

ANALYSIS OF JAPANESE SENTENCES
BY USING SEMANTIC AND CONTEXTUAL INFORMATION

MAKOTO NAGAO AND JUN-ICHI TSUJII
DEPARTMENT OF ELECTRICAL ENGINEERING
KYOTO UNIVERSITY
KYOTO, JAPAN

Summary

The organization of a natural language (Japanese) parser is described. The parser can transform fairly complex sentences into abstract structures marked for case. A variation on the system developed by Woods called an "Augmented Transition Network" is used as the program for analysis. The parser utilizes detailed semantic dictionary descriptions and contextual information abstracted from sentences analyzed in sequence. It is claimed that intuitive reasoning, which is not easily formalized by rigid logical operations, plays an important role in language understanding. Some intuitively appealing schemas of representation for both the semantic descriptions of words and context are discussed. Meanings of verbs are described by using a 'case' concept. Additional information is attached to case frames of each verb to indicate what changes the case elements in the frame may undergo and what events may occur in succession. Meanings of nouns are also expressed in case-frame-like descriptions. Nouns also have relational slots which must be filled in by other words or phrases. The context is represented in a form similar to that of the semantic network of Simmons or the nodespace of Norman along with some added special lists (NS - Noun Stack, HNS - Hypothetical Noun Stack, TL - Trapping List). These lists contain objects mentioned in previous sentences or pending problems which may be resolved by succeeding sentences. The objects in NS are ordered according to their degrees of importance in the context. Several new techniques based on heuristically admissible operations are presented to analyze 1) complex and long noun phrases 2) conjunctive phrases 3) anaphoric expression and 4) omitted words in phrases or sentences. The results of applying the parsing program to the sentences in a textbook of elementary chemistry are also presented.

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I INTRODUCTION

In this paper we describe the organization of the natural language parser developed over the last two years. This forms an important part of a question-answering system under development with natural language (Japanese) input. The parser can transform fairly complex sentences into abstract structures marked for case. It utilizes detailed semantic dictionary descriptions and contextual information abstracted from the preceding sentences.

For the present, we have confined the domain of the system to the field of elementary chemistry where we can describe the semantic world in rather concrete terms. At the same time, various complex events occur in this field. For example, substances which participate in particular events may disappear, new substances may emerge, or some properties of the substances may be altered. To treat these complex situations, it was necessary to formally represent relationships between events and changes of state and to devise an appropriate schema of representing context.

In most approaches to the understanding of natural language through artificial intelligence, schemas which entail rigid logical operations are used to represent both knowledge and context. Logical operations appear to be necessary for solving some kinds of problems in natural language, especially at the deep deductive level of understanding. However, intuitive reasoning is not easily formalized in terms of logical operations. It is our contention that intuitive reasoning is completely based on the language activity in the human brain. Associative functions relating to semantic similarities between words, semantic depth of an interpretation and

probability of associative occurrence of events are inherent factors in intuitive understanding and the reasoning process.

Y. Wilks (1975) in his system carries out intuitive reasoning by employing the notion of 'semantic preference'. His system seems to work well on analyzing local relationships among words. However, in order to analyze more global relationships (e.g., in dealing with complex cases of anaphora) we require access to ~~more~~ information than can be contained in formulas (templates) ~~associated~~ with the lexicon. We find Wilks' use of 'CS-inference rules' rather awkward. The system would be much improved if accompanied by an appropriate schema for representing context.

'Case grammar' sentence-analysis theories such as those of Fillmore (1968) and Celce-Murcia (1972) are based on the semantic relationships between verbs and nouns $\leftrightarrow$ events and concepts. R. F. Simmons (1973; 1975), D. A. Norman (1973), D. E. Rumelhart (1973) and so on follow these theories to represent knowledge and context in their systems. We also adopted case grammar and modified it to account for Japanese sentences. We represent context in the form of a semantic network. An input sentence is transformed into a corresponding deep case structure. This structure is assimilated with the ~~semantic~~ network constructed from previous sentences.

Japanese is a typical SOV language. The word order is rather arbitrary except that the main verb comes last. Cases such as subjective, objective and dative are syntactically indicated by postpositions, but a postposition can be used for several deep cases ambiguously. Hence the determination of underlying sentential structures rests heavily on an understanding of the semantic relations between the main verb and nouns. Moreover in Japanese the words which are essential in understanding a sentence are often omitted without pronominal reflexes. Our system can

infer from the semantic descriptions of words what kinds of phrases should be supplied to fill lexical gaps and search the contextual representation to find appropriate fillers.

The final analysis produced by our parser is a semantic network. This could be used for the internal representation of data in a question-answering system or as an intermediate expression in machine translation. However, it is still too early to report on the results of these projected applications.

The parser consists essentially of four fixed components.

1) The grammar consists of rules written in PLATON. PLATON is a new programming language which is a variant of the system developed by Woods (1970) called 'Augmented Transition Network'. PLATON has additional facilities for pattern matching and flexible backtracking. A grammatical rule in PLATON consists of two parts: pattern rewrite which is expressed as a pair of syntactic patterns, and semantic and contextual check which is an arbitrary LISP function. When a rule is to be applied, the semantic and contextual check is employed to determine whether the rule is semantically and contextually feasible. For the present we have about two hundred rules for the analysis of Japanese sentences. These rules are devised to combine various syntactic patterns in Japanese with appropriate semantic and contextual checking functions. PLATON is presented in more detail in another paper by Nagao and Tsujii (1976).

2) In the dictionary are stored words along with their various semantic relationships. We express the meaning of a word in terms of how it may be related to other words. The meaning of a verb is described in the form of 'activity patterns' in the verb dictionary. An activity pattern

is actually the case frame of a verb and additional related information. The case frame represents what case relations the activity entails and what kind of referents will be appropriate for each case slot. Additional information provided feeds into the 'change' or 'causative' component used by Norman (1973). Such information indicates how one activity pattern may be related to another by causal relationships and what related change may occur in the semantic network representing context. From such information we can infer what activities and change will follow the present activity.

The meanings of nouns are also expressed in the case-frame-like descriptions. They also have relational slots which will be filled in by other words or phrases.

3) The contextual representation is similar in form to the semantic network of R. F. Simmons (1973;1975) or the nodespace of D. A. Norman (1973). In this representation there are two kinds of nodes. The C-node corresponds to a concept typically expressed by a noun. The S-node corresponds to an event. An event is a realization of an action pattern and each argument of the pattern is assigned a C-node. C-nodes are related to S-nodes by the case labeled relations. These relations are bidirectional.

The following list shows the relations used in the network:

(i) Deep Case Relations. ACT, OBJ, PLACE, TIME -- A deep case relation connects an S-node with its argument C-node.

(ii) Attributive Relations: VOLUME, COLOR, MASS, SHAPE -- An attribute relation connects a C-node with its value. We can distinguish two C-nodes associated with the same lexical entry but different values of attributes.

(iii) Token substitution. TOK -- TOK is used to connect a node with

a lexical entry.

(iv) Event-Event Relation CAUSE, IMPLY -- Two S-nodes are sometimes connected by a particular relation. The relations are sometimes expressed explicitly in the surface sentence by a special conjunction such as NODE (because), NARABA (if) and so on.

In our system the semantic network is accompanied with special lists (Noun Stack-NS, Hypothetical Noun Stack-HNS, Trapping List-TL). We call these lists Intermediate Term Memory. Contextual functions work on these lists to search appropriate nodes of the semantic network which correspond to the referents of anaphoric expressions or the unexpressed elements of sentences.

(4) Semantic and Contextual functions are programmed in LISP. These functions are incorporated in the PLATON rules along with rewriting patterns. A contextual function takes as arguments the semantic constraints a target node must satisfy and returns the node when an appropriate node is found from the semantic network. A semantic function checks descriptions in the dictionary to determine whether the combination of two words is semantically permissible. For analyzing noun-noun combinations, we provide sixteen semantic functions.

The whole system is written in LISP1.6 which is implemented on a minicomputer, TOSBAC-40. The minicomputer is equipped with 64KB as main memory and 512KB as secondary core memory. The LISP1.6 uses the secondary memory as virtual storage. The dictionary consists of about 400 nouns, 200 verbs and 100 adjectives and other categories. The parser with rules and the dictionary occupies about 50K cells. The LISP uses a soft-ware

paging mechanism, and the main memory is rather small in comparison with the secondary memory. The content of the dictionary is stored on a disc in the form of S-expressions. Consequently, the speed of execution is slow. It takes typically about 10 to 15 minutes to analyze sentences which contain 3 to 5 simple sentences and 10 to 15 noun phrases.

II LEXICAL DESCRIPTIONS OF WORDS

2.1 Noun Description

Most nouns have a definite meaning by themselves. We call these Entity Nouns. An entity noun is considered to represent a set of objects, and therefore is taken as a name of the set. The objects belonging to the set may share the same properties. By introducing another property the set may be divided into a number of subsets, each of which is expressed by another noun. We describe such set-inclusion relationships and set properties in the noun dictionary.

We represent a property of a noun by an attribute-value pair expressed as (A V). For instance, the dictionary entries for the nouns 'material' and 'liquid' are:

```

material      (( SP)(ATTR(STATE)(MASS)(COLOR)(SHAPE) ----- ))
liquid       (( SP material)(ATTR (STATE *LIQUID)(SHAPE NIL )))
  
```

The descriptions (STATE)(MASS) and so on in the definition of 'material', lack values (V) showing that 'material' may have arbitrary values of these attributes. In the definition of 'liquid', there is a SP-link to 'material', which means that 'material' is a super-set concept of 'liquid', or that 'liquid' is a subset or a lower concept of 'material'. Objects belonging to

a subset are considered to have the same properties as the objects of the super-set, in addition to the properties described explicitly in its definition.

By the above descriptions, we can see that the value of the attribute STATE of 'liquid' is *LIQUID, and that of SHAPE is the special value NIL. The *LIQUID is one of the primitive value markers. The primitive value markers are indicated by the preceding The value NIL indicates that 'liquid' can not have any value of SHAPE By tracing up the SP-links, we can retrieve all the (A V) pairs of an object. We assume the value of an attribute of a lower concept has precedence over that of the upper concept For instance we can obtain the following full description of 'liquid'

```
liquid ((ATTR (STATE *LIQUID) (SHAPE NIL)(MASS)(COLOR) ----- ))
```

These upper-lower relationships among entity nouns are not expressed by a tree structure Some nouns may share properties with more than one noun 'Water' is such an example 'Water' has the properties of both 'liquid' and 'compound' Since we permit a noun to have several upper concepts, the relationships are represented by a lattice as shown in Figure 2 1.

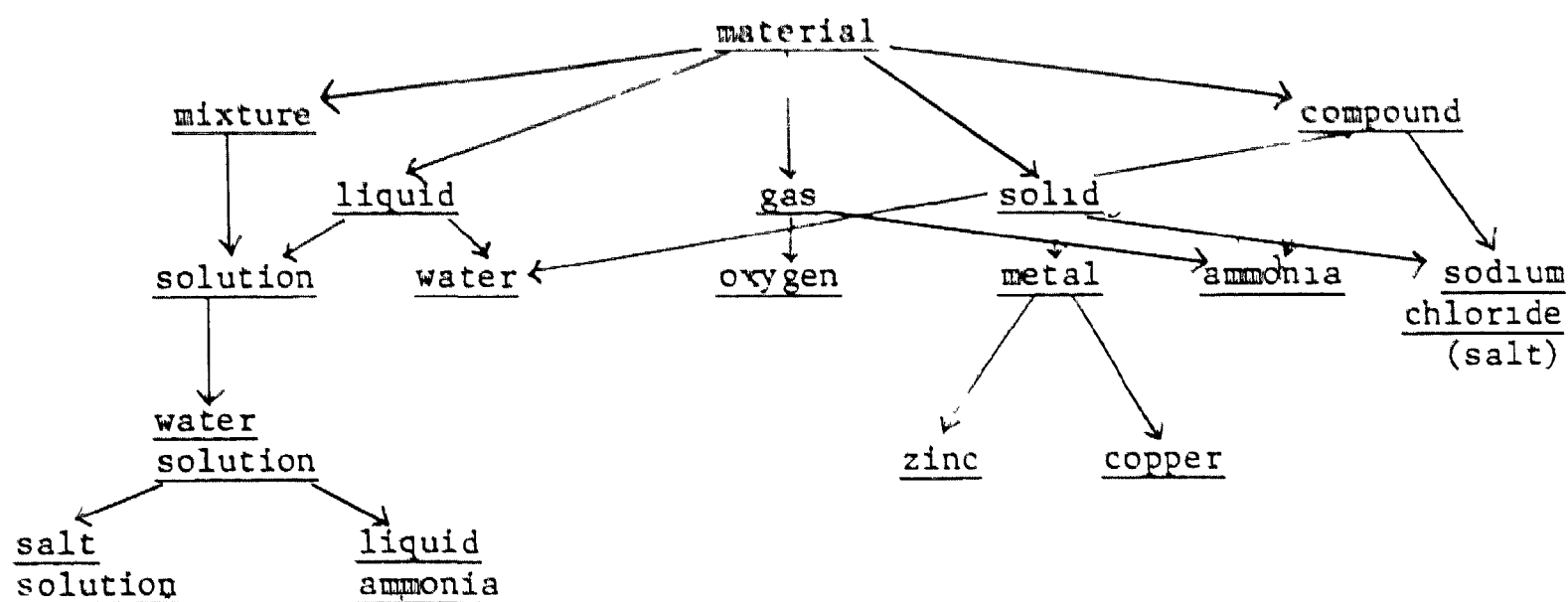


Figure 2 1 Upper-lower relationships among nouns

Although most nouns are regarded as entity nouns, there are a few nouns which have relational functions. We call them Relational Nouns; 'Father' is a familiar example. In order to identify a person indicated by the word, we have to know whose father he is. In the chemical field we can easily find such nouns (e.g., 'weight', 'temperature', 'color', and 'mass'). These are called Attribute Nouns. Their meanings are described in a different way from that of ordinary nouns. Figure 2.2 shows some examples. Here, A-ST designates the standard attributive relation which is expressed by the word. The description (NF N-A) shows the noun belongs to the group of attribute nouns.

(OOKISA	((NF	N-A)	(A-ST	VOLUME MASS LENGTH AREA)	
size				(SP ZOKUSEI RYO)	attribute quantity
(IRO	((NF	N-A)	(A-ST	COLOR)(SP ZOKUSEI SHITSU)	attribute quality
color					

* An attribute noun may express more than one standard attribute. OOKISA (size) expresses VOLUME, MASS, LENGTH OR AREA. The attribute it expresses in context depends upon what entity noun is used with it.

** Attribute nouns are further classified into two groups, quantitative and qualitative. A qualitative attribute noun cannot be a case element of a verb which requires quantitative nouns. The verbs FUERU (increase) and HERU (decrease) are such examples of verbs.

Figure 2 2 Attribute Nouns

'Liquid' is another relational noun. The Japanese word which corresponds to 'liquid' is EKITAI. While 'liquid' in English can be either a noun or an adjective, EKITAI in Japanese is categorized syntactically as a noun. But semantically EKITAI has two different meanings, one corresponding to the noun usage of 'liquid', the other corresponding to the adjective

usage of it. The noun EKITAI in the adjective usage is called a Value Noun with the attribute STATE. Another word AKAIRO (red color) is also a value noun of the attribute COLOR. Figure 2.3 shows the description of these nouns in the noun dictionary.

```
( EKITAI      ( (NF N-E)(SP  BUSSHITSU)(ATR  (STATE  LIQUID)(SHAPE  NIL))
  liquid      material

              ( (NF N-V)(V-DESCRIPTION (STATE *LIQUID)) )

(AKAIRO      ( (NF N-E)(SP  IRO ))
  red        color

              ( (NF N-V)(V-DESCRIPTION (COLOR *RED)) )
```

Figure 2 3 Value Nouns

There are other kinds of relational nouns Action, Prepositional, Anaphoric and Function nouns. An action noun is the nominalization of a verb. For example, KANSATSU (observation) is the nominalization of the verb KANSATSU-SURU (observe) We describe this in the dictionary by giving a link to the original verb and by adding other information

There are not postpositional particles in Japanese for every preposition in English. Some special nouns play the role of English prepositions. We call such nouns Prepositional Nouns Because a prepositional noun usually has more than one meaning just as an English preposition has, we attach semantic conditions to help disambiguate them Figure 2.4 shows example of lexical descriptions of prepositional nouns

```

( MAE          ( (NF N-P)(F-DESCRIPTION
before
in front of    ((CAT ACTION)          TIME BEFORE)

                ((AND (CAT N-E)(LOWER DOUGU
                                instrument

                BUSSHITSU))          PLACE IN-FRONT-OF ))))
                material

( NAKA          ( (NF N-P)(F-DESCRIPTION
in
                (( OR (LOWER YOUKI )(LOWER
                                container

                EKITAI)) PLACE IN) )) )
                liquid

```

Figure 2.4 Prepositional Nouns

Corresponding to each meaning we give a triplet. The first element is the semantic condition. If the condition is satisfied, the corresponding second element is adopted as the meaning. If not, the next triplet is tried. The second element of a triplet represents the whole meaning of the phrase. For example, the whole meaning of the phrase TSUKUE [desk-entit noun] NO [of] UE [on-prepositional noun](on the desk) is PLACE. The third element of a triplet expresses the relationship by which the other noun in the phrase may specialize the whole meaning.

2.2 Verb Description

Verbs, adjectives, and prepositions in English have relational meanings with nouns. A verb represents a certain activity, while the agent associated with the activity is not inherent to the meaning of the verb (neither is the object which the activity affects, nor the other components). These components appear in a sentence with certain loose relations to a verb.

In our system the meaning of a verb is described by setting up several relational slots which will be filled in by nouns. In this sense the meaning of a verb is not confined to itself, but is related to nouns.

We describe these relations by using the case concept introduced by C. J. Fillmore (1968). Case may be looked upon as a role which an object plays in an activity. Because several objects usually participate in an activity, there are several cases associated with an activity. An object is expressed by a noun phrase, and an activity by a verb. A sentence instantiates an activity by supplying noun phrases to the cases associated with the activity. We call such instantiated activity an Event. The problem is to decide what case a noun phrase holds in relation to a verb in any particular event.

Though there are usually some syntactic clues in a sentence as to how it instantiates an activity, they are not enough to decide the case relationships between noun phrases and a verb. To establish these relationships we need both syntactic and semantic information. A verb has its own special usage patterns. That is, certain cases are necessary for the activity and certain objects are preferable as fillers for the case. We call these labeled patterns Case Frames for Verbs, and express them as a list of case pairs such as (CASE NOUN). A verb usually has more than one case frame corresponding to different usages. A typical description of a verb is shown in Figure 2.5

(TOKASU	(CF				
melt	((ACT	NINGEN	)(OBJ	KOTAI)	(IN EKITAI))
dissolve		human being		solid	liquid
	((ACT	NINGEN	)(OBJ	KOTAI)	(INST))
		human being		solid	
	((ACT	SAN	)(OBJ	KINZOKU	))
		acid		metal	

Figure 2.5 A typical description of
a verb

According to this description, we understand the verb TOKASU (melt, dissolve) has two different usages. In one usage the verb takes the ACTOR case, and prefers to take the sub-concepts of the noun NINGEN (human being as the case element. In such a way case frame descriptions are closely tied to noun descriptions, especially with the upper-lower concept relationships among nouns.

There are two types of cases, Intrinsic and Extrinsic cases. The intrinsic cases of a verb are essential ones for the activity, but extrinsic cases are not. For example, the cases of TIME and PLACE, which express when and where an event occurs, are extrinsic for ordinary verbs. Most activities can be modified by these extrinsic cases, but the kinds of nouns preferred for these case elements do not strongly depend on the kinds of activities. Therefore we describe only the intrinsic cases in the verb dictionary. We set up fourteen cases as shown in Table 2.1 for the analysis of sentences in a textbook of elementary chemistry

TABLE 2.1

(1) ACT : ACTor is responsible for action.

- (a) KARE-GA IOU -O SHIKENKAN-NI IRERU
he-(ACT) sulfur -OBJ test tube-(IN, PLACE, etc.)put in

He puts sulfur in a test tube

In the chemical field, a chemical object is often regarded as ACTor of an action, though it does not exercise intention in regard to action.' For example, the underlined word in the following sentence is regarded as ACT.

- (b) ENSAN -WA DOU -O TOKASU.
hydrochloric acid -(all cases) copper -OBJ melt

Hydrochloric acid melts copper.

(2) SUBJ : SUBJect is the primary topic of a sentence

- (a) KITAI-NO TAISEKI -GA FUERU.
 gas volume -(SUBJ) increase

The volume of the gas increases

- (b) IOU -WA KIIROI
sulfur -(SUBJ) yellow

Sulfur is yellow.

(3) OBJ OBJect is the receiving end of an activity. It is affected by the activity.

- (a) KARE-GA MIZU -O NESSURU
 he-(SUBJ) water -(OBJ) heat

He heats the water.

- (b) ENSAN -GA AEN -O TOKASU
 hydrochloric acid -(ACT) zinc -(OBJ) melt

Hydrochloric acid melts zinc.

(4) IOBJ This case is semantically the most neutral case. It is an object or concept which is affected by an activity, and which is not OBJect. This case is usually specialized by the other cases such as PLACE, TO, IN and so on, depending on the semantic interpretation of the verb itself

TABLE 2.1 (continued)

- | | | | | | |
|-----|--------|--------|--------------------------|---------|----------|
| (a) | DOU | -O | <u>ENSAN</u> | -NI | TSUKERU. |
| | copper | -(OBJ) | <u>hydrochloric acid</u> | -(IOBJ) | dip |
| | | | | (IN) | |

(Someone) dips copper in hydrochloric acid

- (5) FROM , FROM describes a former position or state in time or space of the entailed SUBJect or OBJect of the verb.

- (a) SHIKENKAN -KARA BEEKAA -E EKITAI-O UTSUSU.
test tube -(FROM) beaker -(PLACE) liquid-(OBJ) pour

(Someone) pours the liquid from the test tube into the beaker.

- (6) RESULT ; RESULT is to the future as FROM is to the past It describes the resultant position or state as the entailed SUBJECT or OBJECT of the verb.

- (a) MIZU -GA SUIJOUKI -NI NARU.
water -(SUBJ) steam -(RESULT) become

The water becomes steam

- (7) INST ; INSTRument is an object used as the tool or device by which an activity is carried out

- (a) GASU-BAANAA -DE MIZU -O NESSURU.
gas burner -(INST) water -(OBJ) heat

(Someone) heats water by a gas burner.

- (8) TO ; This is the destination in time or space of something in the action

- (a) SUIBUN- -GA NAKUNARU TOKI MADE NESSHI TSUZUKERU.
water -(SUBJ) be gone time-(TO)till heat continue

(Someone) continues to heat (it) till the water is gone.

TABLE 2.1 continued

(9) FACT ; FACT is used to indicate sentential complementizers.

(a) KORE. -O SHITSURYUHOZON-NO HONUSOKU -TO IU.
it -(OBJ) the conservation of mass law -(FACT) call

We call it the law of conservation of mass.

(10) PLACE ; PLACE is used to indicate locations in space of the action

(a) ARUCOORU-RANPU-NO YOKO -NI BEEKAA -O OKU.
alcohol lamp side -(PLACE) beaker -(OBJ) put

(Someone) puts a beaker on the side of an alcohol lamp.

(11) IN , IN indicates a more specific relation to PLACE.

(a) MIZU -O SHIKENKAN -NI IRERU.
water -(OBJ) test tube --(IN) pour

(Someone) pours water in a test tube.

(12) SOURCE ; This shows constituent materials of compounds.

(a) ENSOSANNATORIUMU -WA ENSO, SANSO, NATORIUMU -KARA
sodium chlorate -(SUBJ) chlorine oxygen sodium -(SOURCE)

DEKITEIRU
consist

Sodium chlorate consists of chlorine oxygen and sodium.

(13) CAUSE , This shows a reason or cause of the activity.

(a) NESSHITA-TAME -NI HAGESHIKU KAGOUSURU
heat -reason -(CAUSE) violently react

Because (someone) heats (them), (they) react violently.

(14) TIME , Time indicates location in time of the action.

(a) NESSHITA -TOKI -NI SANSO -GA HASSEISURU
heat time -(TIME) oxygen -(SUBJ) be generated

Oxygen is generated when (someone) heats (it).

In order to resolve the syntactic ambiguity of a sentence, it is also necessary to utilize contextual information obtained from preceding sentences. When one knows a certain event has occurred, he can anticipate successive events that will occur and what changes the objects participating in the event will undergo. This kind of expectation plays an important role in understanding sentences. Various kinds of associations cluster conceptually around individual activities. One can perform contextual analysis of language by explicating these associations.

We append this kind of experiential knowledge to the case frames of verbs. The following two items are described for each verb in the verb dictionary:

- (1) CON this refers to the consequent activities which are likely to follow the activity of the verb, but not necessarily.
- (2) NTRANS this refers to the resultant effects on objects in view of how the objects are influenced by the activity. In our system the influence on the objects is described by the following three expressions:

- (a) (ADD case a-set-of-(A V)-pairs)

- (b) (DELETE case a-set-of-attributes)

- (c) (CREATE lexical-name-of-an-object a-set-of-(A V)-pairs)

(a) means that the object in the case indicated by the second element comes to have a set of properties indicated by the third element. (b) is for the deletion of a set of properties from the object. (c) shows that some objects will be created by the activity.

A typical example using a CON expression is shown in Figure 2 6

```

( IRERU (CF
  put in
  ((( ACT NINGEN      )(OBJ BUSSHITSU)(IN  YOKU1))
    human beings      material      container
    (CON (ARU (SUBJ (*OBJ))(PLACE (IN *IN))))))
    exist
  )

```

The function * retrieves the designated case-element of the current frame.

Figure 2.6. Example of a CON expression

When we have completed the analysis of the sentence

```

IOU      -O      SHIKENKAN  -NI      IRERU
sulfur   -(OBJ)  test tube  -'IN, RESULT, etc.)  put in

```

Someone puts sulfur in a test tube

each case of the case frame of the verb IRERU (put in) is instantiated by an object referred to in the sentence. Then we can instantiate the expression of CON, and the result is 'the sulfur is in the test tube' Figure 2 7 shows an example using an NTRANS expression.

```

(TOKASU      ( CF
  melt
  dissolve
  ((( ACT NINGEN      )(OBJ KOTAI)(INST))
    human beings      solid
    (NTRANS (ADD OBJ (STATE *LIQUID))))
  (( ACT NINGEN      )(OBJ KOTAI)(IN EKITAI))
    human beings      solid      liquid
    (NTRANS (CREATE YOEKI
      solution
      ( SOLVER *IN))
      ( SOLVENT *OBJ))))))

```

Figure 2 7. Example of an NTRANS expression

In this expression one can see the verb TOKASU has two different meanings. One corresponds to 'melt', and the other to 'dissolve in'. When we analyze the sentence,

DOU	-O	TOKASU.
copper-	(OBJ)	dissolve, melt

Someone melts copper

we adopt the first case frame of TOKASU (melt) because it gives the highest matched value against the sentence (see section 3.4). As the result of evaluating the NTRANS expression in the case frame, we conclude the copper is now in the liquid state. In the lexical description 'copper' is a lower concept of 'solid', so that copper in general behaves as a solid object. But the copper in the above sentence comes to have the attribute value pair (STATE *LIQUID) and will behave as 'liquid' in the succeeding sentences.

On the contrary, when we analyze the sentence

SHIO	-O	MIZU	-NI	TOKASU
salt	-(OBJ)	water	-(IN, PLACE, etc.)	melt, dissolve

Someone dissolves salt in water.

the second case frame of TOKASU (dissolve in) gives the highest matched value. After the sentence instantiates the case frame, a new object (i.e., a solution which consists of salt and water) will be created.

CON AND NTRANS are thus important in the contextual analysis of sentences. The detailed analysis procedure using these expressions is described in section 4.2.

III ANALYSIS OF NOUN PHRASE

3.1 Properties of a Noun Phrase

In Japanese, two or more nouns are often concatenated by the postposition NO to form a noun phrase. Because there are many different semantic relationships among nouns concatenated by NO, we must decide what relationships may hold among the nouns. Typical examples are shown in Figure 3.1.

EKITAI	-NO	JUTAI	-NO	SANSO	-NO	TAISEKI	
liquid		state		oxygen		volume	
the volume of the oxygen in the state of liquid							
HANNOU	-NO	ATO	-NO	NAOTORIUMU	-NO	TAISEKI	-NO HENKA
reaction		after		sodium		volume	change
changes of the sodium's volume after the reaction							

Figure 3.1. Examples of NOUN+NO phrases

The phrase NOUN+NO can modify, in principle, any or all of the succeeding nouns in the extended NO construction so that many different patterns of modification relationships are syntactically permitted. We must decide which one is correct by considering semantic restrictions.

We have identified sixteen semantically acceptable NOUN NO NOUN combinations. These are shown in Table 3.1. (See pgs. 23-25 for this table) Corresponding to these relationships we prepared sixteen primitive functions. These functions are applied in turn to a noun phrase to decide what relationship holds between two nouns. The order in which these functions are applied is based on the frequency and the tightness of the relations. Each function checks only one semantic relation. In order to illustrate how these functions perform their tasks, the following example of noun + prepositional noun'

TABLE 3.1. Admissible noun-noun
Combinations

(1) (value noun)+(attribute noun)

(ex) KOTAI -NO JOUTAI
solid state

(2) (value noun)+(entity noun)

(ex) EKITAI NO IOU
liquid sulfur

(3) (entity noun)+(attribute noun)

(ex) EKITAI -NO IRO
liquid color

(4) (noun)+(prepositional noun)

(ex) HANNOU -NO MAE
reaction before

(5) (anaphoric noun)+(noun)

(ex) MOTO -NO BUSSHITSU
former material

(6) (attribute noun)+(entity noun)

(ex) (TAKAI) ONDO -NO EKITAI*
high temperature liquid

*In this usage, the attribute noun should be modified by another noun or adjective, which specifies the value of the attribute.

(7) (noun)+(action noun)

(ex) SANKADOU -NO KANGEN
oxidized deoxidization
copper

IRO -NO HENKA
color change

TABLE 3.1 continued

(8) (time)+(noun)

(ex)	(HANNOU	-NO)	MAE	-NO	DOU
	reaction		before		copper

*The noun-noun combination, 'reaction-NO before' expresses the 'time' before the reaction.

(9) (place)+(noun)

(ex)	(SHIKENKAN	-NO)	NAKA	-NO	FKITAI*
	test tube		in		liquid

*The noun-noun combination, 'test tube-NO in' expresses the 'place' in the test tube.

(10) (noun)+(conjunction noun)

(ex)	SANKA	-NO	TAME*
	oxidization		in order to
			by reason of

*In Japanese, some nouns are used to elucidate the case relationships between a noun phrase and a verb. The noun TAME in this example expresses cases such as CAUSE or PURPOSE.

(11) (entity noun)+(entity noun)

(ex)	NATORIUMU	-NO	KAGOBUTSU
	sodium		compound

The first entity noun is a constituent element of the object expressed by the second noun

(12) (entity noun)+(entity noun)

(ex)	SANKADOU	-NO	SANSO*
	oxidized copper		oxygen

*The second noun is a constituent element of the object expressed by the first noun

TABLE 3.1 continued

(13) (entity noun)+(entity noun)

(ex)	SHIKENKAN	-NO	SOKO*
	test tube		bottom

*The second noun refers to part of the object expressed by the first noun.

(14) (entity nouns)+(entity noun)

(ex)	KARIUMU, NATORIUMU	-NADO	-NO	KINZOKU*
	potassium, sodium	etc.		metal

*The nouns 'potassium' and 'sodium' are lower concept nouns of the last noun 'metal'

(15) (name)+(noun)

(ex)	SHITSURYUHOZON	-NO	HOUSOKU
	the conservation of mass		law

(16) Others

(ex)	1cm ² ATARI	-NO	CHIKARA
	per 1cm ²		pressure

phrase is given.

The noun MAE is a prepositional noun, and its semantic description is shown in Figure 2.4. We note that this word has two different meanings

JIKKEN	-NO	MAE	
experiment		time	preceding
		place	in front of

The function for the analysis of this kind of phrase checks at first whether the second noun MAE is a prepositional noun. If it is not, then this function fails and returns the value NIL. In this example, because the word MAE is a prepositional noun, the checking proceeds further. The description in Figure 2.4 shows that if the preceding noun is an action noun (i.e., if it is a nominalization of a verb) then MAE has the first meaning. Because the noun JIKKEN (experiment) satisfies this condition, the checking succeeds and the function returns the value T. The result of the analysis is shown in Figure 3.2(a). On the other hand, if the input is

TSUKUE	-NO	MAE	
desk		before, in front of	

then the word TSUKUE (desk) satisfies the condition of the second meaning, and the result is as shown in Figure 3.2(b).

(a) JIKKEN -NO MAE
 experiment { before : time
 { in front of : place }

TIME
 |
 | before • experiment

(b) TSUKUE -NO MAE
 desk { before time
 { in front of place }

PLACE
 |
 | in front of desk

Figure 3 2. Results of analyses of noun and prepositional noun phrase

In this way the sixteen checking functions not only test whether a certain semantic relationship holds among input words, but also disambiguates the meanings of input words

3.2 Analysis of a noun phrase

We analyze a noun phrase by using the above sixteen checking functions subject to the limitation that related noun groups may not overlap. As stated before, 'noun + postposition NO' phrases and adjectives can modify only the succeeding nouns. We stack in the temporary stack noun phrases and adjectives for which the nouns to be modified have not been determined. The analysis of a noun phrase is carried out by scanning words one-by-one from left to right. If we scan an adjective or a determiner, we stack the word in the temporary stack. If we scan a noun, we pick up a word from the temporary stack and check whether it can modify the noun. This checking is done by the

above functions if the stack word is a noun. We also have the checking functions relating nouns to adjectives or determiners. The dictionary content of an adjective is just the same as that of a value noun. The semantic checking function between an adjective and a noun will test whether the noun can have the attribute which is modifiable by the adjective. The checking of the determiner differs somewhat and is explained in a later chapter.

The checking process will stop when there are no words in the temporary stack or a word is picked up that fails to modify the noun being scanned. The noun is then stacked in the temporary stack. If the temporary stack contains only one noun and there are no words to be scanned in the noun phrase, the analysis succeeds and returns the noun in the stack. The returned noun is called the Head Noun of the noun phrase. These processes are illustrated in Figure 3.3. (See pgs 29-30 for this figure.)

If there are no words to be scanned next and the temporary stack contains more than one word, then the analysis fails and backtracks to the decision points of the program. A decision point in the analysis of a noun phrase is any point at which two words have been related semantically. The relationship between two words established during the analysis is the one determined by the function which succeeds first. Because the order of checking functions is somewhat arbitrary, in some cases a relationship which has not been checked may be preferable to the established relationship. This is illustrated in the examples below.

(1) Temporary Stack = empty

ii) TS = test tube

*A check of the semantic relationship between 'test tube' and 'in' is performed

in test tube

iii) TS = place

*A check of the semantic relationship between 'place' and 'red' is performed, but it failed to establish a new concept. Therefore, 'red' is placed on the top of TS.

(iv) TS =

red	place
-----	-------

*The next scanned word is 'liquid'. Since it is a noun, a check of the relationship between the noun and the words in TS is performed. The check succeeds because the combinations (value noun)+(entity noun) and (PLACE)+(entity noun) are semantically permissible.

(v) TS = liquid

Figure 3 3

There are no words to be scanned, and the TS contains only one word. Hence, the analysis of this noun phrase succeeds.

The result is as follows. (The head noun of this noun phrase is 'liquid'.)

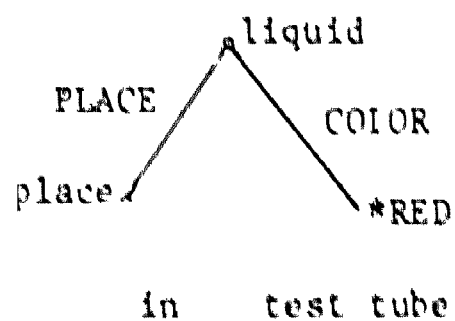


Figure 3.3 continued

EKITAI	-NO	JOUTAI	-NO	HENKA
liquid		state		change

the change of state of the liquid

EKITAI	NO	JOUTAI	-NO	SANSO
liquid		state		oxygen

oxygen in the liquid state

In the first example the word JOUTAI (state) designates an attribute of EKITAI (liquid) and EKITAI corresponds to a visible, real object. JOUTAI (state) in the second example designates an attribute of SANSO (oxygen), and the word EKITAI does not correspond to a real object but is used to specify the attribute 'state' of the oxygen. These examples show that the word EKITAI (liquid) has two different usages. According to these usages, there are two different semantic constructions of the phrase EKITAI-NO JOUTAI as shown in Figure 3.4.

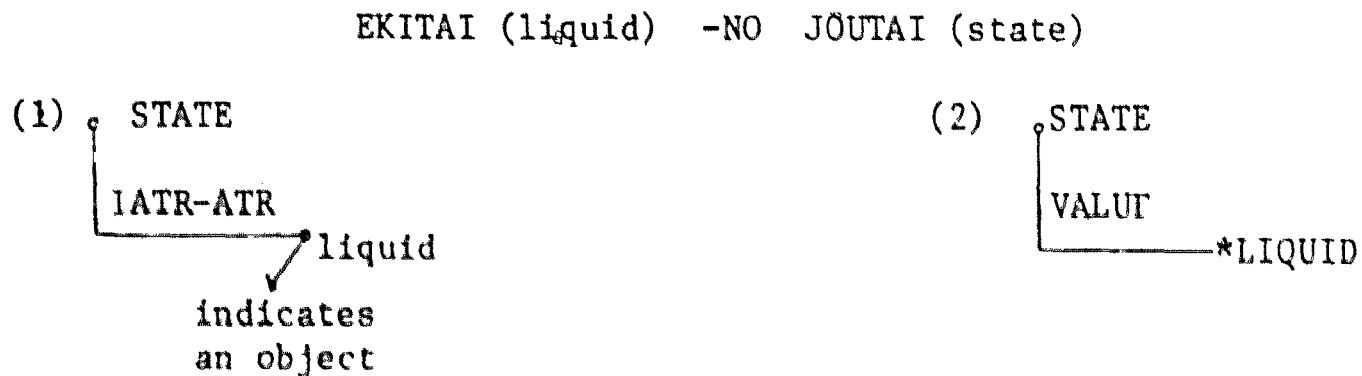


Figure 3.4. Two different deep structures
for the phrase EKITAI NO JOUTAI

Because we analyze a noun phrase from left to right, we cannot determine which usage is correct until we recognize the rightmost word HENKA (change, transition) or SANSO (oxygen). However, a semantic checking function disambiguates the multiple meanings of the word EKITAI. If the disambiguation is recognized to be incorrect in subsequent processing, we must be able to

backtrack to the decision point at which this temporary disambiguation was made. We implemented such a process by using PLATON's backtracking facilities. This process is illustrated in Figure 3.5. (See pgs. 33-34 for this figure).

3.3 Analysis of Conjunctive Phrases

The words in Japanese which correspond to 'and' and 'or' are categorized as special postposition; some of them are shown in Table 3.2. We call them Conjunctive Postpositions.

TABLE 3.2 Conjunctive postpositions in Japanese

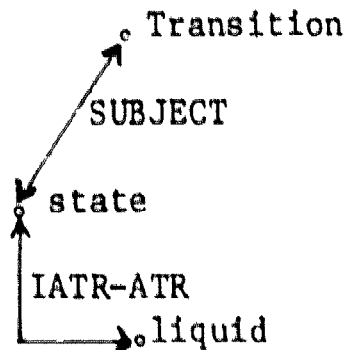
postposition	corresponding English
TO	and (closed listing)
YA	and (open listing)
MO	and (also)
KA	or

In Japanese as well as in English it is difficult to determine the scope of a conjunction. There are some phrases which have the same syntactic structure, but semantically different constructions. Some examples are shown in Figure 3.6. On the other hand, some phrases have different surface structures but convey the same meaning as is illustrated in Figure 3.7. As there are few syntactic clues in these examples, we must analyze them by using semantic information. (See pgs 35 and 36, respectively, for these figures)

At the first stage of the analysis of a noun phrase, we try to find conjunctive postpositions. If we cannot find them, the normal analysis sequence described above is applied on the noun phrase. If there is a conjunctive postposition, the following steps are performed

Input ; EKITAI -NO JOUTAI -NO HENKA
 liquid state transition

result :



Input ; EKITAI -NO JOUTAI -NO SANSO
 liquid state oxygen

Steps of Analysis:

(i) TS = empty

liquid -NO state -NO oxygen
 ↑
 scanned word

(ii) TS = liquid

liquid -NO state -NO oxygen
 ↑
 scanned word

(iii) TS = state

liquid -NO state -NO oxygen
 ↑
 scanned word

*At this point, the first meaning of 'liquid' has been adopted because the checking function for (entity noun)+(attribute noun) is applied before the function for (value noun)+(attribute noun). That is, the word 'liquid' indicates a physical object.

**The semantic check between 'state' and 'oxygen' fails, because the attribute noun 'state' has been linked to the liquid by the relation IATR-ATR and an attribute noun cannot be linked with two different entity nouns

***So the program will go back to step (11).

Figure 3.5 Example of backtracking in the analysis of a noun phrase

(iv) TS = liquid

liquid -NO state -NO oxygen
 ↑
 scanned word

*The semantic check between 'liquid' and 'state' proceeds further. The semantic checking function for (value noun)+(attribute noun) succeeds. This function adopts the second meaning of 'liquid'.

(v) TS = state

liquid -NO state -NO oxygen
 ↑
 scanned word

*At this time, because the noun 'state' is only linked to the value *LIQUID, the check between 'state' and 'oxygen' succeeds. The result is as follows. Notice that the noun 'liquid' does not express a real object but the value of the attribute 'state'

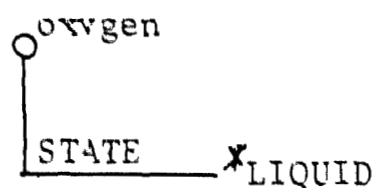


Figure 3.5 continued

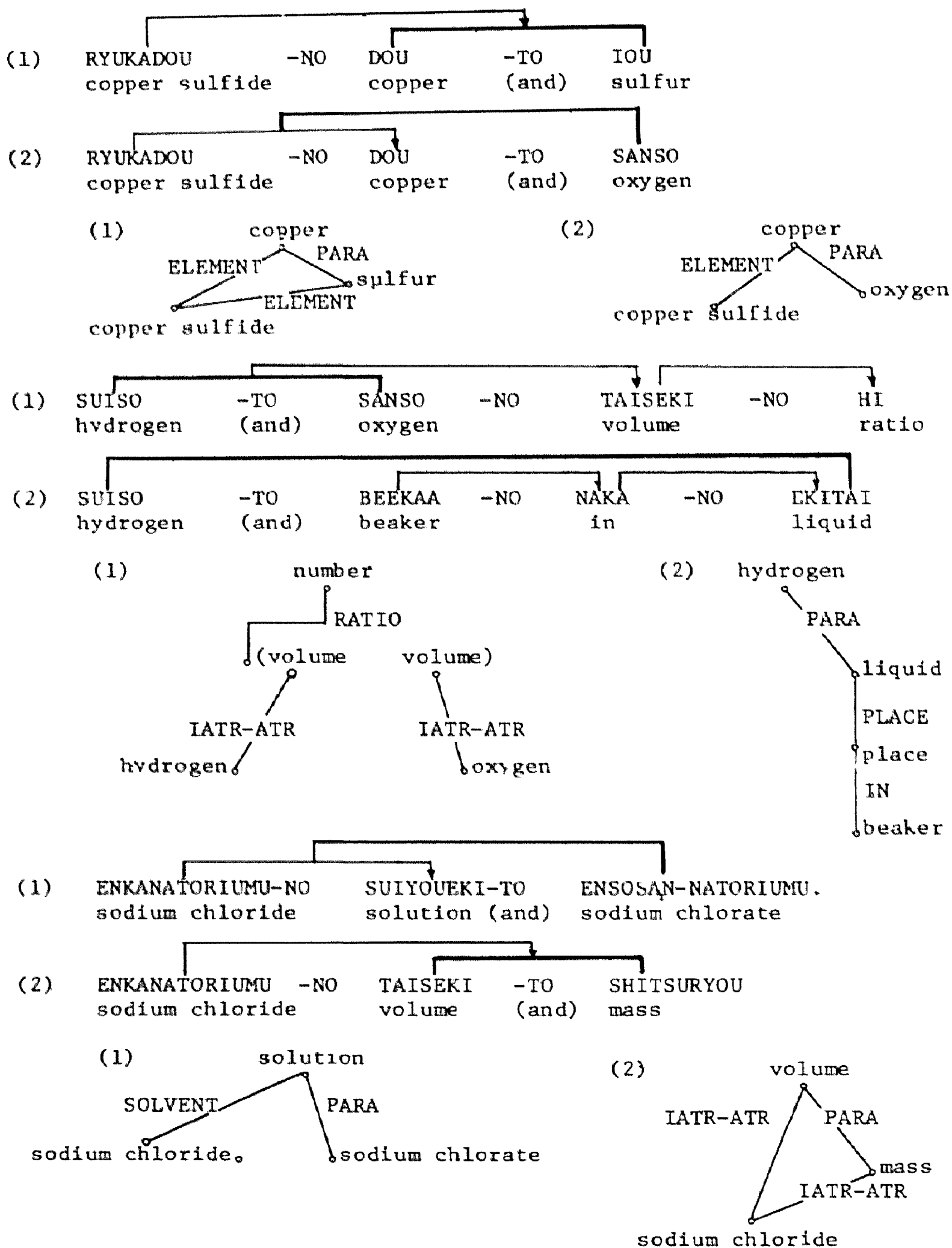
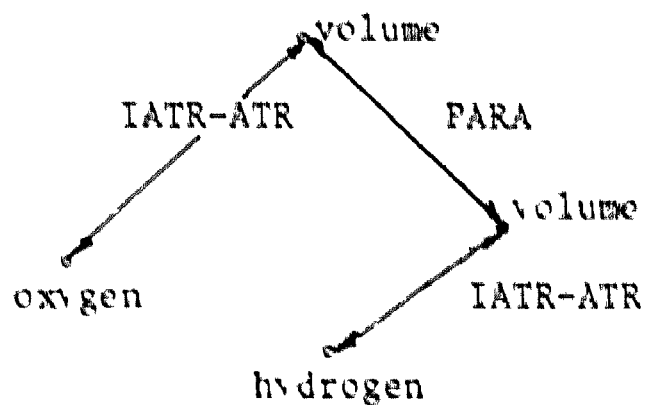


Figure 3.6 Examples of conjunctive phrases

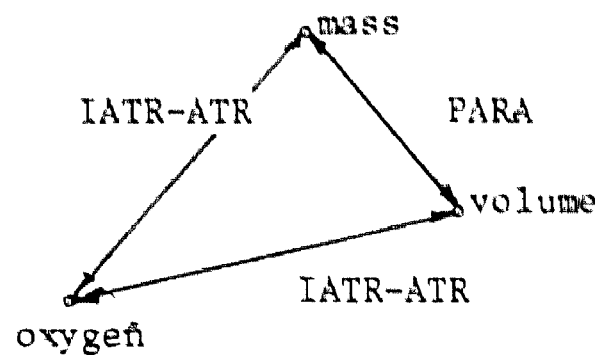
(1) SANSO -NO TAISEKI -TO SUIISO -NO TAISEKI -(TO)
 oxygen volume (and) hydrogen volume

(2) SANSO -TO SUIISO -NO TAISEKI
 oxygen (and) hydrogen volume



(1) SANSO -NO SHITSURYOU -TO SANSO -NO TAISEKI - TO)
 oxygen mass (and) oxygen volume

(2) SANSO -NO SHITSURYOU -TO TAISEKI -(TO)
 oxygen mass (and) volume



*(TO) is an optional element in these sentences

Figure 3 7 Examples of differing surface structures conveying the same meanings

Step 1. The conjunctive postposition T_0 is often followed by another postposition T_0 in the succeeding part (Figure 3.7). Hence if we find T_0 in the phrase, we do the following; if not, go to step 2. We search for the second postposition in the succeeding part. If it is found, then the noun phrase before the first postposition and the noun phrase interposed between the first and the second postpositions are paralleled. We employ the normal noun phrase analysis to the interposed noun phrase, then go to step 4. If we cannot find the second postposition, we then go to step 2

Step 2. If a conjunctive postposition is not T_0 , or there is no second T_0 , we execute the following substeps. (Noun-1 designates the noun before the first postposition.)

- a. Search for a noun identical to Noun-1 in the succeeding part. If found, let it be Noun-2, and go to step 3
- b. If Noun-1 is not an entity noun, then search for a noun which belongs to the same category as Noun-1. If found, let it be Noun-2, and go to step 3
- c. Search for a noun which has an upper concept in common with Noun-1. If found, let it be Noun-2, and go to step 3.

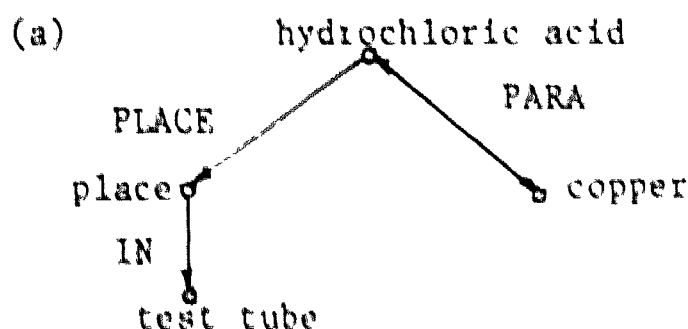
Step 3. The phrase between the postposition and Noun-2 are analyzed by the normal noun phrase analysis. This is now the second of the two parallel phrases under consideration.

Step 4. The phrase before the postposition is analyzed by the normal noun phrase analysis

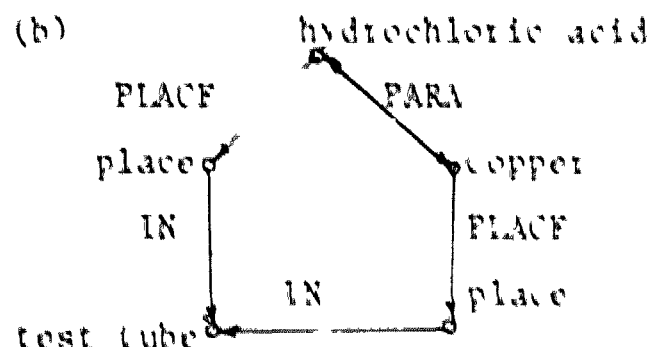
Step 5. It is necessary to determine what portion of the phrase before the postposition relates exclusively to Noun-1. To determine the left end of the Noun-1 phrase (e.g., in Figure 3.8 below), we pick words one-by-one

from left to right, and check whether each word can modify Noun-2. The first word found which cannot modify Noun-2 is considered the left end of the first phrase (Noun-1 phrase).

SHIKENKAN -NO NAKA -NO ENSAN TO DOU -(TO)
test tube in hydrochloric acid copper



the hydrochloric acid in the test tube
and the copper



~~the~~ hydrochloric acid and copper
in ~~the~~ test tube

Figure 3:8 Two different constructions according to the two different determinations of the left end of the conjoined phrase

Step 6. Words to the right of Noun-2 are checked to determine their relation to the conjunctive phrase and its conjuncts. Checking proceeds from left to right.

The analysis of the following phrase is illustrated in Figure 3.9.

RYUKADOU -NO DOU -TO IOU -NO SHIISURYO -NO HI
copper sulfide copper (and) sulfur mass ratio

the ratio between the mass of the copper and the sulfur which constitute copper sulfide

(See pgs. 39-40 for this figure)

3 4 Analysis of a Simple Sentence

Japanese is a typical SOV language in which ACTOR, OBJECT and other case elements usually appear before the verb. The construction of a typical Japanese sentence is shown in Figure 3.10 (see pg 40). A verb may govern

PHRASE.

RYUKADOU	-NO	DOU	-TO	
copper sulfide		copper	(conjunctive pp---and)	

IOU	-NO	SHITSURYOU	-NO	HI
sulfur		mass		ratio

meaning: the ratio of the masses of copper and sulfur of copper sulfide

sequence of analysis

- (1) Step 1. Find the conjunctive postposition TO.

RYUKADOU	-NO	DOU	TO	IOU	-NO	SHITSURYOU	-NO	HI
copper sulfide		copper		sulfur		mass		ratio
former part				succeeding part				

- (2) Step 2c. Find from the succeeding part the noun which belongs to the same category as 'copper'. In the above phrase, the noun 'sulfur' is found.

RYUKADOU	-NO	(DOU	-TO	IOU	-NO)	SHITSURYOU	-NO	HI
copper sulfide		copper		sulfur		mass		ratio
		temporarily determined scope of the conjunctive phrase						

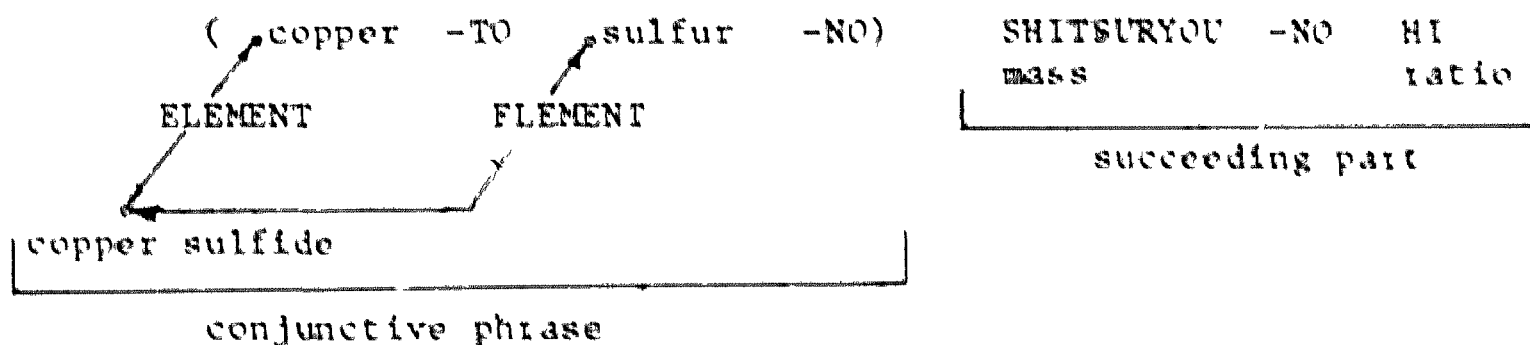
- (3) Step 3 not applicable

- (4) Step 4 Analyze the phrase before the postposition TO

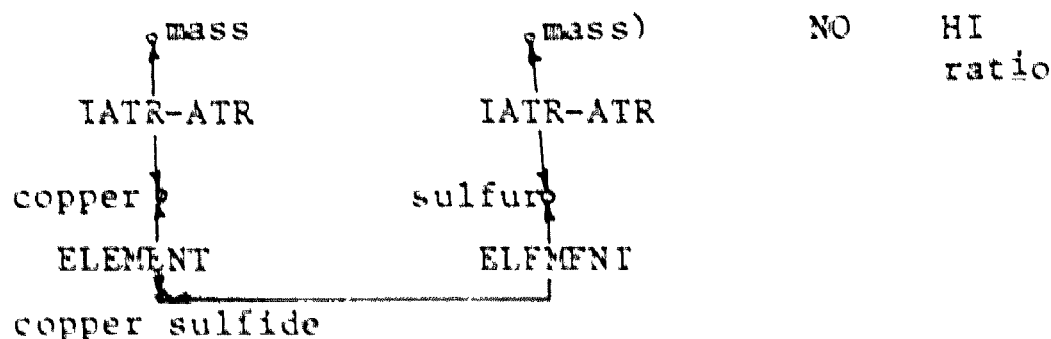
(	copper = TO	IOU	-NO)	SHITSURYOU	-NO	HI
		sulfur		mass		ratio
ELEMENT ↓ copper sulfide						

Figure 3 9

- (5) Step 5. The second noun of the conjunctive phrase, 'sulfur' is checked against the leftmost noun of the phrase before the postposition 'copper sulfide'. This noun is related to the first noun of the conjunctive phrase, 'copper'. 'copper sulfide' is also seen to be related to 'sulfur'. This places the left boundary of the Noun-1 phrase immediately to the left of 'copper'.



- (6) Step 6. The two nouns, 'copper' and 'sulfur', in the conjunctive phrase are checked against nouns in the portion following Noun-2. Because the noun 'mass' can be related to only individual physical objects, the noun 'mass' is duplicated for 'copper' and 'sulfur'.



The noun 'ratio' is related to a conjunctive phrase as a whole. Hence, we obtain the following result for the entire conjoined phrase

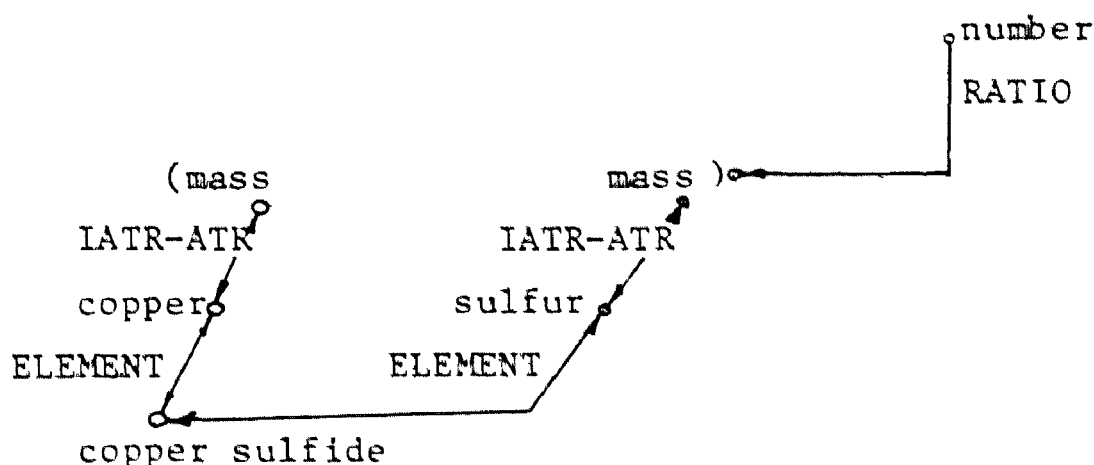
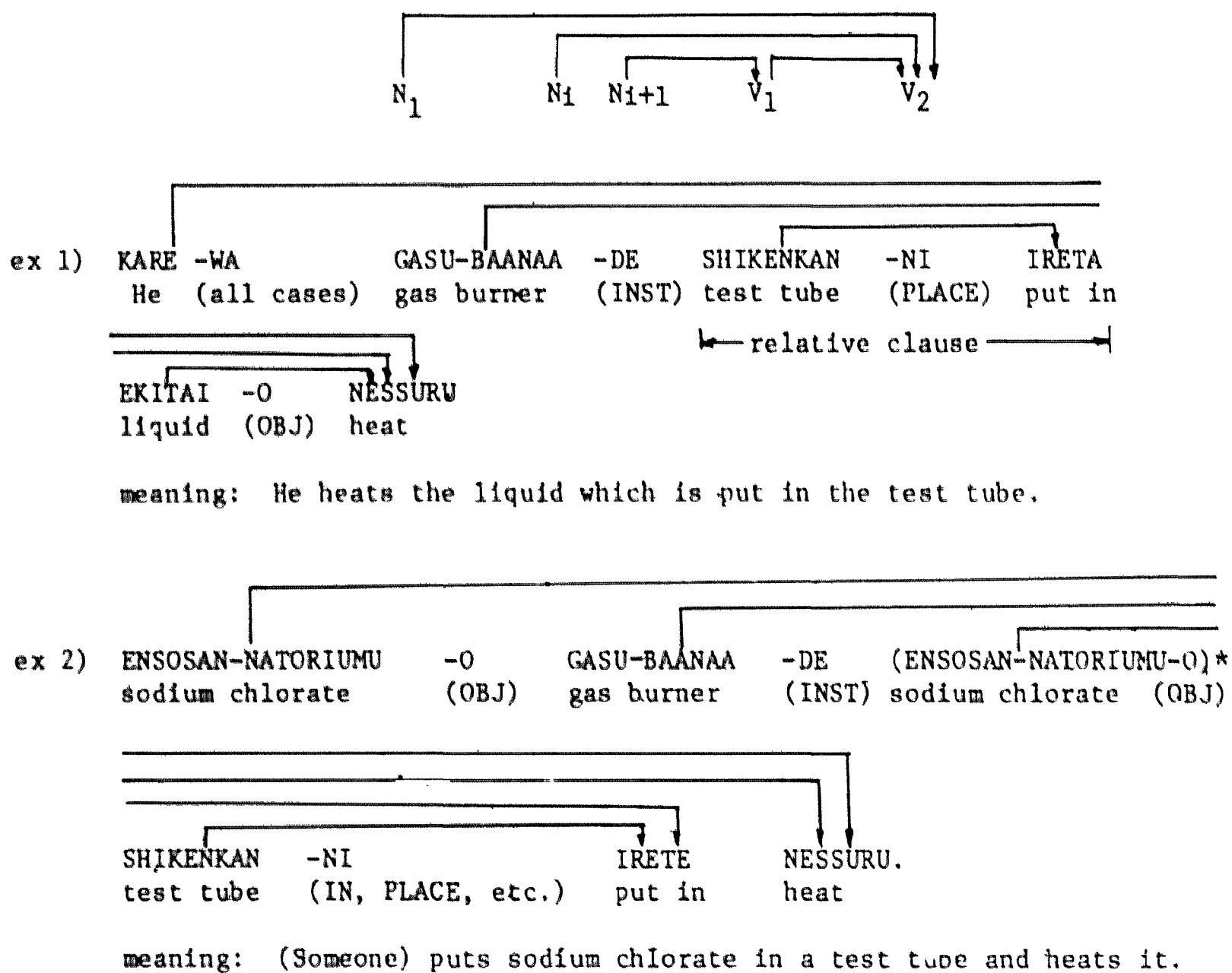


Figure 3.9 continued



(*)Usually this phrase is omitted.

Figure 3.10 Typical Japanese,
Sentences

several noun phrases -- case elements -- preceding it. A relative clause modifying a noun may appear in the form '- - - verb + noun - - -'. The right end of the scope of the clause is easily identified by finding the verb, but the left end is harder to identify. In Figure 3.10 the noun phrase NP₁+1 is a case element of verb V₁. The noun phrase NP₁ is governed by verb V₂. Because the rule projections hold (i.e., clauses do not overlap) in Japanese as in other languages, all noun phrases between NP₁+1 and V₁ are governed by V₁, and the noun phrases before NP₁ are governed by V₂. However, boundaries as between NP₁ and NP₁+1 cannot be determined uniquely by syntactic clues alone. To determine them we must use semantic relationships such as case relationships between noun phrases and verbs.

In English case in surface structure is generally evident in the order of phrases. In Japanese, the ordering of noun phrases is relatively free. A postposition attached to a noun phrase usually shows the case which the noun phrase plays in the sentence. The postpositions usually used in Japanese and the deep cases corresponding to them are tabulated in Table 3.3

TABLE 3.3 Postpositions in Japanese and case relationships

postposition	case
-GA	ACT. SUBJ
-NO	NMOD (ACT, SUBJ)
-O	OBJ
-NI	RESULT, IN, IOBJ, TO, PLACE, CAUSE, TIME
-HE	TO
-TO	FACT, RESULT, TAISHO
-KARE	FROM, SOURCE, CAUSE, METHOD, PLACE, TIME
-YORI	FROM, SOURCE
-DE	INST, SOURCE, CAUSE, METHOD, PLACE, TIME
-MADE	TO
-WA	all cases
-DAKE	
-MO	all cases
-SHIKA	

From this table one can see that a postposition in surface structure does not necessarily correspond to a unique deep case. In the course of analysis we must assign appropriate case labels by considering the case frames of the main verb along with meanings of the head nouns of the noun phrases.

A postposition also plays the role of a delimiter which shows the right boundary of a noun phrase. The outline of the analysis of a simple sentence is as follows

- (1) At first the program looks for a verb in the input sentence. Because there may be embedded sentences which modify nouns in the main sentence, there is usually more than one verb in the input sentence. The program picks up the leftmost verb of the sentence
- (2) The string before the verb is segmented by locating postpositions
- (3) Since each segment is assumed to constitute a noun phrase, it is passed to the program which analyzes noun phrases.
- (4) When all the segments are analyzed and the head nouns are determined, the program checks each noun phrase against the verb asking whether a case relationship will be satisfied between the noun phrase and the verb. The checking is carried out right to left starting with the phrase nearest the verb
- (5) When there are no more noun phrases to be checked, or when a noun phrase which cannot be a case element of the verb is found, the checking is terminated. If there remains an intrinsic case slot of the verb which has not been filled, we search for an appropriate noun to fill the slot from the context. This searching process will be explained in section 4.

We determine whether a noun phrase can be a case element of a verb by the following syntactic and semantic clues

- (1) The type of postposition which follows the noun phrase. This marks case in the surface structure.
- (2) The case frames of the verb.
- (3) The meaning of the head noun of the noun phrase

The postposition delimits a set of possible cases by which the noun phrase may be related to a verb. We must choose an appropriate one from this set by using the second and third types of information. The case slot fillers in a case frame of a verb are relatively upper concept nouns. A sentence is considered to be an instantiation of a case frame, and the nouns employed will be lower concept nouns of the nouns in the case frames.

Suppose we analyze the sentence.

SHOKUEN	-O	MIZU	-NI	TOKASU
salt	(OBJ)	water	(IN, RESULT, TIME, etc.)	melt, dissolve

(Someone) dissolves salt in water.

We can check whether the sentence matches the case frame of TOKASU

TOKASU ((ACT human)(OBJ material)(IN liquid))
melt
dissolve

The checking is performed by considering whether 'salt' is a lower concept noun of 'material', and whether 'water' is a lower concept noun of 'liquid'

Because a case frame contains only intrinsic cases of a verb, we check extrinsic ones when a noun phrase is found not to be an intrinsic case element of the verb. That is, we check whether the postposition can mark the TIME or PLACE, and whether the noun phrase is an instance of the

noun 'place' or 'time'.

The above process may appear straightforward. But sentences can have several possible interpretations for the following reasons

- (1) A verb may have more than one usage (i.e., a verb may have several case frames)
- (2) A postposition can indicate more than one case. Some postpositions can occur with almost any case; WA is an example.
- (3) A noun modified by an embedded sentence is usually a case slot filler of the embedded sentence. But we may have no syntactic clues as to what case to assign to the noun

In the event of multiple interpretations the program derives labeled interpretations showing all possible case relationships between specific nouns and verbs. We choose the interpretation showing the preferable matching of nouns and case by using an evaluation function below which has been established empirically.

$$(CFN, C1, C2, C3) = \frac{6 \times C1 + 2 \times C3}{CFN} + \frac{C2}{2}$$

CFN : number of intrinsic cases in a case frame

C1 . number of intrinsic case elements which are filled by the noun phrases in the sentence

C2 . number of extrinsic case elements which are filled by the noun phrases in the sentence.

C3 . number of intrinsic case elements which are filled by the noun phrases in the preceding sentences

The value of this function indicates the degree of matching between a sentence and the case frame of the verb in question. The trial frame which

gives the highest matched value is selected. We then proceed to the analysis of the remaining strings. If the selection is found to be wrong, during the succeeding analysis, control comes back to the point at which the decision was made, discards it, and chooses the pattern which gives the next highest matching value.

IV CONTEXTUAL ANALYSIS

4.1 Basic Approach to Contextual Analysis

Our view of the process of sentence understanding is roughly as follows. One reads sentences from left to right and understands them in succession. When he/she cannot understand a sentence satisfactorily, he/she refers back to the preceding sentences to obtain a key to understanding. If he/she cannot find what is needed, he/she leaves the question pending and proceeds to the next sentence. If a phrase or a sentence is found which seems to solve the question, then he/she checks whether it can really resolve the question. If so the sentence is properly organized into the previous context and the question is dismissed. In any case the pending question is likely to be dismissed as time passes.

We feel this process of sentence understanding is not especially complex. It can be realized through an artificial intelligence approach. While we recognize that some kinds of problems may be solved only by using complicated logical operations, we think most problems in language understanding can be solved by relatively simple operations. Logical operations may only be effectively applied on a complete data base in which all the necessary axioms (corresponding to human knowledge) are declared and no contradictory axioms exist. In the course of reading sentences, one has

only partial knowledge about the context, and therefore, his knowledge is not complete. However, he can understand the meanings of sentences before he reads through the entire set. This means that one is content with incomplete deductions for understanding sentences. For this reason, we employ rather than logical operations, heuristically admissible operations which use an intermediate term memory structure and various semantic relationships described in the dictionary.

We conceive of three types of memory. Long term memory incorporates knowledge of the world, not considered here. Short term memory is for immediate recall of unanalyzed strings under consideration. Intermediate term memory is limited but contains a structured representation of recently analyzed strings and strings under analysis. We summarize our approach as follows:

- (1) Context is entered into the intermediate term memory.
- (2) Two kinds of intermediate term memory are prepared. One is for representing the current contextual content, and the other is to sustain pending questions. The former is further divided into the noun stack (NS) and the hypothetical noun stack (HNS). The latter is called the Trapping List (TL).
- (3) Contextual analysis is performed after the processing of each syntactic unit such as a noun phrase or a sentence which conveys a unitary idea.
- (4) NS is organized such that theme words of sentences can be easily retrieved. Here 'theme words' mean the key subjects mentioned in the sentences.
- (5) Sometimes we have to refer to the succeeding sentences in order to understand a sentence. In such cases we do not immediately refer

to the succeeding sentences, but instead hold a pending question in TL to be resolved in the course of analyzing the succeeding sentences.

4.2. Memory Structure for Contextual Information

The analysis of a sentence is primarily grounded in the semantic description -- case frame -- of a main verb. Contextual analysis is mainly grounded in accumulated information about nouns. The objects or concepts that are the themes of the sentences, and what has been predicated of them can usually be characterized in terms of the nouns appearing in the sentences, and these offer important clues for contextual analysis.

We assign a different LISP atom (produced by the LISP function 'gensym') to each noun which appears. Information about each is entered on the respective property list. The flags tabulated in Table 4.1 are used.

TABLE 4.1 Information attached to a noun atom

relation	content
LFA	link to the dictio. i.e. lexical descriptions
SATR	(A V) pairs which specify this object
CASE	link to the case-frame in which the object appears
PRE	link to any noun atom which appears in the previous sentence, and which represents the same object as this atom
POST	the inverse relation of PRE
SMOD	link to any relative clause which modifies this object
PARA	link to any noun atoms which appear in a conjunctive phrase together with this object

We can retrieve all the descriptions given for an object to which a noun has been assigned. We stack these LISP atoms called Noun Atoms on NS and HNS

(A) Noun Stack (NS)

When we start to analyze a sentence, we stack a list of noun atoms which are assigned to the nouns in the sentence. These noun atoms are reordered according to their degrees of importance. NS has the construction shown in Figure 4.1

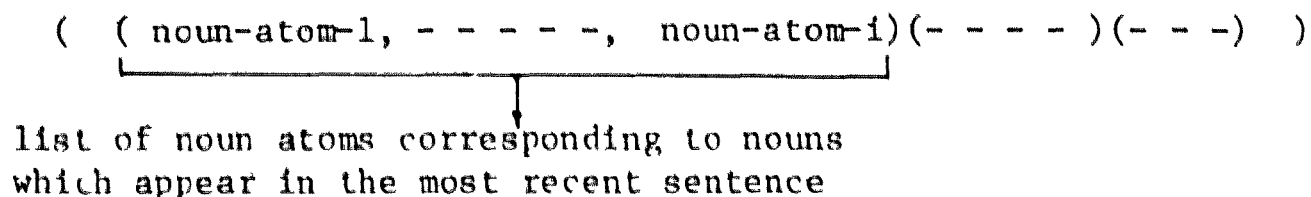


Figure 4.1 Construction of NS

To decide how important a word is, we use the following heuristics.

- (1) In Japanese a theme word is often omitted or expressed by a pronoun in succeeding sentences after it appears once. In other words, the word which is omitted or expressed by a pronoun is an important word for the understanding of a sentence.
- (2) A theme word may appear as "subject" in the surface structure. To emphasize a word which is OBJ-case in deep case structure, or to de-emphasize a word in the ACT-case which is not worth mentioning, the passive voice may be used. This places a stressed word in the subject position of the sentence which would otherwise appear as object or indirect object
- (3) The importance of a head noun in a noun phrase is greater than that of other nouns.

A simple example of ranking by importance is shown in Figure 4.2, zinc appears in all the sentences and is the theme word.

Input sentence

N1			N2	N3
RUTSUBO	-NI		100gr-NO	SHITSURYOU-NO
melting pot	(PLACE, TIME, IOBJ, etc.)			mass
N4			N5	
AEN	-O	IRETE	GASU-BAANAA	-DE
zinc	(OBJ, IOBJ)	put in	gas burner	(PLACE, INST, etc.)
NESSHI,	TOKASHITA.			
heat	melt (PAST TENSE)			

Meaning of the input sentence:

- S1. (Someone) put 100g of zinc in a melting pot
- S2 (Someone) heated it by a gas burner.
- S3. (Someone) melted it.

Changes of NS

Beginning of the analysis of S1: ((N4 N3 N2 N1))

End of the analysis of S1 ((N4 N1 N3 N2))

Beginning of the analysis of S2 ((N5)(N4 N1 N3 N2))

End of the analysis of S2 ((N4 N5)(N4 N1 N3 N2))

Beginning of the analysis of S3 (NIL (N4 N5)(N4 N1 N3 N2))

End of the analysis of S3 ((N4)(N4 N5)(N4 N1 N3 N2))

Figure 4.2 Changes of NS

(B) Hypothetical Noun Stack (HNS)

We first show examples which cannot be properly analyzed without HNS.

(a) SUIISO -TO SANSO -O 2:1 -NO WARIAI -DE KONGO-SHI,
hydrogen oxygen (OBJ) two to one ratio intermix

KONO KONGOUKITAI -NI - - - - -
this gas mixture (PLACE) - - - - -

(Someone) intermixes hydrogen and oxygen in the ratio of two to one.
- - - - in this gas mixture - - - - -

(b) SHOKUEN 5gr -O MIZU 100cc -NI TOKASU.
salt five grams (OBJ) water 100cc (IN) dissolve

KONO SUIYOUKEI -WA - - - - -
the solution

(Someone) dissolves 5 grams of salt in 100cc of water.

The solution is - - - - -

In these two examples, though the demonstrative KONO (the, this) is used, the object referred to does not appear explicitly in the preceding sentence. The object referred to is produced as the result of the event which is expressed by the preceding sentence. As mentioned before, we append to case frames in the verb dictionary descriptions of any objects which may be created if the verb is used.

TOKASU (dissolve) has the case frame:

((ACT human)(OBJ material)(IN liquid))

and this case frame has the additional description:

(NTRANS (CREATE 'solution ('solvent (* IN))
('solute (* OBJ)))).

The symbol * in this description is a LISP function which fills the

specific case elements indicated in the argument from the current realization of the case frame. The sentence

SHOKUEN	5gr	-O	MIZU	100cc	-NI	TOKASU.
salt		(OBJ)	water		(IN)	dissolve

associated with the above case frame results in the following interpretation: a new object, a solution whose solvent is water and whose solute is salt results. We represent this newly produced object in HNS instead of NS for the following two reasons.

1. As the description is based on uncertain knowledge, it is likely, but not necessarily so that the object is produced in the real world. If we find some descriptions of this derived object in the succeeding sentences, we will decide it really exists and transfer the representation from HNS to NS.
2. Because the newly produced object is referred to in the succeeding sentences sometimes by different words or by syntactically different forms, it is convenient to stack them individually in HNS.

4.3 Estimation of the Omitted Words

In the analysis of a Japanese sentence it is important to supply omitted words drawing from preceding or succeeding sentences. To do this we must be able to:

1. recognize that a word is omitted and
2. search for an appropriate word to fill the gap

Our contention is that an individual syntactic unit such as a noun phrase or a simple sentence conveys a definite idea; a noun phrase may designate a certain definite object, a concept, or whatever, and a simple sentence may describe a definite event. In order that a simple sentence describe a definite event, each intrinsic case element of the case frame must be

specified by particular objects. We can detect an omitted word by searching for unspecified case elements in a case frame. Moreover, we can guess from the case frame what kind of nouns should be supplied to fill any gaps.

In this manner we can detect and supply omitted words by using the semantic descriptions in the dictionary.

(1) Omitted Words in a Simple Sentence

When we have finished the analysis of a simple sentence, we check whether there remain some intrinsic cases to be specified. If there remain some, we search for appropriate fillers in the preceding sentences. The searching process is carried out in the following way.

(i) We search through HNS first, because an object newly created by the preceding event is often the theme object of the present event.

(ii) In Japanese, identical case elements in succeeding sentences are apt to be omitted. So the previous sentence is searched for elements having the same case relation as the one under consideration through NS.

(iii) If the above processes fail, then we check the words in NS or all the words that have appeared in the three previous sentences one-by-one until we find a semantically admissible word.

(iv) If we cannot find a suitable word, we set up a problem in the trapping list TL (mentioned in the next section).

Some results of the processing are shown in Figure 4.3. (pgs. 54-56).

(2) Omitted Word in a Noun Phrase

A noun is classified as either an entity word or a relational word. Most nouns have definite meaning by themselves, and are regarded as entity words. However, some kinds of nouns have relational meaning. That is to say, they have slots in their meaning to be filled in by other words, in

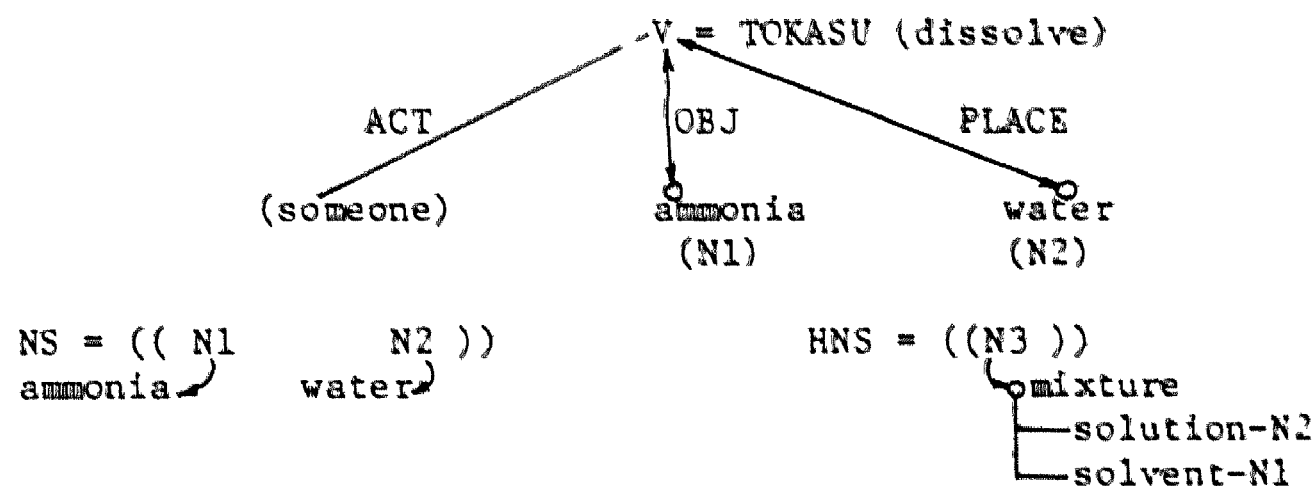
(a) Input sentence:

AMMONIA	-O	MIZU	-NI	
ammonia	(OBJ)	water	(PLACE, TIME, IOBJ, etc.)	
TOKASHI,		RITOMASUSHI	-O	TSUKERU.
dissolve, melt		litmus paper	(OBJ, IOBJ)	soak, put, etc.

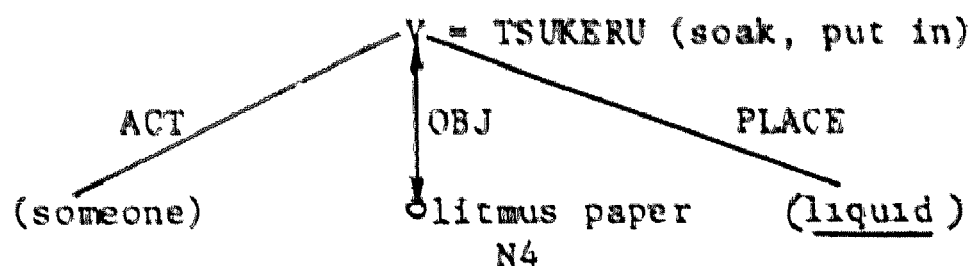
meaning: (Someone) dissolves ammonia in water and puts litmus paper (in it)

Analysis Process:

result of the analysis of the first sentence



*intermediate result of the analysis of the second sentence



*final result obtained after searching

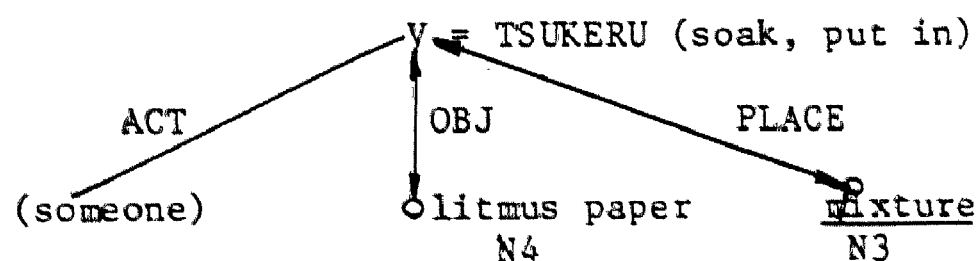


Figure 4.3

(b) Input sentence:

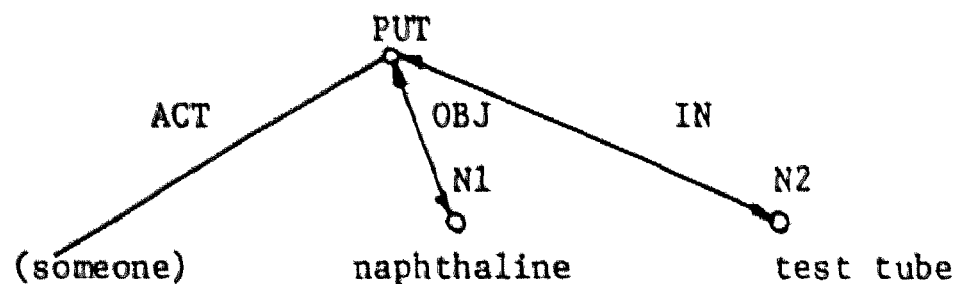
NAFUTHARIN	-O	SHIKENKAN	-NI
naphthaline	(OBJ, IOBJ)	test tube	(PLACE, IOBJ, IN, etc.)

IRE,	GASU-BAANAA	-DE	NESSHITE,	TOKASHI,	KANSATSUSURU.
put in	gas burner	(INST, METHOD)	heat	melt	observe

meaning: (Someone) puts naphthaline in the test tube.
(Someone) heats (it) by a gas burner.
(Someone) melts (the naphthaline).
(Someone) observes (the naphthaline).

Analysis Process:

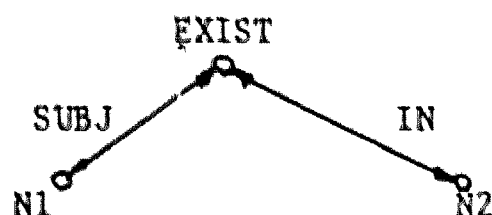
*result of the analysis of the first sentence



NS = ((N1 N2))

HNS = NIL

temporary assertion:



*intermediate result of the analysis of the second sentence

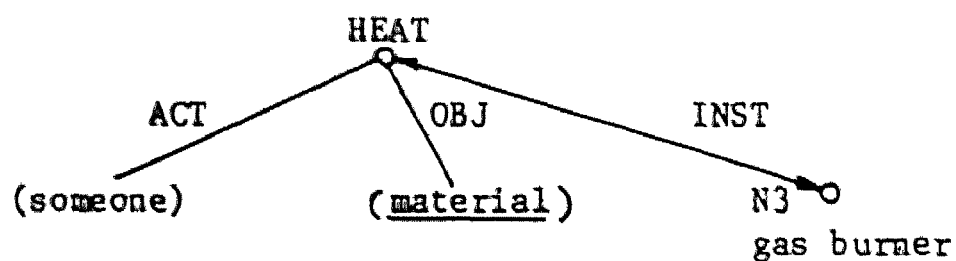
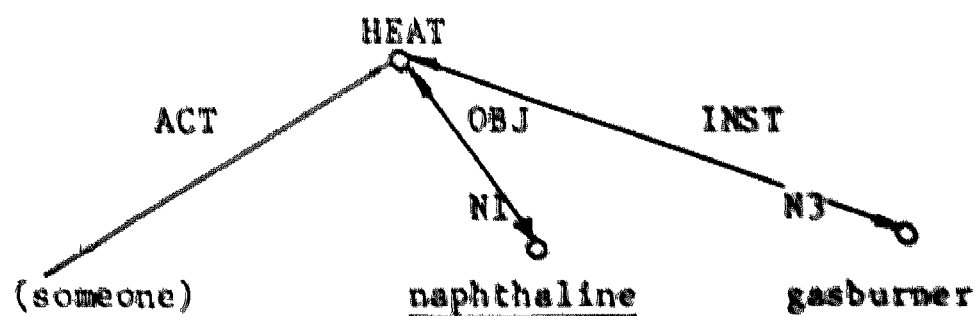


Figure 4.3 continued

*final result after searching



NS: = ((N1 N3)(N1 N2))

*Though the third and fourth sentences also have empty case markers, they are properly filled in. The following result is obtained.

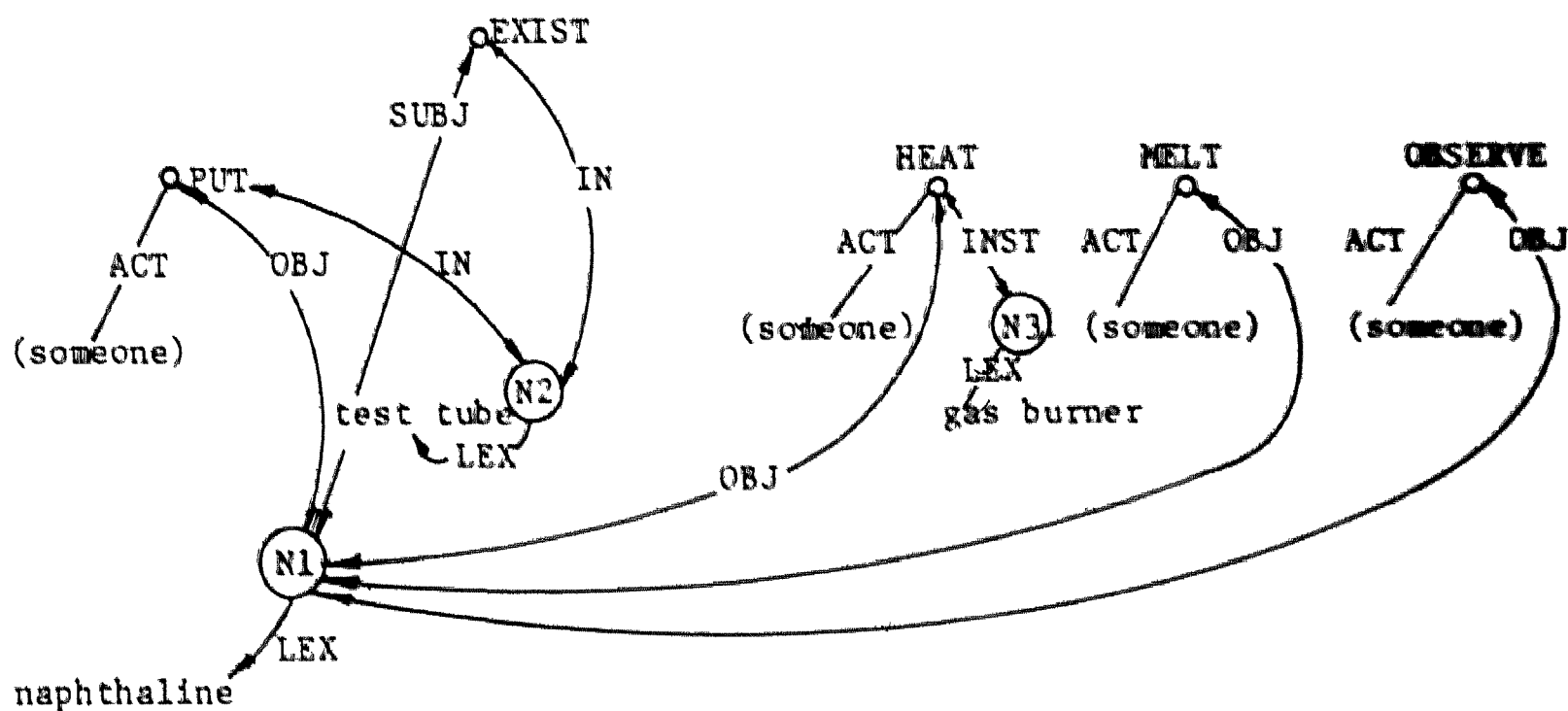


Figure 4.3 continued

order that they express definite ideas. Sometimes a relational noun is used alone in a noun phrase. In this case the relational noun must be semantically connected with other words which are omitted in the present noun phrase. Such examples are shown in Figure 4.4 below.

- (1) IOU -O NESSURU TOKI IRO -GA HENKASURU.
 sulfur (OBJ, IOBJ) heat when color (SUBJ) change

meaning: When (someone) heats sulfur, the color changes.

The phrase 'IRO -GA is a noun phrase but it is incomplete
 color (SUBJ)

by itself. We can easily understand the color means 'the color of the sulfur.

- (2) ENSAN -O SHIKENKAN -NI
 hydrochloric acid (OBJ) test tube (PLACE, TIME, etc.)

20cc IRERU.
 put in

meaning: (Someone) puts 20cc of hydrochloric acid in a test tube.

*The word 20cc is put in a separate position from ENSAN (hydrochloric acid) in the sentence. It, however, specifies an attribute of the acid, VOLUME.

Figure 4.4

As the final step in the analysis of a noun phrase, we check whether there remain relational nouns which have no definite meaning. If found, we search through NS for words which are suitable to fill in the slots of the nouns. The searching process is the same as for omitted words in simple sentences. Sometimes the omitted words exist in succeeding sentences, so we can set up a problem in TL, if we cannot find an appropriate word in the preceding sentences.

(3) Detailed Description of the Trapping List (TL)

Most anaphoric expressions and omitted words are well analyzed by searching through the preceding sentences. However, we need sometimes to refer to succeeding sentences in order to analyze a sentence properly. The sentences shown in Figure 4.5 are examples.

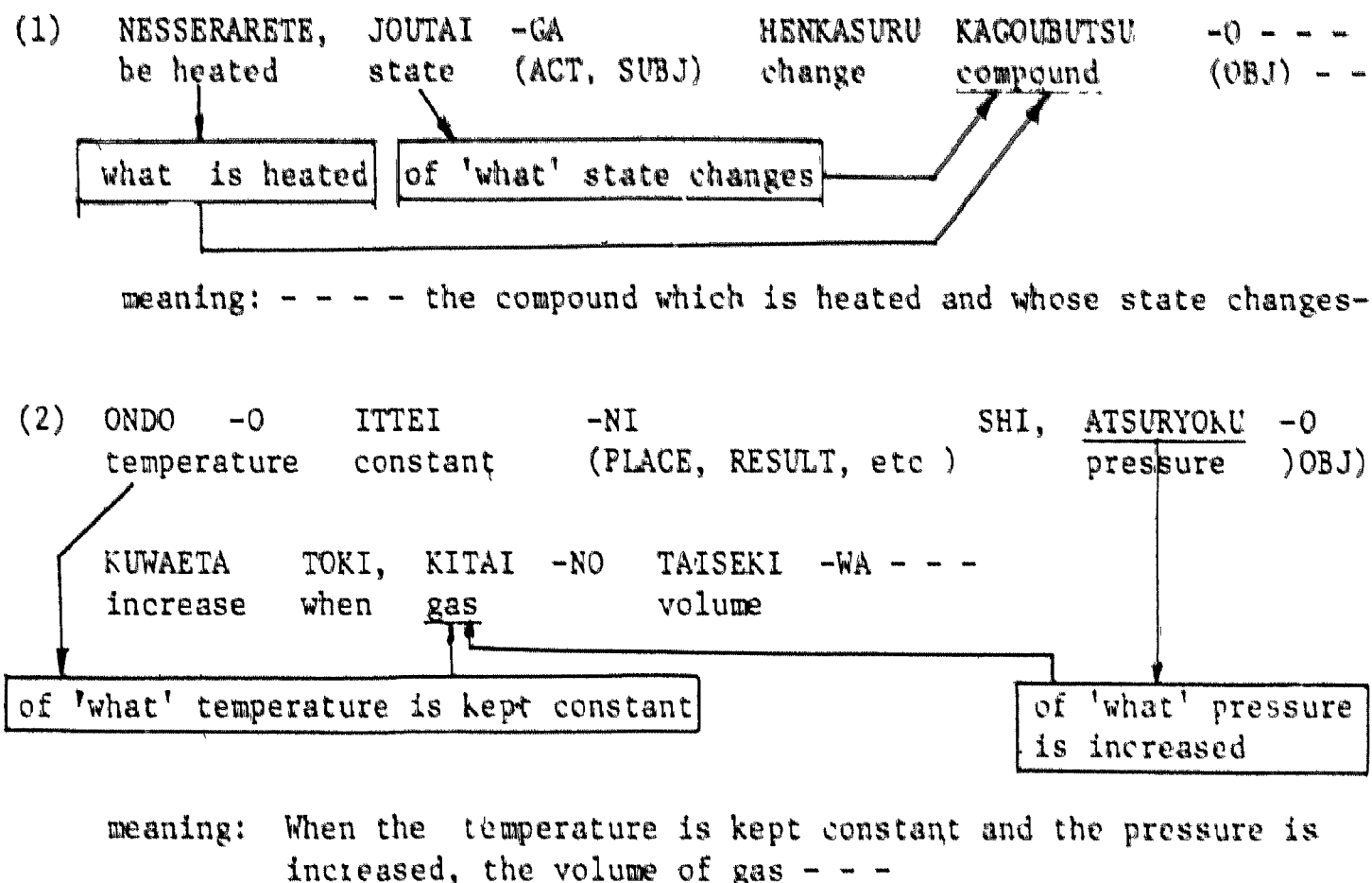
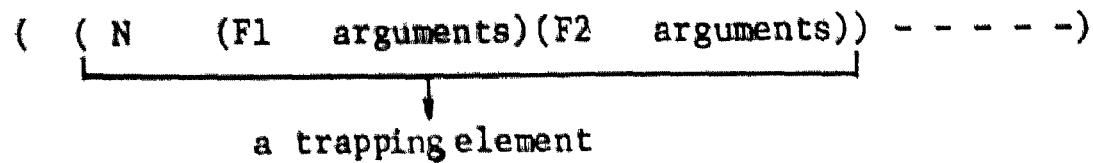


Figure 4.5 Examples where omitted words appear in succeeding sentences

Because the preceding sentences have already been analyzed and both HNS and NS have been set up, it is easy to refer to the preceding sentences. On the other hand we cannot immediately refer to the succeeding sentences if this is called for.

To solve this problem we set up a trapping list TL. The basic organization of TL is shown in Figure 4.6. A trapping element is a triplet



N: number

F1: arbitrary lisp function

F2: arbitrary lisp function

Figure 4.6 Construction of TL

and corresponds to a pending problem. When we cannot find an appropriate word in the preceding sentences for an omitted word or an anaphoric expression, we put a new trapping element in TL. At this time the first of the triplet, N, is set to zero. When a noun phrase in a succeeding sentence is analyzed we pick up nouns from the noun phrase one-by-one and check whether the present noun can resolve a pending problem in TL by evaluating the function F1 in the trapping element.

We have defined several LISP functions for the function F1. These functions work as follows.

(i) They check whether a noun at hand can solve the problems in TL.

(ii) If it can do so; they update the data (for example, if the function F1 is the function which searches the words in TL for filling in the omitted case element, then the function will put the present noun in the case frame), and return the value 'DELETE'. Then the system will delete the trapping element from TL.

(iii) If it cannot do so, the system adds 1 to N, the first element of the trapping element. When N exceeds five, the trapping element is deleted from TL. That is, it is decided that the problem corresponding to the trapping

element can not be solved at all. Before the deletion of a trapping element its third element, the function F2, is evaluated. Thus far F2 has only been used to provide default values to allow some interpretation of pending problems.

By using the idea of TL, we can separate various checking mechanisms from the main program. They can be invoked automatically when a noun appears in a sentence. The idea of TL resembles that of E. Charniak's 'demon' (1972). When his system encounters a certain word, for example, 'piggy bank', it creates a demon which tries to catch from the succeeding sentences any word (e.g., money) related to the key word. We fear that unnecessary knowledge will clog the system with a 'combinatorial explosion' resulting from the proliferation of demons. Our trapping element is put in TL only temporarily to compensate for any missing elements to be retrieved from succeeding parts. Hence the unnecessary proliferation of elements may be avoided.

4.4 Processing of Anaphoric Expressions

In Japanese anaphora is expressed by using the articles KONO, KORE, and KORERA which correspond roughly to 'the', 'this' and 'these' in English. The pronoun KORE is used to designate a single object in the preceding sentences, and the pronoun KORERA is used to designate plural objects. The article KONO is used as a constituent of a noun phrase. Though the articles in English modify the first succeeding noun, KONO often modifies a noun at some distance. An example is given in Figure 4.7.

	noun		noun		noun
KONO	SHIKENKAN	-NO	NAKA	-NO	DOU
this	test tube		in		copper

{the copper in this (inside of) the test tube
{this copper in the test tube

Figure 4.7

In this example there are three nouns following the article which can be modified by it syntactically. We must decide the preferable modification pattern by using contextual information. In the analysis of a noun phrase, we scan the words one-by-one from left to right. When we catch the article KONO, we put it in the temporary stack. The word will then be checked to see whether it can modify a noun in the following noun phrase. When we scan the noun SHIKENKAN (test tube) in Figure 4.7, we check whether the object indicated by it was already mentioned in the preceding sentences. If it was, then the article KONO is regarded as modifying the noun 'test tube'. If not, the article is stacked again. In this way the article will be checked against the nouns in the noun phrase until the noun modified by it is found.

The article KONO is used in the following two ways:

(1)	SANSO	-GA	ARU	<u>KONO</u>	SANSO	-O	- - - -
	oxygen	(SUBJ, ACT)	exist		oxygen	(OBJ)	

There is oxygen

The oxygen - - - - -

The noun SANSO modified by the article KONO is the same entity noun which appears in the first sentence.

(2)	SANSO	-GA	ARU.	<u>KONO</u>	TAISEKI	-O
					volume	(OBJ)

There is oxygen.

The volume of the oxygen - - - - -

In this case KONO alone designates the entity noun SANSO which appears in the first sentence. This usage is permitted only if the noun modified is a relational noun. If the noun has only a relational meaning, the second usage appears more often than the first.

The meaning descriptions of articles and pronouns like KONO are procedurally expressed by LISP functions. The functions in the dictionary will

be evaluated if we find such words in a sentence. The function for KONO operates in the following way.

(1) A check is made to see if the succeeding noun is relational. If the noun has only a relational meaning, it is first assumed that the article KONO is of the second usage and we go to step (3). If not, we go to step (2).

(2) The first usage of KONO has the following three varieties.

(i) SANSO -GA ARU. KONO SANSO -O - - - -

There is oxygen. The oxygen - - - -

The noun modified by the article is the same noun which appears in the preceding sentence.

(ii) SANSO -GA ARU. KONO KITAI -O

There is oxygen The gas - - - -

The noun 'gas' modified by the article is an upper concept noun of the referent noun 'oxygen'.

(iii) SANSO -TO SUIISO -O KONGOUSURU. KONO KONGOUKITAI -O- -
oxygen and hydrogen (OBJ) mix gas mixture (OBJ)

(Someone) mixes oxygen and hydrogen. The gas mixture - - -

The article modified a nominalized form of the first sentence. The first sentence instantiates the case frame of the verb 'mix'. We evaluate the NTRANS description of the case frame and obtain a new inferred object 'mixture', whose elements are the oxygen and the hydrogen. The noun KONGOUKITAI modified by the article is a lower concept noun of the inferred noun (mixture) in HNS.

According to these three varieties, we provide the following three check routines. The order of checking is shown in Figure 4.8

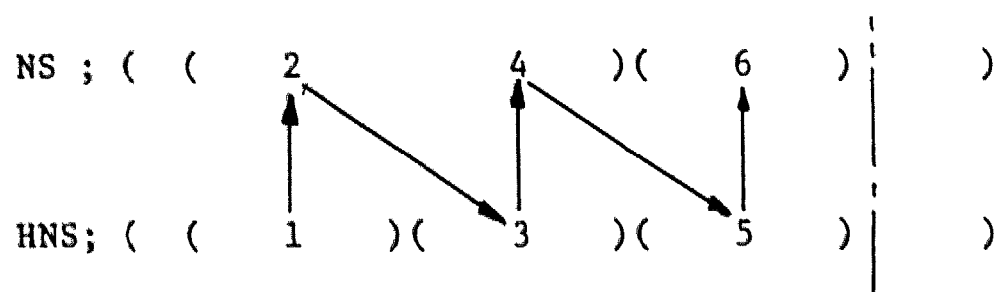


Figure 4.8 The order of checking

- (check 1) Is there in the list the same noun as the noun modified by KONO.
- (check 2) Is there in the list a lower concept noun of the noun modified by KONO.
- (check 3) Is there in the HNS list an upper concept noun of the modified noun, and are its properties consistent with those of the modified noun.

If we can find a noun which satisfies one of these three conditions, we decide that it is the referent noun. If we cannot, the function for KONO returns the value NIL.

- (3) If the noun which follows the article has a relational meaning, the meaning description of the noun has slots which must be filled in by other words. What kind of nouns is preferable for the slots is described in the meaning description. We search in NS and HNS for an object which satisfies the description. For example suppose the input is

SANSO	-GA	ARU.	KONO	TAISEKI	- - -
oxygen	(ACT SUBJ)	exist		volume	

The noun TAISEKI is an attribute noun. So we look for a noun which may have the attribute and recognize that oxygen is appropriate. Another example is

SHIKENKAN	-GA	ARU.	KONO	NAKA	-NI - - -
test tube	(ACT SUBJ)	exist		in	(PLACE, RESULT)

There is a test tube.

In the (test tube) - - -

The noun NAKA (in) is a prepositional noun which requires a 'container' or 'liquid'. We can easily recognize the test tube as a lower concept noun of 'container.' Therefore we assume the word KONO is used for the test tube. If we find no such nouns, we suppose that the article KONO is not of the second usage but of the first. So we will go to step 2.

The pronoun KORE (this, it) is used in sentences as a case element. We can predict the kind of objects designated by the pronoun by using the case frame description of the verb in a sentence. The postposition attached to the pronoun indicates a set of possible cases. By taking from the frames the cases which belong to the set, we can obtain the semantic descriptions which are satisfied by the object designated by the pronoun. So we search through HNS and NS for an object which satisfies the descriptions. Consider the following:

MIZU	500cc	-GA	ARU.	<u>KORE</u>	-NI	SHOKUEN
water		(ACT SUBJ)	exist		(PLACE, RESULT,	salt
					TIME - - -)	
2gr	-O	IRERU				
	(OBJ)	put in				

There are 500cc of water.

In this(water)(someone) puts in 2 grams of salt.

The set of possible cases for the postposition NI is (PLACE, RESULT, TIME, BENEFICENT - - -), and the case frames of IRERU (put in) have the case PLACE. We can predict that the pronoun KORE (this, it) fills the PLACE case in the sentence. The semantic description says that a lower concept noun of 'container' or 'liquid' is preferable as the PLACE case of the verb IRERU (put in). The object 'water', which is a lower concept noun of 'liquid', is found in NS, and is determined to be the object designated by the pronoun

We have some other pronouns and articles in Japanese which are analyzed in the same way. We provide different LISP functions for different pronouns and put them in the dictionary definitions of these words.

T. Winograd treated the same problems in his excellent system SHRDLU (1971; 1972). However, the world which his system can deal with is very limited. In order to construct a system which can treat a wider range of sentences, the system should be equipped with the schema representing the relationships between events and object (an event may imply the occurrence of new objects or changes in the properties of objects). In real world sentences, there exists more complex phenomena about anaphoric expressions and omissions of words than those treated in SHRDLU. We do not claim that our system can treat such complex phenomena, but we hope that our system can be evolved to cover such phenomena by means of combining contextual analysis procedure with semantic descriptions of words.

V ANALYSIS OF COMPLEX SENTENCES

In the previous sections we described the semantic and contextual analysis procedure of our system. In this section we explicate by using example sentences how these functional units are organized in order to analyze fairly complex sentences.

(1) Suppose the input sentence is

ASSHUKU-SARETE	TAISEKI	-GA	HENKA-SURU	TOKI	-NO	SANSO	-NO
be compressed	volume	(SUBJ ACT)	change	time		oxygen	
				when			
JOUTAI	-O	KANSATSUSHI,	SONO	ATSURYOKU	-O	SOKUTEISHI,	
state	(OBJ)	observe	the, its	pressure	(OBJ)	measure	
SORE	-O	GURAFU	-NI	ARAWASU.			
it	(OBJ)	graph	(PLACE, RESULT)	express			

(Someone) observes the state of the oxygen when it is compressed and the volume (of it) changes, measures the pressure, and expresses it by a graph.

The sentence is analyzed by the following steps.

1. The program first tries to find the leftmost verb, and analyzes the clause governed by the verb. The sentence ASSHUKUSARETE (be compressed) is analyzed first. This sentence has an irregular structure in the sense that there are no explicit case elements before the verb. All case elements are omitted in this sentential part. By checking the inflection of the verb (ASSHUKU-SURU (to compress) ---ASSHUKUSARE (to be compressed)), we recognize that the sentence is in the passive voice. The lexical description of the verb in the word dictionary indicates that it takes two intrinsic cases, that is ACTOR and OBJECT. In a Japanese sentence especially in the field of chemistry, the case element ACTOR is apt to be neglected. Therefore we adopt a dummy filler for the ACTOR to represent the author of the sentence or some other human being. As there are no preceding sentences, we cannot fill in the OBJECT case immediately. So we set up the pending problem in TL which will watch the analysis of the succeeding strings to fill the gap

2 The clause TAISEKI-GA HENKA-SURU will be analyzed next. The verb HENKA-SURU (change) requires only SUBJ case. The postposition GA attached to the noun TAISEKI (volume) possibly implies the case SUBJ. The noun TAISEKI is a lower concept noun of 'attribute', which satisfies the semantic condition for the case element. So this sentence is analyzed in a straightforward manner. However, because the noun TAISEKI is an attribute noun, we must find the corresponding entity noun. That is, we must identify the object whose volume is being referred to. As we cannot find such an object in the preceding sentences, we set up a pending problem in TL. By checking the inflection of the verb HENKASURU (change) and noting that it is immediately followed by a noun, it is recognized that the sentence is an embedded sentence modifying the following noun TOKI (time, when). We then

connect this sentential part with the noun TOKI by using the relation SMOD (MODified by a Sentence).

3. When we analyze the next clause,

TOKI	-NO	SANSO	-NO	JOUTAI	-O	KANSATSU-SURU
time		oxygen		state	(OBJ)	observe
when						

we first perform the analysis of the noun phrase TOKI-NO SANSO-NO JOUTAI.

The combination of the two nouns TOKI (time) and SANSO (oxygen) is semantically permissible because 'oxygen' is a lower concept noun of 'material', and can be modified by a word which designates a special point of time. The noun TOKI (time) is modified by the sentential part analyzed at step 2, and designates the time when the event expressed by the sentential part occurs. The combination of SANSO (oxygen) and JOUTAI (state) is also permissible.

The nouns TOKI (time), SANSO (oxygen) and JOUTAI (state) in the noun phrase activate the trapping elements in TL. The noun SANSO (oxygen) satisfies the conditions of the two trapping elements set up by steps 1 and 2. That is, SANSO (oxygen) fills in the case OBJ of the first clause. TAISEKI (volume) in the second clause is regarded as the volume of the oxygen in the current clause.

4. The next clause ATSURYOKU-O SOKUTEISHI presents no new problems. However a referent for the noun ATSURYOKU (pressure) must be found. 'Oxygen' in the preceding sentence is easily found to satisfy the conditions for having the quality ATSURYOKU (pressure).

5. The remaining steps follow along similar lines. The results of the parsing of the expression are shown in Figure 5 1. (pg. 68).

(2) The next example shows how HNS is used. Suppose the input sentence is

(1) - Input sentence:

ASSHUKUSARETE, TAISEKI -GA HENKASURU TOKI -NO
be compressed volume (ACT SUBJ) change when

SANSO -NO JOUTAI -O KANSATSUSHI, SONO ATSURYOKU -O
oxygen state (OBJ) observe the pressure (OBJ)

SOKUTEISHI, SORE -O GURAFU -NI SURU.
measure it (OBJ) graph (IOBJ, RESULT, etc.) represent

meaning: (Someone) observes the state of oxygen which is compressed and whose volume changes. (Someone) measures the pressure and represents it as a graph.

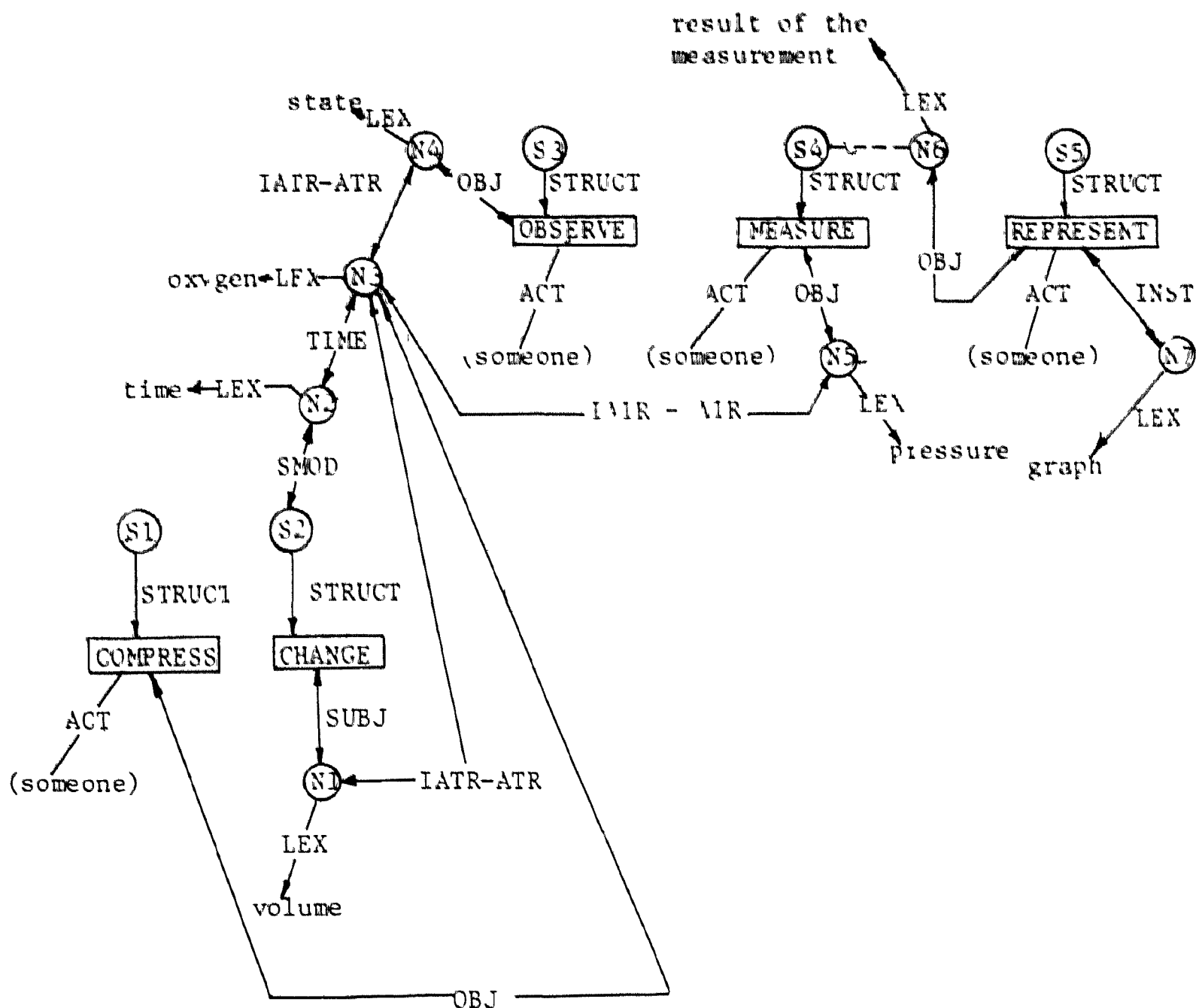


Figure 5 1

SUI SO	-TO	SAN SO	-O	KONG OUSHI, KONO	KONG OUKITAI	-NI
hydrogen	and	oxygen	(OBJ)	mix	the	gas mixture

TEN KASURU	-TO	BAKU HATSU-SHI,	MIZU	-GA	DEKIRU.
fire	(if, when)	explode	water	(SUBJ, ACT)	be made

If (someone) mixes hydrogen and oxygen, and fires the gas mixture, then (it) explodes and water results.

The following steps are performed.

1. When the analysis of the first clause SUI SO-TO SAN SO-O KONG OUSHI is complete, the case frames of the verb KONG OUSHI are instantiated. The NTRANS expression of the case frame which obtains the highest matched value is determined. As the result a new object 'mixture' is created and the elements of the mixture are hydrogen and oxygen. This newly created object is put into HNS.

2. The noun phrase KONO KONG OUKITAI-NI (to the gas mixture) in the clause is modified by the anaphoric determiner KONO (this) which requires a referent. The noun KONG OUKITAI (gas mixture) is a lower concept noun of 'mixture' having as components gaseous objects. We search in the HNS and NS and find the object 'mixture' in HNS whose elements are the hydrogen and the oxygen.

3. The object 'gas mixture' is the theme of the succeeding sentences. It fills in the omitted case ACT of the third clause and FROM case of the fourth clause. Figure 5.2 shows the result of the parsing (see pg. 70).

Table 5.1 below shows the score obtained by applying our parsing program to the sentences in a junior high school chemistry textbook.

(2) Input sentence:

SUIISO	-TO		SANSO	-O	KONGCOUSHI
hydrogen	(conjunctive pp - - - and)		oxygen	(OBJ)	mix
KONO	KONGOUKITAI	-NI	TENKASURU	-TO	
this	gas mixture	(OBJ, IOBJ, PLACE, etc.)	ignite	(conjunctive pp - - - if, when)	
HAGESHIKU	KAKAKUHENKASHI,	MIZU	-GA	DEKIRU.	
violently	react	water	(ACT SUBJ)	be produced	

meaning: If (someone) mixes hydrogen and oxygen and ignites it, then the gas reacts violently and water is produced.

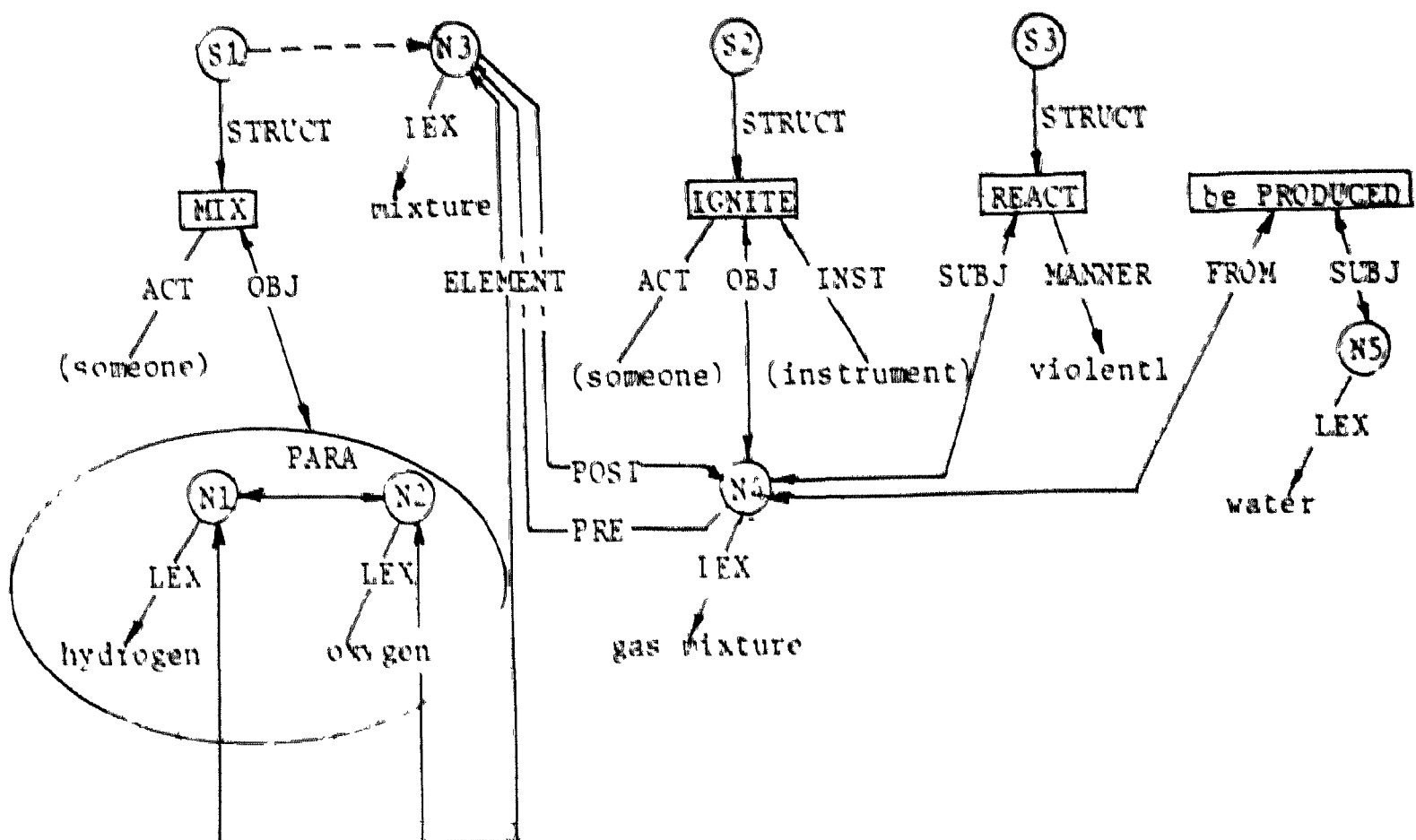


Figure 5 2

TABLE 5.1 Successes and Failures Schema

	total no. tried	successes	failures
noun phrases	312	286	26
conjunctive phrases	372	349	23
sentences	280	254	26

VI CONCLUSION

We can summarize our interpretive procedure as follows:

- (a) Through the use of grammatical case we describe patterns of activity in the verb dictionary. The descriptions also contain information as to how activities are connected with each other and how activities change objects.
- (b) The meaning descriptions of nouns are based upon the upper and lower concept relationships and attribute value pairs. Some kinds of nouns are regarded as having relational meanings. Their meaning descriptions are similar to those of verbs, adjectives, and prepositions. By using these descriptions we can analyze fairly complex and long noun phrases where there are few syntactic clues.
- (c) We do not use logical expressions to represent context. Contextual information is represented in the form of what we call intermediate term memory. This in combination with the semantic descriptions of words has enabled us to perform efficient analyses dependent on contextual information.
- (d) We have developed a programming language which makes it easy to write grammars for natural language and to control the analysis procedure.

By using this language, we can incorporate naturally semantic and contextual analyses into syntactic analysis. We do not need a large and involved program which is responsible for the semantic interpretation of the output given by the syntactic analysis component. Instead, we provide many simple and small functions for semantic and contextual analyses.

We have obtained fairly good results with our approach. The contextual analysis program on the other hand can treat only local contexts. In order to treat more global contexts, we feel the following improvements will be necessary:

(i) We must provide our system with an appropriate schema corresponding to human long term memory in order to represent the state of the world. The system must have frameworks to express spatial relationships among objects time relationships among events and so on.

(ii) At the present stage we have only one relationship CON to connect one activity with another. However, human knowledge of the world accommodates various kinds of relationships among activities, such as cause, purpose, reason, etc. These relationships may play an important role not only in the analysis of sentences, but also in the inference processes in answering a question.

(iii) The descriptions of verb meanings using case work rather well for analyzing verb-centered sentences. However, the results of analysis depend on what verbs are used in surface sentences. Hence, the sentences which convey the same meaning but are expressed by using different verbs may be transformed into different internal representations. This is a serious drawback when constructing question-answering systems or other kinds of intelligence systems. In order to avoid this drawback, we attached a set

of transforming rules to each case frame similar to the descriptions used in R. F. Simmons' system (1973). We feel, however, that this method is rather awkward and that deeper structures should be employed (similar to 'conceptual dependency' proposed by R. C. Schank (1973a;1973b)).

(iv) In order that a system be able to communicate with people in a flexible and natural manner, it must be able to derive inferences from incomplete data bases. Therefore we must design a procedure other than the uniform proof procedure such as the resolution proof procedure.

(v) It is necessary to apply our method in fields different from chemistry and to test whether our semantic description method should be changed or not.

There are many scholars who are interested in using case structures as a representation of natural language utterances. B. Bruce (1975) offers a good survey and a unified point of view in favor of case systems. We also believe that the case system is a promising approach to the representation of meanings in natural language. Further we believe that the idea of case gives us a useful tool for representing knowledge of human beings.

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BIBLIOGRAPHY

- Bruce, B. 1975. "Case System for Natural Language", J. of Artificial Intelligence.
- Celce, M. 1972. "Paradigms for Sentence Recognition." In SDC Final Report HRT-15092/7907.
- Charniak, E. 1972. "Toward a Model of Children's Story Comprehension". MAC-TR266.
- Fillmore, C. 1968. "The Case for Case". In Universals in Linguistic Theory, (Bach and Harms, eds.).
- Nagao, M. and J. Tsujii. 1976. "PLATON - A New Programming Language for Natural Language Analysis", (forthcoming in AJCL).
- Norman, D. 1973 "Memory, Knowledge and the Answering of Questions". In Contemporary Issues in Cognitive Psychology: The Lovaia Symposium (Winston, ed.).
- Rumelhart, E. and D. Norman. 1973. "Active Semantic Networks as a Model of Human Memory". Proc. IJCAI-73.
- Schank, R. 1973a. "Identification of Conceptualizations Underlying Natural Language". In Computer Models of Thought and Language (Schank and Colby, eds.).
- _____ 1973b "Margie Memory, Analysis, Response, Generation and Inference on English". Proc IJCAI-73.
- Simmons, R. 1973. Semantic Networks. Their Computation and Use for Understanding English Sentences". In Computer Models of Thought and Language (Schank and Colby, eds.)
- _____ 1975. "The Clown Microworld". In Theoretical Issues in Natural Language Processing (Schank and Webber, eds)
- Wilks, Y. 1975 "An Intelligent Analyzer and Understander for English" Comm. ACM
- Winograd, T. 1971 "Procedures as a Representation for Data in a Computer Program for Understanding Natural Language" MAC TR-84.
- _____. 1972 Understanding Natural Language Academic Press.
- Woods, W. 1970. "Transition Network Grammars for Natural Language Analysis Comm. ACM.

