Abstract

It is known that VP-ellipsis and VP-anaphora are typologically different phenomena. English has VP-ellipses whereas Korean has VP-anaphora. The goals of this paper are (i) to develop a unified algorithm which can analyze these two different phenomena and (ii) to explain them using the developed resolution algorithm. In order to analyze these phenomena, this paper incorporates Jäger (2010)'s anaphora resolution mechanism into the typed feature structure formalism of Head-driven Phrase Structure Grammar (HPSG). In this paper, VP-ellipsis and VP-anaphora are analyzed as follows. First, English *do* and Korean *kuleha-ta* are introduced with the Geach value, and this value is changed with a *slash-elimination* rule. Then, one constituent combines with another by ordinary syntactic rules, while the information on the target predicate is percolated up. When a potential source appears, a *slash-introduction* rule is applied. Then, the source predicate activates the *VP-resolution* rule, and the target predicate is connected with the source in the semantic representations.

1 Introduction

Ellipsis is one of the interesting topics in syntax and semantics, since syntactically elided parts have to be recovered in the semantic interpretation. It is also an interesting area in computational linguistics where the syntax and semantics of words and sentences are computationally implemented.

As the sentences in (1) illustrates, English has VP-ellipsis phenomena.

(1) a. John came, and Mary [$_{VP}$ came], too.
b. John came, and Mary did [$_{VP}$ ~~come~~], too.

The VP parts of two conjuncts are identical in (1a), and the VP of the second conjunct is elided in (1b) while the dummy auxiliary *do* takes the past tense in the second conjunct.

Whereas English has VP-ellipsis, Korean has VP-anaphora phenomena. Let's see the example sentences in (2).

(2) a. Chelsoo-ka o-ass-ko, Younghee-to [$_{VP}$o]-ass-ta.
Chelsoo.NOM come.PAST.and Younghee.too come.PAST.DECL
'Chelsoo came, and Younghee came, too.'

b. * Chelsoo-ka o-ass-ko, Younghee-to [$_{VP}$~~o~~]-ass-ta.
Chelsoo.NOM come.PAST.and Younghee.too come.PAST.DECL
'Chelsoo came, and Younghee came, too.'

c. * Chelsoo-ka o-ass-ko, Younghee-to [$_{VP}$~~ha~~]-yss-ta.
Chelsoo.NOM come.PAST.and Younghee.too come.PAST.DECL
'Chelsoo came, and Younghee came, too.'

d. Chelsoo-ka o-ass-ko, Younghee-to [$_{VP}$kuleha]-yss-ta.
Chelsoo.NOM come.PAST.and Younghee.too come.PAST.DECL
'Chelsoo came, and Younghee came, too.'

Since the VP parts of two conjuncts in (2a) are identical, the VP of the second conjunct is elided in (2b) but it results in an ungrammatical sentence. In (2c), we have a *ha*-support, which is similar to *do*-support in the English sentence in (1b), to take a past tense morpheme *-ess*. However, the *ha*-support does not save the sentence. On the other hand, in (2d), the pro-form *kuleha-ta* is inserted into the elided VP position, and it makes the sentence grammatical. In this sentence, the pro-form *kuleha-ta* refers to the verb *o-ass-ta* 'come' in the first conjunct. The example sentences in (1) and (2) demonstrate that English has VP-ellipsis phenomena but that Korean has VP-anaphora.

The goals of this paper are (i) to develop a unified algorithm which can analyze these two different phenomena and (ii) to explain them using the developed algorithm.[1] In order to analyze both VP-ellipsis and VP-anaphora phenomena in HPSG (Pollard and Sag, 1994; Sag et al., 2003; Kim and Sells, 2008), this paper adopts basic ideas from Categorial Grammar (CG) and provides resolution algorithms for these two different phenomena.

This paper follows the tradition of previous studies and calls the site for VP-ellipsis and VP-anaphora the *target* and the elided VP or the antecedent VP the *source*. Though there are many interesting syntactic phenomena related to VP-ellipsis or VP-anaphora such as quantifiers, scope, strict/sloppy reading, and so on, this paper only focuses on how to search for the source predicate from the target site.

2 Previous Approaches to VP-Ellipsis and VP-Anaphora

2.1 VP-Ellipsis in HPSG

In the traditional HPSG framework, ellipsis has been analyzed with one of the NICE properties where NICE refers to negation, insertion, contraction, and ellipsis. For example, the following pair of sentences contains an ellipsis. (Sag et al., 2003, p. 419)

(3) a. Would there be any point in asking for seconds?
b. Yes, there would.

Here, the second sentence (3b) contains an ellipsis, and the elided VP is *be any point in asking for seconds*.

In order to handle this kind of ellipsis phenomena, Sag et al. (2003, p. 419) proposed the following *d-rule* in their accounts.

[1]This paper is not the first trial to provide a unified analysis of two typologically different phenomena, VP-ellipsis and VP-anaphora. Several previous studies including Hardt (1993) proposed the possibility that VP-ellipsis and VP-anaphora can be analyzed with similar (resolution) algorithms.

$$\begin{bmatrix} \textit{d-rule} & \\ \text{INPUT} & \left\langle \boxed{1}, \begin{bmatrix} \textit{aux-v-lxm} \\ \text{ARG-ST} \left\langle \boxed{2} \right\rangle \oplus \boxed{A} \end{bmatrix} \right\rangle \\ \text{OUTPUT} & \left\langle \boxed{1}, \begin{bmatrix} \textit{aux-v-lxm} \\ \text{ARG-ST} \left\langle \boxed{2} \right\rangle \end{bmatrix} \right\rangle \end{bmatrix}$$

Figure 1: *d-rule* for Ellipsis

Through this *d-rule*, the input Attribute-Value Matrix (AVM) is mapped onto the output AVM. As you can observe in this *d-rule*, the argument structure of the auxiliary lexeme *aux-v-lxm* is changed through the rule and the complement of the auxiliary is deleted in the output AVM.

If we explain the sentence (3b) using this *d-rule*, it will be as follows. First, the input feature structure of the auxiliary *will* will be as in Figure 2. (Sag et al., 2003, p. 419)

$$\left\langle \textit{will}, \begin{bmatrix} \textit{word} & \\ \text{SYN} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{FORM } \textit{fin} \\ \text{AUX } + \\ \text{POL } - \\ \text{AGR } \boxed{1} \end{bmatrix} \\ \text{VAL} & \begin{bmatrix} \text{SPR} \left\langle \begin{bmatrix} \text{AGR } \boxed{1} \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \\ \text{ARG-ST} \left\langle \text{NP} \right\rangle & \\ \text{SEM} & \begin{bmatrix} \text{MODE } \textit{prop} & \\ \text{INDEX } s_1 & \\ \text{RESTR} & \left\langle \begin{bmatrix} \text{RELN } \textbf{will} \\ \text{SIT } s_1 \\ \text{ARG } s_2 \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle$$

Figure 2: The Auxiliary *will* before *d-rule*

If the auxiliary *will* goes through the *d-rule* in Figure 1, the AVM of Figure 2 is changed into that of Figure 3.

$$\left\langle \textit{will}, \begin{bmatrix} \textit{word} \\ \text{SYN} \begin{bmatrix} \text{HEAD} \begin{bmatrix} \text{FORM } \textit{fin} \\ \text{AUX } + \\ \text{POL } - \\ \text{AGR } \boxed{1} \end{bmatrix} \\ \text{VAL} \begin{bmatrix} \text{SPR } \left\langle \boxed{2} \begin{bmatrix} \text{AGR } \boxed{1} \end{bmatrix} \right\rangle \\ \text{COMPS } \langle\rangle \end{bmatrix} \end{bmatrix} \\ \text{ARG-ST } \left\langle \boxed{7}\text{NP} \right\rangle \\ \text{SEM} \begin{bmatrix} \text{MODE } \textit{prop} \\ \text{INDEX } s_1 \\ \text{RESTR } \left\langle \begin{bmatrix} \text{RELN } \textbf{will} \\ \text{SIT } s_1 \\ \text{ARG } s_2 \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle$$

Figure 3: The Auxiliary *will* after *d-rule*

As you can see in the AVM in Fogure 3, the COMP value becomes NULL after applying the *d-rule*. This implies that the auxiliary *will* takes no complement. This means that the VP part is elided in the sentence (3b).

Even though this kind of analysis can explain how the sentence (3b) can be formed, it does not provide an account for which VP is elided after the auxiliary *will* and how the elided part can be recovered from the sentence. As mentioned in the Section 1, since the goal of this paper is to provide a resolution algorithm for VP-ellipsis and VP-anaphora, a more technical algorithm will be developed to account for which VP is elided after the auxiliary *will* and how the elided part can be recovered from the sentence.[2]

2.2 VP-Ellipsis and VP-Anaphora in CG

Through a series of papers (Jacobson, 1996, 1999, 2000, 2001), Pauline Jacobson has developed an alternative categorial approach to pronominal anaphora resolution and applied it to a wide range of empirical phenomena. She introduced a third slash connective that is responsible for anaphoric dependencies, and she used the

[2]I don't deny that VP-ellipsis and VP-anaphora demonstrate different syntactic distributions. As pointed out by many previous studies including Hankamer and Sag (1976) and Sag and Hankamer (1984), the syntactic behaviors of VP-ellipsis are different from those of VP-anaphora. I don't deny the facts. What I want to mention in this paper is that these two different phenomena can be handled with similar resolution algorithms even though they show different syntactic behaviors.

notation A^B for signs of category A that needs an antecedent of category B. On the other hand, Jäger (2010) used other notation $A|B$ to stress the similarity with the other slashes. In their analyses of anaphora, a pronominal *himself* has a category $NP|NP$, and it translates into $\lambda x.x$.

Based on the category and meaning of *himself*, Jacobson analyzed the sentence *John likes himself* as in Figure 4.

$$
\dfrac{
 \dfrac{\mathit{John}}{\begin{matrix}\text{JOHN'}\\ np\end{matrix}}\,\mathit{lex}
 \qquad
 \dfrac{
  \dfrac{\dfrac{\mathit{likes}}{\begin{matrix}\text{LIKE'}\\(np\backslash s)/np\end{matrix}}\,\mathit{lex}}{\begin{matrix}\lambda yz.\text{LIKE'}(yz)\\(np\backslash s)/np|np\end{matrix}}\,\mathbf{Z}_{\lessgtr}
  \quad
  \dfrac{\mathit{himself}}{\begin{matrix}\lambda x.x\\np|np\end{matrix}}\,\mathit{lex}
 }{\begin{matrix}\lambda z.\text{LIKE'}(z)\\np\backslash s\end{matrix}}\,\mathbf{A}_{>}
}{\begin{matrix}\text{LIKE'JOHN'JOHN'}\\ s\end{matrix}}\,\mathbf{A}_{>}
$$

Figure 4: Jacobson's Analysis of the Sentence *John likes himself*

A Geach rule **Z** is applied to the verb *likes*. Its syntactic category is changed from $(np\backslash s)/np$ to $(np\backslash s)/np|np$, and its semantic interpretation is changed from LIKE' to λyz.LIKE'(yz).[3] Then, the verb *likes* combines with the NP *himself* by $\mathbf{A}_{>}$. Then, the VP *likes himself* combines with the NP *John* by $\mathbf{A}_{<}$.[4] As the final semantic interpretation demonstrates, Jacobson's analysis also succeeded in capturing the meaning of reflexive *himself*.

Jäger (2010) developed a Lambek Calculus with Limited Contraction (LLC) in his book, where a limited version of the Contraction is complied into the logical rules of a logical connective. In his analyses of anaphora, a pronominal *himself* has a category $NP|NP$, and it translates into $\lambda x.x$. Based on the category and meaning of *himself*, she analyzed the sentence *John likes himself* as in Figure 5.

[3]Jacobson (2008, p. 49) mentioned that **Z** is a operation which takes a type $<$a,$<$e,b$>>$ and maps it into a type $<<$e,a$>$,$<$e,b$>>$ such that $\mathbf{Z}(\alpha)=\lambda f[\lambda x[\alpha(f(x))(x)]]$.

[4]Here, $\mathbf{A}_{>}$ refers to a *forward functional application* $\mathbf{A}_{<}$ to a *backward functional application*.

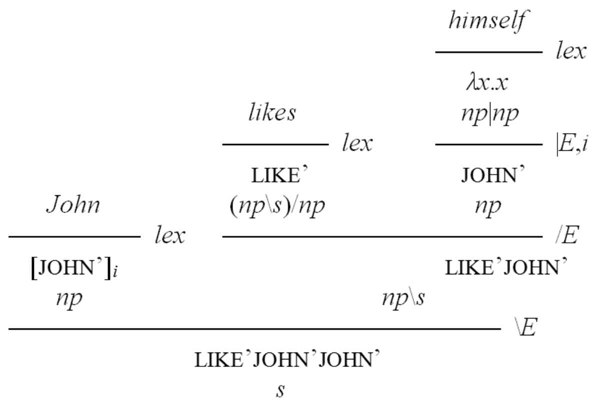

Figure 5: Jäger's Analysis of the Sentence *John likes himself*

For the word *himself*, the $|$-elimination rule is applied. Its syntactic category is changed from *np*$|$*np* to *np*, and its semantic interpretation is changed from $\lambda x.x$ to JOHN'. Then, the $/$E is applied when the verb *likes* combines with the NP *himself*, and the $\backslash$E is applied when the NP *John* combines with the VP *likes himself*.[5] As we may observe in the final semantic interpretation, Jäger's analysis also correctly captured the meaning of reflexive *himself*.

Then, the dummy auxiliary *do* in English and the pro-form *kuleha-ta* in Korean may have a category $(S\backslash NP)|(S\backslash NP)$ whose translation is $\lambda P.P$. As for category combinatorics for the anaphora, Jacobson adopted Geach rules while Jäger (2010) used $|$-elimination and $|$-introduction rules in the analyses. Based on the category and meaning of the auxiliary *did*, she analyzed the sentence *John walked and Bill did* as in Figure 6. (Jäger, 2010, p. 187)

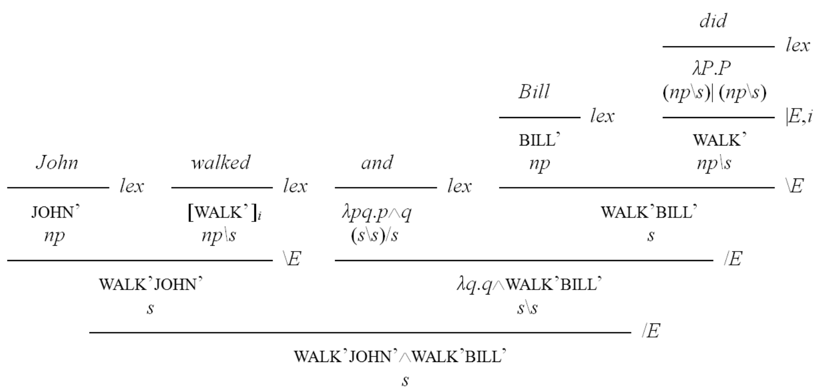

Figure 6: Jäger's Analysis of the Sentence *John walked and Bill did*

[5] Here, $/$E corresponds to a *forward functional application* and $\backslash$E to a *backward functional application* respectively in the CG literature.

For the word *did*, the $|$-elimination rule is applied. Its syntactic category is changed from $(np\backslash s)|(np\backslash s)$ to $np\backslash s$, and its semantic interpretation is changed from $\lambda P.P$ to WALK'. Then, the $\backslash$E is applied when the NP *Bill* combines with the verb *did*, and the /E is applied when a conjunction and combines with the S *Bill did*. Likewise, the $\backslash$E is applied when the NP *John* combines with the verb *walked*. Finally, the /E is applied when the first conjunct *John walked* combines with the second one *Bill did*. As the final semantic interpretation demonstrates, Jäger's analysis correctly recovers the elided part of VP-ellipsis in English.

3 VP-Ellipsis and VP-Anaphora Resolution in HPSG

3.1 Basic Ideas

For the purpose of analyzing both VP-ellipsis and VP-anaphora phenomena in HPSG, this paper incorporates Jäger's anaphora resolution algorithms. In this paper, English VP-ellipsis and Korean VP-anaphora are analyzed as follows. First, the English auxiliary *do* and the Korean pro-form *kuleha-ta* are introduced with the Geach value, and this value is changed with a *slash-elimination* rule. Then, one constituent combines with another by ordinary syntactic rules in HPSG, while the information on the target predicate is percolated up. When the target predicate meets a potential source predicate, a *slash-introduction* rule is applied and the Geach value was changed again. Then the potential source predicate activates the *VP-resolution* rule, and the target predicate is connected with the source in the semantic representations.[6]

3.2 Type Hierarchy and AVM

In order to provide a unified analysis to VP-ellipsis and VP-anaphora phenomena, this paper incorporates Jäger's ideas into the typed feature structure formalism of HPSG and modifies type hierarchy and feature structures as follows.

In the Lexicon, a new type *ellip-ana-aux-v-lxm* is introduced into the type hierarchy as in Figure 7, and English *do* and Korean *kuleha-ta* are instances of *ellip-aux-v-lxm* and *ana-aux-v-lxm* respectively. The AVM for the type *ellip-ana-aux-v-lxm* is shown in Figure 8.

Four attributes/features are introduced into the typed feature formalism: GEACH, ELLIP/ANTE, ASTORE, and PRED-ST. The first one encodes whether a Geach rule is applied or not. If a Geach rule is applied, its value becomes +. If the VP-ellipsis/VP-anaphora resolution algorithms are activated, its value becomes -. For the second attribute, if the given auxiliary is an instantiation of *ellip-aux-v-lxm*, the auxiliary has ELLIP and it refers to the label of the elided VP. If the given auxiliary is an instantiation of *ana-aux-v-lxm*, the auxiliary has ANTE instead and it refers to the label of the antecedent VP. The third attribute PRED-ST contains the

[6] This paper assumes that Minimal Recursion Semantics (Copestake et al., 2005) is used in the semantic interpretation.

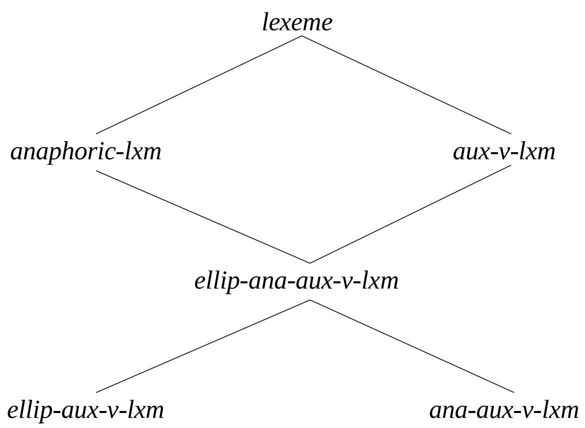

Figure 7: Hierarchy for the Type *ellip-ana-aux-v-lxm*

$$\left[\begin{array}{l}
\textit{ellip-ana-aux-v-lxm} \\
\text{STEM } \textit{*dlist*} \\
\text{SYN} \left[\begin{array}{l} \textit{syn} \\ \text{CAT} \left[\text{HEAD } \textit{verb}\right] \\ \text{GEACH } \textit{boolean} \end{array}\right] \\
\text{SEM} \left[\begin{array}{l}
\text{HOOK} \left[\begin{array}{l} \text{LTOP } \textit{handle} \\ \text{INDEX } \boxed{1}\ \textit{index} \\ \text{XARG } \textit{handle} \end{array}\right] \\
\text{KEY } \boxed{2} \\
\text{RELS} \left\langle \boxed{2} \left[\begin{array}{l} \textit{relation} \\ \text{PRED } \textit{string} \\ \text{ARG0 } \boxed{1} \\ \text{ARG1 } \textit{index} \\ \text{ELLIP/ANTE } \textit{handle} \end{array}\right] \right\rangle \\
\text{HCONS} \langle\rangle
\end{array}\right] \\
\text{ASTORE} \left[\text{VP-ANA } \textit{*list*}\right] \\
\text{PRED-ST } \textit{*list*} \\
\text{DTRS } \textit{*list*}
\end{array}\right]$$

Figure 8: AVM for the Type *ellip-ana-aux-v-lxm*

predicates of the sentences. The fourth attribute ASTORE (anaphoric expression store) contains the HCONS values in A-HCONS (anaphoric expression HCONS), that encode which source predicate refers to which target predicate.

3.3 Slash Rules

Three types of slash rules are introduced into the type hierarchy to analyze VP-ellipsis and VP-anaphora phenomena in HPSG. They are *slash-elimination* rule (|E), *slash introduction* rule (|I), and *VP-resolution* rule (VP-Resol). These rules are organized in the type hierarchy as follows.[7]

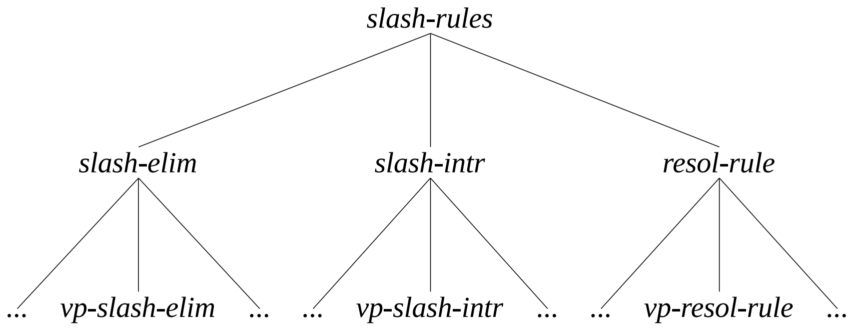

Figure 9: Type Hierarchy for Slash Rule

A *slash-elimination* rule changes the value of GEACH from - to +. Along with this change, a hook for the target predicate has to be stored in other parts of the AVM. A *slash-introduction* rule is triggered when the target predicate meets a potential source predicate, and this rule changes the value of GEACH from + to -. A *VP-resolution* rule finds out the source predicate and connects the target predicate with its source predicate.

4 An Analysis of VP-Ellipsis in English

Based on the AVM of the type *ellip-aux-v-lxm* in Figure 8 and the slashes rules in Figure 9, the overall analysis processes of English VP-ellipsis are as follows. Here, the important operations are marked with Step A, Step B, and Step C.

In the Step A, the English *do* introduced into syntax with the feature [GEACH -].[8] Then, when there is an *ellip-aux-v-lxm* with [GEACH -], a *slash-elimination* rule (|E) is applied and the feature structure of *do* are changed as shown in Figure 11.

[7]Jacobson (2008) also proposed similar unary rules, though her formalism is different from mine.

[8]Although VP-ellipsis and VP-anaphora are two different phenomena, the function of an auxiliary *do* in the English VP-ellipsis seems to be similar to that of the pro-form *kuleha-ta* in Korean. Jacobson (2008, p. 57) also mentioned similar idea. She said that, in the analysis of VP-ellipsis, *note that we are not positing a silent proform in the ellipsis site; the auxiliary itself is the 'proform'*.

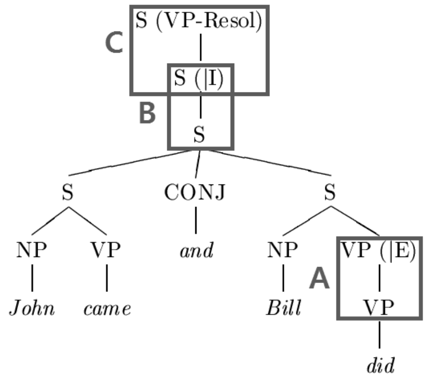

Figure 10: An Example Analysis of VP-Ellipsis

After the *slash-elimination* is applied, the GEACH value is changed from - to +, and HCONS includes a new *qeq* whose HARG value is equal to the ELLIP value of English *do*. Here, LARG will refer to the handle of the source predicate in the final step of the algorithm. This HCONS value is stored in A-HCONS of VP-ANA.

Then, the top part of feature structure in Figure 11 is percolated up until PRED-ST contains a potential source predicate. In the English sentence (1), when the first conjunct *John came* combines with *Mary did*, since PRED-ST contains a potential predicate (*came*), a *slash-introduction* (|I) is applied in Step B and the AVM of Figure 11 is changed into that of Figure 12 (Step B).

$$\left[\begin{array}{ll}
\text{SYN} & \left[\begin{array}{l}\text{CAT}\left[\text{HEAD } \textit{verb}\right]\\ \text{GEACH} +\end{array}\right]\\
\text{SEM} & \left[\begin{array}{l}\text{RELS}\left\langle \boxed{5}\left[\begin{array}{l}\textit{do_ellip_rel}\\ \text{LBL } \boxed{6}\\ \text{ARG0 } \boxed{7}\\ \text{ARG1 } \boxed{8}\\ \text{ELLIP } \boxed{9}\end{array}\right]\right\rangle\\ \text{HCONS}\left\langle \boxed{12}\left[\begin{array}{l}\textit{qeq}\\ \text{HARG } \boxed{9}\\ \text{LARG } \textit{handle}\end{array}\right]\right\rangle\end{array}\right]\\
\text{ASTORE } \boxed{B} & \left[\text{VP-ANA}\left\langle\left[\text{A-HCONS } \boxed{12}\right]\right\rangle\right]\\
\text{PRED-ST}\langle\rangle &
\end{array}\right]$$

$$\left[\begin{array}{ll}
\text{SYN} & \left[\begin{array}{l}\text{CAT}\left[\text{HEAD } \textit{verb}\right]\\ \text{GEACH} -\end{array}\right]\\
\text{SEM} & \left[\begin{array}{l}\text{RELS}\left\langle \boxed{5}\left[\begin{array}{l}\textit{do_ellip_rel}\\ \text{LBL } \boxed{6}\\ \text{ARG0 } \boxed{7}\\ \text{ARG1 } \boxed{8}\\ \text{ELLIP } \boxed{9}\end{array}\right]\right\rangle\\ \text{HCONS}\langle\rangle\end{array}\right]\\
\text{ASTORE} & \left[\text{VP-ANA}\langle\rangle\right]\\
\text{PRED-ST}\langle\rangle &
\end{array}\right]$$

did

Figure 11: Applying a *slash-elimination* Rule

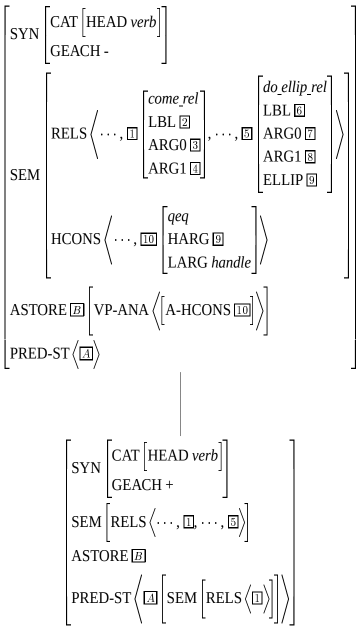

Figure 12: Applying a *slash-introduction* Rule

This rule changes the value of GEACH from + to -, which implies that there is a potential source predicate for the VP-ellipsis phenomena. This potential source predicate will activate the *VP-resolution* rule.

In Step C, the *VP-resolution* rule (VP-Resol) is applied when (i) the value of GEACH is - and (ii) VP-ANA is not empty. Then, the AVM of Figure 12 is changed into that of Figure 13.

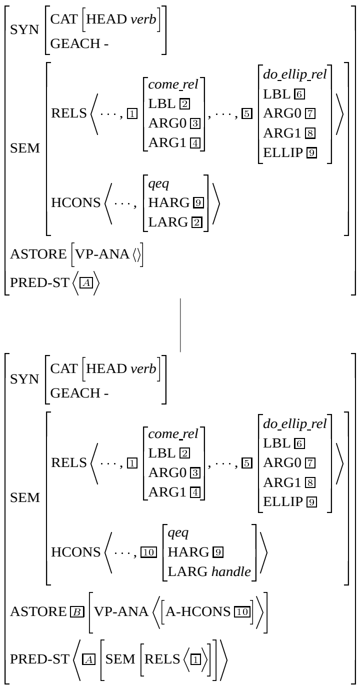

Figure 13: Applying a *VP-resolution* Rule

Since the PRED-ST value has the AVM of the verb *came* in the first conjunct, it also contains the RELS value of *came* in the MRS. Then, the *VP-resolution* rule searches for the LBL value of the source predicate *came* and it connects the value to the LARG value of A-HCONS (in VP-ANA). Then, after the LARG of A-HCONS gets its value, VP-ANA becomes empty. This implies that the handle of the ELLIP value of *do_ellip_rel* is identical to the LBL value of *come_rel*, which in turn means that the head of the elided VP is *come*.[9]

5 An Analysis of VP-Anaphora in Korean

On the other hand, the VP-anaphora in Korean can be analyzed as follows, based on the AVM of the type *ana-aux-v-lxm* in Figure 8 and slashes rules in Figure 9.

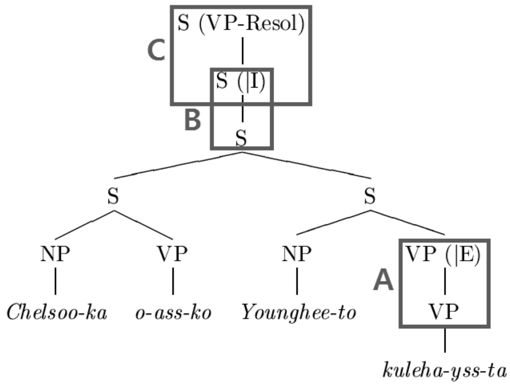

Figure 14: An Example Analysis of VP-Anaphora

As in English example, the important operations are marked with Step A, Step B, and Step C.

In the Step A, the Korean pro-form *kuleha-ta* introduced into syntax with the feature [GEACH -]. Then, since there is an *ana-aux-v-lxm* with [GEACH -], a *slash-elimination* rule (|E) is applied and the AVM of *kuleha-ta* is changed as shown in Figure 15.

[9]The VP-ellipsis resolution algorithm developed in this paper may be applied to the analysis of Antecedent Contained Deletion (ACD) constructions, though some problems such as Kennedy's puzzle Kennedy (1994) has to be solved.

$$
\begin{bmatrix}
\text{SYN} & \begin{bmatrix} \text{CAT} & \begin{bmatrix}\text{HEAD } \textit{verb}\end{bmatrix} \\ \text{GEACH} & + \end{bmatrix} \\
\text{SEM} & \begin{bmatrix} \text{RELS} & \left\langle \boxed{5} \begin{bmatrix} \textit{kuleha-ta\_ana\_rel} \\ \text{LBL } \boxed{6} \\ \text{ARG0 } \boxed{7} \\ \text{ARG1 } \boxed{8} \\ \text{ELLIP } \boxed{9} \end{bmatrix} \right\rangle \\
\text{HCONS} & \left\langle \boxed{12} \begin{bmatrix} \textit{qeq} \\ \text{HARG } \boxed{9} \\ \text{LARG } \textit{handle} \end{bmatrix} \right\rangle \end{bmatrix} \\
\text{ASTORE } \boxed{B} & \begin{bmatrix} \text{VP-ANA} \left\langle \begin{bmatrix} \text{A-HCONS } \boxed{12} \end{bmatrix} \right\rangle \end{bmatrix} \\
\text{PRED-ST} & \langle\rangle
\end{bmatrix}
$$

$$
\begin{bmatrix}
\text{SYN} & \begin{bmatrix} \text{CAT} & \begin{bmatrix}\text{HEAD } \textit{verb}\end{bmatrix} \\ \text{GEACH} & - \end{bmatrix} \\
\text{SEM} & \begin{bmatrix} \text{RELS} & \left\langle \boxed{5} \begin{bmatrix} \textit{kuleha-ta\_ana\_rel} \\ \text{LBL } \boxed{6} \\ \text{ARG0 } \boxed{7} \\ \text{ARG1 } \boxed{8} \\ \text{ELLIP } \boxed{9} \end{bmatrix} \right\rangle \\
\text{HCONS} & \langle\rangle \end{bmatrix} \\
\text{ASTORE} & \begin{bmatrix} \text{VP-ANA } \langle\rangle \end{bmatrix} \\
\text{PRED-ST} & \langle\rangle
\end{bmatrix}
$$

kuleha-yss-ta

Figure 15: Applying a *slash-elimination* Rule

After the *slash-elimination* is applied, the GEACH value is changed from - to +, and HCONS includes a new *qeq* whose HARG value is equal to the ANTE value of the Korean pro-form *kuleha-ta*. Here, LARG will refer to the handle of source predicate in the final step of the algorithm. This HCONS value is stored in A-HCONS of VP-ANA.

Then, the top part of feature structure in Figure 15 is percolated up until PRED-ST contains a potential source. In the sentence (2), when the first conjunct *Chelsoo-ka o-ass-ko* combines with *Younghee-to kuleha-yss-ta*, since PRED-ST contains a potential predicate (*o-ass-ko*), a *slash-introduction* is applied and the AVM of Figure 15 is changed into that of Figure 16 (Step B).

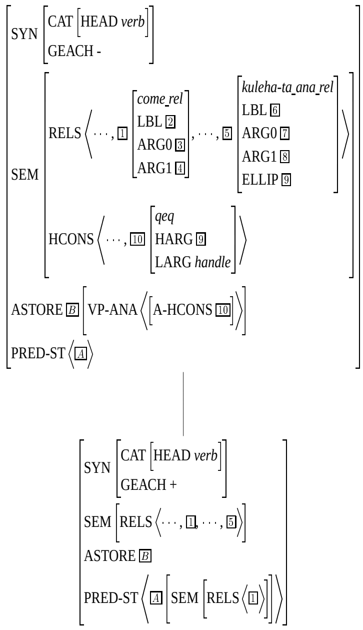

Figure 16: Applying a *slash-introduction* Rule

This rule changes the value of GEACH from + to -, which implies that there is a potential source predicate for the VP-anaphora phenomena. This potential source predicate will activate the *VP-resolution* rule.

In Step C, as in the analysis of English VP-ellipsis, the *VP-resolution* rule (VP-Resol) is applied when (i) the value of GEACH is - and (ii) VP-ANA is not empty. Then, the AVM of Figure 16 is changed into that of Figure 17.

$$
\begin{bmatrix}
\text{SYN} & \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD } \textit{verb} \end{bmatrix} \\ \text{GEACH -} & \end{bmatrix} \\
\text{SEM} & \begin{bmatrix} \text{RELS} & \left\langle \cdots, \boxed{1} \begin{bmatrix} \textit{come\_rel} \\ \text{LBL } \boxed{2} \\ \text{ARG0 } \boxed{3} \\ \text{ARG1 } \boxed{4} \end{bmatrix}, \cdots, \boxed{5} \begin{bmatrix} \textit{kuleha\_ana\_rel} \\ \text{LBL } \boxed{6} \\ \text{ARG0 } \boxed{7} \\ \text{ARG1 } \boxed{8} \\ \text{ELLIP } \boxed{9} \end{bmatrix} \right\rangle \\
\text{HCONS} & \left\langle \cdots, \begin{bmatrix} \textit{qeq} \\ \text{HARG } \boxed{9} \\ \text{LARG } \boxed{2} \end{bmatrix} \right\rangle \end{bmatrix} \\
\text{ASTORE} & \begin{bmatrix} \text{VP-ANA } \langle\rangle \end{bmatrix} \\
\text{PRED-ST} & \left\langle \boxed{A} \right\rangle
\end{bmatrix}
$$

$$
\begin{bmatrix}
\text{SYN} & \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD } \textit{verb} \end{bmatrix} \\ \text{GEACH -} & \end{bmatrix} \\
\text{SEM} & \begin{bmatrix} \text{RELS} & \left\langle \cdots, \boxed{1} \begin{bmatrix} \textit{come\_rel} \\ \text{LBL } \boxed{2} \\ \text{ARG0 } \boxed{3} \\ \text{ARG1 } \boxed{4} \end{bmatrix}, \cdots, \boxed{5} \begin{bmatrix} \textit{kuleha-ta\_ana\_rel} \\ \text{LBL } \boxed{6} \\ \text{ARG0 } \boxed{7} \\ \text{ARG1 } \boxed{8} \\ \text{ELLIP } \boxed{9} \end{bmatrix} \right\rangle \\
\text{HCONS} & \left\langle \cdots, \boxed{10} \begin{bmatrix} \textit{qeq} \\ \text{HARG } \boxed{9} \\ \text{LARG } \textit{handle} \end{bmatrix} \right\rangle \end{bmatrix} \\
\text{ASTORE } \boxed{B} & \begin{bmatrix} \text{VP-ANA} \left\langle \begin{bmatrix} \text{A-HCONS } \boxed{10} \end{bmatrix} \right\rangle \end{bmatrix} \\
\text{PRED-ST} & \left\langle \boxed{A} \begin{bmatrix} \text{SEM} \begin{bmatrix} \text{RELS } \langle \boxed{1} \rangle \end{bmatrix} \end{bmatrix} \right\rangle
\end{bmatrix}
$$

Figure 17: Applying a *VP-resolution* Rule

Since the PRED-ST value includes the AVM of the verb *o-ass-ko* of the first conjunct, it also contains the RELS value of *come_rel* in the semantic interpretation. Then, the *VP-resolution* rule searches for the LBL value of source predicate *come_rel* and it connects the value to the LARG value of A-HCONS (in VP-ANA). Then, after LARG of A-HCONS gets its value, VP-ANA becomes empty. This implies that the handle of the ANTE value of *kuleha-ta_ana_rel* is identical to the LBL value of *come_rel*, which in turn means that *kuleha-yss-ta* refers to *o-ass-ko*.

6 Conclusion

In this paper, a unified resolution algorithm was developed which can account for both VP-ellipsis and VP-anaphora in HPSG. In order to analyze these two phenomena, this paper incorporated Jäger's anaphora resolution mechanism into the typed feature structure formalism of HPSG, and these two typologically phenomena were explained using the unified resolution algorithm.

In this paper, English VP-ellipsis and Korean VP-anaphora were analyzed as follows. First, the English auxiliary *do* and the Korean pro-form *kuleha-ta* were introduced with the Geach value, and this value was changed with a *slash-elimination* rule. Then, one constituent combined with another by ordinary syntactic rules in HPSG, while the information on the target predicate was percolated up. When the target predicate met a potential source predicate, a *slash-introduction* rule is applied and the Geach value was changed again. Then, the source predicate activates the *VP-resolution* rule, and the target predicate is connected with the source in the semantic representation.

Through the analysis, we observed that both VP-ellipsis and VP-anaphora could be analyzed with a unified resolution algorithm. This was possible by incorporating the type *ellip-ana-aux-v-lxm* and three kinds of slash rules in the type hierarchy.

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