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Bidirectionality in Montague Semantics

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0　Introduction

In analyzing a sentence like "John seeks a unicorn", Richard Montague (1973) proposed that two different analysis trees should be given to make a distinction between the *de dicto* (or nonreferential) reading and the *de re* (or referential) reading of the given sentence.

In Hayashi (1982,1985) the present author showed that exactly the same result could be obtained by using a non-traditional method which was called a bidirectional functor analysis. This bidirectional analysis was unique in allowing the analyst to use not only the leftward intransitive verb phrase like "seeks a unicorn" but also the rightward intransitive verb phrase like "John seeks".

In this paper we would like to discuss the validity of this bidirectional analysis briefly and demonstrate how it works for representing some grammatical phenomena such as scope ambiguity of quantifiers and intensional verbs, relativization, intensional expressions, and so on. A more flexible framework reflecting some of our linguistic intuitions will be evident if we use this bidirectional functor analysis.

1　Leftward and Rightward Intransitive Verb Phrases

We admit two kinds of intransitive verb phrases in our system; a leftward intransitive verb phrase and a rightward intransitive verb phrase. The leftward intransitive verb phrase is the combination of a transitive verb and an object noun phrase and is so called because the phrase combines with the subject noun phrase to the left to make a sentence. On the other hand, the rightward intransitive verb phrase is the combination of a transitive verb and a subject noun phrase and is so called because the phrase combines with the object noun phrase to the right to make a sentence. The former is familiar to any linguist while

the latter is not. We understand a transitive verb as having a function toward two directions — left and right — to make up an intransitive verb phrase. This is why we call our analysis bidirectional.

In order to understand our bidirectional semantic framework, we have to begin with reconsidering in what way we process our language data in our communication. For the sake of discussion our primary concern in this section will be confined to the function of extensional transitive verbs. (Intensional transitive verbs will be treated in the next section.)

Let us first consider a very simple declarative sentence like (1) in which a transitive verb *love* is included. The translation of (1) into the language of intensional logic is shown in (2) in the form of standard Montague notatiion.

(1) John loves Mary.

(2) love (j, m)

Montague used only a unidirectional analysis which consistently allows a transitive verb combine with an object noun phrase to make up an intransitive verb phrase. He maintained that sentence (1) has no ambiguity at all. But is that true all the time?

Sentence (1) will be paraphrased into two distinct cleft (or emphatic) sentences as shown in (3) and (4).

(3) It is John that loves Mary.

(4) It is Mary that John loves.

Except for *loves Mary* in (3) and *John loves* in (4), the structure of these two sentences are exactly the same. If *loves Mary* in (3) is an intransitive verb phrase, then what else can *John loves* be other than an intransitive verb phrase? If *loves Mary* in (3) denotes the set of the things (or persons) that loves Mary , then what else can *John loves* denote other than the set of things (or persons) John loves? This means that when the focus (or emphasis) is on the subject noun phrase *John* in (3) or when it is on the object noun phrase *Mary* in (4), we are certainly connecting these noun phrases with the different set of things; with the set of things that loves Mary in the former case or with the set of things that John loves.

In our actual communication process using a sentence as in (1) there exist two distinct ways of understanding the world (in this case the love-relation between John and Mary) and we always select one of them to express the world, whichever choice we make resulting in the same expression. Only when our focus is shifted from one point to another and it becomes necessary for this focus to be expressed, do these differences come to the surface as shown in (3) and (4). In this stricter sense the sentence in (1) can never

be unambiguous as Montague contended.

This observation will lead us to adopt a new notation of intentional logic, so that, in place of (2), we can represent this ambiguity of the sentence in (1). The new notation which reflects a distinction between a leftward intransitive verb phrase and a rightward intransitive verb phrase has to become one of a somewhat unconventional kind. So sentence (1) will be translated as something as shown in (5) and (6), each of which corresponds to (3) and (4) respectively.

(5) (love (m)) (j)   (= (2))

(6) ((j) love) (m)

Remember that the logical notation in (5) is nothing but a notational variant of (2) indicating that the leftward intransitive verb phrase *loves Mary* is combined with the subject noun phrase *John*. The notation in (6) indicates that the rightward intransitive verb phrase *John loves* is combined with the object noun phrase *Mary*. Remember also that the noun phrase *Mary* acts as an object of a sentence in our natural language expression but acts as a subject in our logical notation.

Now let us here turn to a passive form of that sentence. The passive sentence and its crude logical representation corresponding to (1) will be shown as in (7) and (8) respectively.

(7)   Mary is loved by John.

(8)   be loved by John (m)

In (8) it is clear enough that the unanalyzed phrase *be loved by John* is an intransitive verb phrase and denotes the set of the things which is loved by John. This means that there exists the set of the things being in a love-relation with John. From this intransitive verb phrase the speaker (or listener) grasps both the underlying subject John and this love-relation together as something that denotes a set, and he or she interprets that the sentence is true if Mary is a member of that set. Mary is understood as a member of the set of things being loved by John— in other words, as a member of the set of the things that John love. Therefore, we will be able to represent the underlying logical relation of (7) as something as in (9), which is different from the conventional representation shown in (2).

(9)   ((j) love) (m) $_{passive}$

Remember that the notation in (9) is exactly the same except for an attached subscript, indicating that it is realized as a passive sentence in (7). The noun phrase *Mary* in this case acts as a subject both in our natural language expression and in our logical notation. The logical relatedness of an active sentence and a passive sentence is in this way properly

represented.

2 Intensional Constructions

One of the most famous contributions Montague made to the semantics of natural language is the clarification of intensional constructions of natural language. Based on Frege's distinction of *Sinn* and *Bedeutung*, Montague made a clear distinction between *intension* and *extension* of the expression.

Consider the following example in (10) with an intensional transitive verb *seek.*

(10) John seeks a unicorn.

In sentence (10) Montague identified two distinct meanings shown as in (11) and (12). By giving two different analysis trees, he showed that the translation of each interpretation into the language of intensional logic would be something as shown in (13) and (14) respectively.

(11) John seeks at least one unicorn.

(12) There is a particular unicorn that John seeks.

(13) seek' (j, $\widehat{Q}\vee$ y [unicorn' (x) $\wedge$ Q (x)])

(14) $\vee$ x [unicorn' (x) $\wedge$ seek' (j, $\widehat{P}$ P (x))]

According to our bidirectional functor analysis framework, however, the translations corresponding to (11) and (12) will be given as in (15) and (16) respectively. Translation (15) results from an analysis using a leftward intransitive verb phrase and translation (16) from an analysis using a rightward intransitive verb phrase.

(15) (seek' ($\widehat{Q}\vee$ y [unicorn' (x) $\wedge$ Q (x)])) (j)   (= (13))

(16) $\vee$ x [unicorn' (x) $\wedge$ ((j) seek') ($\widehat{P}$ P (x))]

Note that, as shown in the previous section, translation (15) is a notational variant of (13) . But translation (16) represents much more accurately than does translation (14) the rightward intransitive verb phrase which appears as *John seeks* in the relative clause (12). This example suggests that our bidirectional functor analysis is related to the description of relative clause constructions in an essential way. (We will treat relativizations in the next section.)

Although Montague tried to formulate intensional constructions of transitive verbs with regard to the object noun phrase, he or his followers have never mentioned intensional constructions of transitive verbs with regards to the subject noun phrase. Intensional transitive verbs such as *seek* or *believe* form an intensional construction only with the object noun phrase. It seems to me that some psychological transitive verbs such

as *frighten* or *worry* also form an intentional construction with the subject noun phrase.

Consider the following example (17) with a psychological verb *frighten.*.
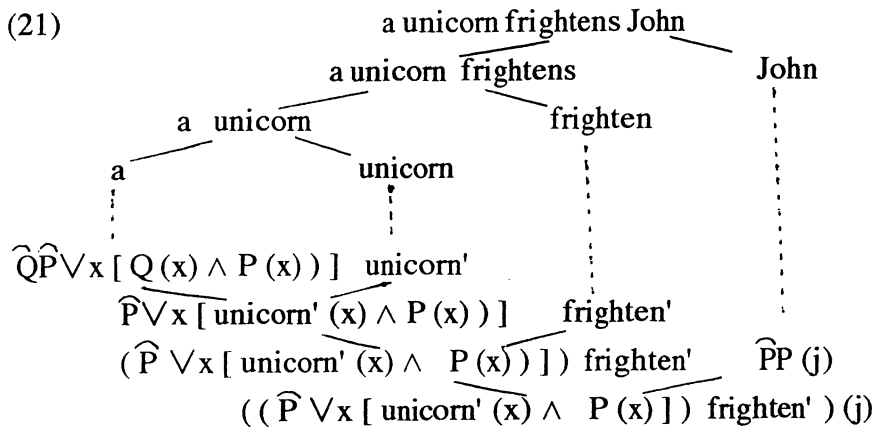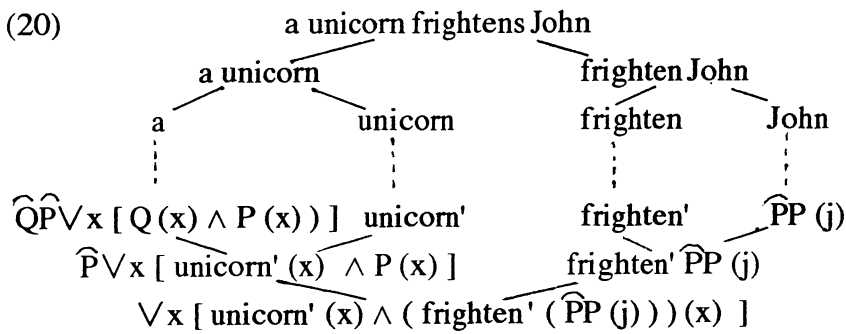
(17)   A unicorn frightens John.

The psychological verb *frighten* can take an intensional noun phrase in its subjective position and construct an intensional construction. So the sentence (17) will be interpreted intensionally as in (19) as well as extensionally as in (18) with regard to the subject.

(18)   There is a particular unicorn that frightens John.

(19)   The concept of at least one unicorn frightens John.

When interpreted as in (19), the subject noun phrase *a unicorn* is an intension of the phrase—i.e. the concept of a unicorn. Whether there exists a unicorn in our world or not, the concept of the animal can frighten John in his psychological world. Our bidirectional functor analysis of sentence (17) corresponding to (18) and (19) will be shown as in (20) and (21) respectively.

(20)

a unicorn frightens John
 ├─ a unicorn
 │   ├─ a
 │   └─ unicorn
 └─ frighten John
     ├─ frighten
     └─ John

$\widehat{Q}\widehat{P}\bigvee x\,[\,Q(x) \wedge P(x)\,)\,]$ unicorn'   frighten' $\widehat{P}P$ (j)

$\widehat{P}\bigvee x\,[\,unicorn'\,(x) \wedge P(x)\,]$ frighten' $\widehat{P}P$ (j)

$\bigvee x\,[\,unicorn'\,(x) \wedge (\,frighten'\,(\widehat{P}P\,(j)\,)\,)\,(x)\,]$

(21)

a unicorn frightens John
 ├─ a unicorn frightens
 │   ├─ a unicorn
 │   │   ├─ a
 │   │   └─ unicorn
 │   └─ frighten
 └─ John

$\widehat{Q}\widehat{P}\bigvee x\,[\,Q(x) \wedge P(x)\,)\,]$ unicorn'

$\widehat{P}\bigvee x\,[\,unicorn'\,(x) \wedge P(x)\,)\,]$ frighten'

$(\widehat{P}\bigvee x\,[\,unicorn'\,(x) \wedge P(x)\,)\,]\,)$ frighten' $\widehat{P}P$ (j)

$(\,(\,\widehat{P}\bigvee x\,[\,unicorn'\,(x) \wedge P(x)\,]\,)$ frighten'$\,)$ (j)

Therefore, the semantic translation of (17) is shown as in (20') for the extensional subject and (21') for the intensional subject.

(20') $\bigvee x\,[\,unicorn'\,(x) \wedge (\,frighten'\,(\widehat{P}P\,(j)\,)\,)\,(x)\,]$ ·

(21') $(\,(\,\widehat{P}\bigvee x\,[\,unicorn'\,(x) \wedge P(x)\,]\,)$ frighten'$\,)$ (j)

In the interpretation of (21') the intension of the subject noun phrase *a unicorn* is

represented accurately as $\hat{P} \lor x \, [\, unicorn'(x) \land P(x) \,]$.

However, if the object noun phrase of a given sentence is not a quantified noun phrase as in (17), then a framework that uses exclusively a leftward intransitive verb phrase can never capture the intensional constructions in the subject position. This is because the analysis tree will lead to an extensional subject as is shown in (20'). The result is the same even when the object noun phrase is introduced later into the analysis tree. Montague's unidirectional approach has a limitation in this respect. Of course we have to set up a new meaning postulate in order to give an extensional translation for the extensional transitive verbs other than these psychological verbs.

3 Relative Clauses

In the history of compositional Montague semantics various researchers have proposed different kinds of approach in an attempt to give an adequate framework for the description of relative clause constructions (among others, Partee (1972), Cooper (1975), Bach & Cooper (1978), Gazdar (1981), Janssen (1983)). Based on the bidirectional functor analysis the author proposed a CN-CN\CN analysis of relative clause constructions (Hayashi (1985)).

The CN-CN\CN analysis depends entirely on the use of the leftward and rightward intransitive verb phrases and the analysis is implemented by assigning the following category (22) and translation (23) to a relative pronoun . (The possessive case of pronouns is not treated here.)

(22) CN\CN/IV

(23) $\hat{P}\hat{Q}\hat{y}\, [\, P(y) \land Q(y) \,]$

By (22) and (23) we mean that a relative pronoun is understood as a functor that combines with a (leftward or rightward) intransitive verb phrase to the right and that combines with a common noun phrase to the left to make up another common noun phrase. When combined with an intransitive verb phrase to the right the relative clause becomes a kind of adjectival phrase which has a category of CN\CN.

Let us consider the following examples of relative clause constructions.

(24) a girl who loves John

(25) a boy who Mary loves

Given a translation as in (23) to a relative pronoun *who* , the interpretation of the relative clauses corresponding to (24) and (25) will be shown as in (26) and (27) respectively.

(26) $\hat{P} \lor x \, [\, [\text{ girl' } (x) \land (\text{ love' } (j)) (x) \,] \land P (x)]$

(27) $\hat{P} \lor x \, [\, [\text{ boy' } (x) \land ((m) \text{ love' }) (x) \,] \land P (x)]$

As we have seen in the previous sections, the word combination *loves John* in (24) and *Mary loves* in (25) is understood as a leftward intransitive verb phrase and a rightward intransitive phrase respectively. Each of these intransitive verb phrases combines with a preceding pronoun *who* to make up an adjectival relative clause *who loves John* or *who Mary loves*, which again combines with a preceding common noun *girl* or *boy* to make up a common noun phrase *girl who loves John* or *boy who Mary loves*, and then with a determiner to make up a complex relativised noun phrase in (24) or in (25)..

Cooper, Gazdar and Janssen, in their NP-S analysis, all had to assume some kind of hypothetical constructs such as **R**, *R*, or **of kind**$_n$ in a noun phrase, each of which is assumed to denote a property . They are free variables for which a relative clause is substituted. In their treatment a relative clause is assumed to denote a property.

In our bidirectional framework a relative clause is assumed to denote a function from property to property. That is why we call our analysis of relative clauses a CN-CN\CN analysis. By assuming such a grammatical construct as a rightward intransitive verb phrase it becomes possible for us to give a category like (22) to a relative pronoun.

Another reason why we assume a relative clause to denote a function from property to property will be given by considering an attributive and predicative use of adjectives. Both sentences in (28) and (29) must have the same translation like (30) in our logical translation.

(28) a snobbish lady

(29) a lady who is snobbish

(30) $\hat{P} \lor x \, [\, [\text{ lady' } (x) \land \text{ snobbish' } (x) \,] \land P (x)]$

While a predicative adjective *snobbish* in (29) can be translated into *snobbish'*, an attributive adjective *snobbish* in (28) cannot be translated into *snobbish'* since the latter is a function from property to property and its category is CN/CN. The translation of the attributive adjective might be something like $\hat{P}\hat{y} \, [\, P(y) \land \text{ young' } (y) \,]$ of which the semantic type is $(t / e) / (t / e)$. By giving these different translations to an attributive adjective and a predicative adjective we can arrive at the desirable semantic interpretation in (30). Note here that the attributive adjective *snobbish* in (28) and the relative clause *who is snobbish* in (29) plays exactly the same function to a common noun *lady* from the opposite direction. If the category of the attributive adjective *snobbish* is CN/CN, the category of the relative clause *who is snobbish* must be CN\CN, i.e. a function from property to property. These observations have led us not to assume a free variable in the

noun phrase, but to give a relative pronoun a category and a translation as in (22) and (23). A relative clause is here understood as having an attributive function to a preceding common noun to make up a common noun phrase.

Let us end this section by giving an example of stacking relative clauses in (31) and its interpretation of this example in (32).

(31) a lady who is snobbish who John loves

(32) $\widehat{P} \vee x$ [lady' (x) $\wedge$ snobbish' (x) $\wedge$ ((j) love') (x) $\wedge$ P (x)]

4 Scope Ambiguity of Quantifiers and Intensional Verbs

It is necessary for an analyst to exclude any scope ambiguity of quantifiers in the syntactic level, so that every natural language expression could exhaustively be translated into a well-formed formula of intensional logic. Ambiguity can arise even when there is no element of intensionality, as we have discussed in section 2. This is because quantifying noun phrase can be introduced in more than one order . If a sentence contains two quantified noun phrases as in (33), then we will have two different readings of it as shown in (34) and (35).
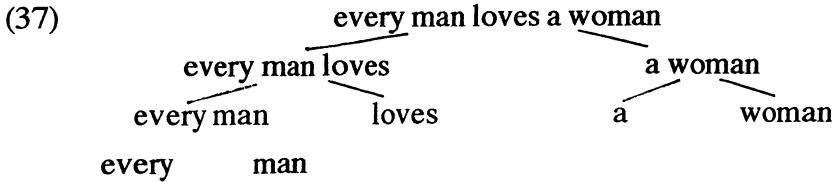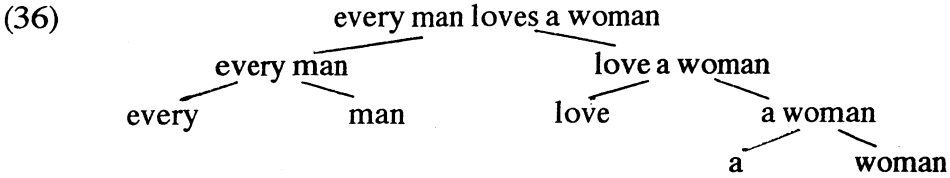
(33) Every man loves a woman.

(34) Every man loves at least one woman.

(35) There is a particular woman who every man loves.

The subject noun phrase *every man* is understood to have a wider quantifier scope than the object noun phrase *a woman* in reading (34), and *vice versa* in reading (35).

These differences in our reading is represented by giving two different analysis trees in Montague grammar, where an element introduced later into the analysis tree is understood as having a wider scope than is an element introduced later. In these analysis trees the derivational history of the sentence is represented along with the rules applied to make up a surface structure. Therefore they have to rely on the use of variables in order to allow an element which is supposed to be introduced earlier to have a wider scope than an element which is supposed to be introduced later. A variable is introduced first and later in the derivational history this variable is substituted for a real noun phrase. But one thing we have to remember here is that only a unidirectional function is permitted for a transitive verb in the traditional Montague grammar, exclusively generating leftward intransitive verb phrases.

Compare two analysis trees (36) with (37) and also their translations (38) with (39) respectively.

(36)
                       every man loves a woman
          every man   love a woman
   every   man   love   a woman
                                      a   woman

(37)
                       every man loves a woman
        every man loves   a woman
     every man   loves   a   woman
  every   man

(38) $\bigwedge x\,[\,man'(x)\ \rightarrow\ \bigvee y\,[\,woman'\,(y)\ \wedge\ (\,love'\,(y)\,)\,(x)\,]\,]$

(39) $\bigvee y\,[\,woman'\,(y)\ \wedge\ \bigwedge x\,[\,man'(x)\ \rightarrow\ (\,(x)\,love'\,)\,(y)\,]\,]$

In our bidirectional approach, however, a transitive verb is free to apply in either direction, leftward or rightward, generating rightward intransitive verb phrases as well as leftward intransitive verb phrases. In these analysis trees the order of the introduction of a noun phrase, i.e. which one is introduced earlier or later, depends entirely on whether a given sentence is analyzed as having a leftward intransitive verb phrase or a rightward intransitive verb phrase. If we choose an analysis having a leftward intransitive verb phrase as in (36), then the subject noun phrase will be introduced later having a wider quantifier scope as shown in (38). If we choose an analysis having a rightward intransitive verb phrase as in (37), then the object noun phrase will be introduced later having a wider quantifier scope as shown in (39).

Compared with Montague's analysis our bidirectional analysis is much simpler since we do not rely on using such a noun phrase variable as $\widehat{PP(x_0)}$. Nevertheless, we can obtain essentially the same result representing the scope of noun phrase quantifiers. Besides, there is something more than that. Just pay your attention to the last part of each translation in (38) and (39), and you will notice the love-relation between x and y is represented in the way that will be shown in (40) and (41) respectively. (Recall also the examples given in (3) and (4) in section 1.)

(40) It is x that loves y.

(41) It is y that x loves.

These translations reflect the fact that our focus is on x in (38) and (40) and on y in (39) and (41), while Montague and others gave a rather flat translation *love (x,y)* to either of the counterpart of their translations.

What does it imply for us to disambiguate the scope of quantifiers? Of course it is nothing but to determine the range of the operation of one quantifier over other to get to an accurate interpretation of a given expression. But this is done only by focusing our

attention on one quantified noun phrase over other. Therefore, to disambiguate the scope of quantifiers means nothing but to make a distinction of this focus shifting from one point to another, i.e. from one quantified noun phrase to another quantified noun phrase. For this reason the kind of translation that reflects not only the unambiguous scope relation of quantifiers but also the unambiguous focus relation of quantified noun phrases is much more preferable than the kind that does not.

Let us make here a brief remark on the scope ambiguity of intensional transitive verbs. In section 2 we have mentioned that there exist two kinds of intentional transitive verbs; transitive verbs such as *seek* or *believe* that form an intensional construction with regard to the object noun phrase and transitive verbs such as *frighten* or *worry* that form an intensional construction with regard to the subject noun phrase.

Consider example (13) in section 2 again which is one of the translations Montague gave to sentence (2) with an intensional verb *seek*. What is involved here is not the scope problem of quantifiers but of intensional verbs. By taking the intension of quantified noun phrase $\hat{Q} \vee y$ [*unicorn'* (x) ∧ Q (x)] into the scope of intensional verb *seek* Montague could give a referent without any commitment of the existence of *a unicorn* at at a given point of reference. This is also the case in our example of bidirectional translation in (15), because translation (15) is considered to be a notational variant of (13).

But what about the example in (21')? The intension of quantified noun phrase $\hat{P} \vee x$ [*unicorn'* (x) ∧ P (x)] appears to the left of the psychological verb *frighten*. This might seem to be a little bit perplexing since we are used to understanding that a governed string always appears to the the right of a governing string. Contrary to the intensional verbs like *seek* or *believe*, the psychological intensional verbs like *frighten* or *worry* are the kind that governs a string in opposite direction as to the scope operation. Our bidirectional approach permits this to happen and a meaning postulate will take care of the case. Anyway, the intension of a noun phrase will not necessarily have to have a non-empty extension in the subject position.

5 Summary

As we have seen our bidirectional framework is based on the assumption that a transitive verb can combine with an element to the left or to the right. This assumption will lead us to form not only a conventional leftward intransitive verb phrase but also a non-conventional rightward intransitive verb phrase. The leftward intransitive verb phrase is the combination of an object noun phrase and a transitive verb, while the rightward

intransitive verb phrase is the combination of a subject noun phrase and a transitive verb. The rightward intransitive verb phrase is assumed to denote the set just as is the leftward intransitive verb phrase. This means that it can combine with an object noun phrase to form a sentence.

Consequently, the structure of a sentence is considered to be twofold; NP+VP and VP+NP. One thing we have to remember is that in the VP+NP structure where the rightward intransitive verb phrase is involved the surface object is treated as a logical subject in our translation into the language of intensional logic. In order to represent these structures we adopt a somewhat different logical notation of a sentence structure.

The twofold structure of a sentence reflects the shifting of the focus of our attention from one place of a sentence to another. When our focus is on the subject the sentence structure turns out to have a leftward intransitive verb phrase. When our focus is shifted to the object the sentence structure turns out to have a rightward intransitive verb phrase.

When we talk about the scope ambiguity of quantifiers or intensional verbs, or even when we talk about the relative clause constructions, we are in fact talking about where our focus is on. Our focus is always shifting from one place to another and never comes to a standstill.

Although our bidirectional functor analysis is still at far from a sophisticated level and much remains to be improved, the author believes it will be able to shed a new light on some of language phenomena which still remain in the dark.

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