcal{L}_k{}^{Tm} \rightarrow \mathrm{A} \times \mathrm{B} \qquad \textbf{(2)}$$

Here, A is the set of logical properties, and B is the set of logical relations. The formulation in (2) simply says that the set of all logical forms relativized to a theory of logical form rendered in the formulas of a logic is a subset of the set of all possible logical forms, and that the set of logical forms so construed is mapped onto a Cartesian product of the set of logical properties and the set of logical relations. Logical properties designate truth values, whereas logical relations are relations between sentences, or rather propositions which are linked by chains of inferences. For instance, entailment, implication, equivalence etc. are different types of logical relations which are determined with respect to a set of sentences. The mapping Ψ may be a little idealized in view of the possibility of certain approximations that might exist at the interface between logical properties and logical relations. Be that as it may, logical forms constitute a means of making sense of what logical properties and logical relations are. The following examples illustrate this well.

(1) John jumped and Mary ran. [$J(j) \wedge R(m)$]
(2) John jumped. [$J(j)$]

(J=jumped; R=ran; j=John; m=Mary)

Two sentences from English are given above with their logical forms alongside. The logical form of each sentence determines whether it is true. This is the core of what logical property is. Plus the sentence in (1) entails the sentence (2) in that if John jumped and Mary ran, it must be the case that John jumped. This is a case of logical relation. This can be simply checked by just looking at the logical forms. We may now see how logical forms help arrive at the logical properties and logical relations. Similar results can also be found in the Davidsonian account of logical form the problems of which (involving the validity of structural entailments like the ones in (1-2) in terms of the logical forms of sentences) have been pointed out by Jackson (2007). We shall have more to say on this as we proceed.

On the Notion of Logical Form (LF)

Logical Form (LF) within Generative Grammar is a level of syntactic representation which is interpreted by a semantic system (that is, the C-I system). LF represents properties of syntactic form relevant to semantic interpretations or aspects of semantic structures that are expressed syntactically (May, 1985). The rationale for devising LF bears upon Russell's and Frege's concerns about the relation of logical form to the syntax of natural language. The assumption is simply that the logical form corresponding to the semantic structure does not necessarily correspond to the syntactic form of natural language. In fact, it dates back to the Greek thinkers including Aristotle who bothered about this mismatch, and then it became a topic of enormous interest in the twentieth century thinking on language and logic. That logical form is masked by the syntactic structure of natural language can be illustrated with an appropriate example from Seuren (2009).

(3) Coffee grows in Africa.

Even if one may be inclined to say that the grammatical subject in (3) is 'coffee', and the rest constitutes the predicate, 'be in Africa' characterizes the property, insofar as the logical property of the sentence is concerned. Hence 'be in Africa' is the logical predicate, and 'the growth of coffee' is the logical subject. This is shown in (4) below.

(4) + **P** (Be in Africa) ([growth of coffee])

The symbol 'P' in (4) stands for the predicate/property. This underlines the similarity of LF with logical form in terms of the purpose these formal notations are devised for. We will say more on this. The nature of representation of meanings assigned to structures at the level of LF is important, inasmuch as LF is a syntactic level of representation. As a matter of fact, the representation of structures at LF is derived from representations at other independent descriptive levels each of which has its own well-formedness conditions and formal representations. However, the recent version of the *Minimalist* model of grammar has done away with such levels in order that syntactic structures are directly mapped onto LF representations (see for details, Chomsky 2001). In all, LF attempts to characterize the extent to which a class of semantic interpretations that can be assigned to syntactic structures as a function of their grammatical properties. However, this should not be taken to mean that LF represents all possible aspects of semantic interpretations that can be assigned to syntactic structures. For important parallels, one may also make reference to unification-based accounts (Shieber, 1986; Pollard & Sag, 1987), which align syntactic and semantic structures in terms of a *unification* of feature matrixes. The formal description of such alignments constitutes the interface between syntax and semantics.

Under such an approach, there is a separate level, somewhat akin to LF, called *Quasi-Logical Form* (QLF), which represents quantificational scope patterns, but not relative scope. Relative scope disambiguation stands in some algorithmic relationship with QLF. In Montague Grammar, for example, the notion of semantic interpretation is subtly different. Even if within Montague Grammar English expressions—or any natural language expressions—are translated into expressions of Intensional Logic (IL) which are given model-theoretic interpretations, this translation into IL does not quite parallel what LF does in Generative Grammar. The translation into IL expressions is thought to be immaterial, because model-theoretic interpretations are *real* semantic interpretations (Dowty, Wall & Peters, 1981). Categorial grammars too have carried such insights forward. However, what motivated the development of LF as a separate syntactic component was the apparently bizarre behavior of quantificational noun phrases (QNPs) which lead to differences between surface structures and covert structures in natural languages. A suitable example of this kind is the following.

(5) Every linguist likes a language.

This can have two different LF representations based on the two different interpretations—which is a matter of relative scope.

(6) i. $[_S$ a language$_2$ $[_S$ every linguist$_1$ $[_S$ e_1 likes e_2 $]]]$

ii. $[_S$ every linguist$_1$ $[_S$ a language$_2$ $[_S$ e_1 likes e_2 $]]]$

On the reading represented in (6ii), every linguist likes some language or the other, whereas on the other reading given in (6i), there is a single language which is liked by all linguists. This gives us a characterization of LF in linguistic terms. This will turn out to be helpful while we inspect the ways in which they share certain formal correspondences or differ from each other.

Logical Form and LF: Formal Similarities

Before we embark upon a description of the differences, some parallels between logical form and LF can be highlighted. A caveat is in order here. For any discussion on logical form formulas in first-order logic will be employed throughout the paper, although types of higher order logics, for instance, Montague semantics, are important on independent grounds (Corcoran, 2001). Besides, the familiarity and the level of appropriateness of first-order logic for natural language will be an added advantage. Logical form presents a useful point of comparison with LF, although the exact choice of representation of logical form, of course, differs from theory to theory and a specific notation needs to be chosen for uniformity and consistency. Note that both logical form and LF have been designed in order to uncover the semantic/logical properties hidden by grammatical forms, and hence are both translations of natural language sentences in a kind of meta-form. In Quine's (1970) words, they can both be 'paraphrases of natural language sentences'. The LF representations of the example in (5) aligned with their counterparts rendered in logical form show the parallels. The sentence (5) is thus repeated below as (7).

(7) Every linguist likes a language.

Logical Form (Logic):

i. $\exists y\ [\text{Language}(y) \wedge \forall x\ [\text{Linguist}(x) \rightarrow \text{Likes}(x, y)]\ ]$
ii. $\forall x\ [\text{Linguist}(x) \rightarrow \exists y\ [\text{Language}(y) \wedge \text{Likes}(x, y)]\ ]$

Logical Form (LF):

i. $[_S$ a language$_2$ $[_S$ every linguist$_1$ $[_S$ e_1 likes e_2]]]

ii. $[_S$ every linguist$_1$ $[_S$ a language$_2$ $[_S$ e_1 likes e_2]]]

Logical form and LF are fundamentally distinct too. This is what we turn to now.

How Distinct are Logical Form and LF?

The differences between logical form and LF will now be unpacked. A caution needs to be exercised at this juncture. The task of pointing out the differences between logical form and LF does *not* in itself carry any presupposition that we have taken for granted the validity of LF or of logical form. Rather, it should be borne in mind that the goal of understanding the form of semantic interpretation requires unpacking the set of background assumptions that support the construction of logical form or LF. This is what we aim at while, of course, cleaving to the main goal of the paper.

Quine's postulated difference between logical form and deep structure can be in essence applied to that between logical form and LF which are used for quite different purposes. While logical form of natural language sentences is used in logic for logical calculations and inferential implications, LF as a level of syntactic representation yields semantic interpretations. Furthermore, logical form is *externally* motivated, and on the other hand, LF is *internally* motivated, insofar as it is a part of the internalized architecture of grammar reckoned to be the faculty of language, which is in turn a part or component of the mind/brain. Syntactic representations at LF can be fed into the Conceptual-Intentional (C-I) system which deals with matters of concepts, discourse properties of grammar and also intentionality (Chomsky, 1995). But it is *not necessary* that logical form has to be anchored to a mental system, although one may attempt to characterize it in a way amenable to its mental grounding. This possibility will be explored later on.

A. Differences in Ontology and Formal Representations

Logical form and LF have ontological differences. Logical forms are constructed in the language of a theory of logic that contains two quantifiers: the existential quantifier ($\exists$) and the universal quantifier ($\forall$), while LFs, in virtue of being expressed in natural language, contains a whole range of quantifiers, aside from $\exists$ and $\forall$, like 'most', 'many', 'two', 'few', 'likely', 'seem' etc. (Harman, 1970). Even if it is quite true that many other quantifiers such as 'most', 'many', 'two', 'few' etc. can be defined within logical form in terms of the generalized quantifier theory'

(Keenan & Westerstahl, 2011), the question as to how these quantifiers can be made a part of first-order logic—or of any other logic, for that matter—still remains. Such differences in ontology give rise to fundamental differences between logical form and LF.

From another perspective, differences in formal representations make logical forms distinct from LF. The examples in (8-10) exhibit this difference.

(8) Sam killed every tiger.
LF: $[_S$ every tiger$_1$ $[_S$ Sam killed e_1]]
Logical Form: $\forall x\, [Tiger(x) \rightarrow Killed\ (s, x)]$

(9) Most linguists sleep.
LF: $[_S$ most linguists$_1$ $[_S$ e_1 sleep]]
Logical Form: (most x: x is a linguist) [Sleep(x)]

(10) Few philosophers like metaphysics.
LF: $[_S$ few philosophers$_1$ $[_S$ e_1 like metaphysics]]
Logical Form: (few x: x is a philosopher) $\exists y\, [Metaphysics(y) \wedge Like(x, y)]$

Note that even if restricted quantification has been used in (8-10), the introduction of natural language quantifiers such as 'few', 'most' into logic has made this possible.

B. Differences in the Representation of Crossed Binding

Crossed binding is one of the interesting phenomena that can reveal crucial differences between logical form and LF. Crossed binding, as has been observed in the Bach-Peters sentence, is a problem for LF. The example (11) taken from May (1985) shows this clearly.

(11) Every pilot who shot at it hit some MIG that chased him.

This sentence can have two LF representations in (12).

(12) i. [[every pilot who shot at it]$_1$ [[some MIG that chased him]$_2$ [e_1 hit e_2]]]
ii. [[some MIG that chased him]$_2$ [[every pilot who shot at it]$_1$ [e_1 hit e_2]]]

It can be observed that in (12i) the pronoun 'him' is bound by the hierarchically higher antecedent 'every pilot…', while in (12ii) the antecedent 'some MIG…' binds only the pronoun 'it'. The problem the sentence gives rise to is that the two bindings are not represented in a single LF representation—which has motivated May to propose an operation called 'absorption'.

$$\ldots [NP_i \ \ldots \ [\ NP_j \ \ldots \rightarrow \ldots [NP_i \quad NP_j\ ]_{i\,,j} \ldots \qquad \mathbf{(3)}$$

As the formulation in (3) shows, the operation 'absorption' converts (*n*-tuples of) unary quantifiers into binary (*n*-ary) quantifiers.

Crossed binding, on the other hand, does not pose a problem for logical forms. No mechanism like *absorption* is, therefore, required.

(13) i. $\forall x\ [\text{Pilot}(x) \wedge \exists y\ [\text{MIG}(y) \wedge \text{Shot at}(x, y)] \rightarrow \text{Hit}(x, y) \wedge \text{Chased}\ (y, x)\ ]$

ii. $\exists y\ [\text{MIG}(y) \wedge \forall x\ [\text{Pilot}(x) \rightarrow \text{Chased}\ (y, x) \wedge \text{Shot at}(x, y) \wedge \text{Hit}(x, y)]\ ]$

For simplicity, we have, ignored case in the representations of logical form above. It may be noted that the LF representations in (12) have partial correspondences to the representations in (13), although crossed binding is reflected in the either of logical forms in (13i-ii), but not in any single one taken alone. Thus the LF representation in the formulation (3) does not fully correspond to (13i-ii), thereby giving rise to a sort of partial homology. The mapping process itself blocks the representational transfer. The repercussions will be discerned, as we move on.

C. Differences in the Representation of Crossover

The phenomenon of crossover is another linguistic case which will provide a crucial platform for the differences in question.

(14) *His$_i$ cat loves every boy$_i$.
(15) *Her$_i$ friend loves some spinster$_i$.

Co-reference between the NPs is indicated by the indexes. The sentences above are argued to be banned owing to the covert movement (at LF) of the QNPs ‘every boy’ and ‘some spinster’ in such a manner that they end up crossing the pronominals (‘his’ (in 14) and ‘her’ (in 15)). The relevant LF representations are provided below:

(16) $[_S$ every boy$_1$ $[_S$ his$_i$ cat loves e_1]]]
(17) $[_S$ some spinster$_1$ $[_S$ her$_i$ friend loves e_1]]]

This does not have a reflection in the logical forms for (14) and (15), contrary to facts in natural language:

(18) $\forall x\ [\text{Boy}(x) \rightarrow \exists y[x\text{'s cat}(y) \wedge \text{Loves}(y, x)]]$
(19) $\exists x\ [\text{Spinster}(x) \wedge \exists y[x\text{'s friend}(y) \wedge \text{Loves}(y, x)]]$

The gender differences have been ignored here. Surely one can posit some further syntactic rules that can be added to formal logic in order to express some constraints to bar the constructions in (14-15). However, this establishes that logical forms do not have the required constraints which can otherwise preclude the expression of sentences such as those in (14-15), regardless of whether the extra syntactic rules are postulated or not. In other words, logical forms can sometimes overgenerate or overrepresent natural language sentences, while LF does not. There is another line of reasoning that one may take recourse to; it appears that (18) can also be a representation for a sentence such as "Every boy is loved by his cat". Even if we grant this possibility, nothing changes the fact that logical form *may not* differentiate between (14) and the sentence "Every boy is loved by his cat". That is the crux of the problem. A similar tone is also echoed in Jackson (2007). Consider the following sentences (20a-c) now.

(20) a. Mary felled the tree into the lake with the axe.
b. The tree fell into the lake.
c. The tree fell with the axe.

There is a logical entailment from (20a) to (20b), but not from (20a) to (20c) when (20c) is interpreted with an instrumental reading of ‘with the axe’. Now let’s look at another example (21) with its logical form given below.

(21) *Bart sneezed with the pepper
$\exists x\ [Pepper(x) \wedge \forall y\ [Pepper(y) \leftrightarrow y=x] \wedge Sneezed\text{-}with(B, x)]$

There is a problem here pointed out by Jackson, and he does so in the context of the Davidsonian framework of logical forms. The fact that the putative logical form of (20a) entails the putative logical form of (20c) does nothing to guarantee that (20a) will also entail (20c), just as it does not do so to make (21) a grammatical sentence of English. This is because of the fact that there is no mapping from the object-language sentences onto the formulas of the metalanguage (first-order logical formulas).

D. Differences in the Representation of Binding

The differences between logical form and LF can also be looked at in terms of certain general cases of binding. The following examples from Miyagawa (2010), slightly changed, show this.

(22) His_i mentor seems to every trainee_i to be callow.
(23) Jack_i’s mother seems to him_i to be great.

The approximate logical forms of (22-23) are given below.

(24) $\exists y\ [Mentor(y) \wedge \forall x\ [Trainee(x) \rightarrow Mentor\text{-}of(y, x) \wedge Seems\text{-}to\text{-}be\text{-}callow(y, x)]]$

(25) $\exists x\ [j\text{'s } mother(x) \wedge Seems\text{-}to\text{-}be\text{-}great(x, j)]$

The logical form representation in (24) does not encode the facts about movement in (22), given that the noun phrase ‘his mentor’ is supposed to have moved from a position below ‘every trainee’: $[_S$ seems to every trainee_i [[his_i mentor] to be conservative]]. The example in (25), on the other hand, does not reflect the correspondence between the surface form and its LF representation, for a movement of ‘Jack’s mother’ below ‘him’ would have led to a violation of the binding principle C, which rules out a co-reference between the referring expression ‘Jack’ and the pronoun ‘him’ when ‘Jack’ is below ‘him’ in the hierarchy of the tree diagram.

This shows that LFs are sequence-dependent, and thus sensitive to levels of representations in the architecture of grammar. Logical forms are not sequence-dependent in this way.

Taking Stock

We can now take stock of what we have garnered thus far. LF is a part of a derivational sequence of computations $<D_1 \ldots D_n>$, where each D_i is computed from the output generated by D_{i-1}. Let D_n designate the stage at which LF is computed. Besides, LF is also sensitive to constraints that bear upon computational considerations of locality, economy and other syntactic constraints (global or local) which also drive $<D_1 \ldots D_{n-1}>$. Thus it is clear that LF is derivationally constructed, while logical forms are constructed without any reference to a sequence of operations. However, logical forms are constrained not only by *logical conservatism*, which demands an economy in extensions in a logical theory, but also by *ontological conservatism*, which favors fewer ontological commitments (Menzel, 1998). LF, just like the rest of syntax, is constrained by *computational parsimony*, which favors fewer operations, in addition to being restricted by *Inclusive Condition*, which bans entities not present in the Numeration (a selection of lexical items from the lexicon). In a sense then, *Inclusive Condition* can mirror *ontological conservatism*.

There is another phenomenon that we would like to consider before we move on to the relevant discussion on the issue of semantic interpretation with respect to what has been found.

(26) John wondered [which picture of himself] Bill saw.
(27) John wondered [which picture of himself] Bill took. (Runner, 2002)

Runner (2002) argues that [$_{VP}$ take [$_{DP}$ picture]] must be a unit at LF for idiomatic interpretation, but in fact ‘take’ (verb) and ‘picture’ (Determiner Phrase (DP)) can be separated at LF with the idiomatic interpretation intact. The following examples show this.

(28) John takes two pictures every day.
(29) John took every picture that Bill did [e].

Runner argues that LF is not the level where ‘take picture’ is interpreted. But logical forms are neutral with respect to whether [$_{VP}$ take [$_{DP}$ picture]] is interpreted idiomatically or not. Consider the examples below. Note that (31) is a representation of (29), while (30) represents the usual idiomatic interpretation of [$_{VP}$ take [$_{DP}$ picture]].

(30) Takes-picture (j) (here j=John)
(31) $\forall x$ [Picture (x) $\wedge$ Took(b, x) $\rightarrow$ Took(j, x)] (here b= Bill)

In sum, logical forms can represent and handle the semantics of certain linguistic phenomena which are not reflected or represented at the level of LF. This reinforces the case for their fundamental differences.

Mental Grounding and Logical Form

We are aware that LF is a syntactic component of the language faculty, and hence it can be grounded in the mental substrate. We may wonder what consequences will possibly emerge when logical forms are so grounded in the mind? In fact, Fodor’s (2000) postulated identity of logical forms of propositional attitudes with the syntactic properties of mental representations corresponding to propositional attitudes can provide a good testing ground. For Fodor, the *isomorphy* of the logical form of a propositional attitude (such as a belief or thought) with the syntactic properties of the mental representation corresponding to the propositional attitude explains how thoughts are causally efficacious in driving cognitive processes. This invites fiendish problems, as we will see now.

(32) a. M1~ John walks. $\longrightarrow$ F(j)
b. M2 ~ Max walks. $\longrightarrow$ F(m)

(33) a. M3~ Crystal is bright. $\longrightarrow$ $G(c)$ / $\lambda x\ \forall y\ [{}^{\cup}x(y) \wedge G(y)]$
b. M4 ~ John is bright. $\longrightarrow$ $G(j)$

(34) a. M5~ Crystal is bright. $\longrightarrow$ $G(c)$ / $\lambda x\ \forall y\ [{}^{\cup}x(y) \wedge G(y)]$
b. M6~ Summer is bright. $\longrightarrow$ $G(s)$ /

Some readers can get a flavor of the Chierchian notation for the word ‘crystal’ or ‘summer’. The ${}^{\cup}x$ symbol converts a nominal (an entity *e*) into an adjectival *property* (a type of a predicate <*e*$\rightarrow$*t*>, as in ‘Blue is my favorite color’, for example). Here, *M* refers to a mental representation, and the logical forms of the propositional attitude sentences are placed alongside the sentences, as indicated by arrows. The propositional attitude sentences can be thoughts or beliefs, or anything one likes. This is immaterial for our purpose at hand. We may simply note that everything looks fine in (32) where each of the propositional attitude sentences is mapped onto a unique logical form which can be identified with the syntactic property of the mental representation in question. But (33a) gives rise to an indeterminacy which cannot be resolved from within the sentence in question because ‘crystal’ can be a name for a person or an object; it needs context which is not a syntactic property. The case in (34) leads to a damaging inconsistency on the grounds that both the sentences have two different logical forms, and at the same time, possess the same single logical form. Without the relevant context, we may never be able to decide between these logical forms which are assumed to correspond to the syntactic properties of mental representations. We as humans can decide whether the word is a name or a common noun, but the corresponding mental presentation considered all by itself cannot. Importantly, LF may bypass this problem, as it is anchored to the C-I system at which the discourse interpretations of anaphors, pronominals can obtain (Avrutin, 1999). The C-I system can resolve the indeterminacy when the relevant pairs in (33-34) are interpreted after they are shipped to it. Clearly, logical form and LF produce different in empirical consequences as well.

Reflections on the Nature of Semantic Structures and Semantic Interpretation

The long and the short of it is that LF and logical forms project distinct scenarios of semantic computationality. To the extent that logical forms are mentally grounded, semantics appears to be *minimally* computational on the grounds that structured forms of linguistic meaning cannot be manipulated in accordance with well-defined rules which, when operating on those structured forms, do not always yield correct outputs or even do not produce any outputs due to indeterminacy. This is so regardless of whether logical forms represent or encapsulate syntactic properties of propositional attitudes or of natural language sentences. And, on the other hand, to the extent that LF is *intrinsically* a part of the mental organization realizing the putative computational system of the language faculty, semantics seems to be *maximally* computational in virtue of the rule-bound faithfulness to the syntactic properties of natural language sentences across a range of linguistic phenomena. The mind included, logical form resists rendering semantics computational, while LF makes semantics maximally computational. Conversely, minus the mind, logical form is maximally computational given that certain computable functions are defined on logical forms, and on the other hand, the question of judging, on the basis of an examination of LF, whether semantics is computational or not becomes meaningless precisely because LF is intrinsically a part of the mentally grounded language faculty. Which scenario is truer of semantic interpretations, given that the property of semantic interpretation is supposed to be encoded or represented in both logical form and LF? The problem becomes more severe, especially when we observe that semantics or the realization of semantics in the mind is computational to a certain extent and yet it is not so to that extent. This looks like a contradiction, although in a relativized condition. Looking at LF, we come to believe that computational operations on the structured forms of semantic interpretations can be defined in order that they are exploited for cognitive interfaces. But we tend to resist this conclusion as soon as we look at the consequences that derive from logical form being made subject to the same constraints and restrictions as LF is.

To understand the nature of this dilemma far more deeply, we shall have to scrutinize a number of other related assumptions that underscore the set of presuppositions and assumptions entertained thus far. One of the deeply-entrenched assumptions is that semantics is like arithmetic or algebra such that logical formalisms are used to express facts about natural language meanings just like they are employed to express facts about arithmetic or algebra, and LF constitutes a model of those facts, that is, facts about natural language meanings. Implicit in this is another assumption that LF models facts about natural language meanings which are as real as facts about the natural world, in that such facts are supposed to be out there in the world. In other words, this belief presupposes that logical form does not in fact model aspects of natural language meanings, but rather expresses objective facts about natural language meanings just like set theory, for example, expresses arithmetical facts when it is used to describe mathematical facts and generalizations. In addition, this also presupposes that the model of facts about natural language meanings, that is, LF is distinct from the facts about natural language meanings in themselves. That these assumptions are fallacious can be revealed by carefully inspecting the underlying analogy drawn between semantics and any branch of mathematics.

In this context the case of physics serves as an appropriate example because the basis of the analogy lies in physics. First of all, facts, or rather the description of facts, about the physical reality in terms of geometrical (or mathematical) formalisms/structures are identical to and not thus *separable* from the model(s) of these facts in theoretical physics. What this means is that there is no transition from a level/stage of description of physical facts in mathematical structures to a level/stage of construction of a model of these facts about the physical reality. Had it not been the case, mathematical structures would perhaps be considered to be representational metalanguages in which physicists tend to couch, by convention or otherwise, their physical facts, and for this very reason, physical facts can be couched in other possible representational metalanguages (such as natural languages or programming languages or codes etc.). But this is certainly not true of physics. Abstract physical descriptions are in themselves mathematical objects; the mathematical descriptions, say, in quantum mechanics or relativity theory or even in string theory are all mathematical structures, not models derived from descriptions of physical facts. Thus mathematics is not a special garb that physical facts wear to become visible; rather, physical reality itself is a mathematical reality.

Second, what holds true in the context of theoretical physics is not ipso facto true of the relationship between logic and meaning in natural language. Logic is a well-defined system of axioms which help derive certain theorems from those axioms based on inferences (inductive or deductive or abductive) through human interpretations. One can thus use the logical metalanguage to represent meaning in natural language (as formal semanticists do using set-theoretic structures and truth conditions). But then one can also use, with equal ease, conceptual schemas (in Cognitive Grammar, for example) or conceptual spaces/graphs (as in artificial intelligence) to represent the very meanings in natural language. Hence logic or logical formalisms (that is, logical forms) are not the *only* metalanguage in which meanings or facts about meaning can be described. Within the Generative tradition, LFs constitute another metalanguage that represents aspects of meaning expressed syntactically.

However, one may now complain that this does not correctly describe the role of LF since the derivation of logical relations and logical properties from LF representations cannot be executed, except by making a reference to the logical structures. And if so, LF as a model of facts about natural language meanings must rely on logical formalisms that express the logical relations and logical properties of natural language sentences. Hence, for example, the logical relation of entailment from (ii) to (i) can be deduced from (7/5) by means of the calculation of the relevant truth-conditions. One may check that if there is a single language that every linguist likes, it must be the case that every linguist likes some language or the other, regardless of whether the language happens to be the same language or not. The situation described by (ii) is a more specific scenario subsumed under the more general one described in (i).

i. $\exists y\,[\text{Language}(y) \wedge \forall x\,[\text{Linguist}(x) \rightarrow \text{Likes}(x, y)]\,]$
ii. $\forall x\,[\text{Linguist}(x) \rightarrow \exists y\,[\text{Language}(y) \wedge \text{Likes}(x, y)]\,]$

In this sense, one can make the reasonable claim that logical relations and logical properties can be deduced from facts about natural language meanings which LF models in virtue of those facts objectively present in natural language sentences. But then LF as a model of facts about natural language meanings becomes *intrinsically* linked to the formalism of logical forms, which is disastrous because the grounding of logical forms in the mind *in the intended manner* has its deleterious consequences, as observed above, which can eat into the relation of conceptual dependence between LF and logical form. Apart from that, if logical relations and logical properties deduced from facts about natural language meanings can be represented or modeled in formal representational notations other than LF, the possibility of having different equivalently valid models for the same set of semantic facts is at odds with the state of affairs in theoretical physics, for this goes against the requirement that there should be a unique correspondence between a formal representation and any natural language sentence. For example, the theory of conceptual spaces (see Gärdenfors 2004) can represent many aspects of logical relations and logical properties that can be deduced from facts about natural language meanings, while, on the other hand, it is nonsensical to say that Maxwell's equations describing the properties of electromagnetism can be expressed with the same degree of faithfulness in formats other than mathematics. Another example seems pertinent here. Feynman diagrams which represent the interactions of fundamental particles in particle physics are an aid in the understanding of the mathematical expressions. Hence one cannot understand Feynman diagrams ignoring the mathematics that underlies Feynman diagrams. Feynman's diagrams are not, strictly speaking, an alternative to the mathematical expressions.

Furthermore, the differences between LF and logical form are not akin to those between different formats for representing number. Even if it is true that one can write numbers in binary or decimal or countless other ways, and that this does not of course change the fact that arithmetical operations are algorithmic because the details of the algorithm just vary appropriately based on the representation used, this is not equally true of semantics. Again, the assumption that semantic objects are like mathematical objects and semantic facts are like mathematical facts plays a large part in getting it rooted in our linguistic inquiry. Had this supposition been true, we would not have found mutually opposite consequences in two different conditions (a condition that includes the mind and a condition minus the mind). This is not true of mathematical objects or facts, since numbers written either in the binary format or in the decimal format do not thereby lead to different consequences in the faithfulness with which the decimal format or the binary format can represent numbers. Nor do numbers vary based on where they are grounded—whether in machines (such as calculators, elevators, cell phones etc.) or in human minds, for instance. The ontology of semantics is way different from that of mathematics both in form and in nature. The latter may lie in the Platonic realm, whereas the former cannot perhaps be of such nature, given that the very metalanguages that encode or represent semantics are not uniform in their representational faithfulness, and that semantic objects are not merely reified representations, they subsist on human contexts and interpretations. For example, the property of being a prime number may be independent of human cognitive processes that conceptualize the property of being a prime number, but the property of semantic interpretation in a sentence such as 'John smokes everyday' is not independent of the human interpretation process. Of course, not all of semantics may be computational. Also, one should note that the differences between LF and logical form do not simply reduce to differences in algorithmic details; rather, the differences point to the sizable dissimilarity in the computable functions which can be defined on them in that the differences rest on unmistakable alterations in the functions that map relevant inputs onto outputs over the domain of structured forms of semantic interpretations.

Implications for Reasoning in Natural Language

It is now worth seeing what implications for the nature of reasoning in natural language ensue from the observation that semantic representations are bogged down in the relativistic quandary surrounding the relation between semantics and its computational realization in the mind/brain. If this is so, reasoning and inference making activities in natural language cannot also be said to be computationally realized in the mind/brain in any determinate sense. A form of reasoning is aimed at teasing apart inconsistent or conflicting scenarios with respect to knowledge claims and interpretations. Such reasoning may also be captured in terms of metalanguages (logical/symbolic rules etc.). If the semantic structures underlying such linguistic reasoning are such that we cannot tell whether they are computationally realized in the mind/brain, how can we even get nearer to any notion of whether reasoning in natural language can be computationally realized in the mind/brain?

In fact, this conclusion obtains independent of any efficacy of any metalinguistic code/system in computationally implementing reasoning in natural language. The reason is simple. Even if a specific metalinguistic code/system achieves considerable success by (computationally) representing reasoning in natural language in its own form, that does not show anything about whether what is represented (reasoning in natural language) is *intrinsically* computable in the same way. Given these deeper problems associated with any determination of the question of whether semantic, or for that matter, reasoning in natural language is computationally realized or not, it is not surprising to see that Hodgson (2012) has argued that plausible reasoning—a form of reasoning (generally captured in the Bayesian theorem) in which the premises do not lead to the conclusion by virtue of mechanically applicable (or otherwise) logical rules but rather support the conclusion as a matter of reasonable but fallible judgment— is not determined by any algorithmic or law-like processes. It applies at a level of mind where computations properly construed do not apply. For him, this level is the computational level of mind in Marr's three-level schema construed by him to be the *overt* or outer level of mind where algorithms or programs do not apply. He has also added that to argue that plausible reasoning is determined by algorithms or laws at the neural level is a severe fallacy because making such an argument is itself is a type of plausible reasoning. So this leads to circularity. However, the present work casts doubts even on possible (computable) functions that may be defined on semantic representations in terms of logical forms or LF.

Conclusion

Perhaps the question of semantic representations as semantic interpretations which can be computationally manipulated is itself ill-formed and misleading. Or perhaps to have a grip on this really hard question, we need to look into very nature of meaning itself without foisting it on computation. Whatever our choice is, it is not easy.

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