

THE JAPANESE GOVERNMENT PROJECT FOR MACHINE TRANSLATION

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1 OUTLINE OF THE PROJECT

The project is funded by a grant from the Agency of Science and Technology through the Special Coordination Funds for the Promotion of Science and Technology, and was started in fiscal 1982. The formal title of the project is "Research on Fast Information Services between Japanese and English for Scientific and Engineering Literature". The purpose is to demonstrate the feasibility of machine translation of abstracts of scientific and engineering papers between the two languages, and as a result, to establish a fast information exchange system for these papers. The project term was initially scheduled as three years from the fiscal year of 1982 with a budget of about seven hundred million yen, but, due to the present financial pressures on the government, the term has been extended to four years, up to 1986.

The project is conducted by the close cooperation between four organizations. At Kyoto University, we have the responsibility of developing the software system for the core part of the machine translation process (grammar writing system and execution system); grammar systems for analysis, transfer and synthesis; detailed specification of what information is written in the word dictionaries (all the parts of speech in the analysis, transfer, and generation dictionaries), and the working manuals for constructing these dictionaries. The Electro-technical Laboratories (ETL) are responsible for the machine translation text input and output, morphological analysis and synthesis, and the construction of the verb and adjective dictionaries based on the working manuals prepared at Kyoto. The Japan Information Center for Science and Technology (JICST) is in charge of the noun dictionary and the compiling of special technical terms in scientific and technical fields. The Research Information Processing System (RIPS) under the Agency of Engineering Technology is responsible for completing the machine translation system, including the man-machine interfaces to the system developed at Kyoto, which allow pre- and

post-editing, access to grammar rules, and dictionary maintenance.

The project is not primarily concerned with the development of a final practical system; that will be developed by private industry using the results of this project. Technical know-how is already being transferred gradually to private enterprise through the participation in the project of people from industry. Software and linguistic data are also being transferred in part. Finally, complete technical transfer will be done under the proper conditions.

The Japanese source texts being used are abstracts of scientific and technical papers published in the monthly JICST journal *A Current Bibliography of Science and Technology*. At present, the project is only processing texts in the electronics, electrical engineering, and computer science fields. English source texts will be abstracts from INSPEC in these fields. The sentence structures used in abstracts tend to be complex compared to ordinary sentences, with long nominal compounds, noun-phrase conjunctions, mathematical and physical formulas, long embedded sentences, and so on. The analysis and translation of this type of sentence structure is far more difficult than ordinary sentence patterns. However, we have not included a pre-editing stage because we wanted to find the ultimate limitations on handling this type of complex sentence structure.

Our system is based on the following concepts:

1. The use of all available linguistic information, both surface and syntactic. The writing of as detailed as possible syntactic rules. The development of a grammar writing system that can accept any future level of sophisticated linguistic theory.
2. The introduction of semantic information wherever necessary to enable the syntactic analysis to be as accurate as possible. The importance of semantic information not over-estimated; a well-balanced usage of both syntax and semantics. Heavily seman-

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tics-oriented analysis is very attractive and effective for sentences within narrow limits, but a system of that type cannot cope with the complicated structures found in descriptions of the wider world where semantic description becomes almost impossible.

3. There are many exceptional linguistic phenomena that are more word-specific than explainable in general linguistic theory. The system should be able to accept word-specific rules. In our system, these rules are written into the lexical entries, with the priority given to these grammar rules in the analysis, transfer, and synthesis phases. This mechanism allows the system to be upgraded step by step by the accumulation of linguistic facts and word-specific rules in the dictionary and effectively bypasses any deadlock in system improvement.
4. The system must be able to produce an output with an imperfect sentence structure and containing untranslated original words rather than fail in cases where the analysis was imperfect. From the post-editor's point of view, an imperfect output is far preferable to no output at all.

Many other concepts and methods have been developed in our machine translation system, and these are explained in the sections following. This paper concentrates on the main features of the Japanese to English translation system. Details of the English to Japanese system, which is also included in our national machine translation project, is being developed, and the result will be published shortly.

2 THE GRAMMAR WRITING SYSTEM, GRADE

2.1 OBJECTIVES OF THE SOFTWARE SYSTEM

In developing a machine translation system, the grammar rules should accurately reflect the intention of the grammar writer. This is fundamental to the achievement of a good grammar system. One of the basic necessities of any machine translation system is a programming language to write the grammar composed of the language for specifying the grammar rules and the accompanying execution system.

A grammar-writing language for machine translation that is powerful must fulfill the following requirements:

1. The language must allow manipulation of linguistic characteristics in both source and target languages. The linguistic structure of Japanese differs greatly from that of English. For instance, in Japanese, the restrictions on word order are not so strong, and some syntactic components can be omitted. A grammar writer must be able to reflect these sorts of characteristics.
2. It is desirable that the grammar-writing language use the same framework for writing the grammars in the analysis, transfer, and synthesis phases. The grammar writer should not be forced to learn several different systems for the different translation stages.

With these points in mind, we developed a new software system for machine translation comprising the language used to specify the grammar rules and the execution system. We call it GRADE (GRAMMAR DESCRIber).

2.2 THE STRUCTURE OF GRADE

The data format used to express the structure of a sentence during the analysis, transfer, and generation phases has a large influence on the design of the grammar writing language. GRADE uses an annotated tree structure to represent the sentence structure during the translation process. Grammatical rules in GRADE are described in the form of tree-to-tree transformations with each node annotated. The annotated tree in GRADE is a tree structure whose nodes are annotated by sets of property-value pairs. This tree-to-tree transformation gives a great power of expression to rewriting rules that can be used in the grammars for the analysis, transfer, and synthesis phases of the machine translation system. Annotation parts can be used to express information such as syntactic category, number, semantic markers, and other properties. They can also be used as flags to control rule application.

A **rewriting rule** in GRADE consists of a declaration part and a main part. The **declaration part** has the following four components:

- **Directory entry part**, containing the grammar writer's name, the version number of the rewriting rule, and the last revision date. This part is not used at execution time. The grammar writer can access the information using the HELP facility in GRADE.
- **Property definition part**, where the grammar writer declares the property names and their possible values.
- **Variable definition part**, where the grammar writer declares the names of the variables.
- **Matching instruction part**, where the grammar writer specifies the mode of application of the rewriting rule to an annotated tree.

The **main part** specifies the transformation in the rewriting rule, and has the following three parts:

- **Matching condition part**, which describes the conditions for the structure of trees and the property values of nodes.
- **Substructure operation part**, which specifies the operations for the parts of the annotated tree that match the conditions written in the matching condition part.
- **Creation part**, which specifies the structure and the property values of the transformed annotated trees.

The matching condition part allows the grammar writer to specify not only a specific structure for an annotated tree but also structures that may repeat several times, structures that are optional, and structures where the order of the substructures is unrestricted.

The substructure operation part specifies operations on the parts of the annotated tree that match in the matching condition part. It allows the grammar writer to assign a property value to a node, or to assign a variable

to a tree or property value. The variable is declared in the variable declaration part. It also allows him to call a subgrammar, a subgrammar network (which is explained below), a dictionary rule, a built-in function, or a LISP function. In addition, the grammar writer can specify a conditional operation using the IF-THEN-ELSE statement.

The structure and the property values of the transformed annotated tree are written in the creation part. The transformed tree is described by node labels that are used in the matching condition part or the substructure operation part.

The matching instruction part of a rewriting rule specifies the application path through the annotated tree. Paths through the trees are specified by combinations of the four basic modes: left-to-right, right-to-left, bottom-to-top, and top-to-bottom.

GRADE allows the grammar writer to divide the whole grammar into several subgrammars and to describe the phases of the translation process separately. A subgrammar may correspond to a grammatical unit such as the parsing of a simple noun phrase or the parsing of a simple sentence. The network of subgrammars forming the whole grammar allows the grammar writer to control the translation process in detail. If the subgrammar network in the analysis phase consists of the subgrammar for a noun phrase (SG1) and the subgrammar for a verb phrase (SG2) in this sequence, the GRADE executor first applies SG1 to the input sentence, and then applies SG2 to the result.

2.3 SOME SPECIFIC FEATURES OF GRADE

GRADE allows a grammar writer to write word-specific grammar rules as a subgrammar at the word dictionary entry level. A subgrammar written in a dictionary entry is called a dictionary or lexical rule. A dictionary rule is specific to a particular word in the dictionary.

A dictionary rule is called by the CALL-DIC function in the substructure operation part. When CALL-DIC is executed by an entry word and rule identifier as keys, the dictionary rule is retrieved and is applied to the part of the annotated tree specified by the grammar writer.

Any grammar writing language must be able to resolve the syntactic and semantic ambiguities found in natural languages. GRADE allows the grammar writer to merge the results of all possible tree-to-tree transformations for a particular subgrammar. However, it must avoid any combinatorial explosion when it encounters ambiguities.

For instance, let us take the case where a grammar writer writes a subgrammar to analyze the case frame of a verb, containing two rewriting rules; one rule is to construct a VP (verb phrase) from a V and NP (verb and noun phrase), and the other is to construct a VP from a V, NP, and PP (verb, noun phrase, and prepositional phrase). When he specifies the NONDETERMINISTIC-PARALLELED mode for the subgrammar, the GRADE executor applies both rewriting rules to the input tree, constructs two transformed trees, and merges them into a new tree whose root node has the special PARA property. The root node is called a para node and the subtrees under this node are the trees that have been transformed by the rewriting rules. Figure 1 shows this mode applied to create a para node.

The grammar writer can select the most suitable subtree under the para node by applying an subgrammar that assigns a priority value to each subtree and using a built-in function that orders the subtrees according to their values.

A para node is treated the same as other nodes in the current implementation of GRADE. The grammar writer can use the para node as he wants, and can select a subtree under a para node at a later application of the grammar rule.

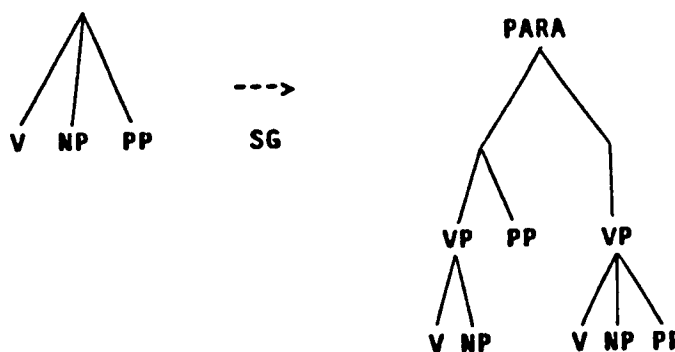


Figure 1. Example of para node formation.

2.4 SYSTEM CONFIGURATION AND ENVIRONMENT

The system configuration of GRADE is shown in **Figure 2**. Grammar rules written in GRADE are first translated by the GRADE translator into internal forms, expressed as S-expressions in LISP. The internal forms of the grammar rules are applied to the input tree that is output by the morphological analysis program. The rules are applied by the GRADE executor, and the results are sent to the morphological generation program.

The GRADE system program is written in UTILISP (University of Tokyo Interactive LISP) and implemented on a FACOM M382 computer, which can handle Chinese characters. The system will also run on the Symbolics 3600. The system program contains about 10,000 lines.

3 THE DICTIONARIES

Because our system is based on the "transfer" approach, there are three separate dictionaries (for analysis, transfer, and synthesis). In this project, Japanese words are classified into 12 major categories (parts of speech) and 46 subcategories according to their morpho-syntactic behaviour. English words are classified into 14 major categories and 28 subcategories. The outline of the dictionaries of different kinds is explained in this section. The details are available in the Japanese literature.

3.1 THE JAPANESE ANALYSIS DICTIONARY

3.1.1 ANALYSIS DICTIONARY FOR VERBS

Some Japanese verbs are used in a wide range of circumstances, each usage expressing a subtly different "meaning". These must all be translated into English

differently. Distinguishing these different usages requires careful investigation of the context around the verb. As described in section 2, GRADE allows the definition of grammar rules that are applied only to specific lexical items. We use this capability to discriminate between verb usages. However, many verbs have only two or three different usages at most. We prepared a fixed format for the lexical coding of these verbs. Descriptions in this format are converted to internal representation in GRADE automatically by a program. For verbs that have a wide range of usages, where the rules need to be written based on a variety of heuristic information, the grammar rules can be written directly in GRADE, bypassing the fixed format. In the fixed format, a verb can have several case frames corresponding to different usages. A case frame in Japanese is represented as a set of triplets like:

(Surface-Case-Mark	Deep-Case	Constraints-on NP)
<SCM>	<DC>	<CON>

SCM is a set of postpositional case particles, one of which follows the noun phrase to fill the case. DC expresses the deep case interpretation of the relationship between the verb and the noun phrase. CON specifies a set of semantic markers that the noun phrase to fill the case should have. Note that the deep case interpretation of the same surface case particle changes depending on the verb.

We listed 103 postpositional case particles and 33 deep case relations in Japanese, and 32 deep case relations in English (**Table 1**), which we believe to be sufficient for Japanese to English translation. **Figure 3** gives a list of semantic markers used for semantic specification of the nouns in CON.

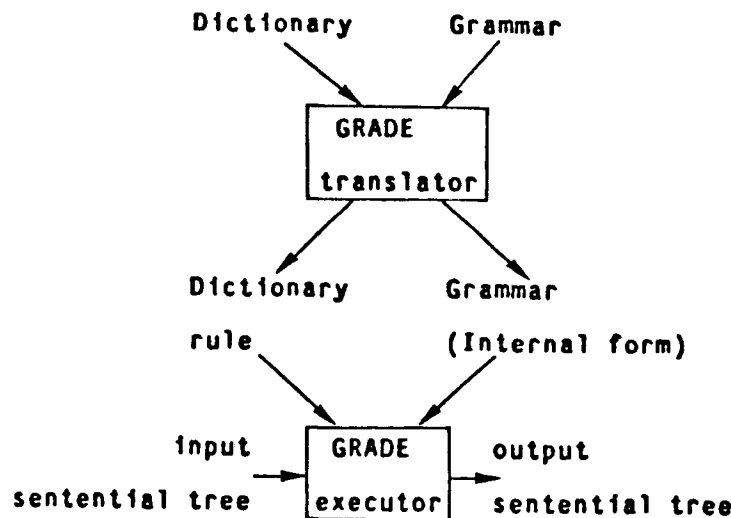


Figure 2. System configuration of GRADE.

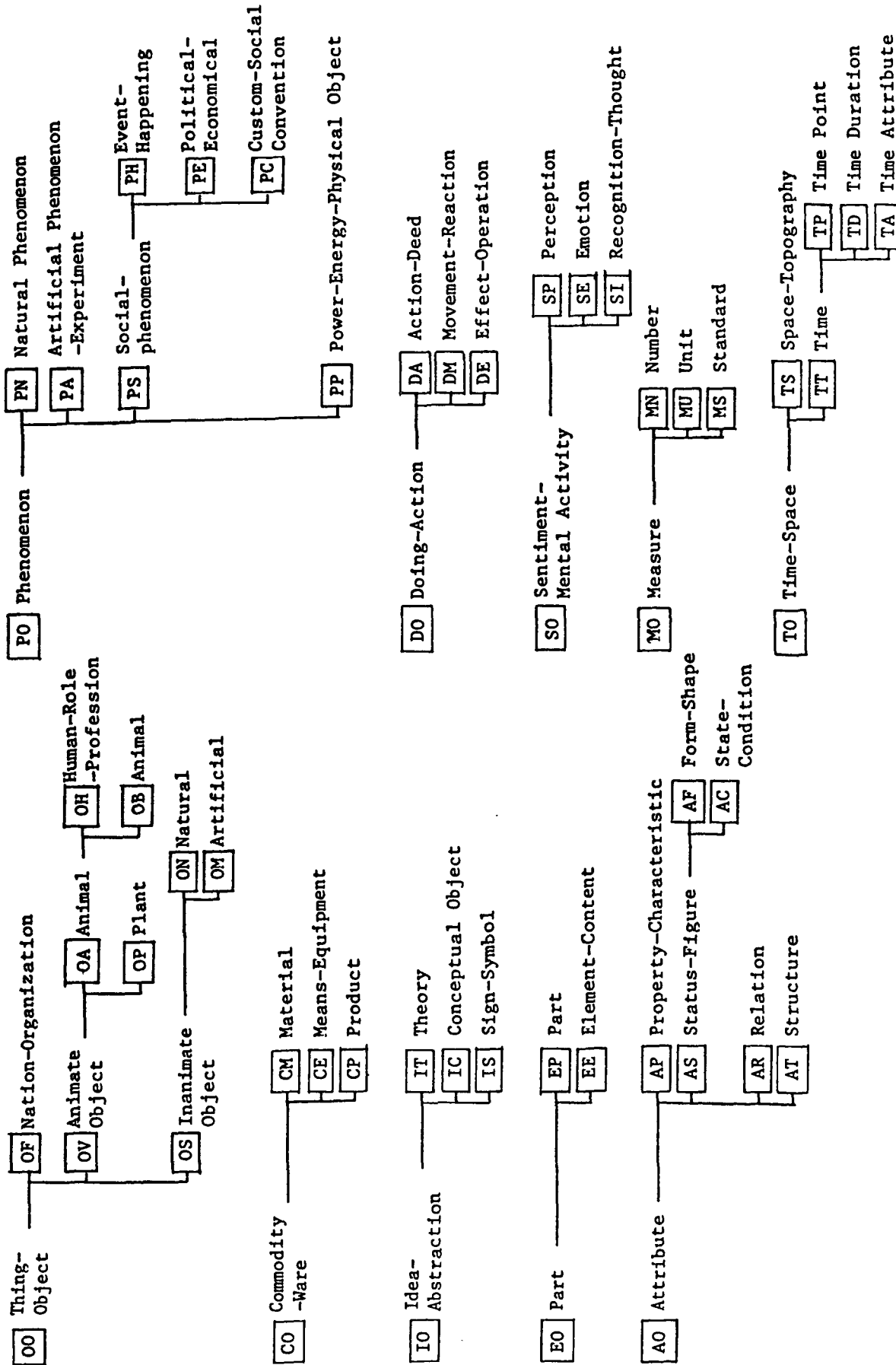


Figure 3. System of semantic primitives for nouns.

Table 1. English case labels.

1. AGenT	17. RANge
2. Gausal-POtency	18. COmpaRison
3. EXPeriencer	19. TOOI
4. OBJect	20. PURpose
5. RECipient	21. Space-FRom
6. ORIgin	22. Space-AT
7. SOUrce	23. Space-TO
8. GOAI	24. Space-THrough
9. COntent	25. Time-FRom
10. PARtner	26. Time-AT
11. OPPonent	27. Time-TO
12. BENeficiary	28. DURation
13. ACCompaniment	29. CAUse
14. ROLe	30. CONdition
15. DEGrec	31. RESult
16. MANner	32. COncession

Since one case frame corresponds to one usage of a verb, and each usage corresponds to a different "meaning" of the verb, the lexical properties of verbs are represented by the properties of each case frame. The following properties are coded for each case frame.

- a. Aspectual features: stative, semi-stative, durative, resultant, transitional.
- b. Volition: volitional verb, non-volitional verb.
- c. Possible transformations of surface case markers: Some auxiliary verbs that follow the verb and express passive, or causative voice, etc., change the surface case marking; that is, the postpositional case particles described in SCM are changed. Which auxiliary verbs can follow, and what transformation of surface case markers is caused by an auxiliary verb, depend on the verb itself, and so are marked as a lexical property of the verb.
- d. Idiomatic expressions: Information on collocation; for example, which nouns and adverbs are often collocat-ed with the verb are described in this column.
- e. Lexical entry in transfer dictionary: As described before, a verb may have more than one case frame, each of which corresponds to one "meaning" of the verb. The transfer dictionary contains an entry for each meaning. Thus a single surface verb in Japanese may correspond to several different entries in the transfer dictionary. On the other hand, certain usages of different surface verbs may be reduced to a single entry in the transfer dictionary, if they are synony-mous.
- f. Semantic class: This property is used for semantic classification of verbs such as "mental-action", "physical-transfer", etc.
- g. Miscellaneous properties: Several other minor prop-erties are coded in the current dictionary.

3.1.2 ANALYSIS DICTIONARY FOR NOUNS

The following properties are described using the fixed noun format:

- a. Subcategorization of nouns: proper noun, common noun, action noun, adverbial noun, postpositional noun, conjunctive noun, complementizer.
- b. Semantic codes: The semantic codes shown in Figure 3 are used.
- c. Information on collocation: Adjectives, nouns, etc., which often occur together with a noun are specified. This information plays a role similar to the case frame of a verb, and is effective in discriminating the differ-ent usages and meanings of nouns.

We also have fixed formats for words in the other morpho-syntactic classes. All words in the dictionary have, besides the above information, the properties listed in **Table 2**.

Table 2. Properties of Japanese words in the dictionary.

lexical item	subject code
word length	lexical entry in the transfer dictionary
word stem	semantic codes (for nouns, verbs)
pronunciation	thesaurus codes (for nouns)
part of speech	idiomatic expressions
sub-categorization of part of speech	case frames (for verbs, adjectives)
conjugation	
synonym	
derivations (noun, verb, adjective, adverb)	
related words	

3.2 THE JAPANESE TO ENGLISH TRANSFER DICTIONARY

3.2.1 TRANSFER DICTIONARY FOR VERBS

Different verb usages are discriminated during the analy-sis phase. This means that usage ambiguities are partially resolved before the transfer phase. However, the concept of "meaning" (usage) applied to a single word is very vague and in fact depends greatly on the language pairs we have for translation. For example, the verb *NOMU* in Japanese can be used in the following ways:

- Tabako-wo NOMU → smoke a cigarette
- Kusuri-wo NOMU → take medicine
- Mizu-wo NOMU → drink water

These three cases should be translated differently. In a similar way, the English verb *to wear* is used as:

- Wear a suit → Suutsu-wo KIRU
- Wear black shoes → Kuroi Kutsu-wo HAKU
- Wear spectacles → Megane-wo KAKERU
- Wear a wristwatch → Udedokei-wo SURU

These four cases should be translated differently into Japanese. Some might claim that these verbs are very ambiguous and have different meanings; but this contradicts the intuitive conclusion that suggests it is reasonable to consider that the target language simply has more specific verbs in these cases. In other words, discrimination in meaning at the analysis stage is not sufficient to select the appropriate target verb in these cases.

The verb transfer dictionary is divided into two parts: a word selection part and a mapping part. The word selection part is used to choose appropriate target verbs by referring to semantic markers of the case elements. The semantic markers currently being used appear to be insufficient to decide appropriate target verbs in certain cases. We cannot, for instance, distinguish *medicine* and *cigarette* with the current set of semantic markers, which is relevant to choosing appropriate English verbs for *NOMU*. However, we can treat such problems by specifying word selection rules in the noun transfer dictionary.

The mapping part gives the correspondence of the deep cases in Japanese and English. In most cases, the Japanese deep case maps to the same deep case in English. There are, however, certain deep cases that are interpreted differently in the two languages.

Sometimes a single Japanese verb can not be translated into a single English verb and has to be paraphrased using a combination of a verb and another element such as a noun or a prepositional phrase. For example,

SHISAKUSURU → develop (something) on a trial basis

Such linguistic expressions are also treated in the mapping part.

Although many verbs in the transfer dictionary are coded in this fixed format and converted to lexical rules in *GRADE* by a program, we also write lexical rules directly for verbs that have a wide range of usages.

3.2.2 TRANSFER DICTIONARY FOR NOUNS

Some Japanese words that behave morpho-syntactically as nouns have to be translated into English words in other morpho-syntactic classes. Such class conversions should be treated in the transfer dictionary, because they are highly dependent on the lexical item. For example:

- | | |
|--|----------------------------|
| (i) TAIWA-KEISHIKI-de
(interaction)
→ to execute interactively | JIKKOUSURU
(to execute) |
| (ii) PUROGURAMU-MOODO-de
(program mode)
→ to execute in program mode | JIKKOUSURU
(to execute) |

The above two examples have exactly the same structures in Japanese (where the noun phrases *TAIWA-KEISHIKI-de* and *PUROGURAMU-MOODO-de* fill the same deep case, "manner") but translate to different English structures simply because an appropriate lexical item exists for (i) but not for (ii).

The fixed format for nouns includes the following items:

- a. Conditions on the sequence of words in the preceding part:
A set of default rules that translate Japanese postpositional case particles to English prepositions is provided in the transfer grammar. However, these default rules are often violated, because certain English nouns require specific prepositions. This kind of information is coded in this column.
- b. Conditions on the sequence of words in the succeeding part:
Postpositions that follow the noun often give a clue to the morpho-syntactic class conversion.
- c. Collocation with verbs:
Certain combinations of nouns and verbs in Japanese are translated into English as single verbs, and certain combinations of nouns and verbs such as *kusuri* (medicine) and *NOMU* (to smoke, to drink, to take) require specific translation of the verb (*to take*). This is the kind of information coded here.

3.3 ENGLISH GENERATION DICTIONARY

The format for verbs includes the following items:

- a. Components: In the transfer phase, certain Japanese verbs are translated into English expressions containing not only verbs but also prepositional phrases and/or adverbial particles (*off*, *up*, etc.). These complex expressions have separate entries in the generation dictionary, and the structural descriptions for the complex expressions are given here.
- b. Verb patterns: The verb codes from the *Longman Dictionary of Contemporary English* are used to specify the syntactic patterns a verb can take.
- c. Aspectual features: stative, transitive, process, completive, momentary.
- d. Voice: usually passive, can be used in passive voice, cannot be used in passive voice.
- e. Volition: volitional verb, non-volitional verb.
- f. Agent of *to*-infinitive: SUBJECT (*I promise him to go*), OBJECT (*I want him to go*).
- g. Case frames: A case frame of a verb is expressed by a set of quadruplets like:

Surface-Case	Deep-Case	Syntactic-Form	Semantic-Code
SC	DC	SF	SEC

SF is a list of numbers, each of which expresses one syntactic form the case element can take:

1. noun phrase
2. infinitive without *to*
3. *to*-infinitive
4. *-ing*
5. *that*-clause
6. *wh*-clause
7. adjective
8. *-ed*

The formats for other parts of speech are described in the Japanese literature.

4 JAPANESE SENTENCE ANALYSIS

4.1 ANALYSIS STRATEGIES

As pointed out by Wilks, semantic information cannot be used as constraints on single linguistic structures; it can be used only as preference cues to help choose the most feasible interpretation from among all the syntactically possible interpretations. We believe that many types of preference cues, besides semantic ones, exist in real texts, and these cannot be captured by CFG rules. By making use of various types of preference cues, our analysis grammar for Japanese can work almost deterministically to give the most preferable interpretation at the first output, without extensive semantic processing.

In order to integrate heuristic rules based on various levels of cues into a unified analysis grammar, we have introduced the following principles in the analysis of Japanese sentences:

1. Explicit control of rule application: Heuristic rules can be ordered according to their strength.
2. Multiple relation representation: Various levels of information including morphological, syntactic, semantic, and logical are expressed in a single annotated tree and can be manipulated at any time during the analysis. This is required not only because many heuristic rules are based on heterogeneous levels of cues but also because the analysis grammar should be able to perform semantic/logical interpretation of sentences at the same time, and the rules for these phases should be written using the same framework as the syntactic analysis rules.
3. Lexicon-driven processing: We can write heuristic rules specific to a single or a limited number of words, such as rules concerned with collocation among words. These rules are strong in the sense that they almost always succeed. They are stored in the lexicon and invoked at the appropriate time during the analysis without decreasing efficiency.
4. Explicit definition of analysis strategies: The whole analysis phase can be divided into steps. This makes the whole grammar efficient, natural, and easy to read. Furthermore, strategic consideration plays an essential role in preventing undesirable interpretations from being generated.

Figure 4 shows the overall organization of our current analysis grammar. The main components are:

1. Morphological Analysis
2. Analysis of Simple Noun Phrases
3. Analysis of Simple Sentences
4. Analysis of Embedded Sentences (relative clauses)
5. Analysis of Sentence Relationships
6. Analysis of Outer Cases
7. Contextual Processing (processing of omitted case elements, interpretations of *ha*, etc.)

The analysis produces dependency tree structures showing the semantic relationships between the words in the input sentence.

4.2 TYPICAL STEPS IN THE ANALYSIS GRAMMAR

4.2.1 SIMPLE SENTENCES

As described in 3, the analysis dictionary for verbs contains verb case frames that are expanded to GRADE rules with unrestricted word order to obtain a match with the input sentence structure. Certain verbs such as *ARU*, *NARU*, *SURU*, *MOTSU*, etc., which have a wide range of usages, are discriminated by directly coding SGN in the dictionary.

4.2.2 RELATIVE CLAUSES

Relative clause constructions in Japanese express several different relationships between modifying clauses (relative clauses) and their antecedents. Some relative clause constructions cannot be translated into English as relative clauses. We classified Japanese relative clauses into four types, according to the relationship between the clause and its antecedent. Because these four forms of relative clauses have the same surface forms, like

------(verb) (noun)
Relative Clause Antecedent

careful processing is required to distinguish between them. We have developed a sophisticated analysis procedure that uses the various levels of heuristic information.

4.2.3 NOUN PHRASE CONJUNCTIONS

Noun phrase conjunctions often appear in abstracts of scientific and technical papers. It is important to analyze them correctly, especially in correctly determining the scope of the conjunction, because they often lead to a proliferation of the analysis results. We have many heuristic rules based on various types of information. Some are based on surface lexical items, some on word morphemes, and some on semantic information. They are used differently in different conjunctive structures. We can distinguish strong heuristic rules (that is, rules that almost always give correct scopes when applied) from others. In fact, there is some ordering of heuristic rules according to their strength. In GRADE we can define arbitrary ordering of rule applications by using subgrammar networks and also by ordering rewriting rules inside a subgrammar. This capability of being able to control the rule application sequence is absolutely necessary in integrating heuristic rules based on heterogeneous types of information into a unified set of rules.

4.2.4 SENTENCE RELATIONSHIPS AND OUTER CASE ANALYSIS

In Japanese there are several different syntactic constructions corresponding to English subordinators and coordinators like *although*, *in order to*, *and*, and so on. The correspondence between forms of Japanese and English sentence constructions is not straightforward. Some postpositional particles in Japanese express several different semantic relationships between sentences, and therefore should be translated into different subordina-

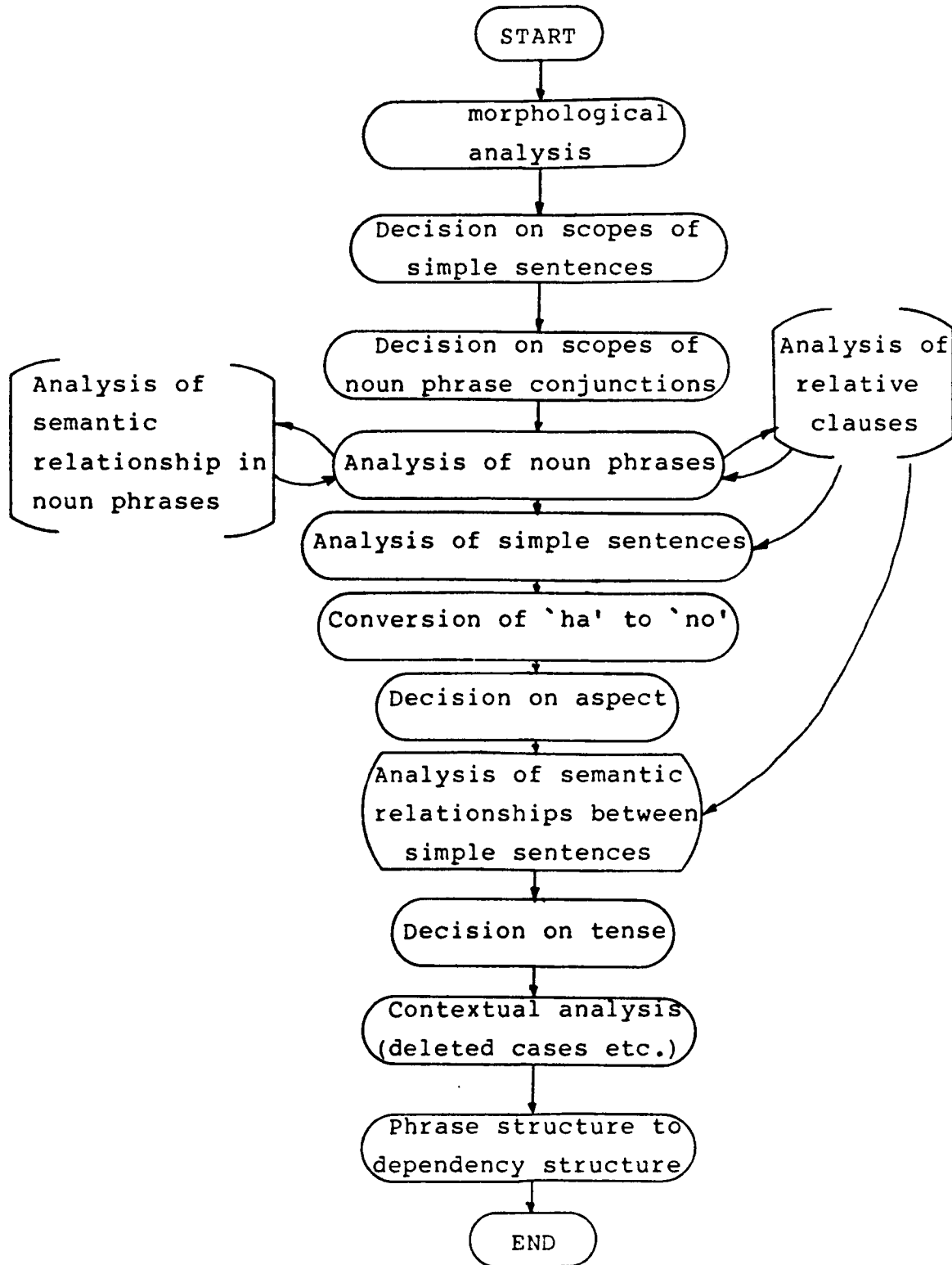


Figure 4. Basic flow of processing.

tors in English according to the semantic relationships. The postpositional particle *TAME* can express either a "purpose-action" relationship or a "cause-effect" relationship. In order to resolve the ambiguity in the semantic relationships expressed by *TAME*, a set of lexical rules is defined in the dictionary for the entry *TAME*. The rules are roughly as follows, where the sequential form (S1, S2) is assumed:

- (i) If S1 expresses a completed action or a stative assertion, the relationship is "cause-effect".
- (ii) If S1 expresses neither a completed action nor a stative assertion, and S2 expresses a volitional action, the relationship is "purpose-action".

Note that whether S1 expresses a completed action or not is determined in a preceding phase by using rules that utilize the aspectual features of the verbs described in the dictionary, and auxiliary verbs following the verb. We have heuristic rules for 57 postpositional particles for sentences conjunctions like *TAME*.

Postpositional particles that follow noun phrases and express case relationships are also very ambiguous in the sense that they express several different deep cases. Although the interpretations of inner case elements are directly given in the verb dictionary as the form of mapping between surface case particles and their deep case interpretations, the outer case elements should be semantically interpreted by referring to the semantic categories of noun phrases and the verb properties.

Lexical rules for 62 case particles have also been implemented and tested.

5 TRANSFER AND GENERATION OF ENGLISH

In principle we use the deep case dependency structure to represent a sentence semantically. Theoretically it is possible to assign a unique case dependency structure to each input sentence. In practice, however, the analysis phase may fail, or it may assign the wrong structure. Therefore, as an intermediate representation, we use a structure that makes it possible to annotate multiple possibilities as well as multiple level representation. Properties at a node are represented as vectors, so that this complex dependency structure is flexible in the sense that different interpretation rules can be applied to the structure.

Transfer and generation rules are organized along the principle that "if a better rule exists, then the system uses it; otherwise, the system attempts to use a standard rule; if that fails, the system uses a default rule". The grammar involves a number of stages of application of heuristic rules. Figure 5 shows the process flow for the transfer and generation phases.

To obtain a more neutral (or target-language oriented) structure, some heuristic rules are activated immediately after the standard analysis of the Japanese sentence is finished. We call such activation the pre-transfer loop. Semantic and pragmatic interpretations are done in the pre-transfer loop. The larger the number of heuristic rules applied in this loop, the better the results.

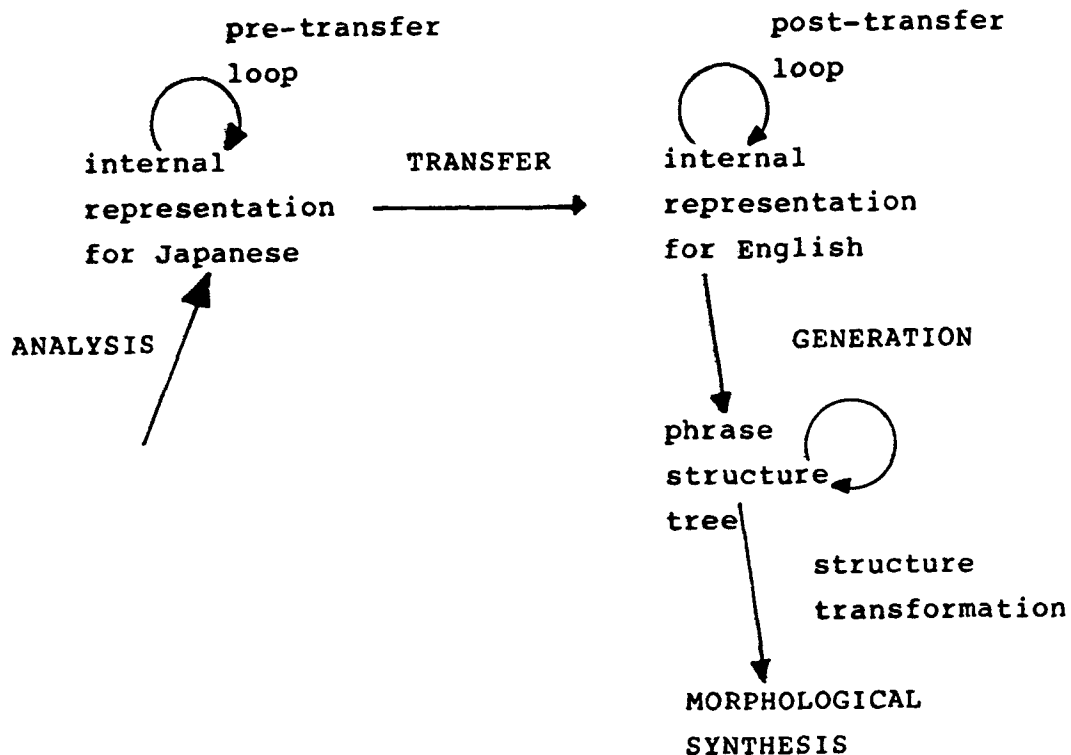


Figure 5. Process flow for the transfer and generation phases.

Table 3. Word selection in target language by using semantic markers.

生ずる	Xが生ずる	X	non-living substance structure	form-1	form X(obj)
			social phenomena	take place	X take place
			action, deed, movement reaction	occur-1	X occur
			standard, property state, condition relation	arise-1	X arise
			∅	produce-2	produce X
XがYを生ずる	Y	non-living substance structure	form-1	X form Y	
		phenomena, action	cause-1	X cause Y	
		∅	produce-2	X produce Y	
		property	improve-1	X improve Y	
上げる	XがYを上げる	measure	increase-2	X increase Y	
		∅	raise-1	X raise Y	

↑ Semantic marker for X/Y

Table 4. Default rule for assigning a case label of English to the Japanese postposition *ni*.

J-SURFACE-CASE	J-DEEP-CASE	E-DEEP-CASE	Default Preposition
に(ni)	RECIPIENT	REC, BENEFICIARY	to (REC — to, BEN — for)
	ORIGIN	ORI	from
	PARTICIPANT	PAR	with
	TIME	Time-AT	in
	ROLE	ROL	as
	GOAL	GOA	to

5.1 WORD SELECTION IN ENGLISH USING SEMANTIC MARKERS

Word selection in the target language is a big problem in machine translation. There are varieties of choices for translation of a word in the source language. The main principles adopted by our system are:

1. Area restriction using field codes, such as electrical engineering, nuclear science, medicine, and so on.
2. Semantic codes are attached to a word in the analysis phase and used for the selection of the proper target language word or phrase.
3. The sentence structure involving the word to be translated is sometimes effective in determining the proper word or phrase in the target language.

Table 3 shows an example of part of the verb transfer dictionary. Selection of the English verb is done from the semantic categories of the nouns related to the verb. A number (i) attached to the verb, like form-1 or produce-2, labels the i-th usage of the verb. When semantic information on the nouns is not available, the

column labelled 0 is applied to produce a default translation.

The expressive power of format-oriented descriptions is, however, insufficient for a number of common verbs such as *SURU* 'to make, to do, to perform, ...' and *NARU* 'to become, to consist of, to provide, ...'. In such cases, we can write the transfer rules directly in GRADE. There must be a constant effort to list varieties of usages with their corresponding English sentence structures and semantic conditions.

A postposition in Japanese represents a case slot for a verb, but it has a variety of usages; thus determination of the English preposition corresponding to each Japanese postposition is quite difficult. It also depends on the verb that governs the noun phrase having that postposition.

Table 4 illustrates part of a default table for determining deep and surface case labels when no higher level rule applies. This sort of table is defined for all case combinations. In this way, we confirm at least one translation to be assigned to an input. The particular usage of a preposition for a particular English verb is written in

the lexical entry for the verb, and the information is used for English sentence generation.

Many odd structures are still left after the pre-transfer loop and the lexical selection, and the internal English representation must be adjusted further into more natural forms. We call this part the post-transfer loop.

Global sentence structures are completely different in Japanese and English, and correspondingly the internal structures are also completely different. The fundamen-

tal differences between the internal representation of Japanese and of English are absorbed in the pre-transfer loop. But before the English generation phase, some structural transformations are still required for cases such as (a) embedded sentence structures, and (b) complex sentence structures. These structural adjustments are performed in the post-transfer loop.

The steps comprising the transfer phase are shown in Figure 6.

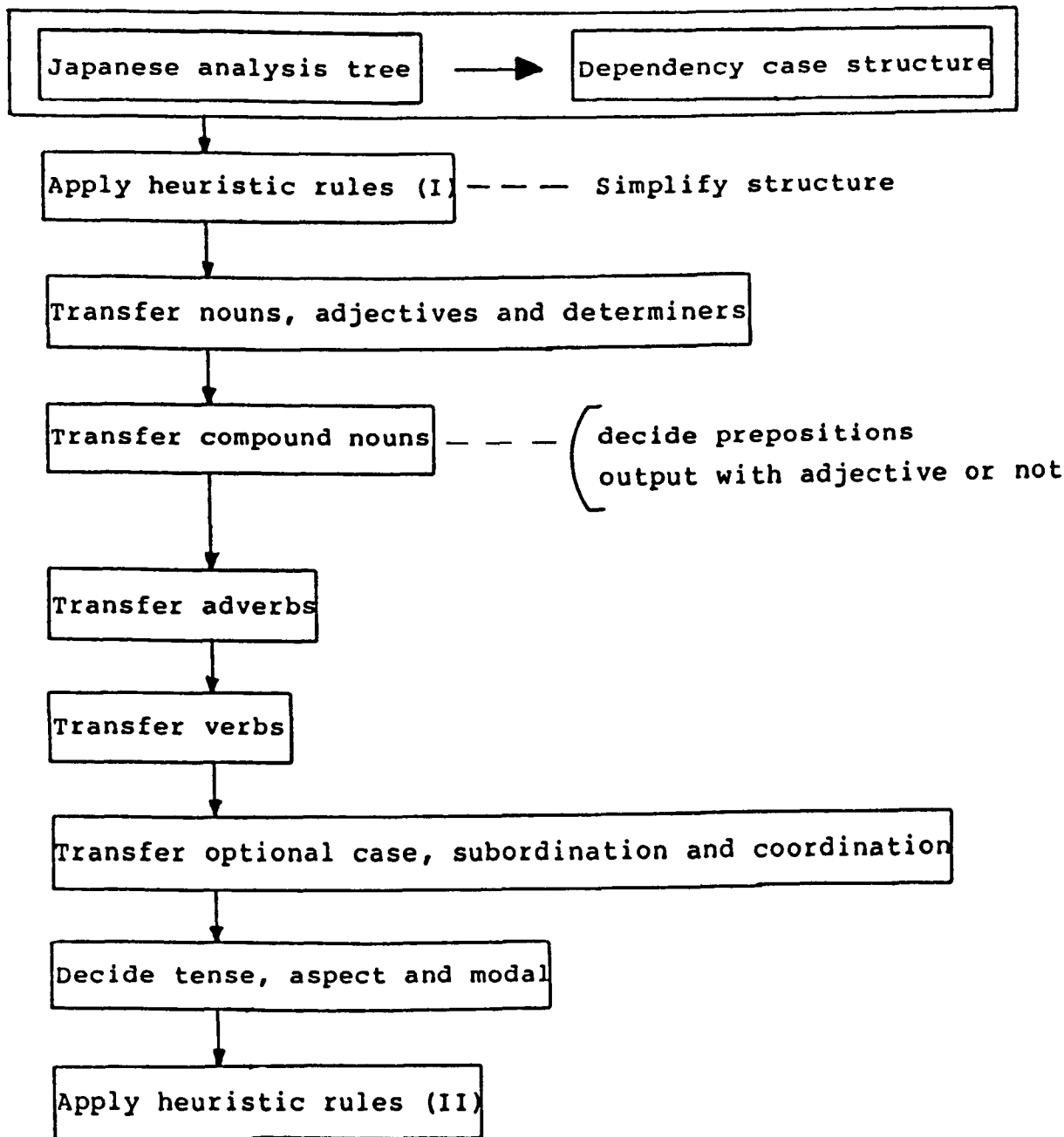


Figure 6. Outline of the transfer phase.

5.2 ENGLISH SURFACE STRUCTURE GENERATION

After transferring from the Japanese deep dependency structure to the English one, the structure is converted to a phrase structure tree with all the surface words attached to the tree.

The conversion is performed top-down from the root node of the dependency tree to the leaf. Therefore, when a governing verb demands a noun phrase expression or a *to*-infinitive expression for its dependent phrase, a structural change must be made to the phrase. Noun-to-verb transformations and noun-to-adjective transformations are often required due to the difference in expressions between Japanese and English. This process moves down from the root node to all the leaf nodes.

After this phrase structure generation process, some sentential transformations are performed. For example:

- When the agent is missing, a passive transformation is applied.
- When the agent and the object are both missing, the predicative verb is nominalized and made the subject by supplementing verb phrases such as *is made* or *is performed*.
- When the subject phrase has a big tree, the anticipatory subject *it* is introduced.
- In compound and complex sentences, same subject nouns are pronominalized.
- Duplication of head nouns in conjunctive noun phrases is eliminated. For example, "uniform component and non-uniform component" is reduced to "uniform and non-uniform components".

Any big structural transformations required in the translation come from the essential differences between English, which is a *DO*-language, and Japanese, which is a *BE*-language. In English, case slots such as tool, cause/reason, and some others often appear in the subject position, while in Japanese such expressions are never used. Transformations of this kind are incorporated in the generation grammar as shown in **Figure 7**. They produce more natural English expressions. The stylistic transformation part of the process is still very primitive. We need to accumulate much more linguistic knowledge and lexical data before we can produce really natural English expressions.

6 EVALUATION OF TRANSLATION QUALITY

The following two aspects of the machine translation output have been adopted to evaluate translation quality. They are to some extent independent indicators.

1. **Intelligibility:** An evaluation of the extent to which the translated text can be understood by a native speaker of the target language. In Japanese to English translation, we evaluate the extent to which an average British or American reader can understand the output without any reference made to the Japanese original.
2. **Accuracy:** The degree to which the translated text conveys the meaning of the original text is evaluated, and a measure of the amount of difference between the input and output sentences. The evaluation is done by Japanese translators specializing in Japanese-to-English translation.

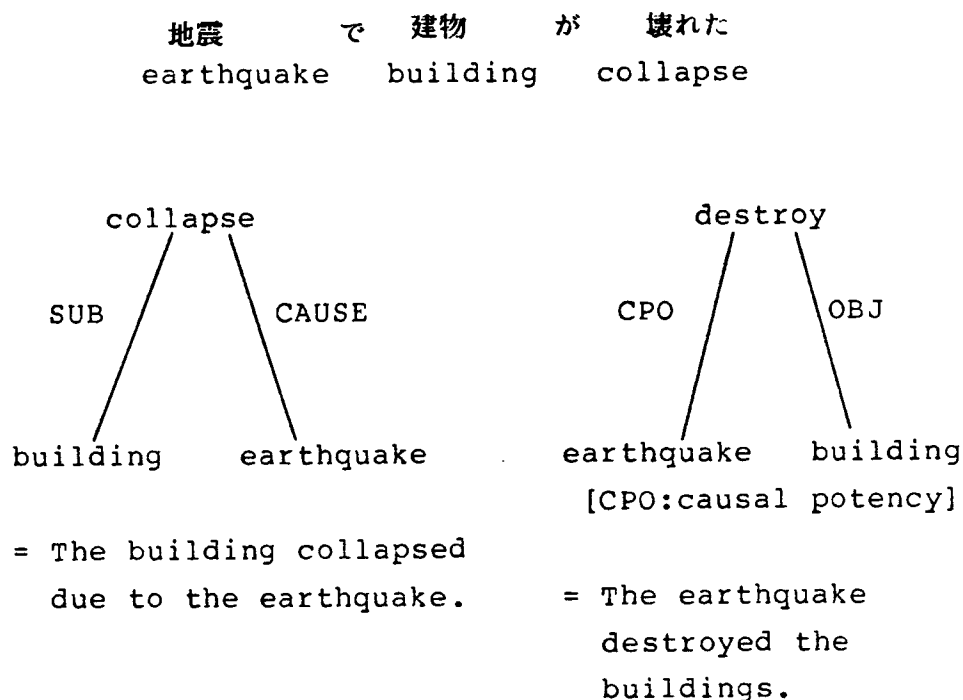


Figure 7. An example of structural transformations in the generation phase.

6.1 INTELLIGIBILITY

Evaluation of intelligibility is based on a scale of 1 to 5; the categories are described below. [See Appendix A for translation examples.]

1. The meaning of the sentence is clear, and there are no questions. Grammar, word usage, and style are all appropriate, and no rewriting is needed.
2. The meaning of the sentence is clear, but there are some problems in grammar, word usage, and/or style, making the overall quality less than 1.
3. The basic thrust of the sentence is clear, but the evaluator is not sure of some detailed parts because of grammar and word usage problems. The problems cannot be resolved by any set procedure; the evaluator needs the assistance of a Japanese evaluator to clarify the meaning of those parts in the Japanese original.
- 4) The sentence contains many grammatical and word usage problems, and the evaluator can only guess at the meaning after careful study, if at all. The quickest solution will be a retranslation of the Japanese sentence because too many revisions would be needed.
- 5) The sentence cannot be understood at all. No amount of effort will produce any meaning.

As the evaluation number increases on the above scale from 1 to 5, intelligibility decreases. The evaluator uses the above scale to evaluate the output sentence without any reference to the Japanese original in the first place. When the output sentence contains untranslated words in Japanese, the English translation of those words is provided by a Japanese rewriter before the evaluation. This evaluation work has been carried out to date by one British and one American evaluator, neither of whom has the ability to read or evaluate Japanese. Both evaluators have one year's experience in proofreading and checking translations of general scientific and technical literature, but neither has specialized knowledge in the field of electrical engineering, which has been used for the input material up to now.

6.2 ACCURACY

Accuracy is evaluated on a scale of 0 to 6; that is, seven categories. [See Appendix B for translation examples.]

- 0) The content of the input sentence is faithfully conveyed to the output sentence. The translated sentence is clear to a native speaker and no rewriting is needed.
- 1) The content of the input sentence is faithfully conveyed to the output sentence, and can be clearly understood by a native speaker, but some rewriting is needed. The sentence can be corrected by a native speaking rewriter without referring to the original text. No Japanese language assistance is required.
- 2) The content of the input sentence is faithfully conveyed to the output sentence, but some changes are needed in word order.

- 3) While the content of the input sentence is generally conveyed faithfully to the output sentence, there are some problems with things like relationships between phrases and expressions, and with tense, voice, plurals, and the positions of adverbs. There is some duplication of nouns in the sentence.
- 4) The content of the input sentence is not adequately conveyed to the output sentence. Some expressions are missing, and there are problems with the relationships between clauses, between phrases and clauses, or between sentence elements.
- 5) The content of the input sentence is not conveyed to the output sentence. Clauses and phrases are missing.
- 6) The content of the input sentence is not conveyed at all. The output is not a proper sentence; subjects and predicates are missing. In noun phrases, the main noun (the noun positioned last in the Japanese) is missing, or a clause or phrase acting as a verb and modifying a noun is missing.

As the evaluation number increases on the above scale from 0 to 6, the accuracy decreases. This part of the evaluation was done by four Japanese translators, each of whom has one or two years experience in Japanese to English translation. The whole evaluation process is monitored by a Japanese translation specialist with extensive experience in translation work.

6.3 RESULTS OF EVALUATION

We describe here the results of the evaluation of the translation of 1,682 sentences taken from the monthly JICST journal *A Current Bibliography of Science and Technology*. Of these, 791 were the ones often referred to for the development of the analysis grammar, and the remaining 891 were added as the test material this time. All the sentences were given to the machine translation system with no pre-editing. The 791 sentences forming the first group were originally selected out of 1000 after eliminating 120 that contained ungrammatical Japanese expressions, and a further 90 that contained long mathematical or chemical formulae. The deletion of the latter was because, in the early stages, the analysis grammar that would deal with formulae had not been completed. The second group of 891 were all those that were in the abstract, without any such selection.

Tables 5 and 6 present the evaluation results for intelligibility and accuracy for the two groups of abstracts. **Table 7** gives a comparison of the two groups. As the system was not tuned to the sentences in the second group, there were many unknown grammatical structures and missing words in the dictionary, which made the evaluation result worse than the first group.

As these tables show, when the accuracy of translation goes down, so too does the intelligibility. We did not find any examples of intelligibility being low when accuracy was high, but we did find a reasonable number of cases where the translation accuracy was evaluated as low, but intelligibility was rated high. **Table 8** lists typical sample sentences for each evaluation type.

Table 5. Evaluation results for the first group of 791 abstracts.

intelligibility	accuracy								defective	total	percentage of total
	0	1	2	3	4	5	6				
1	98	0	9	4	1	2	2	0	116	14.7	
2	0	186	8	28	22	11	4	0	259	32.7	
3	0	1	135	45	42	17	16	3	259	32.7	
4	0	0	20	19	26	10	24	1	99	12.5	
5	0	0	5	2	8	6	36	1	58	7.3	
total	98	187	177	98	98	46	82	5	791		
percentage of total %	12.4	23.6	22.4	12.4	12.4	5.8	10.4	0.6			

Table 6. Evaluation results for the second group of 891 abstracts.

intelligibility	accuracy								defective	total	percentage of total
	0	1	2	3	4	5	6				
1	61	0	7	5	0	3	7	0	83	9.3	
2	0	142	22	27	8	13	9	0	221	24.8	
3	0	0	138	68	44	26	17	4	297	33.3	
4	0	0	10	24	35	16	37	4	126	14.1	
5	0	0	0	1	6	7	149	1	164	18.4	
total	61	141	177	125	93	65	219	9	891		
percentage of total %	6.8	15.8	19.9	14.0	10.4	7.3	24.6	1.0			

Table 7. Comparison between first and second groups for intelligibility.

intelligibility	first group 7 9 1	second group 8 9 1
1	14.7%	9.3%
2	32.7%	24.8%
3	32.7%	33.3%
4	12.6%	14.1%
5	7.3%	18.4%

Table 8. Typical sample sentences in the different evaluation categories.

accuracy	first group 7 9 1	second group 8 9 1
0	12.4%	6.8%
1	23.6%	15.8%
2	22.4%	19.9%
3	12.4%	14.0%
4	12.4%	10.4%
5	5.8%	7.3%
6	10.4%	24.6%
	0.6%	1.0%

Just as there are no clear and objective criteria for evaluating the quality of Japanese to English translations done by humans, standard criteria for judging the results of machine translation have yet to be established. The evaluation methods proposed in this paper are still in the trial stage, and much more refining and improving is still needed.

The translation quality and the amount of post-editing needed is closely related to the quality and nature of the original text. It is quite natural to expect that simple sentences can be translated accurately and intelligibly. We need to develop some way to evaluate the degree of difficulty of the original text along with the translation evaluation. Only within this wider context can accuracy and intelligibility be meaningfully discussed.

The JICST abstracts used in this project were written primarily with the aim of condensing as much information as possible into a few sentences. This means that there are many long sentences, many of which are not very correct from a linguistic point of view. This is one obvious factor contributing to the poor evaluation results shown in Tables 5 to 7.

Evaluation of the quality of machine-translated sentences is closely linked to the way in which the machine translation output is to be used, hence to the ease with which post-editing can be done. Only a minimum of post-editing will be necessary to convey the technical meaning of the original to the specialist in a particular field for the purpose of information service. However, when the translated text is for wide circulation or publication (for example, technical manuals), style and

naturalness of sentential expressions, as well as exact meaning, become more important. Depending on these situations, the yardstick for intelligibility will change as well.

ACKNOWLEDGMENT

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The following addendum is in rough form as it arrived just as the issue was going to press.

Recent achievement of the translation evaluation (as of September 1985)

理解容易性 intelligibility	忠実度 accuracy									本欄合計 total	割合 percentage of total
	0	1	2	3	4	5	6	7	不備 defective		
1	256	1	34	13	6	6	2	0	0	318	24.5%
2	1	274	38	31	26	11	1	0	1	381	29.3%
3	0	0	157	87	79	26	29	0	6	384	29.5%
4	0	0	19	39	60	16	24	1	3	162	12.5%
5	0	0	2	3	18	2	10	0	0	35	2.7%
?				1	1				18	20	1.5%
total	257	275	248	174	190	61	66	1	28	1300	
percentage of total	19.8%	21.2%	19.1%	13.4%	14.6%	4.7%	5.1%	0.1%	2.2%		

APPENDIX A

TRANSLATIONS AND THEIR INTELLIGIBILITY EVALUATION RESULTS

Intelligibility = 1

NO. 335: E82060091_3_1

高周波非自統放電中のドリフト電流の大きさ、荷電粒子密度、電場の分布を数値的に研究した。

Distributions of size, charged particle density and electric fields of drift currents during the high frequency non-self-sustaining discharge were studied numerically.

NO. 87: E82060092_4_1

安定した同時動作アークを実現するための条件を非平衡ブリッジ回路として解析し、計算機を用いて解く。

Conditions for realizing stabilized simultaneously-operated arcs are analyzed as non-balanced bridge circuits, and the solution is made by using computers.

NO. 97: E82060095_5_1

質量、電荷、運動量およびエネルギー保存式を適当な境界条件下で反復有限差分法によって解く。

Mass, charges, momentum and energy preservation formulas are solved by the iterative finite differential method under appropriate boundary conditions.

Intelligibility = 2

NO. 81: E82060020_3_1

真空中の誘電体板に入射する平面波の回折により生じる表面波の複素振幅と等価表面電流分布を積分方程式の数値解により見出す。

Complex amplitudes and equivalent surface current distribution of the surface waves formed by the diffraction of the plane waves emitted to dielectric plates in vacua are found by numerical solutions of integral equations.

NO. 84: E82060020_6_1

平面波到達方向が切線に近いほど不規則部近傍での解の非一様成分振幅は増大、縁による散乱の寄与が増大する。

As the plane wave arrival direction is close to tangents, the nonuniform component amplitude of solutions in the neighborhood of the irregular section is increased, and the number of contributions of the scattering by edges increases.

NO. 87: E82060021_3_1

強度ゆらぎに凍結仮説が成立するとき光電子増倍管電流スペクトル密度二乗平均値は周期性をもつ。

Multiplier photo tube current spectrum root-mean-square values have the periodicity when freezing hypotheses are established in the intensity fluctuation.

Intelligibility = 3

NO. 102: E82060024_3_1

幾何光学理論を反射波の計算に用いる場合、波源と観測点を与えた時の導体面上の反射点を知る必要がある。

Specular points of the conductor surfaces when wave sources and observation points are given have to be known when geometrical optics theories are applied to the calculation of reflected waves.

NO. 107: E82060025_4_1

荷電粒子の運動は準静的共振モード H_{00} の周波数の近くに周波数スペクトルが集中した回折放射バーストをともなうことを明らかにした。

It was done that the motion of charged particles accompanies the diffractive radiation bursts which frequency spectra concentrated in the neighborhood of frequencies of quasi-static resonance mode H_{00} be obvious.

NO. 108: E82060025_5_1

放射エネルギーは粒子が共振器結合スロット上を飛ぶとき最大で粒子固有電磁場の非一様性を反映する。

As for the radiation energy it is maximum when particles fly resonator coupled slots, and the nonuniformity of the particle intrinsic electromagnetic field is reflected.

Intelligibility = 4

NO. 42: E82060011_3_1

電荷の発生原因は生活環境、産業環境のいたる所にあり、材料や運動経過の他に表面の形状状態や導電率、誘電率、湿度などが重要である。

ある as for causes of generation of charges in every place of the living environment and the industrial environment, and forms, conductivity, dielectric constants, humidity of surfaces, and so on are important as well as materials and movement.

NO. 47: E82060012_5_1

実機には軸対称と言えない部分が存在する 경우가多いが、この場合のモデル化には補正係数を導入し、それを非線形反復計算の中に組み入れた。

There were many cases in which the parts exist which 言える in real machine be axi-symmetric but correction factors were introduced for the modeling of this case, and it was incorporated in nonlinear iterative computations.

NO. 50: E82060013_4_1

真横および配列方向から入射した場合、円柱間隔および円柱半径に対する前方、後方散乱断面積および円柱近傍における空間的な合成電界および磁界の等振幅分布を示し、散乱波の特性を明らかにした。

The equiamplitude distribution of the spatial composite electric fields and magnetic fields to intervals of the conducting cylinders and radii of the conducting cylinder in front rear scattering cross section and the neighborhood of the cylinder was shown, and characteristics of scattering waves were done be obvious when the emission was made from sides and array directions.

Intelligibility = 5

NO. 352: E82060195_5_1

手作業から自動整形そう入機械までの各種そう入機械を紹介。

The various insertion machine till automatic forming machines is introduced by the manual operation.

NO. 366: E82060200_3_1

プリント配線自体は集積回路化が進んだが、マザーボード裏の配線は主に巻付け配線である。

Integrated circuits proceed in the printed wiring itself, and the wiring of the mother board reverse is mainly the wire wrapping.

NO. 367: E82060200_4_1

自動機による配線の比率が増大し、手作業の2倍以上になった。

Ratios of the wiring by automatic machines increased, and they became more than two twice of the manual operation.

APPENDIX B**TRANSLATIONS AND THEIR ACCURACY EVALUATION RESULTS****Accuracy = 0**

NO. 70: E82060017_3_1

小規模不均質性をもつ平面不均質媒質からの空間変調波の反射を研究。

The reflection of space modulated waves from the plane nonhomogeneous medium with small-scale heterogeneity is studied.

NO. 73: E82060017_7_1

ランダム不均質成層媒質からの周期変調信号の反射特性を研究。

Reflection characteristics of periodically modulated signals from media of random nonhomogeneous layers are studied.

NO. 74: E82060018_2_1

2つのはん関数の順序積の平均値。

Mean values of ordered products of two functionals.

Accuracy = 1

NO. 77: E82060018_6_1

応答の高次平均が順序キュミュラントで表現され、物理系のG a u s s特性を最大限利用できる。

High-order averages of responses are expressed by the ordinal cumulant, and the Gauss characteristic of physical systems can be utilized to the utmost.

NO. 78: E82060019_2_1

横波の半影域内での電磁場の一様漸近特性。

Uniform asymptotic characteristics of electromagnetic fields in half shadows of transversal waves.

NO. 79: E82060019_4_1

反射場ポテンシャルの正解の漸近特性の解析により横波の半影域からの任意の距離で成立する場の一様漸近式を得た。

Uniform asymptotic equations of the fields established in arbitrary distances from the half shadow region of transversal waves by the analysis of asymptotic characteristics of correct answers of the reflection field potential were obtained.

Accuracy = 2

NO. 172: E82060044_2_1

加速された荷電場のブラデオン部分とタキオン部分への分解。

The analysis of accelerated charged fields to bradyonic and tachyonic parts.

NO. 176: E82060045_3_1

円形加速機中の電子の角度分布を知ることが電子ビームの動力学的の研究及びいくつかの応用にとって重要である。

It is important from research and several applications of dynamics of electron beams to know the angle distribution of electrons in circular accelerators.

NO. 182: E82060046_5_1

カットオフ下の電流密度は電圧とギャップ距離の関数で与えられ実験と相反する。

The current density under the cutoff is given by functions of voltages and gap distances, and the current density under the cutoff contradicts experiments.

Accuracy = 3

NO. 271: E82060070_4_1

実現条件には行列が含まれ、多変数と単一変数の回路網間の基本的差を強調する。

Realization conditions include matrices, and basic differences between single-variable networks are stressed multivariable.

NO. 30: E82060071_4_1

スレーブ側の結線方法, スレーブへの要請など概要を述べた後, いくつかの論理構成の例を示す。

Several examples of the logical composition are given after describing outlines such as methods for connection of the slave side and requests for slaves.

NO. 36: E82060072_5_1

次に, 診断機能について議論した後, 将来の拡張性及びシステム素子の生産販売状況について述べる。

Next, production and marketing situations of the future expansibility and system elements are described after discussing diagnostic functions.

Accuracy = 4

NO. 31: E82060071_5_1

次にスレーブ論理を実行するはん用のアドレス論理回路とデータ制御回路を示す。

The 汎用だ address logical circuits and data control circuits executing the slave logic next are shown.

NO. 44: E82060075_4_1

測定端出力をデジタル化処理して誤差修正を行うが、ケーブルコネクタ間の反射係数、不整合時の損失などの測定例を述べ、精度にも言及した。

The error correction is carried out by processing the measuring terminal output digitally, and measurement examples such as reflection coefficients of cable connectors and losses at the time of the mismatching are described, and the accuracy is also referred to.

NO. 57: E82060079_4_1

方法としては有限差分法を用い、関連式は電磁界法則の積分形によった。

Related equations were based on the integral type of laws of electromagnetic field as methods by using finite differential methods.

Accuracy = 5

NO. 203: E82060051_8_1

DC解の一意性、自励振動回路網のある与えられた領域での漸近安定性を論ずることができる。

The asymptotic stability in the regions by which there is an unique self-excited vibration network of the DC solution and for giving the unique self-excited vibration network of the DC solution can be discussed.

NO. 213: E82060054_7_1

この条件は、よく知られている線形、時不変、集中定数 n ポート回路網の時間域、周波数域の受動性、無損失性条件の非線形な場合への拡張となっている。

This condition becomes the expansion of passivity and losslessness conditions of time region and frequency region of linear and time-invariable well known concentrated constant n -port networks to nonlinear cases.

NO. 222: E82060056_6_1

この方法では電気回路の解析は主としてシステム方程式を使って行う。

Electric circuits are 解析するed by using system equations mainly in this method.

Accuracy = 6

NO. 630: E82060176_5_1

全体で100 km以上のAl管の長さになるが、接合及び施工法を示し、Alの特徴を生かした応用例として紹介。

It becomes the length of Al tubes of more than 100 km in wholes, and junctions and installation methods are shown, and introduced as application examples utilizing features of the Al.

NO. 309: E82060182_3_1

従来の対話式システムと異なり、ピン位置を手手でデジタル化、入力する必要がない。

Unlike conventional interactive systems, pin positions are digitized be manual, and they do not have to be inputted.

NO. 310: E82060182_4_1

ピン位置、ピン数、電流容量によるピン寸法を自動的に最適化する。

Pin dimensions by pin positions, number of pins and current capacity are optimized automatically.

NO. 326: E82060188_3_1

はんだ付けにさいし界面で標記の化合物が形成される。

The soldering forms above-mentioned compounds in interfaces.