ED 055 473 FL 002 345

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TITLE Generating English Discourse from Semantic Networks.
INSTITUTION Texas Univ., Austin.
SPONS AGENCY National Science Foundation, Washington, D.C.
REPORT NO TR-NL-3
PUB DATE Nov 70
NOTE 45p.

EDRS PRICE MF-$0.65 HC-$3.29
DESCRIPTORS Algorithms; *Computational Linguistics; Computer Assisted Instruction; Computer Programs; Deep Structure; Discourse Analysis; *English; Generative Grammar; *Language Research; Phrase Structure; *Semantics; Sentences; Structural Analysis; Structural Linguistics; Surface Structure; *Syntax; Tables (Data); Transformation Generative Grammar; Transformations (Language)

ABSTRACT

The system described in this report is designed for use as a computational tool that allows a linguist to develop and study methods for generating surface strings from an underlying semantic structure. Initial findings with regard to form-determiners (such as voice, form, tense, and mood), some rules for embedding sentences, and some attention to pronominational substitution are reported. The report discusses how a particular semantic network can be used in conjunction with a grammar to generate sequences of coherent English sentences. The paper first outlines the form of the grammar and lexicon and describes a random generation algorithm that produces syntactically well-formed nonsense. It then shows how the semantic nets are used to control the ordering of grammar rules and lexical selections to generate meaningful discourse. There is also a section on some of the methods and rules for generating multi-sentence discourse. Special emphasis is given to the questions and problems that arise. A list of references is provided. For additional information, see FL 002 344. (Author/VM)

ED0 55473

GENERATING ENGLISH DISCOURSE FROM SEMANTIC NETWORKS

TECHNICAL REPORT NO. NL-3

R. F. Simmons
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November 1970

NATURAL LANGUAGE RESEARCH FOR COMPUTER-ASSISTED INSTRUCTION

Supported By:

THE NATIONAL SCIENCE FOUNDATION
Grant GJ 509 X

Department of Computer Sciences

and

Computer-Assisted Instruction Laboratory

The University of Texas
Austin, Texas

FL002345

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Abstract

A system is described for generating English sentences from a form of semantic nets in which the nodes are word-sense meanings and the paths are primarily deep case relations. The grammar used by the system is in the form of a network that imposes an ordering on a set of syntactic transformations that are expressed as LISP functions. The generation algorithm uses the information in the semantic network to select appropriate generation paths through the grammar.

The system is designed for use as a computational tool that allows a linguist to develop and study methods for generating surface strings from an underlying semantic structure. Initial findings with regard to form determiners such as Voice, Form, Tense, and Mood, some rules for embedding sentences, and some attention to pronominational substitution are reported. The system is programmed in LISP 1.5 and is available from the authors.

GENERATING ENGLISH DISCOURSE FROM SEMANTIC NETWORKS

R. Simmons & J. Slocum

I Introduction

Much of the recent work in language processing research has been concerned with representing factual material in the form of semantic nets for the purpose of answering questions, guiding students in computer aided instruction and counseling, solving problems, etc. In a previous paper a detailed definition of semantic network representations for aspects of English meanings was developed (Simmons 1970b). That paper presented methods for representing the semantic structure of English discourse and lexical information as a network of word-sense concepts connected by deep case relations. Here, after a brief discussion of its place in linguistic theory, an algorithm and a grammar will be described to generate coherent sequences of sentences from the semantic network and its associated lexicon.

<u>Background</u>: Recent variations of transformational theories of linguistics proposed by Lakoff (1969) and Lakoff & Ross (1969) suggest that the process of generating natural language sentences begins with a deep semantic structure and progresses by applying an ordered series of transformations until a surface string of phonemes or graphemes has been derived. Lexical interpretations are allowed to occur at any stage of the process.

Several linguists (McCawley 1968, Bach 1968, Lakoff 1969) have suggested that the predicate calculus offers a suitable notation for representing semantic deep structures of natural language statements. The experience of computational linguists in representing textual meanings for computer language processing can be interpreted in support or in denial of this suggestion. On the one hand, several question answering systems have represented sentence meanings as predicate calculus forms. (See Green & Raphael 1969, Coles 1969, Kellogg 1968.) On the other hand most researchers in this field have used attribute-value or semantic network representations. (See Quillian 1970, Carbonnel 1970, Colby et.al. 1969, and Simmons 1968, 70a.) Both approaches have been moderately successful with regard to the goal of answering English questions by computer, and simple English sentences can be transformed with the aid of appropriate lexicons and grammars into either form. Representing very complicated sentences is a process that is equally poorly defined for either form.

In my mind the semantic network representation offers simplicity of graphic and computational representation and easy readability as clearcut advantages over customary predicate calculus notations. In order to preserve meaning it must be quite as precise as the predicate calculus representation of quantification, specification, and the scope of variables. Because of these and other arguments presented previously (Simmons 1970c) I have chosen to represent semantic structures of sentence meaning in the form of networks of wordsense nodes connected by case relations.

The nature and form of transformations used by linguists for generating sentences has been discussed at length in transformational literature. Jacobs and Rosenbaum (1968) present a detailed treatment of the purpose and form of transformations. Friedman (1969) describes a transformational grammar tester which not only defines the computational form of the transformations but provides generation algorithms for producing phrases and sentences starting from a phrase structure base and applying transformations to achieve the surface structure.

Although various computational linguists have generated coherent sentences and questions from semantic networks (namely, Quillian 1970, Carbonnel 1970, Simmons 1968 and others) their methods have been largely _ad hoc_ and of limited generality.

One recent paper (Woods 1970) has argued for a significant generalization of the linguist's transformational apparatus. Woods represents his English grammar in the form of a state transition network that is augmented with sub-network subroutines and a series of conditions and operations associated with each possible path. He clearly demonstrates that the resulting _augmented state transition network_ is a suitable device for analyzing or generating natural language structures. It is computationally more efficient than the customary form of transformational rules and more powerful; yet it allows the linguist to restrict the power of rules in any way that his theory may require. Woods proves that without restrictions, an augmented state transition network is equivalent in power to a Turing machine.

These ideas of semantic network representations of English meanings and the augmented state transition network representation of transformations are the basis of this paper. In it is presented an algorithm and fragments of grammar for generating sequences of English sentences. Some attention is devoted to methods of assigning pronouns, embedding sentences, and determining voice, mood, aspect and tense of verbs. I believe the approach may serve to suggest to linguistic theorists a useful method for expressing their theories of generative semantics.

II The Generation Grammar & Lexicon

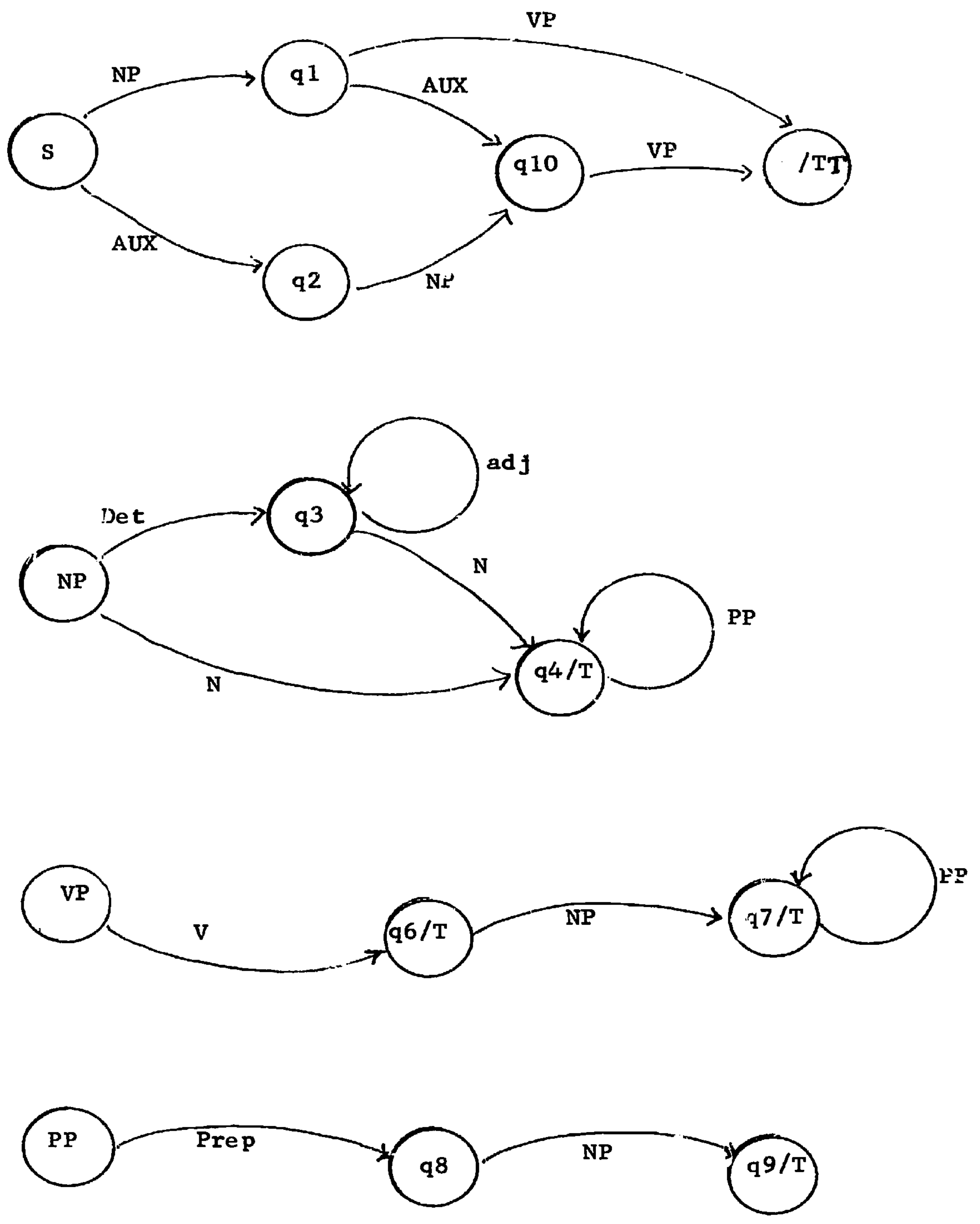
The description of this system of generative semantics will be developed in two sections; this section outlines the form of the grammar and lexicon and describes a random generation algorithm that produces syntactically well-formed nonsense. Section III shows how the semantic nets are used to control the ordering of grammar rules and lexical selections to generate meaningful discourse.

The Grammar: A simple phrase structure grammar can be represented as a state transition network. This can be demonstrated most easily and clearly by an example almost identical to the one Woods (1970, p. 592) used in his illustration of a recursive transition state network. First, the grammar:

NP $\longrightarrow$ (DET) + (ADJ*) + N + (PP*)
PP $\longrightarrow$ PREP + NP
S $\longrightarrow$ NP + (AUX) + VP
S $\longrightarrow$ AUX + NP + VP
VP $\longrightarrow$ V + (NP) + (PP*)

This is a context-free phrase structure grammar using the conventions that, parentheses indicate optionality, and the asterisk indicates one or more occurrences. Figure 1 shows the recursive state network representing the grammar. In this graph, the nodes or states are shown as circles with labels such as "S", "NP", "q7", etc., and the arcs or paths are labelled by phrase names or part of speech designators such as aux, prep, n etc. Some states, such as "q7/T", are marked "/T" to indicate possible terminators of the net or subnet in which they occur.

A simple algorithm can be used to generate sentences from this net. We assume that the algorithm can distinguish wordclass names such as



Note: final states
marked by "/T"

Fig. 1 Recursive Transition Network
After (Woods, 1970)

"det", "adj", "n", etc. from phrase names such as "NP", "VP", "PP", etc. Starting with the symbol "S" we may choose either the "aux" or the "NP" path. Arbitrarily, select "NP". Since it is a phrase name, save the desired state q1 on which "NP" terminates, and find the subnet labelled "NP". This net gives the two choices "det" or "n"; select one, "det" which leads to q3. Since "det" is a terminal wordclass, apply a lexical interpretation to select a determiner from the dictionary; arbitrarily "the". Put "the" as the first element of the output string. Having accomplished the interpretation of that path, the system is now at q3. From q3 there is a choice of adjective or noun paths. Choose adjective, another terminal wordclass; lexically interpret it as "red" to give the output string "the red" and so achieve state q3 again. This time select the noun path labelled "n", interpret it as "wagon" and so achieve state q4. This state is marked "T" to indicate that it is permicted to end an "NP" at this point. Let us do so and discover that the accomplishment of the NP path (as a subnet) led us to state q1, which had been saved previously. From q1, we have only the path "VP" leading to state TT. By following the subnet for VP we might eventuate in a sentence such as "the red wagon broke an axle" and so achieve the S network's terminal state TT, by having generated an NP and a VP.

The reader is invited to explore the net further, starting at S and taking other branches to generate a variety of sentence and question structures.

Table 1 shows a basic LISP algorithm for random generation of sentences from a recursive transition state network grammar. Some of the nonsense sentences generated by this algorithm and the example grammar

```
1.  If S is NIL, Return NIL,

2.  If S is not an atom
      Concatenate    GEN (CAR(S)) & GEN (CDR(S))

3.  If S has terminal marker, /T,
      Return NIL  If RANDOM NBR is greater than .50
      Otherwise, go on to 4.

4.  If S is a word-class name,
      return a randomly selected word of that category

5.  Otherwise,   GEN(SELECT (PATHS (S)))
```

Where:	CAR	returns 1st element of a list
	CDR	returns the remainder of a list
	RANDOM NBR	returns a number between 0 and 1
	PATHS	returns the outgoing path-node pairs from a state
	SELECT	returns an element randomly selected from a list

Table 1 A LISP-type Algorithm for Random Generation of Sentences from a Network Grammar

are shown in Table 2. In the LISP formalism, the network is represented (on the property list) as a set of 1st,-edge,-3rd triples as follows:

1st	Edge	3rd
S	NP	q1
S	AUX	q2
q1	VP	TT
q2	NP	q10
:		
et cetera		

The concatenation of recursive calls to the function GEN automatically follows the paths in the network of the grammar, using LISP machinery for keeping track of what states are on the pushdown stack. The lexicon for these examples is assumed to be simply lists of words that are values of the terminal wordclasses "noun", "det", etc.

Now, having seen how the state network is suitable for representing a phrase structure grammar, let us increase its power (still following Woods' development), by associating with each path a set of conditions and operations. The conditions are tests such as those of syntactic or semantic agreement, the presence or absence of lexical features characterizing a form, etc. The operations ar. transformations of any desired level of simplicity or complexity. If we consider these conditions and operations as functions or subroutines, each of which specifies its set of arguments, we must then indicate what the arguments refer to. For Woods, the arguments are an arbitrary set of registers that contain, as generated, the TYPE of sentence (S or Q), the value of the AUX, of the VERB, of the SUBJECT, of the VP, etc.

In the semantically controlled generator to be described here, these arguments are the relations and their values that characterize a

```
WILL THE LITTLE RED MAN BREAK A WAGON.
COW WILL PULL WAGON.
WILL MARKET TURN ROAD.
WILL THE ROAD PULL WAGON ON MARKET TO THE RED WAGON.
A MARKET BREAK THE RED MAN.
THE RICKETY RED OLD RED MARKET DID BREAK A RICKETY COW ON THE RED MARKET.
THE OLD MARKET TO A RICKETY COW DID PULL COW.
DID MAN BREAK THE WAGON.
MARKET TO MARKET TURN A RICKETY RED COW.
WAGON TO THE RED ROAD PULL THE MAN.
```

Table 2 Nonsense Sentences Generated by Algorithm of Table 1

node in the semantic network. The conditions and transformations associated with a node in the state network are applied to semantic nodes, dividing them, transforming them and finally creating sentence strings from them.

III Generating English from Semantic Nets

Semantic Nets: The elements or objects of a semantic network for representing discourse meanings are concepts and relations. The primitive concept is a wordsense meaning that is itself represented in the lexicon as an object in a set of relations with other objects. Generally, a concept is a set of relation-concept pairs associated with a labelled object such as C1 in the following illustration:

```
C1 - R1 - C2
     R2 - C3
        .
        .
     Rn - Cm
```

A network is defined as follows:

```
Network       --  Node*
Node          --  Node + relation set | L-node
relationset   --  (relation + node)*
relation      --  transformational function
L-node        --  wordsense | terminal element
```

The asterisk signifies one or more repetitions. Nodes are concepts which are sets of relation-node pairs. L-nodes are wordsense references or other terminal elements. The relations are such intersentential connecting meanings as signified by "since", "thus", "because", etc. or deep case relations such as AGENT, OBJECT, DATIVE, etc. each dominating prepositional relations. The relations in the net are associated with transformation functions that can form them into syntactic constituents. (For other purposes such as paraphrase, other transformations are also associated with the relations.)

Both discourse and lexicon are represented in semantic net form. The lexicon uses such relations as PRINTIMAGE, SYNTACTIC WORDCLASS, HYPONYM, ANTONYM, IMPLY, etc. Details of the structure for representing discourse and lexicon are presented in another paper, (Simmons 1970b) and only the minimal description necessary for the understanding of examples is given here.

The semantic representation of a sentence and a portion of the relevant lexical structure are presented in Table 3 to illustrate the relational form of semantic nets. From this table, it can be seen that the sentence "John saw Mary wrestling with a bottle at the liquor bar" has been analyzed into a set of concepts, namely C1-C9, each of which is related by TOK to a lexical wordsense address, L1-L9, where other information concerning the wordsense is located. The concepts are clearly not words--they are named sets of relations with other concepts --but they map into wordsenses that have print images which are words. (In fact, our dictionary specification requires wordsenses to have the relation -WDSNS which maps onto a word which in turn does have print images. This complexity has been omitted from the present example for the sake of a clearer exposition.)

A wordsense may be representable by several words, but it is an unambiguous object of meaning. A concept relates through various relations to a set of other concepts, but it, too, is an unambiguous object. Thus the example sentence is represented as a particular ordered set of unambiguous concepts with explicit relations to each other. This is its semantic representation.

Words such as "saw", "bottle", "bar", etc. obviously each have several sense meanings. The semantic analysis method is assumed to have decided on precisely which wordsense concept is signalled by the choice of a word in context and in this manner mapped a string of words into the network structure of concepts and relations. How this is to be

C1	TOK	L1(see)
	TIM	PAST
	DAT	C2
	OBJ	C3
C2	TOK	L2(John)
	NBR	SING
	DAT*	C1
C3	TOK	L3(wrestle)
	TIM	PROG PAST
	AGT	C4
	OBJ	C5
	LOC	C6
	OBJ*	C1
C4	TOK	L4(Mary)
	NBR	SING
	AGT*	C3
C5	TOK	L5(with)
	POBJ	C7
	OBJ*	C3
C6	TOK	L6(at)
	POBJ	C9
	LOC*	C3
C7	TOK	L7(bottle)
	DET	INDEF
	NBR	SING
	POBJ*	C5
C8	TOK	L8(bar)
	NBR	SING
	DET	DEF
	ASSOC	C9
	POBJ*	C6
C9	TOK	L9(liquor)
	NBR	SING
	ASSOC*	C8

L1	PI	SEE
	PAST	SAW
	3RDP	SING
L2	PI	John
	PLUR	-s
L3	PI	wrestle
	PAST	-ed
	PROG	-ing
	3RDP	-s
L4	PI	Mary
	PLUR	-s
L5	PI	with
L6	PI	at
L7	PI	bottle
	PLUR	-s
L8	PI	bar
	PLUR	-s
L9	PI	liquor
	PLUR	-s

Table 3 Attribute-Value Representation of Example Discourse and Lexicon

accomplished is the subject of another paper (Simmons 1970d and of discussions by Katz (1965), Leech (1970) and Quillian (1970)). Here we will accept it as given by a human analyzing the sentence with his intuitive understanding.

This semantic analysis is partially represented by the graph of Figure 2. This figure suggests how words in a sentence activate cascades of meaning in the lexical nets. Not shown, are the definitional and implicational relationships that characterize each lexical entry for use in paraphrase generation. If these were considered, the complete meaning of a sentence would be represented as that portion of the concept net that it activates--presumably a very large subnet, indeed.

Our purpose here, however, is not primarily to show how the semantic network represents meanings but instead to demonstrate how it can be used in conjunction with a grammar to generate sequences of coherent English sentences. Let us first look at a simple sequence generator that will transform a concept into a sequence of words representing its set of relational pairs. The relational pair is referred to as a relation and its argument node. The sequence generator is an algorithm that translates relations and nodes into their lexical representation. For this example, it will represent relations in the strings it generates in exactly the form they are shown in Table 3; i.e., ASSOC as ASSOC, AGT as AGT, POBJ as POBJ, etc. If the argument node of a relation is an L-node, it prints the PI or print image value; otherwise it expands a C-node, recursively. This sequence generator will ignore such relation pairs as TIM - PAST, DET - Def/indef, NBR- etc.

If we begin with this algorithm at C1, it will generate the following:

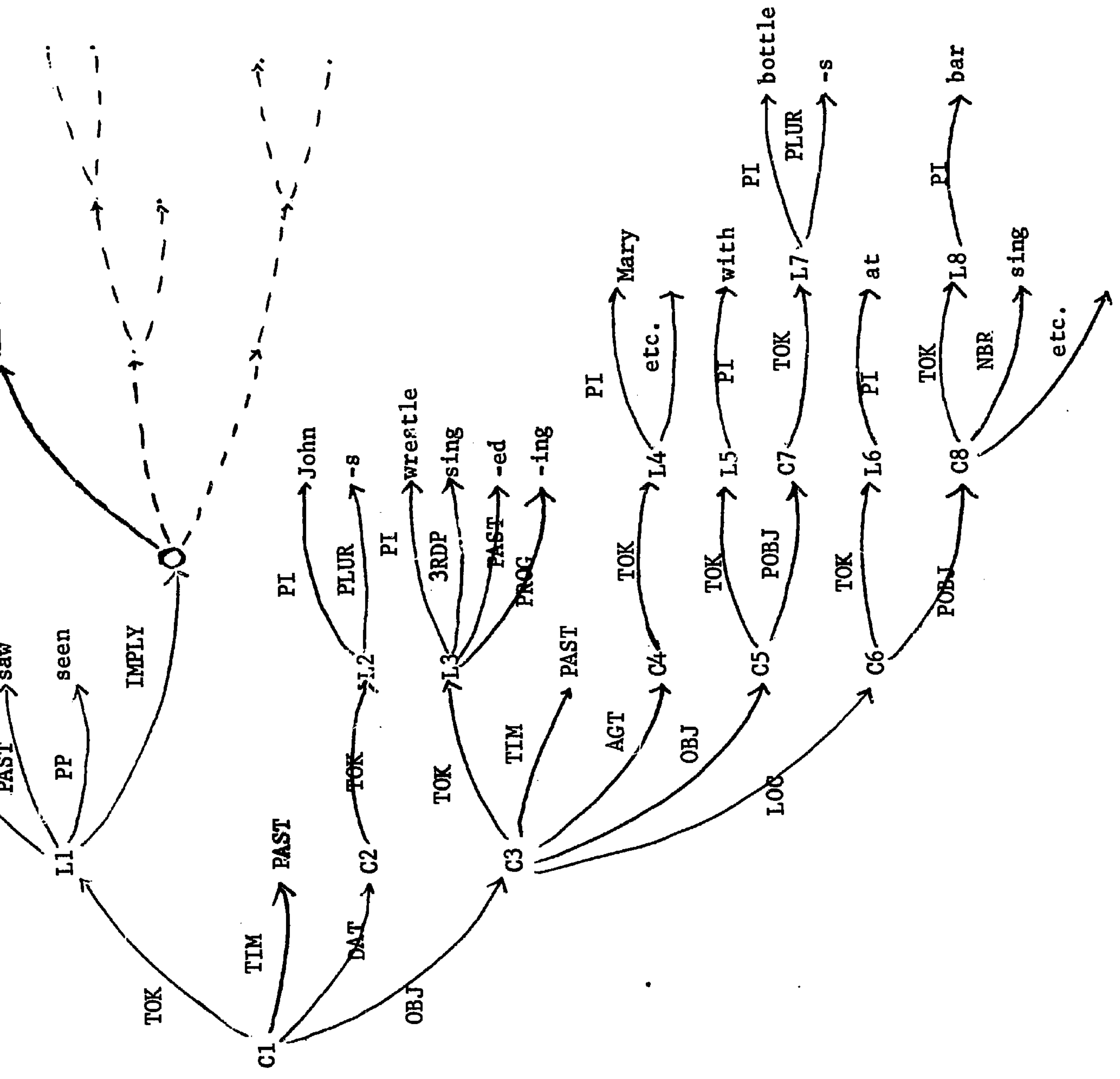


Fig. 2 Partial Graph Representation of Table 3

```
SEE DAT JOHN OBJ WRESTLE AGT MARY OBJ WITH POBJ BOTTLE
  LOC AT POBJ BAR ASSOC LIQUOR
```

This string of words and symbols carries much of the meaning of the original sentence and the simplicity of its generation immediately explains one aspect of the popularity of semantic nets with computational linguists. That is, the syntax of the semantic nets is not vastly dissimilar to that of English phrase constructions. If some of the word-sense nodes map onto more than one English word, additional strings such as "OBSERVE DAT JOHN..." and "...OBJ STRUGGLE AGT MARY..." will also be generated. This shows one level of paraphrase capability inherent in semantic structure--alternate lexical representations of wordsense concepts.

<u>Semantic Generation</u>: We have previously seen that if we apply a syntactic generator to a grammar and lexicon, we obtain nonsense sentences that are syntactically well-formed strings of English words. Here, in simply generating a printable linear representation of a semantic net, the result is a meaningful string of words that is not syntactically well-formed. By applying a set of syntactic transformations (i.e. a grammar) to the semantic relation pairs, the generator can impose the syntactic structure of English onto the lexical interpretation process and so produce well-formed sentences of English.

The key feature of this process seems to be that a recursive transition state network (or for that matter any grammar with transformations) is an ordering of a series of transformation rules. The semantic network is also a complex ordering of semantic relations that conjoin concepts. The semantic relations of discourse are deep case relations and ıer relational meanings that map onto syntactic relations and relational rds in the surface string. Thus, AGT, DAT, INST, SOURCE can map onto e syntactic relations of SUBJECT, OBJECT, and various prepositional rase COMPLEMENTS in accordance with an ordering imposed by the gram- r network. Various syntactic rules--i.e. paths in the network--offer ffering choices of surface strings to represent the relational order- g of concepts in the semantic network. The transformation from mantic to syntactic relation is accomplished by associating as part the content of each semantic relation, the transformation that forms and its concepts into a syntactic constituent of a sentence.

At each node in the transition net grammar, a choice of paths is pically available. In the random generation example the function LECT was used to make a random choice. In generating meaningful ntences from a semantic net, the semantic relations perform this ıoice function. That grammar path is chosen whose name corresponds a semantic relation in the concept being generated. The procedure ll become clearer in the labor of generating a sentence.

For a simple example, the semantic structure of Table 3 will be sed in conjunction with the grammar illustrated in Figure 3 to generate complex sentence. The procedure begins with the selection of a con- ept from the net as a starting point. This concept is labelled S; .e. the relation pair, LAB-S is added to the concept. Although, ideally, ıy concept can be chosen as a starting point if the grammar has an ppropriate set of rules, this example will for the sake of simplicity, tart with concept C1 from Table 3.

S	Agt	Pred	PRED	MAN	VPO
	DAT	Pred		-/-	VPO
Agt	-/-	NPO	VPO	AUX	VP1
DAT	-/-	NPO	VP1	VS	VP2
NPO	POBJ	NP1	VP2	OBJ	VP3
	-/-	NP1		-/-	VP3
NP1	NBR	NP2	VP3	LOC	VP4
NP2	DET	NP3		DAT	VP4
	-/-	NP3		INST	VP4
NP3	MOD	NP3	VP4	-/-	T
	-/-	NP4	OBJ	POBJ	NP1
NP4	NS	T		NBR	NP2
				AGT	PRED

Fig. 3 Grammar for Generating a Sentence from Semantic Net of Fig. 1

C1 is labelled S and the grammar of Figure 3 is entered to find the
elevant node (or rule) beginning with that symbol. The first relevant
ath, S-AGT-PRED is attempted. The structure, C1, is examined to see
f the relation AGT is present. It is not, so the next path, DAT-PRED,
s checked. The relational pair, DAT-C2 is found on structure C1 show-
ng that this path through the grammar is possible. The value of that
air, structure C2, is now labelled DAT. C1 is relabelled PRED (for
uture reference) and the grammar is entered at the DAT node. The
elevant path is DAT-/-NPO. The symbol "/" indicates an unconditional
elabelling corresponding to a unary rewrite rule. Structure C2 is
hus relabelled NPO and the grammar is entered at the NPO node. NPO
ffers the path POBJ-NP1 and /-NP1 showing that the POBJ path is optional
-if present in the structure it indicates a prepositional phrase and
ill be followed; if not present the structure will be unconditionally
abelled NP1. The relation POBJ is not present in C2, so C2 is labelled
P1, and the grammar is entered at that point. The grammar node NP1
ffers only the path, NP1-NBR-NP2. It can only be followed if the
elation NBR is found on the structure as in fact it is on C2 in the
air, NBR-Sing.

NBR is a relation that has associated with it a series of tests
nd transformational operations that can be stated briefly as follows:

1) if value of NBR is Sing
   set NS (<u>N</u>oun <u>S</u>tring) to the value of the Print Image of TOK
2) if value of NBR is Plural
   set NS to the MORPH value for TOK and Plural
3) Add the relational pair NS and its value to the concept.

ORPH is a function of the two arguments which are the lexical values
f TOK of the concept and of that lexical entry's plural form. When

operated with these arguments it returns the print image of the plural form of the word. Since the system being described is realized in LISP, NBR is defined as a LISP function to accomplish the tests and operations. The result of operating NBR as a function was to add to C2 the relation NS with the value "JOHN", and to relabel it as NP2.

Looking up NP2 in the grammar, we see that it has an optional DET path to NP3, which in its turn has an optional MOD path to NP4. Since neither a DETerminer or any MODifiers are present in the semantic structure, the traversing of these paths results in putting the concept at state NP4--i.e. its relabelling as NP4. NP4 (for this simple grammar) leads by the relation NS (noun string) to a terminal state, T. The relation NS is also a function that has the effect of concatenating its value, "JOHN" to the output string being generated. Since the terminal state, T, was reached in the generation of C2, we have now managed to cross the DAT path and achieve the state PRED which had been attached as a label to C1 after using its DAT relation.

PRED offers the optional path, MAN(ner adverb) -VPO which is not realized in C1, so C1 is relabelled VPO via the unary rule "-/-VPO". This node gives only an AUX-VP1 path. The pair AUX-Past is found on C1, and the function AUX prepares a verb string relation VS whose value for this example is "SAW". and attaches the pair VS-SAW to the structure C1. This relabels C1 as VP1. The path VP1-VS-VP2 then places the verb string on the output string and takes C1 to state VP2.

Node VP2 calls for an OBJ relation which is found on C1 in the pair OBJ-C3. C1 is relabelled VP3 for future use after C3 has been developed, and C3 is labelled OBJ. Three paths are offered at node OBJ, namely, POBJ-NP1, NBR-NP2, and AGT-Pred. The first two are for the

s where the object is a prepositional phrase or a noun phrase; the
d is for an agentive verb phrase. C3 is found to have the relation
, AGT-C4, so it is labelled PRED and C4 is labelled AGT, and the pro-
re continues recursively, adding the string "Mary wrestling with a
le at the liquor bar" to the already generated fragment "John saw".
C3 has been generated, control returns to C1 which had been labelled
Since C1 has no further relation pairs, the state T is quickly
eved via VP4 and the process ends with the completed sentence:

JOHN SAW MARY WRESTLING WITH A BOTTLE AT THE LIQUOR BAR.

Additions to the grammar of Fig. 3 can be devised to develop syn-
ic variations of the example sentence and to generate the sentences
result from starting at Concept C3 or C7 and exhausting the concept
ork. Whatever special conditions and transformations are required
be associated with the names of paths in the grammar.

The Generation Algorithm: The algorithm and data structures that
mplish semantically controlled generation are interesting computa-
al structures particularly in view of their simplicity of expression
ISP. Table 4 shows a basic LISP algorithm, called GEN. It has
set up as a sequential program (rather than a more elegant expression)
id its readability. Notes to this table explain the functions
ed in the algorithm.

The grammar network is placed on the LISP property list in the
owing form:

```
(S (GR ((AGT PRED) (DAT PRED) ( etc.) (     ) ) ) )
```

```
      GEN (ST GR) (PROG ( ) )
1.    (COND ((CSETQ J (GET ST TERM)) (RETURN (LIST J)) )
2.    ((NULL(CSETQ J (GET ST LABEL))) (RETURN NIL))
3.    ((NULL (CSETQ J (GET J GR))) (RETURN NIL))
4.    ((NULL (1STRUL J)) (RETURN NIL))
5.    ((UNARY (1STRUL J)) (PROG () ((PUT ST LAB (1ST J))
                                    (DO (1ST J))
                                 (RETURN (GEN ST GR)))))
6.    ((NULL (CSETQ K (GET ST (1ST J))))
               (PROG2 (CSETQ J (CDR J)) (GO 4)))
7.    (PUT K LAB (1ST J ))
8.    (DO (1ST J) K)
9.    (DELETE ST (1ST J))
10.   (PUT ST LAB (2ND J))
11.   (RETURN (GEN K GR) (GEN ST GR)))
```

Notes:
1. GET of a STructure name and a Relation returns the value of the relation.
2. CSETQ (J K) sets J to the value of K.
3. NULL is True for the value NIL, False otherwise.
4. 1STRUL returns the first of a set of rules.
5. 1ST returns the path of the first rule: 1ST(S NP VP) $\rightarrow$ NP
   2ND returns the state value: 2ND(S NP VP) $\rightarrow$ VP
6. UNARY tests for a unary rule as (AGT NP NIL)
7. PUT puts a relation value pair on a structure.

   DO operates a relation as a LISP function whose arguments are the structure of which it is a part.

   DELETE deletes the relation from its structure and the back-link from the structure that it refers to.

   TERM tests if is argument is a terminal point image.

Table 4. Algorithm for Semantically Controlled Generator

The function, GET(S GR) returns the list of path-node pairs leading away from the state S. The semantic structure network, also on the LISP property list, is in a similar form, as follows:

(C1 (DAT C2) (TIM PAST) (TOK L1) (OBJ C3))

The GET of a structure and a relation, i.e. GET(C1 DAT), returns the value associated with the relation, i.e. C2. The relational terms such as AGT, DAT, OBJ, TIM, etc. are each defined as small LISP functions that test for appropriate conditions and apply transformations to the structure. As LISP users know, the use of the property list feature in this system maximizes the efficiency of storage and retrieval operations in the language.

The algorithm is conveniently described in eleven steps corresponding to the numbered sets of statements in Table 4. ST refers to the starting semantic structure node; GR is the grammar to be consulted.

1. Tests to see if a TERMinal print image is developed and returns its listed value if it has.

2. Else, tests to see if semantic STructure has been labelled; returns nil if it has not.

3. Else, tests to see if the label corresponds to an entry node in the grammar; if no such node in the grammar, the value of GEN is nil, i.e. returns nil.

4. This statement is part of a loop with 6. If at any time 1STRUL--the car of the list of rules or paths associated with a node--returns nil, it means that the list has been checked without finding a corresponding semantic relation on the semantic STructure. In this case, GEN returns nil.

5. If the rule in question is unary, the structure is relabelled (as in AGT-NP), the label is operated as a transformation function (usually a NOP), and GEN is called recursively with the relabelled structure.

6. The actual test to determine if 1ST--the CAR of 1STRUL which gives the syntactic relational path--corresponds to a semantic relation in the structure. If not, the next rule in the set is made available through going to Step 4.

7. If the first 6 conditions have been passed, K--the name of a structure which was the value of the relation called for by the grammar and discovered in step 5 on ST--is labelled by that relation name.

8. Operates the function corresponding to that relation.

9. Deletes that relation from the original structure and backlinks to it from K.

10. The original semantic structure, ST, is relabelled by the name of the node to which the syntactic path leads. For example in the rule, S-AGT-PRED, ST would now pick up the label PRED, while K, the new structure, would have been labelled (in step 7) as AGT.

11. The value of GEN is the GEN of the new structure concatenated with GEN of the relabelled old structure.

This is a highly recursive function that terminates when every call to GEN has returned either terminal print images or nils. The concatenation of these results is the output sentence that GEN generates. Because of the presence of backlinks and common references to nouns from different parts of the network, a call to GEN with a single concept structure as its ST argument will usually generate a whole discourse-set of sentences rather than a single sentence. How long or short the sentences are to be is controlled by the grammar and by some decision functions that are mentioned in the next section. What is important to notice here, is that this one algorithm is the primary mechanism for allowing a semantic net to limit and control what sentence structures a grammar can generate.

IV MULTI-SENTENCE DISCOURSE

The structure of semantic networks has been developed to represent aspects of the meaning of multiple sentence texts in such a manner as to enable the answering of questions, the generation and evaluation of paraphrases, and for the even more primary purpose of providing a research vehicle for the study of such complexities of language as coherence, intersentential connections, conditions on embeddings, and rules for pronominalization, anaphora, and ellipsis. Experience with these areas of linguistic research has strongly suggested that the discovery of generative procedures is the most profitable approach to understanding how to analyze the examples of their occurrance in text.

The following short multi-sentence discourse was composed as a basis for study.

> "John saw Mary wrestling with a bottle at the liquor bar. He went over to help her with it. He drew the cork and they drank champagne together."

This brief discourse illustrates some common uses of pronominalization, anaphora, ellipsis, embedding, etc. The development of semantic coding conventions, grammar rules, and generator control features for generating various multi-sentence representations of this discourse has already proved highly instructive.

In this section some of the methods and rules for generating multi-sentence discourse will be described briefly and with special emphasis on the questions and problems that arise.

Generating Sequences of Sentences: The discourse example is represented as a semantic net in its attribute-value form in Table 5. This net can be seen to encode much more detail than previous examples especially with regard to voice, mood, form and tense of verb concepts. Also in addition to the AUX relation, the relation TIM is added to record the relative beginning and ending times of verb events. The additional information was found to be essential for decisions regarding the embedding of sentences. The back links for each concept to concepts that refer to it are shown explicitly as AGT*, INST*, POBJ*, etc. as these are also crucial to the seqıence to sentences in a discourse. The lexical references are foreshortened in this example to show the value of TOK simply as the print image associated with the appropriate wordsense.

The function GEN takes two arguments: a list of one or more concept structure names, and a grammar. It starts the generation process by entering the grammar at node S. Thereafter the intersection of the grammar paths with the concept relations controls the process. Corresponding to the greater variety of relations in the semantic net of Table 4, the grammar must have more paths and more complex transformation functions associated with its paths. A beginning segment of the grammar is shown below:

```
    S - VOICE - TFM
  TFM - FORM  - TENSE
TENSE - TENSE - PROP
 PROP - MOOD  - (terminal)
INDIC - SUBJ  - PRED
IMPER - TOK   - VP1
```

E1	MOOD	INDIC
	TENSE	PAST
	FORM	SIM
	VOICE	ACT
	OBJ	E3
	AGT	E2
	AUX	(1 2)
	TOK	SEE
E2	TYP	SING3
	AGT*	(E15 E12 E10 E1)
	NBR	S
	TOK	JOHN
E3	MOOD	INDIC
	TENSE	PAST
	FORM	PROG
	VOICE	ACT
	OBJ*	E1
	LOC	E7
	DAT	E5
	AGT	E4
	AUX	(0 3)
	TOK	WRESTLE
E4	TYP	SING3
	OBJ*	E12
	AGT*	E3
	NBR	S
	TOK	MARY
E6	TYP	SING3
	NBR	S
	DET	A
	TOK	BOTTLE
E8	TYP	SING3
	MOD	E9
	NBR	S
	DET	THE
	TOK	BAR
E9	DEG	POS
	MOD	E8
	TOK	LIQUOR
E10	MOOD	INDIC
	TENSE	PAST
	FORM	SIM
	VOICE	ACT
	LOC	E11
	AGT	E2
	AUX	(2 3)
	TOK	GO
E11	INF	E12
	LOC	E10
	TOK	OVER
E12	MOOD	INDIC
	TENSE	PAST
	FORM	SIM
	VOICE	ACT
	IOBJ	E5
	OBJ	E4
	AGT	E2
	AUX	(2 3)
	TOK	HELP
E15	MOOD	INDIC
	TENSE	PAST
	FORM	SIM
	VOICE	ACT
	OBJ	E21
	AGT	E2
	AUX	(3 4)
	TOK	DRAW
E16	MOOD	INDIC
	TENSE	PAST
	FORM	SIM
	VOICE	ACT
	MAN	E20
	OBJ	E22
	AGT	E18
	AUX	(4 5)
	TOK	DRINK
E18	SECN	E4
	FIRN	E2
	AGT	E16
	TOK	AND
E20	MAN	E16
	TOK	TOGETHER
E21	TYP	SING
	POSS	E6
	OBJ	E15
	NBR	S
	TOK	CORK
E22	TYP	SING
	OBJ	E16
	NBR	S
	DET	THE
	TOK	CHAMPAGNE

Table 5 Semantic Representation of a Multi-sentence Discourse (prepositions omitted)

This section of the grammar orders the application of transformations on the concept structure for Voice, Active/Passive; for Form, Simple/Progressive/Emphatic; for Mood, Indic/interrog/imperat/subjunctive; and for Tense and Aspect, Pres/Past/Fut/ and their Perfects. It is assumed that values for these relations have been placed previously in the semantic structure as a result of some largely stylistic plan that organized a subnetwork of concepts to be uttered. In this model, the first stage of generating a sentence is to determine its basic form as for example,

```
Active:Prog: Indic:Past:Perfect
John had been seeing ...
```

This is accomplished by the functions associated with the relational terms Voice, Form, Tense, and Mood.

Voice prepares a verbstring. For the Voice value Active, the verbstring is composed of the infinitive form of the verb; for the value Passive, it is BE followed by the -en form of the main verb. Voice also selects one relational pair such as AGT-C1 to be the subject, designated by SUBJ-C1, for example. If the voice is Passive, the SUBJ becomes the POBJ of the preposition BY ; the old OBJ becomes the SUBJ of the verb and the BY-Structure is added to the verb structure, with the relation OBJ-Structure.

Proceeding along the syntactic path, Form is then operated and may further modify the verbstring created by Voice. In the case where the Form is Simple, no operations are performed; if the value is Progressive, the first verb in the string is changed to its -ing form, and BE is added to the string in first position; if the form were Emphatic, DO would be added to the string in first position. The Form operation is then terminated.

According to the syntax, the function Tense and Mood are then operated as a natural sequence through the grammar net, leading finally to a choice of labels that lead into the grammar by the nodes INDICative, INTerrogative, etc. Each of these nodes results in the generation of a different sentence form. This sequencing of basic form determiners of the sentence is a beautiful computational structure that is described in the following paragraphs.

Computational Structure of Voice, Mood, Form & Tense: The model for this syntactic structure is a set of three relational pairs: SUBJ-Value, VSTRING-Value, and OBJ-Value. The VSTRING value is a list or a pushdown stack which allows addition or deletion of first members. The effect of Voice, Form, Tense and Mood in that order is to accumulate the values for these three relational pairs. First, an example to develop a most complex form:

Will the house have been being built by John?

This is signalled by the following values of Voice, etc.

Voice	-	Passive
Form	-	Progressive
Aspect	-	Perfect
Tense	-	Future
Mood	-	Interrogative

VOICE, with the value passive, takes the verb off the top of VSTRING, changes it to the -EN form, "built" and puts it in first position, henceforward called FIRST. It then puts BE on FIRST, and exchanges the FORM values of SUBJ and OBJ, adding the preposition BY to the (original) SUBJ value.

FORM with the value Progressive, changes the verb on FIRST to the -ING form, making BEING and puts BE on FIRST. (We now have BE BEING BUILT). ASPECT applies Perfect, by changing the verb on FIRST to its -EN form and putting HAVE on FIRST: Tense-future is then applied to put WILL on FIRST thus forming a verbstring of WILL HAVE BEEN BEING BUILT with a subject, HOUSE and an object, BY JOHN. MOOD, with an Interrogative value, starts the generation of a sentence with the value of FIRST, and thus the sentence is generated as WILL JOHN HAVE BEEN BUILDING THE HOUSE.

This example is illustrated in Table 6. The general form of the paradigm is shown in Table 7. The effects of the transformations signalled by Voice, Form, etc. cumulate, one on another as seen in the Table 6 example. Certain combinations such as Passive-emphatic and Future-emphatic are not allowed in English. We have also noticed that modals such as "may", "might" etc, appear to follow the same paradigm but have not yet studied their behavior in detail.

When Mood has operated as a function it labels the concept structure either, INDIC, INTERR, IMPER, or SUBJUNCT each of which start different paths in the grammar. For example, IMPER gives the path TOK-VP1 which forms the sentence with the uninflected verb followed only by its predicate arguments. The node INTERR gives the path, FIRST-INDIC. FIRST transforms the first element of the Vstring to the starting position of the sentence, labels the remaining structure INDIC, then generates from the node INDIC. This node gives the ordinary set of paths for declarative sentences, one of which was followed in an earlier example.

CONDITION	RULE	RESULT			
		V STRING		REGISTERS	
		FIRST	REMAINDER		
START	Put verb on FIRST Set SUBJ & OBJ values	BUILD		SUBJ	John
				OBJ	house
VOICE-PASSIVE	Add -en to FIRST Put BE on FIRST EXCHANGE SUBJ & OBJ Add BE to OBJ	BUILD + EN		SUBJ	house
		BE	built	OBJ	by John
FORM-PROGRESSIVE	Add -ing to FIRST Put BE on FIRST	BE + ING	built		
		BE	being built		
ASPECT-PERFECT	Add -en to FIRST Put HAVE on FIRST	BE + EN	being built		
		HAVE	been being built		
TENSE-FUTURE	Put WILL on FIRST	Will	have been being built		
MOOD-INTERROGATIVE	FIRST + SURJ + VSTRING REMAINDER + OBJ will + the house + have been being built + by John				

Table 6 Example of Sentence Form Determination

	Step 2	Step 1		
START	PUT ON FIRST	CHANGE V in FIRST	SUBJ	OBJ
VOICE				
Passive	BE	V + EN	BY(OBJ)	(SUBJ)
Active	-	-	-	-
FORM				
Simple	-	-	-	-
Progressive	BE.	V + ING	-	-
Emphatic	DO	-	-	-
ASPECT				
+Perfect	HAVE	V + EN	-	-
-Perfect	-	-	-	-
TENSE				
Present	-	-	-	-
Past	-	V + ED	-	-
Future	WILL	-	-	-

MOOD	
Indicative	SUBJ - VSTRING - OBJ
Imperative	VSTRING - OBJ (SUBJ)
Interrogative	FIRST SUBJ - REMAINDER OF VSTRING - OBJ
Subjunctive	IF SUBJ - VSTRING - OBJ

Table 7 Paradigm of Sentence Form Determination

Pronominalization:

Suppose now that we have already generated from C1, the sentence: JOHN SAW MARY WRESTLING WITH A BOTTLE AT THE LIQUOR BAR, as in the earlier example and wish to continue with the structure representing "John went over to help Mary with the bottle". This structure is represented by C12 and the network it dominates in Figure 4. Since the tokens JOHN, MARY, and BOTTLE have already been printed in the generation of the first sentence, their subsequent use requires the substitution of pronouns, an anaphoric expression or an elision.

Our method for dealing with these matters is still highly experimental and limited so far to assigning pronouns. When the token of a noun is generated as a print image, the relation pair, PRON-TOK value is put on the structure. When a subsequent generation process calls for that concept, it first checks for a PRON relation; if it is present, PRON operates as a function to return the appropriate form of pronoun for that wordsense in the case being generated. This approach is simple and effective for generating the instances of pronouns in the example discourse, but is obviously only a beginning in one of the more complicated areas of English semantic and syntactic structure.

Sequencing and Embedding Sentences: As far as is represented in the semantic net, there are no sentences; only concept structures. Forming linear or embedded sequences of sentences is a matter controlled by the grammar and the generation procedure. The back references, AGT*, OBJ*, etc, are the semantic relations that key the process. Each time a structure Si refers to another structure Sj by relation R, Sj refers back to Si by R*, the inverse of R. When a noun phrase is generated as an Agent or Object of a verb structure, the inverse relation is deleted; otherwise it would generate an infinite sequence such as : JOHN WHO SAW WHO SAW WHO SAW... This kind of generation follows from the presence of grammar paths or rules such as the following:

```
NP5   OBJ*  NP6
        /   NP6

NP6   AGT*  NP7
        /   NP7

NP7   INST* NP8
        /   NP8
               etc.
```

The use of such a rule operates the R* as a function that:

1) compares the time of the verb concept to be embedded with the event time of the dominating sentence.

2) determines the form of embedding as relativization, and its pronoun, or adverbial clause introduced by BEFORE, DURING, or AFTER in accordance with the temporal relation of the two clauses.

3) determines if an embedding is allowed according to certain style limits such as depth and complexity.

4) finally uses a random number, probability .5, decision as to whether to embed or not, if otherwise possible; and, if an adverbial clause, whether it should be put in a pre-position, embedded, or post-positioned.

5) terminates the NP and puts the new verb concept on a list of sentences still to be generated, or causes the generation of an embedding.

It is worth mentioning that this complexity of decision process requires less space as LISP conditionals then to describe in English. In the event that the decision is to generate an embedding, the choices of relative pronoun or adverbial introducer are recorded as relational pairs on the semantic structure, and the generation algorithm continues its process. If no embedding is to occur, the value of R* is placed on a list of structures to be generated as sentences.

The significant insight that this study of embedding has given us is that, except for embedding stative verb structures, the temporal relations between two events one to be embedded in the other, is of paramount importance. Consider the following sets of examples:*

*a) John who drew the cork went over to help Mary.

*b) John who went over saw Mary wrestling...

c) John who saw Mary wrestling... went over...

?d) John who drew the cork and Mary whom he helped drank champagne together.

and,

a') John before he drew the cork went over to help...

b') Before he went over..., John saw Mary...

c') John went over...after he saw her wrestling...

d') ????

The question marks associated with d and d' suggest that it is usually awkward to separately modify the elements of a conjunction. The contrast of the a b c cases with the a' b' c' examples show that <u>unless the temporal sequence of events is preserved in the surface sequence of verbs</u>, <u>a time relation adverb must be used to signal the temporal sequence</u>.

These remarks and examples give some idea of the difficulties of embeddings. The development of syntactic rules and functions (i.e. transformation and decision procedures) to control the generation of reasonably good complex sentences will probably bring to light numerous other critical conditions usually associated with the verb structure.

*Where the temporal sequence of events is: see -1, wrestle -2, went -3, help -3, drew -4, drank -5.

Example Discourse Generations: The generator function takes a list of structures and the name of a grammar as its arguments. So far we have only experimented with grammars that start the sentence with verb structures. There is no reason why other grammars that start with any concept structure chosen at random, be it noun, preposition, adjective, or adverb, cannot be developed to control the ordering of transformations. For the present system, as each verb structure is generated it is marked off the list. Generally in this discourse all verb structures are inter-related by common arguments such as MARY, JOHN, BOTTLE, etc. with the consequence, that starting with any one, the whole discourse will be generated.

Examples of sequences of sentences that the system with its present grammar and syntactic functions has generated are shown in Table 8. The weaknesses of our present treatment of pronouns and anaphora is apparent in these examples. Such awkwardnesses as "a bottle cork" for "the cork" or " the cork from the bottle" are glaring. In the last example sentence, "Before John drew the cork, he went over to help Mary with a bottle", the use of "a bottle" reveals our present inability to use the information that "the bottle" is the same one with which "the cork" is associated. The data is in the semantic structure but a rule to use it has not been developed.

On the positive side, the example shows that the grammar produces reasonably good English sentences with fairly accurate choices of pronouns and time adverbs. Although the generation algorithm is still experimental and itself subject to modification, it can now support linguistic experimentation with the form and content of grammar rules and transformations for producing connected discourse.

GEN(E1, E16)

JOHN SAW MARY WRESTLING WITH A BOTTLE AT THE LIQUOR BAR.
JOHN WENT OVER TO HELP HER WITH IT BEFORE HE DREW THE CORK.
JOHN AND MARY TOGETHER DRANK THE CHAMPAGNE.

GEN(E3, E16)

MARY WAS WRESTLING WITH A BOTTLE AT THE LIQUOR BAR BEFORE JOHN HELPED HER WITH IT.
JOHN SAW MARY WRESTLING WITH A BOTTLE AT THE LIQUOR BAR.
JOHN WENT OVER TO HELP MARY WITH A BOTTLE BEFORE HE DREW A BOTTLE CORK.
JOHN AND MARY TOGETHER DRANK THE CHAMPAGNE.

GEN(E16)

JOHN AND MARY TOGETHER DRANK THE CHAMPAGNE AFTER HE SAW HER WRESTLING WITH A BOTTLE AT THE LIQUOR BAR.
JOHN BEFORE HE DREW A BOTTLE CORK WENT OVER TO HELP MARY.

GEN(E16, E12)

JOHN HELPED MARY WITH A BOTTLE AFTER HE SAW HER WRESTLING WITH IT AT THE LIQUOR BAR.
BEFORE JOHN DREW THE CORK, HE WENT OVER TO HELP MARY WITH A BOTTLE.

Table 8 Example Discourse Generations

V Discussion and Conclusions

We have only begun using the semantically based generator to experiment with rules for producing English discourse. As a consequence our findings and conclusions are quite limited. The following ten statements summarize our present understanding of semantically controlled generation.

1) A grammar alone generates syntactically well-formed strings of terminal word-classes. Random lexical substitution within these classes usually results in semantically nonsensical sentences.

2) A semantic network and its lexicon alone generates semantically understandable strings of words that are not syntactically well-formed sentences.

3) Semantically controlled generation requires that each semantic relation correspond to one or more syntactic relations and to the corresponding transformations that can change a portion of the semantic representation into a syntactic one. The selection of rules or paths through the grammar is accomplished by selecting only rules whose elements correspond to semantic relations in the net that is being worked on.

4) The grammar imposes an ordering on the application of the transformations. Once a particular rule is applied the grammar alone limits further choices to a non-contradictory ordered set of paths. Within this set, the paths to be chosen are further restricted to those that can represent the semantic relations in the network under consideration.

5) Generation is begun by selecting a node from the net, labelling it S, and entering the grammar at the rule or path labelled S.

6) The first step in the generation process appears to be the selection of a set of form-determiners in terms of values for Voice, Form, Aspect, Tense and Mood. This set probably also includes the choice of modals as has been suggested by Fillmore's (1968) rule; S - Modality + Proposition.

7) At various points in the generation process inverse semantic relations such as AGT*, LOC*, etc. are encountered. These offer the possibility of embedding a sentence. The choice of embedding or not at that point is made by complex criteria which so far relate to relations between the head verb of the sentence and the verb of the sentence to be embedded. The result of applying such criteria probably also affects the values for form determiners, although we have not yet seen how.

8) These observations with regard to embedding and form determination suggest that there exist criteria still unknown for selecting various forms of sentence as a function of context. Applying decision rules based on such criteria would appear to result in a selection of values for the form determiners.

9) This further suggests that a discourse generator stands above a sentence generator in order to select portions of the semantic net from which sentences are to be generated, and to exert thematic control via choice of subjects, form determination, and the ordering of sentences.

10) The generation of anaphoric references is also apparently subject to complex decision rules sensitive to the context. These must

account for the conditions that lead to a choice of a pronoun or some shortened nominal expression as well as accounting for an appropriate use of determiners in many cases. So far, rules have been developed only for substituting pronouns respecting gender, number and case. The substitution can be made for any reference to a noun that has already been used in generating either a sentence or a discourse.

Part of our motivation in devising this system is to make available a tool that will help to augment a linguist's effectiveness in developing grammars for generating sentences and multi-sentence discourse from a semantic structure. As input, the system requires a semantic network representing the meaning of a discourse, a lexicon also in network form, and a grammar network. The grammar paths are the names of transformation rules or functions that are to be applied to the semantic nets which are to be transformed into English.

A standard set of conventions for these functions--in the form of such operation names as ADD, MATCH, DELETE, etc.--is still under development. Efforts are being made to ensure that the resulting language for expressing transformations will be natural to linguists and simpler than the usual transformation conventions.

The system is available as a LISP 1.5 program for the CDC 6600. Only minor modifications in the program are required to fit it to most other LISP implementations. The program so far is expressed in about a hundred lines of LISP expressions. It is available on request from the authors.

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