# A Computational Treatment of Coordinate Conjunctions

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## ABSTRACT

This paper reports on the implementation of a general method for recognizing conjunctional strings in text sentences and for applying detailed welformedness constraints to conjunctional strings with ellipsis. In particular, we describe the conjunction algorithm of the most recent implementation of the New York University Linguistic String Parser (LSP). The algorithm provides for dynamic generation of definitions which cover a rich variety of conjoined word classes or word class sequences encountered in sentences. The algorithm also locates the "zeroed", or implicit, elements which are found in many conjunctional occurrences. This enables the Parser to execute restrictions on structures with ellipsis as though they were complete. It also provides the basis for the transformational expansion of conjunction strings into complete assertions. The expansion transformation is currently operative and will be described in a later paper.

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# A COMPUTATIONAL TREATMENT OF COORDINATE CONJUNCTIONS

Carol Raze

One particularly intricate problem in the computer parsing of natural language texts is the complexity introduced into the parsing system by conjunctions. This complexity is due to the richness of conjunctional constructions and to the material implicit in sentences containing conjunctions. This article describes the current treatment of conjunctions in the New York University Linguistic String Parser (LSP)[1] and how our generalized approach enables the system to handle a very broad range of conjoined structures without adding unduly to the size of the grammar. The conjunction algorithm provides a mechanism for the dynamic generation of the appropriate conjunctional structure whenever a conjunction is encountered in parsing a sentence. Another mechanism locates the "zeroed" or implicit elements which are found in conjunctional occurrences involving ellipsis. This is accomplished by modifying a small number of basic routines used throughout the grammar. The recovery of the zeroed material from the sentence is crucial so that the grammatical and semantic constraints which are the key to obtaining a correct analysis can be applied to all relevant parts of the sentence. The recovery of the zeroed material is also the first step in transformational analysis.

Tables 1 and 2 below give examples of the types of structures which are handled by the conjunction algorithm and others which are still being worked on. This article is divided into five main sections: 1. The Parsing System, 2. Basic Routines of the Grammar, 3. The Definition of Conjunction Strings, 4. Restrictions under Conjunctions, and 5. Conjunction Routines. Sections 2 and 5 are very detailed and can be omitted by the general reader.

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[1] The LSP system has been operative since 1966 in several programmed versions. The main documentation can be found in Refs. 1-5.

TABLE 1

Examples of Structures Handled by the Conjunction Algorithm

| Type of Conjoined Structure | Example Sentence |
|---|---|
| Conjunct is word category | We ate fruit, vegetables, and meat. |
| Conjunct is word category + Adjuncts | Lead comes from the solder or other metal in the can. (2 syntactic parses) |
| Conjunct is complete string | He is not getting all the news but he does not care. |
| Conjunct is segment of string | He read the questions and discussed the answers.<br>The canned baby and infant foods were inspected.<br>(2 syntactic parses; a third not included as too rare) |
| Ellipsis--Middle part of sentence under conjunction is missing | He ate cake and she did also.<br>He ate cake and she cookies. |
| Ellipsis--complete sentence is missing | Lactones inhibit ion transfer but only at high concentrations. |
| Ellipsis in nested structures | He understood our demands but his advisers did not try to. |
| Ellipsis with reference to a nested structure | He tried to understand our demands but his advisers did not. (2 transformational expansions) |

TABLE 2

Examples of Structures Which Are Still Being Worked On

| Type of Conjoined Structure | Example Sentence |
|---|---|
| Ellipsis before conjunction in asymmetrical conjoining | We talked about and admired the candidate.<br>They did not want to but finally accepted our demands. |

## 1. THE PARSING SYSTEM

Before going into the details of the treatment of conjunctions we must review the general features of the parsing system in which the conjunction algorithm is incorporated. The parser obtains a surface structure analysis in the form of a string decomposition of a sentence. In accordance with linguistic string theory [6] each sentence is composed of elementary word sequences of a few given types, statable as word class sequences (called linguistic strings). Each sentence contains one center string (an elementary sentence) and zero or more adjunct strings, adjoined to the left or right of elements of the center string or of other adjuncts. In addition, string occurrences may be restricted with regard to the subclasses of words that can co-occur in the same string or in adjoined strings. A string as a whole may also have adjunct strings (called sentence adjuncts) which occur at stated points in the string.

Figure 1 is an example of the computer output of the string decomposition of One rumor hastily printed can ruin careers. Line 2 in Fig. 1 shows that rumor can ruin careers is the center string which has the form of an assertion. Rumor has a left adjunct string LN whose decomposition is shown on line 3 and a right adjunct string RN whose decomposition is shown on line 4. LN consists of the quantifier one. RN is the passive string called VENPASS which consists of the past participle printed preceded by the adjunct hastily. In this example the object position (PASSOBJ) after the verb is null.

To produce syntactic analyses of natural language sentences the computer program uses two components: a word dictionary [7] and an English grammar [8], both of which are geared to handle English scientific texts. The word dictionary assigns to each word its major syntactic categories, e.g., noun, verb, adjective, etc., which may in turn have subcategories. The grammar consists

FIGURE 1

Computer Output of the String Decomposition of

One rumor hastily printed can ruin careers.

1. SENTENCE = INTRODUCER CENTER ENDMARK

2.

2. ASSERTION = SA SUBJECT SA TENSE SA VERB SA OBJECT RV SA

3. rumor 4. can ruin careers

3. LN = TPOS QPOS APOS NSPOS NPOS

one

4. VENPASS = LVSA VENPASS SA PASSOBJ RV SA

4. printed

5. DSTG = D

hastily

of two parts: a context-free component and a set of restrictions. The context-free component defines the sets of center and adjunct strings of the grammar. The definitions are written in Backus Normal Form. An example of a string definition is:

<ASSERTION> ::= <SA><SUBJECT><SA><TENSE><SA><VERB><SA><OBJECT><RV><SA>.

Each of the elements of ASSERTION is also defined in the grammar. In the above example, SA (sentence adjunct) and RV (post-object right adjunct of verb) are adjunct sets; therefore their occurrence in a sentence is optional. SUBJECT, TENSE, VERB, and OBJECT are positions corresponding to required elements of the string. Each position may have alternate values in different sentences.

The parser analyzes a sentence by building a parse tree for the sentence. The tree represents the particular combination of strings and adjuncts whose terminal nodes combine to produce a well-formed sentence, or more exactly a

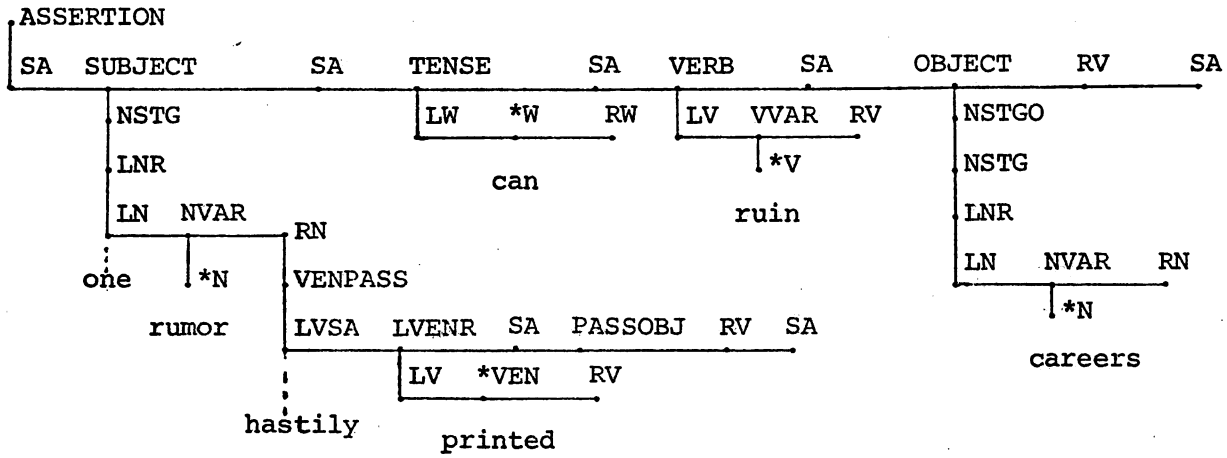
well-formed sequence of word categories which match those of the sentence words. A parse tree of ASSERTION for One rumor hastily printed can ruin careers is shown in Fig. 2. The computer output in Fig. 1 is a compressed version of the parse tree in Fig. 2. In this parse tree the elements of a string are shown as a sequence of connected sibling nodes. Thus the elements of ASSERTION are shown one level below the ASSERTION node, in the order in which they appear in the definition of ASSERTION. The terminal nodes of the tree are either word class symbols which correspond to sentence words (*N = rumors) or are null nodes. The null nodes are automatically satisfied without subsuming sentence words. In adjunct set positions they represent the fact that adjunct occurrences are optional. (In the parse tree diagrams the null nodes are omitted.)

A standard type of structure that is frequently seen in the tree is called the "LXR" node. An example is the LNR node in Fig. 2. An LXR definition consists of three elements: a position for the left adjuncts of X, a core position for the word class X, and a position for the right adjuncts of X. The core position as a rule subsumes a sentence word of class X. For example, in Fig. 2, in the SUBJECT of ASSERTION, NVAR is the core position of LNR and has the value N corresponding to rumor. NVAR (Noun Variants) will have one of several alternate values, namely noun, pronoun, Ving, etc. The "LXR" type structure is important in that both the restrictions and the conjunction mechanism depend on this regularized representation of an element and its adjuncts.

The restrictions are a set of detailed well-formedness rules which must be satisfied before an analysis is accepted. The restrictions may be strictly grammatical, such as one governing the case of a pronoun. Such a restriction will succeed for They ruined careers but not for Them ruined careers. Or the

FIGURE 2

Parse tree* of One rumor hastily printed can ruin careers.




*The terminal nodes which are null are not shown in the parse tree diagrams. In order to keep the tree diagrams as uncluttered as possible the details of certain substructures have been omitted but the sentence word(s) subsumed by those substructures are shown. Three vertical dots below which are sentence words signifies such an omission.

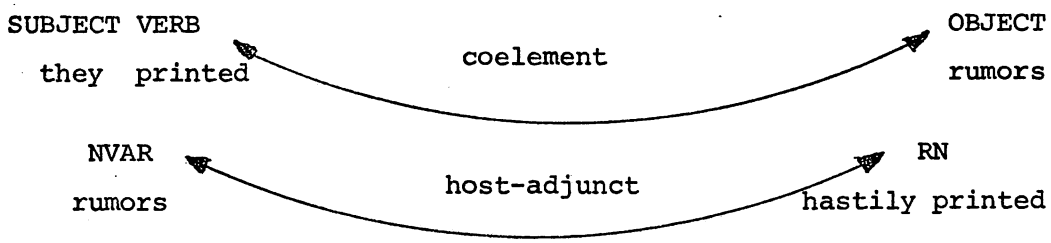
restrictions may express selectional constraints; these will succeed for sequences that are considered possible within a given area of discourse. E.g., in normal discourse one can say They printed rumors but not They printed critics. Each restriction is compiled into a series of basic operations and tests which are performed on the parse tree while parsing a sentence. The restrictions mainly test conditions between two elements of a string or between a string element and its adjunct.

Figure 3 illustrates two of the relations used by restrictions. For the Verb-Object selectional restriction of the grammar to operate on They printed rumors, the coelement relation is used to test whether the co-occurrence of the object (rumors) and the verb (printed) is well-formed. On the other hand, in Rumors hastily printed can ruin careers the host-adjunct relation is used to test the noun rumors and the verb printed since the verb here appears in the

right adjunct string of rumors. Because the restrictions use these basic string relations (coelement, left-adjunct, right-adjunct) so often to test for well-formed sequences, these relations are encoded into basic routines (COELEMENT, LEFT-ADJUNCT, RIGHT-ADJUNCT, etc.), which in turn use basic tree operations (up, down, left, right, test for x, etc.) [9]. For example, in the LNR sequence subsuming one rumor hastily printed, shown in Fig. 2, the routine RIGHT-ADJUNCT goes from the core noun rumor to its right-adjunct string hastily printed.

FIGURE 3

Restrictions Use String Relations




The use of the basic routines by the restrictions greatly facilitates the formulation of the restrictions. One routine contains many tree operations. The use of these routines also facilitates modification of the grammar. If there is a basic change in the grammar, the affected routines are changed but the restrictions themselves do not have to be. The extensive use of routines by the restrictions plays a significant role in the treatment of conjunctions, as will be described later.

Both the restrictions and the routines are written in a programming language developed for the LSP [10]. The syntax of the restriction language includes three main statement types. One part of the language is similar to a subset of English in that the statements consist of a subject followed by a predicate. For example, THE CORE OF THE SUBJECT IS PRONOUN. Another part of the restriction language consists of logical connectives, such as

IF___THEN___, EITHER___OR___, BOTH___AND___, which permit the logical combination of restriction statements. For example,

IF THE CORE OF THE SUBJECT IS PRONOUN X1
THEN X1 IS NOT ACCUSATIVE.

Another type of restriction language statement consists of a series of commands which are used mainly for writing the routines. A command may consist of a basic tree operation such as GO UP, or a call to execute a restriction routine, such as DO ELEMENT(X), or a call to execute another restriction statement, such as DO $1. There are provisions for saving a node in a register and for restoring a node from a register. For example, STORE IN X1, GO TO X1. The commands may also be logically combined.

## 2. BASIC ROUTINES OF THE GRAMMAR[2]

There are about thirty basic routines in the grammar. Described here in detail are the ones which represent the major grammatical relations among words in a sentence and are important in the treatment of conjunctions.

CORE ROUTINE

```
ROUTINE CORE        = DO $CORE-PATH.
$CORE-PATH          = ONE OF $AT-ATOM, $DESCEND-TO-ATOM, $DESCEND-TO-STRING.
$AT-ATOM            = TEST FOR ATOM.
$DESCEND-TO-ATOM    = DESCEND TO ATOM NOT PASSING THROUGH ADJSET1.
$DESCEND-TO-STRING = DESCEND TO STRING NOT PASSING THROUGH ADJSET1.
```

The CORE routine locates the sentence word corresponding to a higher level grammatical element E by descending to a terminal node ("atom") from E. This is done by $DESCEND-TO-ATOM. When CORE descends from E it does not look at structures which are adjuncts, i.e., on list ADJSET1. Thus for One rumor hastily printed can ruin careers shown in Fig. 2, above, the routine CORE,

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[2] A listing of the routines appears as part of the LSP grammar of English in Ref. 8.

starting at SUBJECT, will not search below the left-adjunct node LN (arriving mistakenly at one) and will arrive at N (the noun rumor). Sometimes the starting location of CORE will be an atomic node. This is provided for by $AT-ATOM, which tests whether the current node is an atomic node, i.e., on list ATOM. Sometimes a string occurs in a particular sentence in place of a noun. In His printing rumors ruined careers, shown in Fig. 4, the string NSVINGO satisfies the SUBJECT OF ASSERTION. This situation is provided for by $DESCEND-TO-STRING. Thus CORE starting at SUBJECT in Fig. 4, will locate the string NSVINGO.

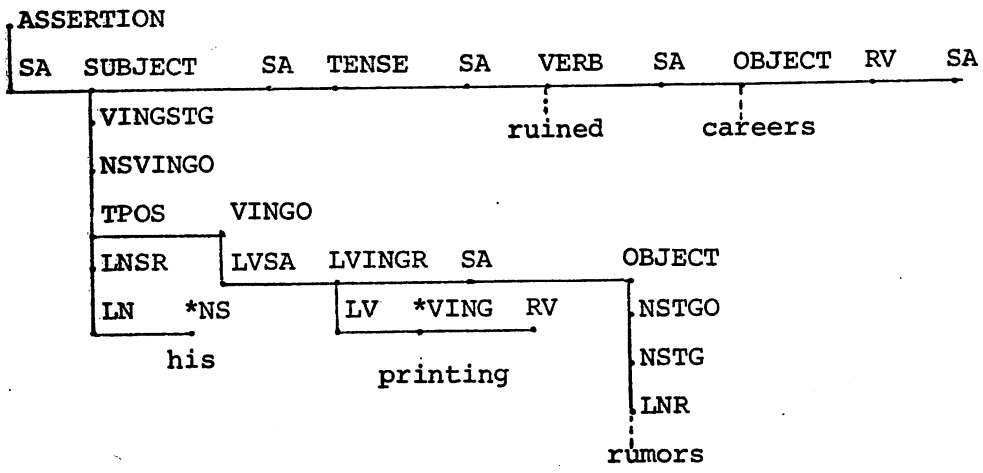
ELEMENT ROUTINE

```
ROUTINE ELEMENT(X) = EITHER DO DOWN1(X)
                     OR $STRING-SEGMENT.
$STRING-SEGMENT    = DO DOWN1(STGSEG);
                     DO DOWN1(X).
ROUTINE DOWN1(X)   = GO DOWN; ITERATET GO RIGHT
                     UNTIL TEST FOR X SUCCEEDS.
```

It is assumed that ELEMENT starts at node Y and that X is an element of the string corresponding to Y. Thus ELEMENT locates X by searching the level below Y. This is done by routine DOWN1(X) which first goes to the level below Y by executing the command GO DOWN and then searches the nodes on that level until it finds X. The latter step is accomplished by an iterate command: ITERATET GO RIGHT UNTIL TEST FOR X SUCCEEDS. In Fig. 2 the execution of ELEMENT(SUBJECT), starting at the string node ASSERTION, will locate the node SUBJECT. Sometimes it is more convenient to define a string Y by using the name of another string X in the definition of Y instead of naming all the elements of X. This is the case in Fig. 4 where VINGO, a defined string of the grammar appears as a string segment of NSVINGO. In this situation not all the elements of NSVINGO are on one level below NSVINGO but some are one level

FIGURE 4

Parse tree of His printing rumors ruined careers.




below the string segment VINGO of NSVINGO. $STRING-SEGMENT, therefore, searches one level below Y for a node on the string segment list STGSEG and if it finds one, it searches for X one level below the string segment. In Fig. 4, ELEMENT(OBJECT), starting at NSVINGO, first locates VINGO by executing DOWN1(STGSEG) and then locates OBJECT by executing DOWN1(OBJECT).

COELEMENT ROUTINE

```
ROUTINE COELEMENT(X) = ONE OF $SAME-LEVEL, $X-IN-SEGMENT, $Y-IN-SEGMENT.
$SAME-LEVEL          = DO COEL1(X).
$X-IN-SEGMENT        = DO COEL1(STGSEG);
                       DO ELEMENT(X).
$Y-IN-SEGMENT        = GO UP;
                       TEST FOR STGSEG;
                       DO COEL1(X).
ROUTINE COEL1(X)     = EITHER DO LEFTR(X)
                       OR DO RIGHTR(X).
ROUTINE LEFTR(X)     = ITERATE GO LEFT UNTIL TEST FOR X SUCCEEDS.
ROUTINE RIGHTR(X)    = ITERATE GO RIGHT UNTIL TEST FOR X SUCCEEDS.
```

Given that X and Y are elements of some string, COELEMENT starts at Y and goes to X. COELEMENT uses several other basic routines: ROUTINE LEFTR(X) goes

left from Y until it locates X; ROUTINE RIGHTR(X) searches to the right of Y to locate X; and combining the two, ROUTINE COEL1(X) searches both sides of Y to find X. In Fig. 4, COELEMENT(SUBJECT), starting at VERB in ASSERTION, locates SUBJECT by executing $SAME-LEVEL. ROUTINE LEFTR(SUBJECT) successfully locates SUBJECT, which is to the left of VERB; this satisfies COEL1(SUBJECT), which satisfies $SAME-LEVEL. If X is in a string segment, COELEMENT will locate it by executing $X-IN-SEGMENT. In Fig. 4, COELEMENT(OBJECT), starting at TPOS, first locates VINGO by executing COEL1(STGSEG). It then locates OBJECT by calling routine ELEMENT(OBJECT). A different situation occurs when COELEMENT(TPOS) starts at OBJECT. This situation is handled by $Y-IN-SEGMENT. First, the string segment VINGO is located by the sequence GO UP; TEST FOR STGSEG. Then TPOS is located by routine COEL1(TPOS), which searches the same level as VINGO to find TPOS.

RIGHT-ADJUNCT ROUTINE

```
ROUTINE RIGHT-ADJUNCT     = DO RIGHT-ADJUNCT-POS;
                            DO CORE.
ROUTINE RIGHT-ADJUNCT-POS = EITHER $ASCNT OR TRUE;
                            DO RIGHTR(RADJSET).
$ASCNT                    = ASCEND TO AVAR OR NVAR OR QVAR OR VVAR.
```

It is assumed that RIGHT-ADJUNCT starts at the core of an LXR type node. It goes to the core of the right-adjunct position in the LXR sequence. For example, in the LXR sequence LN NVAR RN (one rumor hastily printed), shown in Fig. 2, the routine RIGHT-ADJUNCT-POS, starting at N (rumors) ascends to NVAR by executing $ASCNT and then goes to RN by executing the routine RIGHTR(RADJSET). RIGHT-ADJUNCT goes to VENPASS by executing the CORE routine. Thus the passive string VENPASS (hastily printed) is located as the right adjunct of the noun rumor.

LEFT-ADJUNCT ROUTINE

```
ROUTINE LEFT-ADJUNCT = DO LEFT-ADJUNCT-POS;
                       EITHER TEST FOR LN
                       OR DO CORE.
ROUTINE LEFT-ADJUNCT-POS = EITHER $ASCNT OR TRUE;
                           DO LEFTR(LADJSET).
```

LEFT-ADJUNCT is similar to RIGHT-ADJUNCT except it goes to the core of the left-adjunct position of an LXR sequence. If the left-adjunct position is LN, however, the routine stops there since it is assumed that further operations will be specified to locate a particular left adjunct of the noun, e.g., a quantifier or an adjective.

HOST ROUTINE

```
ROUTINE HOST = CORE OF THE HOST-ELEMENT EXISTS.
ROUTINE HOST-ELEMENT = ONE OF $AT-LADJ, $AT-RADJ, $AT-RNSUBJ IS TRUE.
$AT-LADJ = EITHER TEST FOR LADJSET
           OR ASCEND TO LADJSET;
           GO RIGHT.
$AT-RADJ = EITHER TEST FOR RADJSET
           OR ASCEND TO RADJSET;
           EITHER $RV-IN-STRING
           OR GO LEFT.
$RV-IN-STRING = TEST FOR RV;
                STORE IN X100;
                GO UP;
                TEST FOR TYPE STRING:
                EITHER $RV-IN-OBJECT OR $RV-IN-CENTER.
$RV-IN-OBJECT = TEST FOR NTOVO OR NTHATS OR NSNWH OR PNTHATS OR PNTHATSVO
                OR PNSNWH;
                ASCEND TO OBJECT;
                DO VERB-COELEMENT.
$RV-IN-CENTER = GO TO X100;
                DO VERB-COELEMENT.
```

```
$AT-RNSUBJ = EITHER TEST FOR RNSUBJ
             OR ASCEND TO RNSUBJ;
             ASCEND TO SA;
             DO COELEMENT(SUBJECT).
```

It is assumed that the routine HOST-ELEMENT starts at node Y, which is in or at an adjunct position in an LXR structure. It goes from the adjunct position to the core position of the LXR structure. HOST then goes to the CORE of the node located by HOST-ELEMENT. For example, consider the operation of the HOST routine on the parse tree shown in Fig. 2 where HOST starts at the right-adjunct string VENPASS = hastily printed. $AT-LADJ fails but $AT-RADJ ascends to RN by executing ASCEND TO RADJSET and goes left to NVAR. The CORE routine then locates N (rumors). A similar situation occurs when HOST starts at LN. TEST FOR LADJSET succeeds and HOST-ELEMENT goes one node to the right to NVAR. HOST calls the CORE routine which locates N (rumors).

If the HOST routine starts in or at RV (right adjuncts of verb), extra maneuvering is necessary to locate the verb. There are three possibilities. RV may immediately follow the verb as in He ran quickly, shown in Fig. 5. In this case, $RV-IN-STRING fails because the node above RV (i.e., VERB) is not on the string list. HOST-ELEMENT therefore goes left to VVAR, whose core is ran. In some cases, RV follows the object of the verb as in He ran to school quickly, shown in Fig. 6. In this case, $RV-IN-STRING succeeds. The node above RV is the string ASSERTION. $RV-IN-CENTER locates the verbal element VERB (ran) of ASSERTION by calling routine VERB-COELEMENT (a generalized routine for finding a verbal coelement). In other sentences, RV is situated in the middle of an object string. In She told him quickly that he had to leave, shown in Fig. 7, RV is situated after NSTGO (him) in the object NTHATS of the verb told. In this situation $RV-IN-OBJECT locates the verbal element of ASSERTION by ascending to OBJECT and calling routine VERB-COELEMENT.

FIGURE 5

Parse tree of He ran quickly.

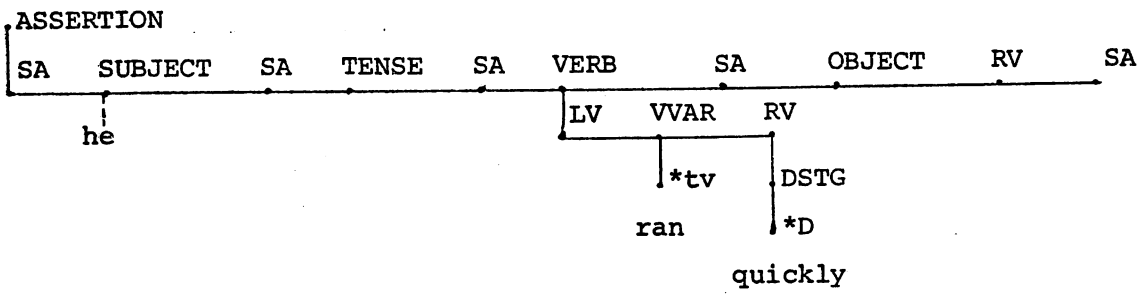



FIGURE 6

Parse tree of He ran to school quickly.

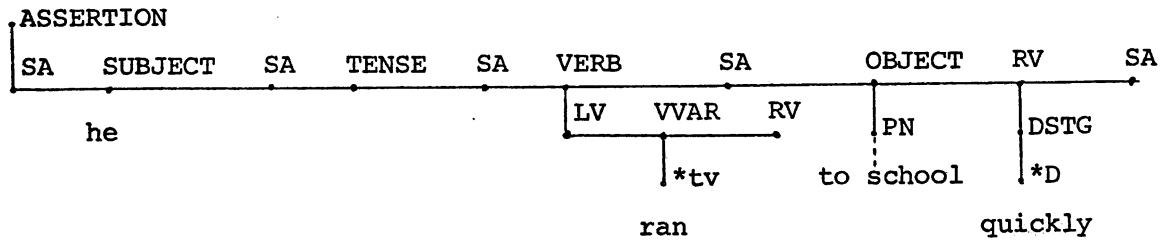
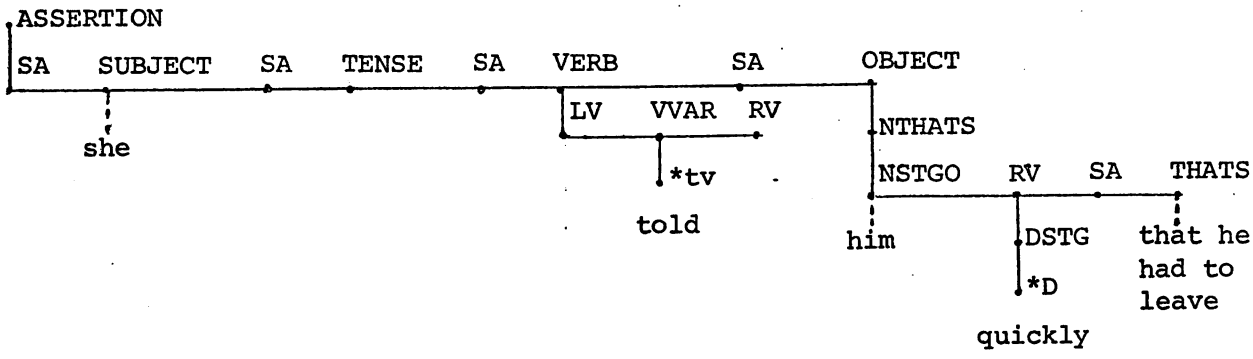



FIGURE 7

Parse tree of She told him quickly that he had to leave.

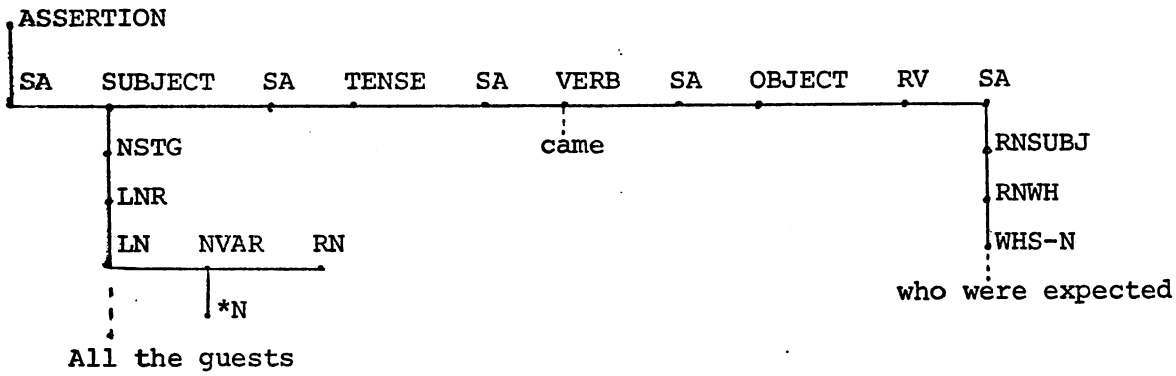



A similar situation arises in sentences where the right adjunct of the subject noun does not immediately follow the noun. In the grammar these occurrences are covered by RNSUBJ in the post-OBJECT sentence adjunct position SA, as shown in Fig. 8. In All the guests came who were expected (Fig. 8),

FIGURE 8

Parse tree of

All the guests came who were expected.




the right adjunct of guests is WHS-N (who were expected). $AT-RNSUBJ locates the position SUBJECT by ascending to SA from RNSUBJ and by calling COELEMENT(SUBJECT) from SA. The HOST routine uses CORE to locate N (guests).

STARTAT ROUTINE

When a node name appears alone (without any routine name) as the subject of a restriction statement, e.g., OBJECT in the restriction statement OBJECT IS EMPTY, the routine STARTAT is invoked, with the node name as argument, e.g., STARTAT(OBJECT).

ROUTINE STARTAT(X) = EITHER DO DOWN1(X) OR TEST FOR X.

It is assumed that X is one level below the current node in which case DOWN1(X) locates X, or that X is the current node in which case TEST FOR X is successful.

## 3. THE DEFINITION OF CONJUNCTION STRINGS

Linguistic string theory provides a concise description of all conjunctional occurrences. An element or a sequence of elements in a string may be conjoined by a conjunctional string which consists of the conjunction followed

by another occurrence of the same type of string element (or elements) that precedes the conjunction. In Hearsay and rumors can ruin careers we have and rumors (AND + SUBJECT = N) conjoined to Hearsay (SUBJECT = N). And in Rumors can ruin careers and can cause much hardship we have and can cause much hardship (AND + TENSE + VERB + OBJECT) conjoined after Rumors can ruin careers (SUBJECT + TENSE + VERB + OBJECT).

Considering that the grammar has over 100 strings and each string has several elements, to include all the conjunctional combinations in the grammar definitions would be to complicate the grammar and to make it immense. Instead an interrupt mechanism is used to achieve the same result.[3] An interruption occurs when a conjunction is reached while parsing a sentence. When an interruption occurs, a conjunctional node is attached to the part of the tree being built. To illustrate, a tree of the noun phrase Hearsay and rumors hastily printed is shown in Fig. 9. After hearsay is matched as a noun an interruption occurs and the special process node ANDSTG is attached to the right of hearsay. However, a restriction limits the insertion of a special process node to occur only in LXR type sequences or in strings, and therefore ANDSTG is rejected in the lowest level. This restriction avoids various redundancies created by conjoining at intermediate levels and regularizes the points of conjunction in the parse tree. When insertion fails, the parser detaches the special process node and continues parsing as if no interruption

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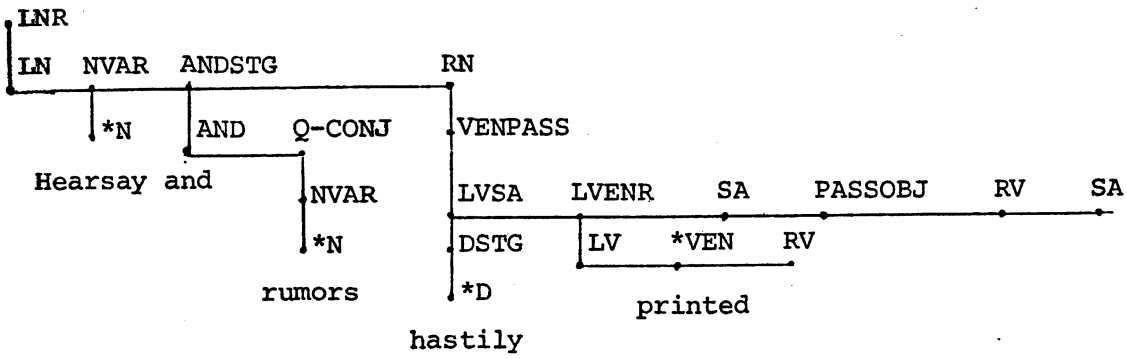
[3]The mechanism described here for generating conjunction strings was first programmed by James Morris for the 1966 IPL version of the LSP (Ref.1, SPR 1). It was expanded in the FAP version of the LSP, programmed by the author (Ref. 1, SPR 2), and is also part of the current FORTRAN implementation by Ralph Grishman (Ref. 4). What is new and is described in this paper is a general method for applying restrictions to conjunctional strings, and overcoming the effects of ellipsis.

FIGURE 9

Parse tree of noun phrase: Hearsay and rumors hastily printed




had occurred. Another interruption may occur, however, after the next element in the tree has been satisfied. Thus for the noun phrase in Fig. 9 an interruption occurs after NVAR is satisfied and ANDSTG is attached to the right of NVAR. ANDSTG consists of and followed by the general conjunctional string Q-CONJ. Q-CONJ contains a restriction which generates a definition for Q-CONJ. Its definition consists of a set of alternate values: the first value is the element to the left of the inserted node, the second consists of the two elements to the left of the inserted node, etc. Thus in Fig. 9 Q-CONJ is NVAR (rumors). The parser resumes by constructing element RN of LNR. Here the right adjunct hastily printed adjoins the conjunction of hearsay and rumors. Another analysis for the noun phrase hearsay and rumors hastily printed is shown in Fig. 10. In this case hearsay has no right adjunct and Q-CONJ consists of the elements NVAR and RN (rumors hastily printed). The difference in these two trees shows the ambiguity in the given sentence.

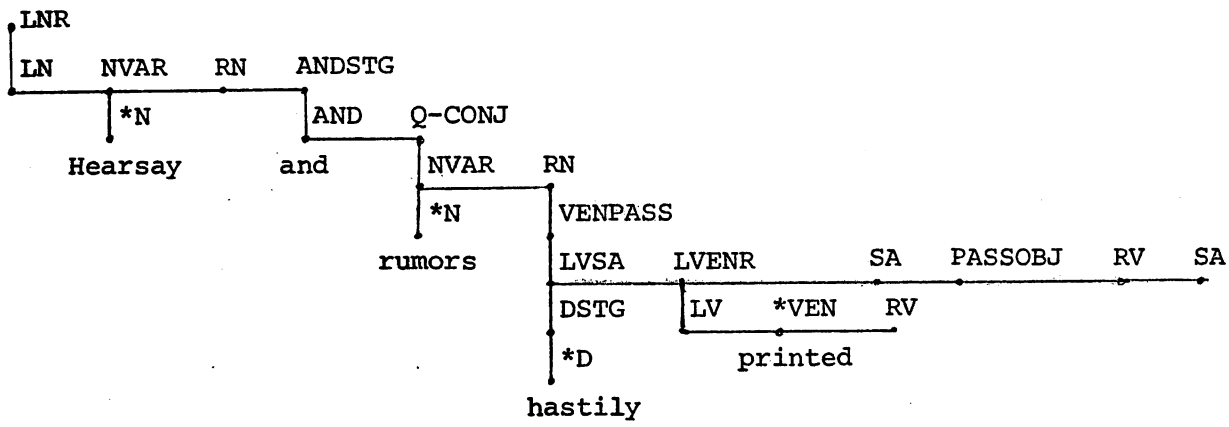
## 4. RESTRICTIONS UNDER CONJUNCTIONS

A sentence with a conjunction presents a problem for the execution of the restrictions. The tree structure will be different from that assumed by the restriction; conjunctional strings will have been inserted and the

FIGURE 10

Another parse tree of noun phrase:

Hearsay and rumors hastily printed




conjunctional strings themselves may be truncated versions of defined strings. To appreciate what this problem means, one must keep in mind that a grammar like that of the LSP for processing English text sentences is very large by comparison with grammars used in most other natural language processing systems, which are directed to particular subsets of English. The LSP grammar consists of approximately 3500 lines. The restrictions comprise by far the largest part of the grammar, and without them, text parsing is out of the question. In addition, we have found that roughly one third of all text sentences contain coordinate or comparative conjunctions, many times in complicated interrelation. It is therefore essential that there be a means for executing restrictions on sentences containing conjunctions.

One solution to this problem is to rewrite all the restrictions so that they test for conjunctions and accomodate truncated segments. This was done in earlier versions of the parser but that involved a tremendous amount of detail and both increased and complicated the grammar enormously. As an alternative, in some cases the sentence can be expanded so that the restrictions operate on complete strings. But in other cases this is not possible because

the expansion necessitates the introduction of certain transformations which should be done later. In the present system we therefore use a general solution whereby restrictions are re-executed automatically for conjunctional occurrences. Thus, in the analysis shown in Fig. 9 of Hearsay and rumors hastily printed the selectional restriction will be executed automatically for the sequences hearsay printed and rumors printed. This is equivalent to expanding the sentence into two assertions, namely, (Someone) printed hearsay and (Someone) printed rumors. The actual expansion is performed in the transformational phase which takes place after the surface analysis is obtained. However, for the correct surface analysis it is crucial that the restrictions operate on expanded or complete strings. Thus, the conjunction computation performs some of the function of expansion prior to the transformational phase.

To apply restrictions to sentences containing conjunctions, a non-deterministic programming mechanism, which we call the stacking mechanism, was incorporated into the parser. This mechanism saves the conjoined structure so that the restriction can be re-executed for the conjoined structure. Because the restrictions depend on the use of routines, this solution necessitated a change mainly in the routines rather than in the restrictions. The routines which were modified are those which locate a basic type of structure in the parse tree, such as the routines CORE, HOST, ELEMENT, LEFT-ADJUNCT, etc. In addition to locating structures the modified routines also test whether or not the structures are conjoined. When a restriction calls a routine which locates a conjoined structure, that routine in turn calls an operator which saves the conjoined structure(s) along with the place of the routine within the sequence of operations being executed in the restriction. The operator puts this information on a re-execution stack. The

routine returns to the original structure located and the restriction interpreter executes the rest of the restriction. At this point the restriction interpreter is "looking at" the original structure located by the routine. When a restriction is successful the restriction interpreter uses the information on the re-execution stack to resume execution of that restriction. The restriction is resumed at the point immediately after the call to the routine so that the routine itself is not called again. Instead however, the restriction interpreter will "look at" the conjoined structure previously located and saved by the routine. For example, when the verb-object selection restriction WSEL1 is executed on the sentence They printed hearsay and rumors, it calls the CORE routine to obtain the core of the object. The CORE routine will go to hearsay, locate and stack rumors, and return to hearsay. WSEL1 will be successful for printed hearsay. WSEL1 will be resumed therefore at the point after the call to the CORE routine and rumors, which was saved by the CORE routine, will be plugged in as though it was just obtained by the CORE routine. WSEL1 will be successful for printed rumors.

In addition to locating conjoined values, the routines also were modified to function properly in the non-conjunctional grammar for new situations due to conjunctions; the routine may be operating in a structure into which conjunctional strings have been inserted or the routine may be operating in a truncated version of a defined string or host-adjunct sequence. For example, the RIGHT-ADJUNCT routine is assumed to start at a node X in an LXR type node. Without conjunctions the RIGHT-ADJUNCT routine goes one node to the right from X to arrive at the right adjunct of X. In Fig. 2, for the noun phrase rumors hastily printed, RIGHT-ADJUNCT, starting at the core position NVAR subsuming rumors, goes one node to the right to arrive at its right adjunct RN (hastily printed). However, with conjunctions the routine must go

right until it lands at a non-conjunctional node. Thus, in Fig. 9, for the noun phrase hearsay and rumors hastily printed, RIGHT-ADJUNCT goes from NVAR (hearsay) past the conjunction string (and rumors) to RN. When RIGHT-ADJUNCT starts in the conjunctional string at NVAR (rumors), RN is not to its right. To go to RN, the routine locates the corresponding preconjunction element NVAR (hearsay) and goes to RN from there.

To illustrate how the stacking mechanism works we will explain in detail how restriction WSEL1 is executed for several sentences with conjunctions. WSEL1 is housed in the center string ASSERTION[4]:

```
WSEL1 = IN ASSERTION:  IF ALL OF $OBJECT-NOUN,
                                 $GOVERNING-VERB,
                                 $FORBIDDEN-NOUN-LIST
                                 ARE TRUE
                       THEN $NOCOMMON.
$OBJECT-NOUN = THE CORE X1 OF THE OBJECT
               X10 IS N OR PRO.
$GOVERNING-VERB = AT X10, COELEMENT VERB X4 EXISTS.
$FORBIDDEN-NOUN-LIST = THE CORE OF X4
                       HAS ATTRIBUTE NOTNOBJ X5.
```

The above restriction statements have the following functions: $OBJECT-NOUN checks that the core of the object position is a noun or pronoun; $GOVERNING-VERB tests that a verb coelement exists; and $FORBIDDEN-NOUN-LIST checks that the given verb has an attribute NOTNOBJ.[5] If all these conditions are

---

[4]WSEL1 is also housed in other strings containing object and verb elements, but for our example we will only consider the string ASSERTION. In the statement $GOVERNING-VERB we can therefore use the routine COELEMENT with argument VERB. In the actual restriction a more general routine VERB-COELEMENT is used. This restriction was described in full, without reference to its operation on conjunction sentences, in Ref. 10.

[5]NOTNOBJ is assigned in the word dictionary to transitive verbs; its attributes for a given verb are those noun subclasses of the grammar which are

satisfied the selection check $NOCOMMON is made.

$NOCOMMON = LISTS X1 AND X5 HAVE NO COMMON ATTRIBUTE.

If the noun does have a subcategory that is on the subcategory list of NOTNOBJ, then $NOCOMMON fails and that noun is not accepted as the object of the given verb.

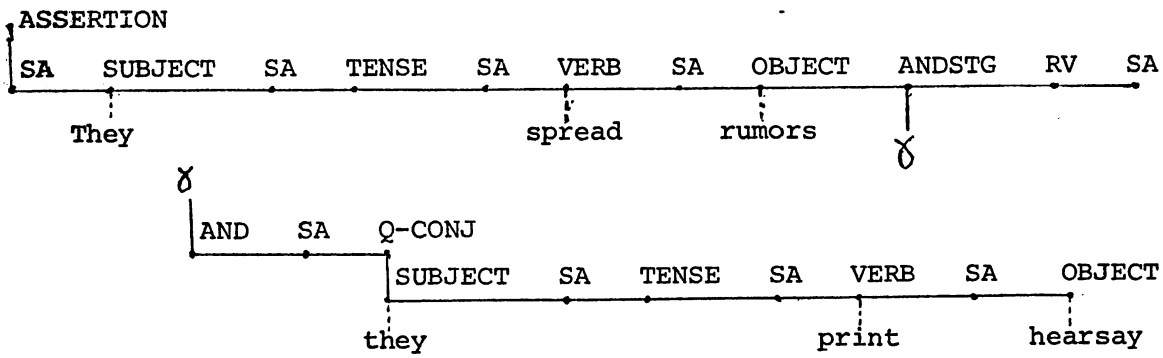
Consider the parse tree for the sentence shown in Fig. 11, They spread rumors and they print hearsay. In $OBJECT-NOUN, in order to go to the core of the OBJECT, OBJECT must first be located. This is accomplished by the routine STARTAT(OBJECT). STARTAT both locates OBJECT and calls the stack operator for each conjoined OBJECT. Thus for the sentence in Fig. 11, STARTAT will go to the first OBJECT (subsuming rumors) and will save the second OBJECT (hearsay). When STARTAT is completed the CORE routine is called to locate the core of OBJECT. In this example it locates the noun rumors.

$GOVERNING-VERB goes to VERB, which is a coelement of OBJECT. It does this by first locating OBJECT (which was saved in register X10 by $OBJECT-NOUN) and by calling the COELEMENT routine. Thus in Fig. 11, COELEMENT(VERB) goes from the first OBJECT to its coelement VERB (spread). It locates all

FIGURE 11

Parse tree of

They spread rumors and they print hearsay.

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not appropriate noun objects of the given verb (in scientific writing).

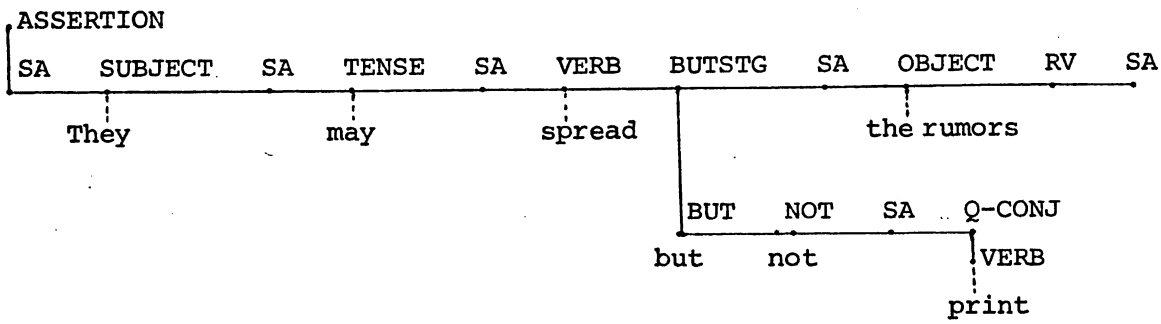
conjuncts of this VERB and determines whether or not to call the stack operator. VERB (spread) has a conjunct but in this case COELEMENT(VERB) will not stack the conjoined VERB (print) because this VERB has its own coelement OBJECT. When COELEMENT returns, the restriction interpreter is looking at the first VERB. WSEL1 is successful for spread rumors. Since there is something on the re-execution stack, the execution of WSEL1 is resumed. It is resumed in $OBJECT-NOUN at the point immediately after the call to STARTAT (OBJECT). However, this time the restriction interpreter is located at the second OBJECT. The core (hearsay) of the second OBJECT is obtained and the rest of the restriction is executed for the second time. In particular, COELEMENT(VERB) goes to the second VERB (print) from the second OBJECT and WSEL1 is successful for print hearsay.

For the sentence shown in Fig. 12, They may spread but not print the rumors, the execution of WSEL1 is different. The OBJECT (the rumors) has no conjunct but the VERB does. In this case the COELEMENT(VERB) routine goes to the first VERB (spread) from OBJECT and saves the second VERB (print) on the re-execution stack. WSEL1 is successful for spread rumors. Its execution is

FIGURE 12

Parse tree of

They may spread but not print the rumors.



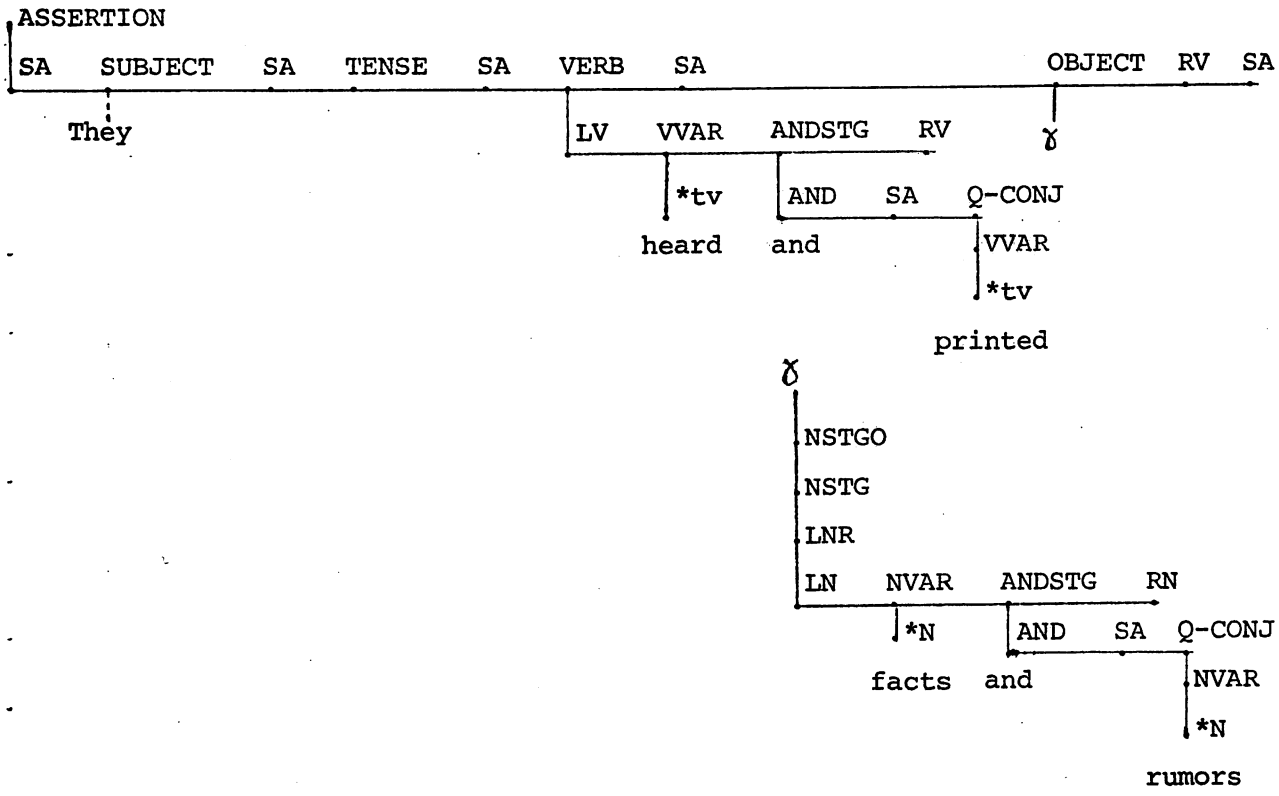
therefore resumed in $GOVERNING-VERB at the point just after the call to COELEMENT(VERB). However, this time the restriction interpreter is looking at the second VERB (print). Therefore the well-formedness of print rumors is also checked.

For the sentence shown in Figure 13, They heard and printed facts and rumors, the execution of WSEL1 is again different from the previous examples.

FIGURE 13

Parse tree of

They heard and printed facts and rumors.




OBJECT itself has no conjunct but the core of OBJECT does. Thus, when CORE is called in $OBJECT-NOUN, the CORE routine will locate N (facts) and will place the second N (rumors) on the re-execution stack. Likewise, the COELEMENT(VERB) routine will not find a conjunct for the VERB position itself. However, the core of the VERB has a conjunct. When CORE is called in

$FORBIDDEN-NOUN-LIST, it will locate tv (heard) and will place the second tv (printed) on the re-execution stack. This will result in WSEL1 being executed for all four verb + object noun sequences: heard facts, heard rumors, printed facts, printed rumors.

The following is an example of how the stacking mechanism helps to resolve syntactic ambiguity. In the sentence He printed rumors and his friend also, there are two possible parses. In one analysis the object of printed consists of the conjoined nouns rumors and friend. This analysis is rejected by WSEL1 in the following manner. When the CORE routine is called in $OBJECT-NOUN, the noun rumors is located and the conjoined noun friend is placed on the re-execution stack. Printed is located by $GOVERNING-VERB. Printed rumors is successful and WSEL1 is re-executed for printed friend. However, printed has NHUMAN on its NOTNOBJ list and friend has a noun subcategory NHUMAN. Thus $NOCOMMON fails and this analysis is rejected.

Another analysis of this sentence contains a second (implicit) occurrence of printed rumors: He printed rumors and his friend also (printed rumors). The conjoined string consists of SUBJECT (his friend) followed by VERB and OBJECT, which both are assigned the values NULLC. The NULLC values are not filled in until the transformational phase. When they are filled in, WSEL1 along with the other selectional restrictions is applied to the string his friend printed rumors also.

Although the changes for CONJUNCTIONS involve some of the basic routines only, the restrictions use these routines so often so that the changes have to be as efficient as possible. Otherwise the execution time of a restriction would be greatly increased.

To save much repetitious moving around the tree, pointers are attached to the appropriate nodes of the tree via a node attribute mechanism, which is

described in Ref. 10. Each element $E_2$ in a conjunctional string of the form $E_1$ CONJ $E_2$ is assigned a node attribute called PRECONJELEM which points to the corresponding element $E_1$ in the string prior to conjunction. Likewise each $E_1$ is assigned a node attribute called POSTCONJELEM which points to the corresponding element $E_2$ in the post-conjunctional string. The node attribute assignments are done by a well-formedness restriction housed on the conjunctional string. Once the node attributes are assigned, the routines can quickly obtain (or check for) conjoined values of a node by using its node attribute POSTCONJELEM. And when a routine is called from inside a truncated string segment, it can quickly move to the corresponding pre-conjunction element by obtaining the node attribute PRECONJELEM. From that point the routine can then locate the appropriate element. For example in Fig. 9, the second NVAR (rumors) has been assigned node attribute PRECONJELEM pointing to a NVAR (hearsay). Using the node attribute PRECONJELEM of the second NVAR, RIGHT-ADJUNCT goes to the first NVAR and then goes two nodes to the right to RN.

## 5. CONJUNCTION ROUTINES

The basic routines of the grammar were modified to handle conjunctions. They were modified to locate the appropriate conjoined structure(s) and call an operator which saves those structure(s). In addition, the routines were modified to function properly in the non-conjunctional grammar for the new situations which occur when conjunctions are present. We will now go into the details of those routines that were modified for conjunctions. The explanations here will be concerned with the modifications only.

Most of the basic routines fall into three categories: 1) those which begin at X or go down to X. STARTAT(X), ELEMENT(X), LAST-ELEMENT and NELEMRT[6] are in this category. These routines concern only one element of a

string or sequence. 2) The routines which go right or left to X. HOST, RIGHT-ADJUNCT, LEFT-ADJUNCT, NEXT-ELEMENT, PREVIOUS-ELEMENT and COELEMENT(X) are in this category. These routines involve two elements of a string or sequence. 3) The routines which start at or go up to X. IMMEDIATE(X), STARTAT(X), PRESENT-ELEMENT, IT, PRESENT-STRING, IMMEDIATE-NODE are in this category. Because the conjunction modification can be generalized depending on which category a routine is in, only several routines are needed to handle various conjunction operations. The actual modification to many of the routines therefore consists of adding a call to one of the few routines which handle conjunctional operations.

The routine that handles stacking for routines of category (1) above is called $STACK-TEST:[7]

```
$STACK-TEST = IF $POSTCONJ THEN $STACK-CONJUNCTS.
$POSTCONJ = THE PRESENT-ELEMENT HAS NODE ATTRIBUTE POSTCONJELEM
                                                        (GLOBAL)
```

It is assumed that the restriction interpreter is "looking at" X when $STACK-TEST is called. If an element $E_1$ has a corresponding element $E_2$ in a conjunctional string $E_1$ will have the node attribute POSTCONJELEM. This provides a quick test to determine whether or not a node has a conjunct. If $E_1$ does not have the node attribute POSTCONJELEM, $POSTCONJ fails and $STACK-TEST is finished; if $E_1$ has the node attribute POSTCONJELEM, the attribute POSTCONJELEM has a value, namely $E_2$. When $POSTCONJ is finished the restriction interpreter will be "looking at" $E_2$.

---

[6] CORE is also in this category, however, this routine needs to perform some extra operations to get to the conjoined core word.

[7] In our system $STACK-TEST is actually a global address instead of a routine. This was done because it is faster to execute an address than a routine.

```
$STACK-CONJUNCTS = VERIFY ITERATE $STACK-X.
$STACK- X = DO $POSTCONJ; STACK.
```

$STACK-CONJUNCTS locates all the conjuncts of the node by iterating $STACK-X. It then returns to the starting node. $STACK-X goes to each conjunct by first executing $POSTCONJ and then calling STACK, the operator which puts the conjunct on the re-execution stack. In Fig. 11, starting at the first OBJECT, $STACK-TEST will call STACK for the second OBJECT. It will return to the first OBJECT, before exiting.

The routines that handle stacking for those routines in category 2 above are called $STACK-FOR-LEFT-TO-X and $STACK-FOR-RGHT-TO-X respectively. We will only go into the details of $STACK-FOR-LEFT-TO-X since $STACK-FOR-RGHT-TO-X is similar. When $STACK-FOR-LEFT-TO-X is called, the restriction interpreter is assumed to be at X. It is also assumed that the routine which called $STACK-FOR-LEFT-TO-X started at some node Y, saved Y in register X200 and went from Y left one or more nodes to arrive at X. For instance, this occurs when the routine COELEMENT(VERB) is called from OBJECT in Fig. 11.

```
$STACK-FOR-LEFT-TO-X = IF $POSTCONJ
                       THEN VERIFY $STACK-IF-NO-Y-RGHT.        (GLOBAL)
```

If X has a corresponding element in a conjunctional string it will have the node attribute POSTCONJELEM. If X does not have the node attribute POSTCONJELEM, $STACK-FOR-LEFT-TO-X is finished. If it does have node attribute POSTCONJELEM, $STACK-IF-NO-Y-LEFT is executed to determine whether or not to stack the conjunct(s):

```
$STACK-IF-NO-Y-RGHT = IF $POSTCONJ
                      THEN EITHER ALL OF $NO-Y-TO-RIGHT,
                                         $DO-STACK,
                                         $STACK-IF-NO-Y-RGHT
                           OR TRUE.
$NO-Y-TO-RIGHT = NOT ITERATE GO RIGHT UNTIL TEST FOR X200 SUCCEEDS.
```

$DO-STACK = STACK.

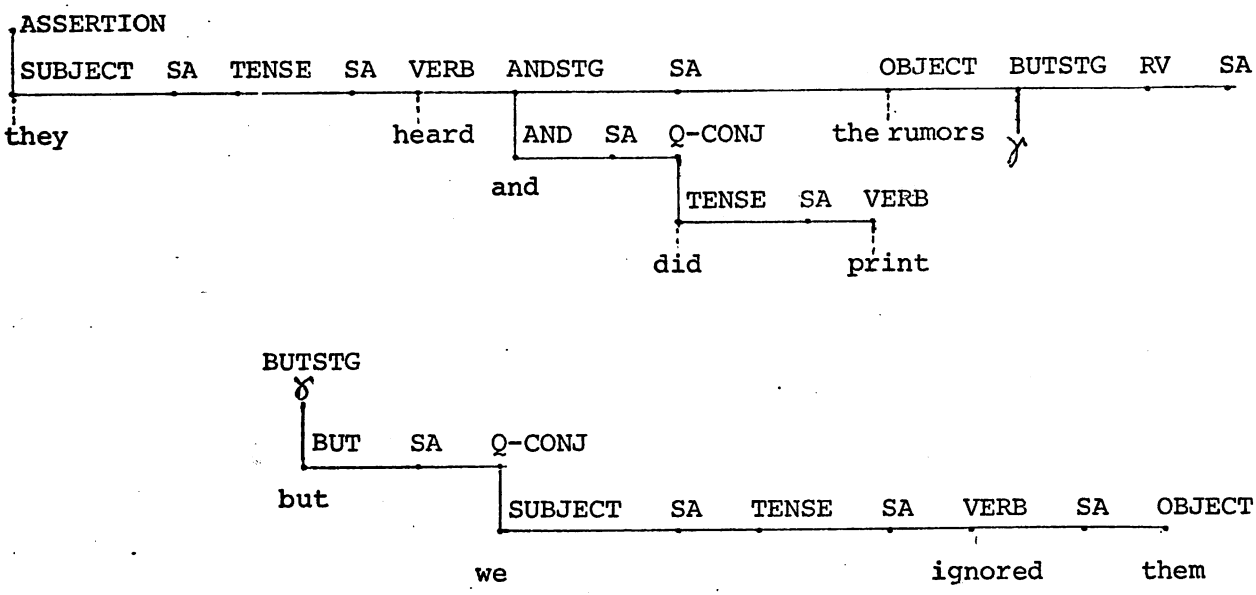
Looking at Fig. 11 assume COELEMENT(VERB) is called when the restriction interpreter is at OBJECT (rumors). The COELEMENT routine locates the first VERB (spread). The premise of $STACK-FOR-LEFT-TO-X is successful because this VERB has a conjunct and $STACK-IF-NO-Y-RGHT is executed. The premise of $STACK-IF-NO-Y-RGHT is successful: a conjunction is found, in this case the second VERB (print). The restriction interpreter remains at the second VERB while the rest of the implication is executed. In this example, there is OBJECT (hearsay) to the right of the second VERB; therefore $NO-Y-TO-RGHT fails. As a result VERB (print) is not stacked. In Fig. 12, if COELEMENT(VERB) is called when the restriction interpreter is at OBJECT (the rumors) the VERB (spread) is located. It has a conjunct, which is stacked. In this case $NO-Y-TO-RGHT is successful since there is no OBJECT to the right of the second VERB.

$STACK-IF-NO-Y-RGHT is recursive so that all the conjoined structures are located and tested. In the above examples if $POSTCONJ is true starting at the second VERB then $STACK-IF-NO-Y-RGHT goes to the next corresponding post-conjunctional VERB and determines whether or not to stack it. In Fig. 14, after executing the premise of $STACK-IF-NO-Y-RGHT the restriction interpreter is at the second VERB. $NO-Y-TO-RIGHT is true and $DO-STACK is executed. It will stack the second VERB. $STACK-IF-NO-Y-RGHT is called recursively and the restriction interpreter is at the third VERB. However, OBJECT (them) is present; therefore $NO-Y-TO-RIGHT will fail and the third VERB (ignored) will not be stacked. Routines COELEMENT, HOST, LEFT-ADJUNCT and PREVIOUS-ELEMENT use $STACK-FOR-LEFT-TO-X. Routines COELEMENT, HOST, RIGHT-ADJUNCT and FOLLOWING-ELEMENT use $STACK-FOR-RGHT-TO-X.

FIGURE 14

Parse tree of

They heard and did print the rumors but we ignored them.




The routines in category 2 were also modified to operate properly if they start in a truncated segment of a defined string or host adjunct sequence. For example, if COELEMENT(OBJECT) is called from the second VERB in Figure 12, the COELEMENT routine will not be able to go left or right to OBJECT. It must first go to the corresponding pre-conjunctional element and then try to go left or right to X from there. This is accomplished by $TO-PRECONJUNCTION-Y.

```
$TO-PRECONJUNCTION-Y = EITHER $PRECONJ OR
                       $ASSIGN-PRECONJELEM                    (GLOBAL)
$PRECONJ = THE PRESENT-ELEMENT- HAS NODE ATTRIBUTE PRECONJELEM.
```

If the starting node has node attribute PRECONJELEM, $PRECONJ will go to the corresponding pre-conjunctional node; otherwise the node attributes PRECONJELEM and POSTCONJELEM have to be assigned. This is accomplished by $ASSIGN-PRECONJELEM:

```
$ASSIGN-PRECONJELEM = VERIFY $LOCATE-CONJNODE;
                      VERIFY $ASSIGN-PRE-AND-POST;
                      DO $PRECONJ.
```

$LOCATE-CONJNODE = ASCEND TO Q-CONJ; GO UP; STORE IN X100.

$ASSIGN-PRE-AND-POST assigns the node attribute PRECONJELEM to the current node. $ASSIGN-PRE-AND-POST is defined in routine PRE-POST-CONJELEM which will be described later. After the node attribute PRECONJELEM is assigned, $ASSIGN-PRECONJELEM goes to the corresponding pre-conjunctional node by executing $PRECONJ. For example in Fig. 12, if COELEMENT(OBJECT) is called from the second VERB, COELEMENT will call $TO-PRECONJUNCTION-Y to go to the first VERB; then it will try to go left or right to locate OBJECT.

Another type of adjustment is needed for restriction routines in category 3 above. The problem occurs when a restriction is executed starting at the conjunctional string Q-CONJ. When the definition for Q-CONJ is generated from the elements of a string, the well-formedness restrictions housed in the elements are transmitted along with the elements. The restrictions on those elements, therefore, were written with the assumption that the starting point is the string that the restrictions were originally housed in--i.e., two nodes up from Q-CONJ. For example in Fig. 12, all restrictions in ASSERTION assume to start at ASSERTION. Thus, the same restriction, starting at Q-CONJ would fail if, for example, we were to test whether the immediate-node of the second VERB is ASSERTION. Therefore, the routines in category 3 execute $UP-THROUGH-Q initially:

$UP-THROUGH-Q = ITERATET $GO-UP-TWICE UNTIL TEST FOR Q-CONJ
FAILS.

$GO-UP-TWICE = GO UP; GO UP.

$UP-THROUGH-Q goes to the node which is two nodes up from the top of a nest of Q-CONJ's.

Routine PRE-POST-CONJELEM assigns the node attribute PRECONJELEM to the elements of Q-CONJ. It is assumed that the starting node is the node above

Q-CONJ. To each element of Q-CONJ that is not on the C-NODE list (ANDSTG, ORSTG, BUTSTG, etc.), it assigns the node attribute PRECONJELEM. Likewise the corresponding pre-conjunction elements will be assigned the node attribute POSTCONJELEM.

```
ROUTINE PRE-POST-CONJELEM = STORE IN X100;
                            DO ELEMENT- (Q-CONJ);
                            DO LAST-ELEMENT-;
                            ITERATE VERIFY $ASSIGN-TEST UNTIL GO LEFT FAILS
$ASSIGN-TEST = EITHER TEST FOR C-NODE OR EITHER $PRECONJ
               [COELl-] OR $ASSIGN-PRE-AND-POST.
```

The routine PRE-POST-CONJELEM saves the starting point in register X100. It then uses the non-stacking routines[8] to go to the last element of Q-CONJ. The node attribute assignments start from the rightmost node of Q-CONJ and proceed left. $ASSIGN-TEST determines whether or not a node attribute should be assigned to a particular node. An assignment is not necessary if the node is on the C-NODE list or if the assignment was already made for the node. If an assignment does not have to be made $ASSIGN-TEST is finished; if one has to be made $ASSIGN-PRE-AND-POST is executed:

```
$ASSIGN- PRE-AND-POST = STORE IN X500;
                        STORE IN X0;
                        GO TO X100;
                        ITERATE $GO-LEFT UNTIL TEST FOR X500 SUCCEEDS;
                        EITHER ITERATE $POSTCONJ [STARTAT]
                        OR TRUE;
                        DO $ASSIGN-POSTCONJELEM;
                        STORE IN X0;
                        GO TO X500;
                        DO $ASSIGN-PRECONJELEM.
```

---

[8] For each routine that stacks, there is a nonstacking counterpart, The non-stacking routines are used for restrictions where stacking is not desired--such as the number agreement restrictions.

$GO-LEFT = ITERATET $UPCONJ UNTIL GO LEFT SUCCEEDS; STORE IN X100.

$UPCONJ = GO UP; TEST FOR Q-CONJ; GO UP.

$ASSIGN-PRE-AND-POST saves the node to be assigned in registers X500 and X0. It then goes to the node saved in X100 (which is initially the starting C-NODE) and locates the corresponding pre-conjunctional element by executing $GO-LEFT until it finds a node which has the same name as that in register X500. That node is saved in X100 so that the search starts there for the next node to be assigned. $ASSIGN-POSTCONJELEM and $ASSIGN-PRECONJELEM assign the node attributes.

We will consider the case where the second OBJECT in Fig. 14 is being assigned node attribute PRECONJELEM. BUTSTG is saved in register X100. $ASSIGN-PRE-AND-POST saves the second OBJECT in registers X0 and X500. It then searches for the corresponding pre-conjunctional element by going left from BUTSTG. The first OBJECT is found. $POSTCONJ fails at the first OBJECT and $ASSIGN-PRE-AND-POST remains there. Node attribute POSTCONJELEM is assigned to the first OBJECT by $ASSIGN-POSTCONJELEM:

$ASSIGN-POSTCONJELEM = ASSIGN THE PRESENT ELEMENT NODE
ATTRIBUTE POSTCONJELEM.

$ASSIGN-PRECONJELEM = ASSIGN THE PRESENT ELEMENT NODE
ATTRIBUTE PRECONJELEM.

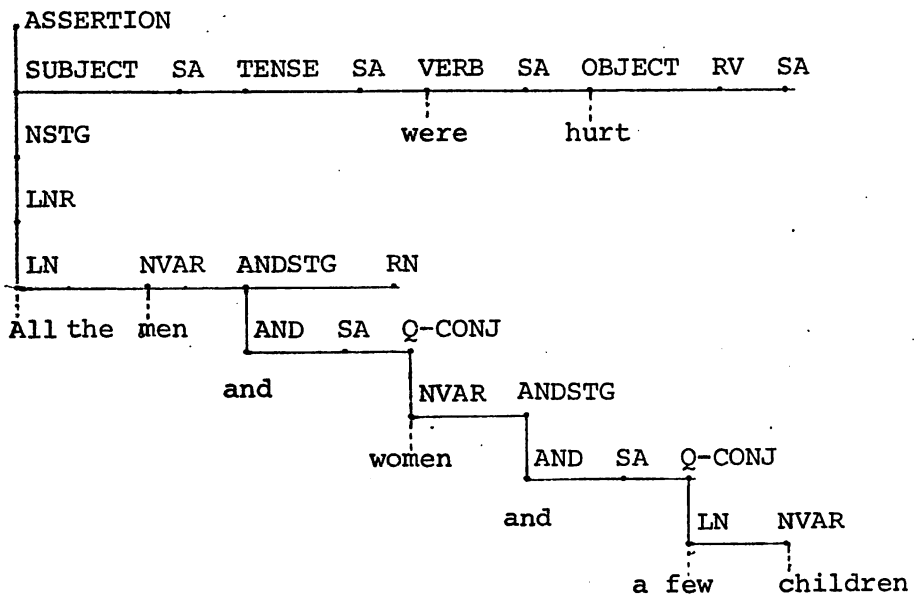
When node attribute POSTCONJELEM is assigned, if there is a node saved in register X0, that node will automatically be assigned as the value of attribute POSTCONJELEM by the node attribute assignment operator. In this case the second OBJECT is in register X0. Therefore the first OBJECT is assigned node attribute POSTCONJELEM with the second OBJECT as its value. After a node attribute assignment is made, register X0 is automatically cleared by the program. This prevents accidental value assignments from occurring in case the grammar writer forgets to clear the register. In the above example, after node

attribute POSTCONJELEM is assigned to the first OBJECT, the first OBJECT is saved in register X0 by $ASSIGN-PRE-AND-POST and the second OBJECT saved in X500 is assigned the node attribute PRECONJELEM with the first OBJECT as its value.

Sometimes a routine starts in a nest of Q-CONJ nodes; the corresponding pre-conjunctional element is not necessarily located on the next higher level. In Fig. 15 when the second LN (a few) is being assigned node attribute PRECONJELEM, PRE-POST-CONJELEM has to go up two Q-CONJ levels to find the corresponding LN. In $GO-LEFT, if the corresponding node is not on the level being searched, $UPCONJ is executed to locate the next level. In the above example, when $GO-LEFT cannot go left from the second NVAR (women), $UP-CONJ goes up to the next higher Q-CONJ and then goes up to the next C-NODE where the search for a corresponding node resumes. Thus LN (a few) is assigned node attribute PRECONJELEM with LN (all the) as its value.

FIGURE 15

Parse tree of All the men and women and a few children were hurt.



In Fig. 14, when the third verb (ignored) is being assigned node attributes by $ASSIGN-PRE-AND-POST, the restriction interpreter goes left from BUTSTG and arrives at the first VERB. The node attributes are chained. Therefore, node attribute POSTCONJELEM of the first VERB should have the second VERB as its value and node attribute POSTCONJELEM of the second VERB should have the third VERB as its value. $ASSIGN-PRE-AND-POST gets the last node of the chain after it arrives at the first VERB. This is done by the section of code . . .; EITHER ITERATE $POSTCONJ [STARTAT] OR TRUE;. . . . In this case VERB (ignored) is assigned node attribute PRECONJELEM with value VERB (print).

Not all restrictions may be re-executed for sentences containing conjunctional occurrences. For example, those restrictions testing number agreement have to be changed to explicitly test for the occurrence of a conjunction. Therefore, those restrictions must use routines that do not stack. Each routine that calls the stack operator has a counterpart which does not. For example CORE calls the stack operator but CORE- does not.

The general conjunction solution applies to the main bulk of sentences containing conjunctions. However, there are some sentences for which the solution does not apply. In He prints rumors and she facts there is zeroing in the middle verb position between the subject and object positions. In this situation the verb is assigned the value NULLC. The filling in of the NULLC values is done in the transformational phase along with the execution of the appropriate well-formedness restrictions.

Because of this general solution only several conjunctional routines had to be written and twenty basic routines had to be changed. This allowed about 200 restrictions to operate on conjunctions without taking explicit account of conjunctions. Since there are about 1000 occurrences of these

routine calls, the economy is significant. And by enabling the restrictions to operate on sentences with conjunctions, this solution reduced the expansion of conjunctional constructions in the transformational phase to a relatively straightforward exercise. In laying the groundwork for this conjunctional solution we have arrived at a concise, formal, and computable description of conjunctional occurrences in the language.

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