CONCEPTUAL TAXONOMY OF JAPANESE VERBS FOR UNDERSTANDING NATURAL LANGUAGE AND PICTURE PATTERNS

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Summary

This paper presents a taxonomy of "matter concepts" or concepts of verbs that play roles of governors in understanding natural language and picture patterns. For this taxonomy we associate natural language with real world picture patterns and analyze the meanings common to them. The analysis shows that matter concepts are divided into two large classes:"simple matter concepts" and "non-simple matter concepts." Furthermore, the latter is divided into "complex concepts" and "derivative concepts." About 4,700 matter concepts used in daily Japanese were actually classified according to the analysis. As a result of the classification about 1,200 basic matter concepts which cover the concepts of real world matter at a minimum were obtained. This classification was applied to a translation of picture pattern sequences into natural language.

1 Introduction

As is generally known, the intellectual activities of human beings are very instructive in higher processing of natural language and picture patterns, especially real world picture patterns. There are three sides to intellectual activity:

(1) Recognition and understanding.
(2) Thinking und inference.
(3) Expression and (intellectual) action.

The system of concepts or knowledge plays an essentially important role in each activity. The base of the system is considered to be placed on those concepts formed by direct association with the real world, which are closely related with both syntactic and semantic structures of natural language. The aim of this paper is to make this system clear from the linguistic viewpoint.[1-3]

There are two linguistic approaches to the analysis of the system. One is the understanding of the outline of the whole system and the other is the detailed analysis of a small part of the system. Compilation of a thesaurus is considered of the former type. Thesauruses compiled so far,[4,5] however, are not sufficient for machine processing because of the following:

1. Abstraction processes of concepts
   As shown in Sect. 2.2, it is important to introduce abstraction processes or conceptualization processes to the system not only for its systematic analysis but also for the "understanding" of natural language and picture patterns. The processes are not taken into consideration in ordinary thesauruses.
2. Interrelation among concepts
   To know semantic interrelation among words are indispensable for natural language processing. This information is not explicitly expressed in ordinary thesauruses.
3. Criterion for classification
   In machine processing it must be shown why a word is classified into such and such term. Ordinary thesauruses do not stress the criteria.

Concepts of verbs are the core of the system from the linguistic viewpoint. We classify almost all concepts of verbs in daily Japanese by association of natural language with the real world, answering the above-mentioned problems. As for problem 1, a working hierarchy along an abstraction process is constructed in the system. As for problem 2, case frames are shown in "simple matter concept," and connecting relations among elementary matter concepts are shown in " non-simple matter concept." As for problem 3, an algorithm is introduced into the classification.

2 Preliminary Considerations

2.1 Meaning Common to Natural Language and Picture Patterns

Putting aside what the meaning of a picture pattern is, let's first discuss how it can be understood. When a picture pattern or picture pattern sequence is given, an infinite number of static or dynamic events can generally be observed within. Suppose that the meaning of each event is described in natural language—in fact, one can express almost all events in natural language apart from the question of efficiency— these descriptive sentences will amount to an infinite number. An ordinary sentence is reduced into simple sentences, each of which is governed syntactically and semantically by a verb. Since there is a finite number of verbs in each language, the meanings of an infinite number of the events involved are roughly divided into the meanings of those verbs and their interrelations.

Now, what is the meaning of *picture patterns* ? In the case of circuit diagrams or chemical structural formulas, we can think of the semantics because they have signs and syntactic relations. In the case of real world picture patterns, however, there exists neither signs nor syntactic relations. Here we observe real world objects named by human beings. If we consider them something like signs, we can think of the syntax, and then the semantics, too. The meanings are common to natural language and picture patterns, although their syntactic structures differ largely from each other.

2.2 Paradigms for Interpretation and Understanding

In order to clarify the notions of interpretation and understanding, first, we propose a working hierarchy of knowledge along the abstraction process, as follows:

Level 1 *Raw data* Data close to copies of things and events in the real world. Image-like data.

Level 2 *Data of visual features* Features extracted from raw data.

Level 3 *Data of conceptual features* Symbolic data associated with visual features. Some of them correspond to Chomsky's syntactic features in the *lexicon*.[6]

Level 4 *Concept data* Data obtained by organizing conceptual features. Most data have names as words. In case of the verb they roughly correspond to Minsky's *surface semantic frames*.[7]

Level 5 *Interconnected concept data* Networks of concept data. A concept can be interconnected with other concepts from various viewpoints. Schank's *scripts* can be regarded as one of this type.[8] Some networks have names as words.

Fig. 1 shows the hierarchy. "Interpretation" is considered as an association of the data at one level with another level. (Here input images are considered as level zero data.) Since the knowledge system has several levels and each level has many domains, interpretation is possible in many ways. If an interpretation is performed under a certain control system that specifies which level and which domain the input data should be associated with, it is called " understanding."

As the level number increases, a level becomes higher because abstractions of concepts proceed. But, which is deeper, level 1 or level 5 ? In natural language understanding, input sentences will probably be interpreted initially at level 4 or 5, then the interpretation may descend to level 1, where level 1 might be deeper than either level 4 or 5. However, if the interpretation of a picture pattern proceeds from level 1 to 5, we think level 5 as the deeper level.

The knowledge system is so massive and complicated that it is necessary to make systematic analyses. Since the number of verbs are finite, concepts of verbs at level 4 provide a clue to systematic and exhaustive analyses of knowledge from the linguistic viewpoint.

The concepts of verbs are divided into two large classes:"simple matter concepts" and "non-simple matter concepts." [2,3]

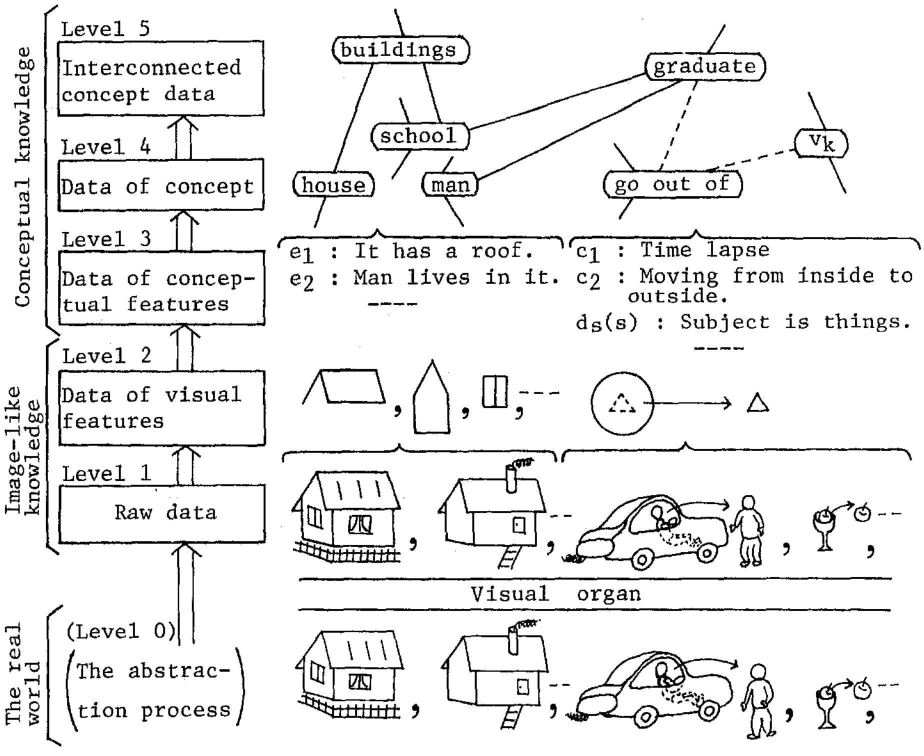


Fig. 1 Hierarchy of the knowledge system

3 Simple Matter Concepts

The simple matter concepts are not reduced into any more elementary matter concepts while the non-simple ones are reduced. Most of them are so concrete that they are well analyzed by direct association with the real world.

3.1 Structural Patterns

An object in the real world identified by a verb is called "matter." Unlike things matter does not occur alone. It arises accompanied by things, events, and attributes, which are called "constituents," so this concept can be regarded as the concept of a dynamic or static relation among constituents and be expressed by

$$v(s,o,o_f,o_t,o_m,o_s,o_w,o_c,p,t,r,\cdots) \qquad (A)$$

where each symbol in parentheses represents a constituent specified below.

s : subjective concept
o : objective concept
o_f: starting point in ac-

tion, or initial stste of change
o_t: finishing or target point in action, or final state of change
o_m: opponent in mutual action
o_s: standard or reference
o_w: way or means(including instrument)
o_c: concept which supplements attributive aspects
p,t,r,·····: place, time, cause(or reason), ·····

Out of these, eight constituents s through o_c are obligatory because they are indispensable for the recognition of matter. In Japanese sentences, the obligatory constituents are often accompanied with such postpositional words as s-*ga*, o-*o*, o_f-*kara*, o_t-*ni*, o_m-*to*, o_s-*ni*, o_w-*de*, and o_c-*to*. But it is difficult to decide the case of a constituent only by such postpositional words.

The combination of obligatory constituents decides the basic frame of matter concepts. Table 1 was obtained after an elaborate investigation of more than 1,500 simple matter concepts. Two comments must be added to Table 1. First, optional constituents participate fairly freely in matter. Table 1 says nothing about this problem. Next, some obligatory constituents are not obligatory in every case.

M1 *(konoha-ga eda-kara) ochiru.*
(A leaf) falls (from the branch).
M2 *(botan-ga shatu-kara) toreru.*
(A button) comes off (the shirt).

In M1 o_f *eda*(branch) is optional because *ochiru* is recognized by observing the vertical movement of a leaf, while in M2 o_f *shatsu*(shirt) is obligatory because *toreru* is not recognized without the existence of a shirt. Constituents o_f, o_t, o_w, and o_c belong to such a group.

3.2 Semantic Contents

In case of semantic contents it is difficult to classify them by examining the combination of constituents, so we adopted a trial-and-error method extracting features for classification from the concepts. Letting a set of simple matter concepts under consideration be **C**, the feature extraction from **C** is performed by the following recursive procedure:

Step 1

Select several elements having similar contents from **C** and extract from them a feature (c_1) which makes them similar.

Step n(≥2)

Let the features extracted up to step (n-1) be c_1, c_2,·····,c_{n-1}. Extract a feature (c_n) in the same way as step 1. (The element so far selected may be adopted in the extraction.) And compare c_n with each $c_i(1\leq i\leq n-1)$.

1) If c_n is independent with each c_i, adopt it as a feature and go to step (n+1).
2) Otherwise,
 2.1) if the contents of c_n/c_i contains that of c_i/c_n, adopt c_n as an upper/lower-grade feature of c_i and go to step (n+1).
 2.2) Otherwise, make c_n as a special feature and go to step (n+1).

Table 1 Types of structural patterns

No.	Pattern	Example
I	v(s)	*(konoha-ga) ochiru.* (A leaf) falls.
II	v(s,o_f)	*(otoko-ga ie-kara) deru.* (A man) goes (out of the house).
III	v(s,o_t)	*(tarō-ga yūbinkyoku-ni) iku.* (Taro) goes (to the post office).
IV	v(s,o_m)	*(torakku-ga basu-to) butsukaru.* (A truck) collides (with a bus).
V	v(s,o_s)	*(ko-ga oya-ni) niru.* (Children) resemble (their parents).
VI	v(s,o)	*(hanako-ga ringo-o) taberu.* (Hanako) eats (an apple).
VII	v(s,o,o_f)	*(untensyu-ga tsumini-o kuruma-kara) orosu.* (A driver) unloads (baggage from the car).
VIII	v(s,o,o_t)	*(seito-ga kaban-ni kyōkasyo-o) ireru.* (Pupils) put (textbooks into knapsacks).
IX	v(s,o,o_m)	*(hikōshi-ga kanseitō-to shingō-o) kawasu.* (A pilot) exchanges (information with a control tower).
X	v(s,o,o_w)	*(hito-ga saji-de satō-o) sukū.* (One) scoops (sugar with a spoon).
XI	v(s,o,o_c)	*(hito-ga soyokaze-o suzushiku) kanjiru.* (Men) feel (a gentle breeze cool).
XII	Others	

Table 2 Features of semantic contents

No.	Semantic feature	Example	Dis*
0·0	Displacement	*ochiru*(fall)	319
0·1	Change in the direction	*mukeru*(turn)	54
0·2	Deformation A	*magaru*(bend)	183
0·3	Spiritual change	*okoru*(get angry)	128
0·4	Sensual change	*kanjiru*(feel)	50
1·00	Deformation B	*yaseru*(get lean)	22
1·01	Change in quality	*kusaru*(rot)	61
1·02	Change in quantity	*herasu*(decrease)	35
1·03	Optical change	*hikaru*(flash)	30
1·04	Colour change	*akamaru*(turn red)	29
1·05	Thermal change	*hieru*(grow cold)	34
1·06	Change in force and energy	*tsuyomaru*(intensify)	53
1·07	Vocal change	*utau*(sing)	52
1·08	Occurence,appearance and disappearance	*arawareru*(appear)	54
1·09	Start,end and stop	*tomeru*(stop)	21
1·10	Temporal change	*hayameru*(hasten)	28
2·0	Continuation	*tsuzuku*(continue)	24
2·1	State	*sobieru*(tower)	29
3·0	Abstract	*motozuku*(base)	98
3·1	Others	*taberu*(eat)	129
Total			1,433

* There are 1,209 different concepts in the classified concepts.

This method was applied to the set of concepts described in Sect. 3.1 and the result is tabulated in Table 2. Here distribution was obtained by the classification of Chapter 5. In Table 2, the first digit 0, 1 and 2 in the classification numbers roughly represent movement, change, and state, respectively.

4 Non-Simple Matter Concepts

Generally, non-simple matter concepts are so abstract in comparison with simple ones that it is hard to show a clear association of natural language with the real world. We emphasize the analysis of how they are composed of simple ones.

4.1 Complex Concept *A*

If two elementary matter concepts v_i and v_j(not necessarily simple ones) are connected according to one of the rules shown in Table 3 and the connected concept is expressed by a Japanese complex word of two verbs for v_i and v_j, it is called a " complex concept of *A*." The rules in Table 3 were obtained from the investigation of about 900 matter concepts which consist of two matter concepts and are expressed by a Japanese complex word.

In rule XXI·I, v_j(*deru*) is an upper-grade concept of v_i(*afureru*) and contains the contents of v_i. Rule XXI·I is concerned with the whole and a part of the same matter, while rule XXI·II with two different matters. The former is considered as a special case of the latter in which two matters coincide with each other.

Rule XXI and XXII are logical while rule XXIII is linguistic. As "cause" is one of the constituents in (A) in Sect. 3.1, XXI may be considered as a part of XXIII .

The semantic contents of complex concept *A* consists of the v_i and v_j contents and their connecting relation.

4.2 Complex Concept *B*

Complex concept *B* consists of several elementary matter concepts and is usually expressed by a Japanese simple word. However, no general rule can be found to connect elementary matter concepts, so a hierarchical analysis was made for a small number of complex concepts of *B* as shown in Fig. 2 and Table 4.

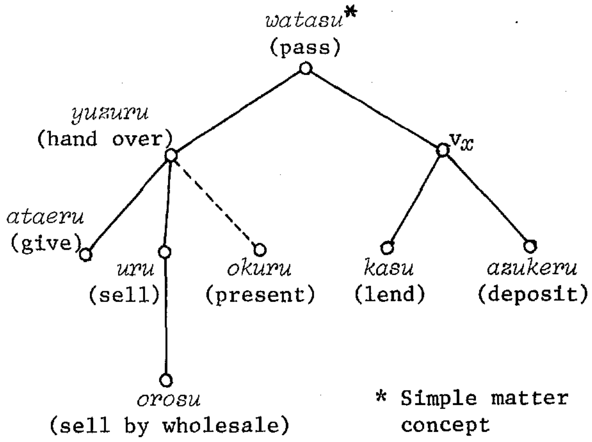


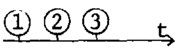
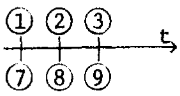
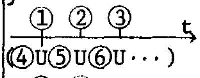
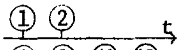
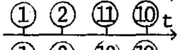
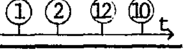
Fig. 2 A hierarchy of complex concepts of *B*

From the diachronic point of view, there seems to be a reason why a complex concept of *B* is expressed by a simple word. The relation among elementary matter concepts can not well be expressed by enumerating each verb as in the case of complex concept *A*. When one is going to designate matter in the real world without the verb identifying it, one must utter several sen-

Table 3 Connecting rules of complex concept *A*

No.	Connecting rule	Example	Remark
XXI	Cause and effect		
XXI·I	Implication	*(mizu-ga) afure-deru.* (Water) overflow-comes out.	If water overflows, water comes out.
XXI·II	Cause and effect	*(dareka-ga watashi -o) oshi-taosu.* (Some one) push-throws (me) down.	If someone pushes me, I am thrown down.
XXII	Logical product	*(sinja-ga) fushi-ogamu.* (Believers) kneel down-pray.	Believers kneel down and pray.
XXIII	Syntactic connection		
XXIII·I	Relation between s and v	*(akago-ga) naki-yamu.* (A baby) cry-stops.	That a baby cries stops.
XXIII·II	Relation between o and v	*(anaunsā-ga genkō-o) yomi-ayamaru.* (An anouncer) read-misses (his manuscript).	An anouncer misses to read his manuscript.
XXIII·III	Relation between o_w and v	*(kanshu-ga shūjin-o) tataki-okosu.* (A guard) knock-awakes (prisoners).	A guard awakes prisoners by knocking them.

Table 4 An analysis of complex concepts of *B*

Complex concept	Relation among elementary concepts	Temporal shift
yuzuru(hand over)	①·②·③	
ataeru(give)	‖ ·[i]	
uru(sell)	‖ ·⑦·⑧·⑨	
orosu(sell by wholesale)	‖ · ‖ ·[ii]	
okuru(present)	(④U⑤U⑥U···)①→(②·③)	
v_x	①·②·⑩	
kasu(lend)	‖ ·⑪	
azukeru(deposite)	‖ ·⑫	

① (Someone(=P_1)) has (something(=A)),② (P_1) passes (A to someone (=P_2)), ③ (P_2) has (A), ④ (P_1) celebrates (P_2), ⑤ (P_1) thanks (P_2), ⑥ (P_1) respects (P_2), ⑦ (P_2) has money, ⑧ (P_2) passes (money to P_1), ⑨ (P_1) has (money), ⑩ (P_2) returns (A to P_1), ⑪ (P_2) uses (A), and ⑫ (P_2) keeps (A).

[i] P_1 is higher than P_2 in grade, and [ii] P_1= wholesaler and P_2=salesman.

"·","U"and "→":logical product, logical sum and implication.

v_x:There is no word to represent it.

Table 5 Surface contents of complex concept *B*

No.	Contents	Example	Dis.
10	Spiritual act		
10·0	Thought·recognition	*mitomeru*(recognize)	35
10·1	Guess·judgement	*sassuru*(guess)	25
10·2	Respect·contempt	*uyamau*(respect)	18
10·3	Haughty·flattery	*hikerakasu*(sport)	20
11	Academic and artistic act		
11·0	Education·learning	*oshieru*(teach)	33
11·1	Creation	*arawasu*(write a book)	11
12	Religious act		
12·0	Belief	*mōderu*(visit a temple or shirine)	16
12·1	Celebration·marriage·funeral	*totsugu*(marry)	16
13	Verbal act		
13·0	Praise·blame	*homeru*(praise)	12
13·1	Instigation·banter	*odateru*(instigate)	12
14	Social act		
14·0	Life	*kurasu*(live)	26
14·1	Fostering	*yashinau*(bring up)	26
14·2	Antisocial·immoral	*nusumu*(steal)	43
14·3	Promise·negotiation	*suppokasu*(breake an appointment)	35
15	Conduct·behavior	*sumasu*(assume a prim air)	25
16	Labour·production		
16·0	Labour·work	*tsutomeru*(serve)	35
16·1	Agriculture·industry·commerce	*akinau*(deal in)	49
17	Possesion		
17·0	Owning·abandonement	*yūsuru*(own)	11
17·1	Getting and giving·losing	*ataeru*(give)	55
17·2	Selling and buying·lending and borrowing	*kau*(buy)	19
18	Investigation·measurement		
18·0	Investigation	*shiraberu*(investigate)	24
18·1	Measurement	*hakaru*(measure)	19
19	Domination·personal-affairs		
19·0	Domination·obedience	*suberu*(dominate)	32
19·1	Personal affairs	*yatou*(employ)	14
20	Attack and defense·victory and defeat		
20·0	Attack and defense	*semeru*(attack)	26
20·1	Victory and defeat·superiority and inferiority	*makasu*(defeat)	19
21	Refuge·escape	*nigeru*(escape)	22
22	Rise and fall·prosperity and decline		
22·0	Rise and fall	*horobosu*(ruin)	11
22·1	Prosperity and decline	*sakaeru*(prosper)	19
23	Others	*moyoosu*(hold a meeting)	333
	Total		1,041

Table 6 Morpheme representing derivative operators

No.	Morpheme	Example	Remark
L	Affix	*kanashi-"garu"* (sad-*"garu"*)	be sad
LI	Formative to conform affix		
LI·I	Prefixal	*"tori"chirakasu* ("take"-scatter about)	scatter about awfully
LI·Ⅱ	Suffixal	*akire-"kaeru"* (be amazed-"return")	be thoroughly amazed
LⅡ	Others		

Table 7 Derivative information

No.	Derivative information	Example	Dis.
50	Emphasis		
50·0	Emphasis	*"tori"-chirakasu* ("take"-scatter about)	101
50·1	Do completely	*odoroki-"iru"* (be surprised-"enter")	55
50·2	Do violently	*shikari-"tobasu"* (scold-"fly")	61
51	Respect·politeness·humbleness	*ossharu* (say)	51
52	Vulgarity	*zurakaru* (run away)	31
53	Poor practice·failure		
53·0	Be ill able to do	*seme-"agumu"* (attack-*"agumu"*)	2
53·1	Lose a chance to do	*kui-"hagureru"* (eat-"miss")	7
53·2	Fail to do in part	*kaki-"morasu"* (write-"leak")	7
53·3	Fail to do	*fumi-"hazusu"* (step-"take off")	16
54	Repetition·habit		
54·0	Do again	*toi-"kaesu"* (ask-"return")	12
54·1	Be used to do	*tabe-"tsukeru"* (eat-"stick on")	29
55	Start		
55·0	Begin to do	*furi-"dasu"* (rain-"come out")	9
55·1	Be just going to do	*ii-"kakeru"* (say-"hang up")	9
56	Completion		
56·0	Have finished	*suri-"agaru"* (print-"go up")	23
56·1	Do from the beginning to the end	*yomi-"tōsu"* (read-"pass through")	5
56·2	Have completed	*nashi-"togeru"* (do-"accomplish")	3
57	Limit		
57·0	Do until the limit	*nobori-"tsumeru"* (climb up-"cream")	20
57·1	Do throughly	*uri-"kiru"* (sell-"cut")	15
58	Others	*omoshiro-"garu"* (interesting-*"garu"*)	209
	Total		665

tences. If such necessities often arise and the relationship is conceptualized, it will be efficient to give it a name.

As for semantic contents, elementary matter concepts and their relationship form a surface contents. Approximately 1,000 complex concepts of *B* were investigated according to the feature extraction method in Sect. 3.2 and the result is tabulated in Table 5.

4.3 Derivative Concept

Some concepts possess a function of deriving a new concept by operating others. Matter concepts derived from operative concepts with both morphemic structures and derivative information as shown in Table 6 and 7 respectively are called "derivative concepts." Table 7 was obtained from the investigation of about 700 matter concepts, most of which are expressed by a complex word and one concept is operative to the other. The derivative information is very similar to the modal information of auxiliary verbs, but it differs in that some matter concepts are operated upon and those operations are fixed.

5 Classification

In order to determine whether analyses in Chapter 3 and 4 are good or not, we classified about 4,700 basic matter concepts in daily Japanese, which are listed in "Word List by Semantic Principles" edited by National Language Research Institue in Japan.^{4}

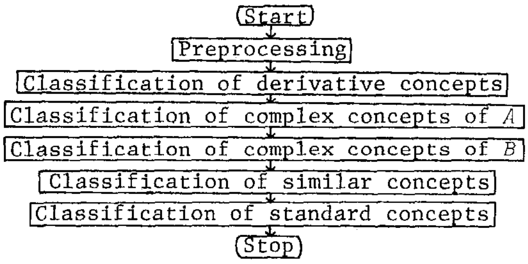
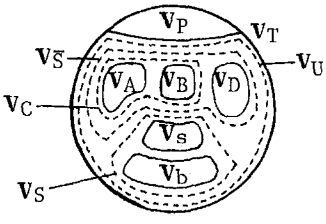


Fig. 3 Procedure of classification



V_T : a set of concepts of under consideration
V_P : a class of concepts excluded by preprocessing
V_U : a set of mutually different matter concepts
$V_{\bar{S}}$: a set of non-simple matter concepts
V_C : a set of complex concepts
V_A : a class of complex concepts of *A*
V_B : a class of complex concepts of *B*
V_D : a class of derivative concepts
V_S : a set of simple matter concepts
V_s : a class of similar matter concepts
V_b : a class of standard concepts

Fig. 4 Relation among sets and classes

5.1 Algorithm of Classification

An algorithm is introduced into the classification, reffering Fig. 3 and 4. The elements or members of $V_x(x=T,U,\cdots)$ are denoted by $V_{xi}(i=1,2,\cdots)$ and the sum and difference in the set theory are denoted by + and −, respectively.

1) Preprocessing

For each V_{Ti} of V_T,

1.1) examine whether V_{Ti} functions with others or by itself. If it functions with others, then it is excluded from V_T.

Example. *-garu*;

1.2) examine whether there is $V_{Th}(h<i)$ which has the same contents as V_{Ti} and is expressed by the same verb as V_{Ti}. If there is such V_{Th}, V_{Ti} is excluded from V_T.

Let›s denote a class of concepts excluded by 1.1) and 1.2) by V_P and let $V_U=V_T-V_P$.

2) Classification of derivative concepts

For each V_{Ui} of V_U,

2.1) if V_{Ui} is expressed by a derivative word, it is classified as a member of term L in Table 6. It is further classified in more detail according to Table 7;

2.2) if V_{Ui} is expressed by a complex word of two verbs and one of these verbs is affixal, then it is regarded as a member of term LI in Table 6, and classified in more detail according to Table 7;

2.3) if V_{Ui} is expressed by neither a derivative word nor a complex word, but it is regarded as a member of one of the terms in Table 7, it is classified into that term. At the same time, it is classified into term LII in Table 6.

Let this class of concepts thus obtained be V_D.

3) Classification of complex concepts of *A*

For each $V_{Ui}(\neq V_{Dj})$ of V_U, if V_{Ui} is expressed by a complex word of two verbs and each concept functions by itself, it is considered as a complex concept of *A* and classified according to Table 3.

The class thus obtained is denoted by V_A.

4) Classification of complex concepts of *B*

For each $V_{Ui}(\neq V_{Dj},V_{Ak})$ of V_U, if its contents does not belong to any term in Table 2, it is regarded as a complex concept of *B*. The class thus obtained is denoted by V_B and subject to the following process:

For each V_{Bi},

4.1) examine its surface structure and classify it according to Table 1;

4.2) examine its surface contents and classify it according to Table 5.

Let $V_{\bar{S}}=V_D+V_A+V_B$ and $V_S=V_U-V_{\bar{S}}$.

5) Classification of similar concepts

In class V_S of simple matter concepts, if there is a group with similar contents, choose a concept as the standard, then classify the remainder as similar concepts.

Example. *Korogeru*(roll), *korobu*(roll), *marobu*(roll), etc. are similar concepts for standard concept *korogaru*(roll).

Counter-example. *Saezuru*(chirp), *hoeru*(bark), *unaru*(roar), *inanaku*(neigh), etc. are not similar concepts for standard concept *naku*(cry).

Here, it is assumed that if a certain concept is a standard concept, it is not a similar concept for another standard one at the same time.

The class of similar concepts thus obtained is denoted as $\mathbf{V}_s$ and let $\mathbf{V}_b=\mathbf{V}_S-\mathbf{V}_s$.

6) Classification of standard concepts

For each V_{bi} of $\mathbf{V}_b$,

6.1) examine its structural pattern and classify it according to Table 1;

6.2) examine its semantic contents and classify it according to Table 2.

In the above process 2) through 6), one concept can be classified into two or more terms if necessary.

5.2 Results and Discussion

First, let's discuss the relation among the obtained classes along the abstraction process. There are two kinds of abstraction processes:(i) extracting common features from concepts as follows; bulldog→dog→animal→living thing→thing, (ii) connecting several concepts to form a new concept as shown in complex concept *B*. From the latter viewpoint, the relation among classes is schematized as indicated in Fig. 5.

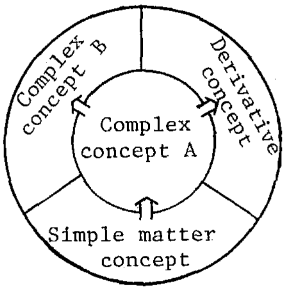


Fig. 5 Relation among obtained classes

Simple matter concepts ($\mathbf{V}_b$) are regarded as the base of matter concepts in the sense that $\mathbf{V}_b$ covers the concepts of real world matter at a minimum and every other matter concept is led from $\mathbf{V}_b$ by a rule. Two simple matter concepts are connected by a rule and form a little bit abstract concept or complex concept of *A*. Several matter concepts are organized by a fairly complicated rule into a new abstract concept or complex concept of *B*. One of the elementary concepts in a complex concept of *A* changes its meaning diachronically and becomes a derivative operator. So, the system of Japanese verb concepts has its own nature—although it is a fact that a large part of the system is universal— and is not manipulated at one level.

Next, Table 8 indicates the distribution of all matter concepts. The minute distribution in each class has been shown in Table 2, 5 and 7, respectively. Table 8 is instructive in investigating the human competence in organizing the language system. For example, if class $\mathbf{V}_b$ is regarded as "primitive" concepts, number 1,209 of $\mathbf{V}_b$ does not side with Schank's classification,[9] but with Minsky's idea.[7] From Table 2, 5 and 7, we can measure the degree of human concern about real world matter. For example, term 0.0 in Table 2 shows human beings are most interested in displacements of objects.

Table 8 Distribution of matter concepts

Class			Distribution
$\mathbf{V}_S$	$\mathbf{V}_b$		1,209
	$\mathbf{V}_s$		529
$\mathbf{V}_{\bar{S}}$	$\mathbf{V}_C$	$\mathbf{V}_A$	901
		$\mathbf{V}_B$	951
	$\mathbf{V}_D$		665
$\mathbf{V}_U = \mathbf{V}_S + \mathbf{V}_{\bar{S}}$			4,255
$\mathbf{V}_P$			485
$\mathbf{V}_T = \mathbf{V}_U + \mathbf{V}_P$			4,740

Finally, we consider that every matter concept under consideration was classified satisfactorily supporting our analyses.

6 Translation of Picture Pattern Sequences into Natural Language

As an application of this taxonomy, system SUPP(System for Understanding Picture Patterns) was constructed.[10-12] The overall system is shown in Fig. 6.

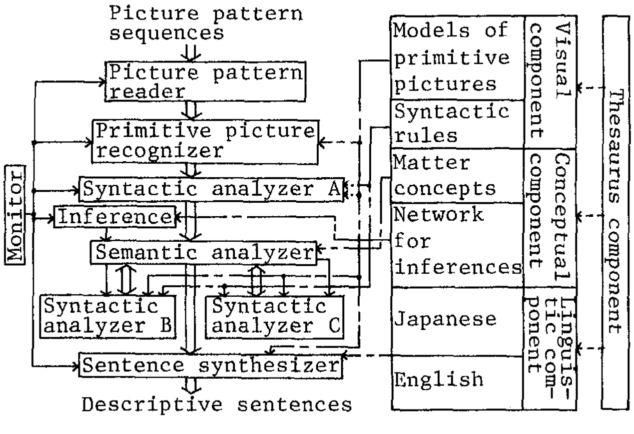


Fig. 6 Organization of the system

6.1 Knowledge System

The knowledge system consists of four components, visual, conceptual, linguistic and thesaurus. The visual component contains models of primitive pictures and syntactic rules, which correspond to level 2 data in Fig. 1. The rules are applied to picture pattern pairs called "before-after" frame pairs.[7]

The conceptual component contains conceptual features, concepts, and networks of concepts, which correspond to level 3 through 5 data, respectively. A matter concept is expressed by

$$[v : c_1c_2\cdots c_1d_1(E_1)d_2(E_2)\cdots d_m(E_m)] \qquad (B)$$

where each c_i denotes a feature of matter itself and is associated with a syntactic rule mentioned above. Each $d_j(\ )$ denotes the case or roll of a constituent and must be filled by a specific instance or concept of constituent. Features $E_j(=e_{j1}e_{j2}\cdots e_{jn})$ specify the conditions its assignment must meet. A network is constructed among similar matter concepts.

The linguistic component consists of dictionaries for the production of Japanese and English sentences. The thesaurus component contains all the classified concepts in Chapter 5 and supports the development of other components.

6.2 Translation Process

A sequence of picture patterns, or two-dimensional line drawings(handwriting is allowed), is input at time $t_0, t_1, \cdots, t_n$. A picture pattern at $t_i(0 \leq i \leq n-1)$ is paired with the one at t_{i+1}, and processed as follows:

1) Primitive picture recognition and syntactic analysis

The picture pattern reader is a curve follower that traces line segments by octagonal scanning. The recognizer is based on Evans's matching program for graph-like line drawings but is improved to handle noisy ones.[13]

The syntactic analyzer A decomposes the complex picture, in which two or more primitive pictures may intersect or touch each other, and recognizes them according to Gestalt criteria. The syntactic analyzer B performs Boolean operations on quantized primitive pictures to check such a relation as "MAN INSIDE HOUSE." The syntactic analyzer C performs numerical operations on the data such as coordinates and transformational coefficients of primitive pictures.

2) Semantic analysis and inference

The semantic analyzer detects the meaning of matter-centred change in picture pattern pairs by top-down analysis. Suppose that matter $[v(s, o_\alpha): c_1c_2\cdots c_1d_s(e_s)d_{o_\alpha}(e_{o_\alpha})]$ is directed by the Inference. The analyzer assigns the role of s to one of the primitive pictures, say P_s, after checking whether P_s meets e_s. It assigns the role of o_α to another primitive picture P_{o_α} in the same way. Then it analyzes each c_i by calling a correspondent sub-program in the syntactic analyzer B or C. If all the analyses end in success, the meaning of $v(s,o_\alpha)$ is detected. The present Inference makes inferences about all the similar concepts in the network in depth-first order, directing each matter concept at a node to the semantic analyzer.

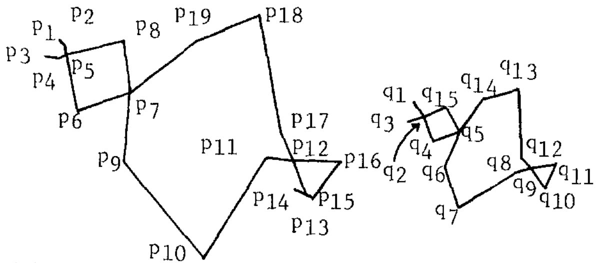
Finally, the synthesizer produces Japanese and English simple sentences.

6.3 Experiments

All the programs except the picture pattern reader are written in Fortran and run under the OSII/VS of the FACOM 230-38S medium scale computer at Oita University. Running with the syntactic analyzer B and C, the semantic analyzer occupies approximately 200K bytes of core. Memory usage for all the dictionaries except the thesaurus component amounts to approximately 90K bytes.

Fig. 7 and 8 indicate an example of the recognition of a primitive picture and the translation of a picture pattern pair, respectively. It took 47 seconds to recognize "bird[1]" in Fig. 7 and 60 seconds to analyze and infer the meanings of matter after the recognition of primitive pictures in Fig. 8.

Katz and Fodor pointed out the three problems of a semantic theory: (i) Semantic ambiguity, (ii) Semantic anomaly, and (iii) Paraphrase.



(a) Preprocessed primitive picture

(b) The model of "bird[1]"

1. Pattern matching

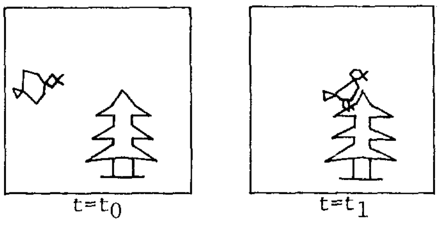
$[p_7 : q_5], [p_9:q_{14}], [p_{19}:q_6], [p_8:q_4], [p_6:q_{15}], [p_{10}:q_{13}], [p_{18}:q_7], [p_5:q_2], [p_{11}:q_{12}], [p_{17}:q_8], [p_{12}:q_9]$

$[p_{16}:q_{10}], [p_{12}:q_9], [p_{15}:q_{11}]$

2. Transformation and similarity

Translation: (524.4, 483.7), scaling: 2.173 times, rotation: 2.290 radian, reflection: in Y-axis. Similarity: 0.718(≤1)

Fig. 7 Recognition of "bird[1]"



(a) Input picture pattern pair

1) *TORI[1] GA UTSURU.*
THE BIRD[1] SHIFTS.

2) *TORI[1] GA SUSUMU.*
THE BIRD[1] MOVES ON.

3) *TORI[1] GA TOBU.*
THE BIRD[1] FLIES.

4) *TORI[1] GA KI NI FURERU.*
THE BIRD[1] TOUCHES THE TREE.

5) *TORI[1] GA KI NI TSUKU.*
THE BIRD[1] STCKS TO THE TREE.

6) *TORI[1] GA KI NI NORU* [2].
THE BIRD[1] GETS[2] ON THE TREE.

7) *TORI[1] GA KI NI NOSHIKAKARU.*
THE BIRD[1] LEANS OVER THE TREE.

(b) Output sentences

Fig. 8 Translation of a picture pattern pair

As for (i) it is important to enumerate all the readings of the input picture pattern pair. The output sentences in Fig. 8 shows SUPP understands to a fair degree the change in the input. As for (ii) the ability in detecting semantic anomaly is important. SUPP checks it by E_j in (B) in Sect. 6.1, but a little bit anomalous sentence 5) or 7) is output because the constructed dictionary of matter concepts is slightly insufficient. As for (iii) the ability in paraphrasing sentences is needed. Output sentences 4) through 7) are an analytical paraphrase of "THE BIRD[1] PERCHES ON THE TREE" although SUPP has no knowledge about "perch."

7 Conclusions

A taxonomy of Japanese matter concepts has been described. It is summarized as follows:

- Simple matter concept
  - Standard concept
    - structural pattern ; 12 types
    - semantic contents ; 20 features
  - Similar concept
- Non-simple matter concept
  - Complex concept *A*
    - connecting rule ; 3 types
    - semantic contents ; each contents of elements and their connecting relation
  - Complex concept *B*
    - connecting rule ; different in each concept
    - surface contents ; 14 features
  - Derivative concept ;
    - derivative operator ; 3 types
    - derivative information ; 9 features

This taxonomy has made clear the outline of the system of all matter concepts in daily Japanese, and by SUPP picture pattern understanding research has come closer to natural language understanding research.

Acknowledgement

The author started his investigation of Japanese matter concepts and the development of SUPP some ten years ago when he was at Kyushu University. The author wishes to express gratitude to Prof. T.Tamati of Kyushu University for his kind guidance and material support.

References

[1] Okada, N. and Tamati, T.: Semantic Information of Natural Language and its Extraction and Classification, Trans. IECE, Japan, 52-C, 10, p. 363(Oct. 1969).

[2] Okada, N. and Tamati, T.: An Analysis and Classification of "Simple Matter Concepts" for Natural Language and Picture Interpretation, Trans. IECE, Japan, 56-D,9,p.523-530(Sept. 1973).

[3] Okada, N. and Tamati, T. : An Analysis and Classification of "Non-Simple Matter Concepts" for Natural Language and Picture Interpretation, Trans. IECE, Japan, 56-D,10,p.591-598(Oct. 1973).

[4] National Language Research Institute(ed.): "Word List by Semantic Principles," Syuei Syuppan, Tokyo, 1964.

[5] Roget, P.(Browning, D.C.(ed.)):"Thesaurus of English Words and Phrases," J.M. Dent and Sons Ltd, London, 1971.

[6] Chomsky, N.: "Aspects of the Theory of Syntax," The M.I.T. Press, Cambridge, Mass., 1965.

[7] Minsky, M.: A Framework for Representing Knowledge, in Winston, P.H.(ed.),"The Psychology of Computer Vision," McGraw-HillBook Co., New York, 1975.

[8] Schank,R.C. and Abelson, R.P.: Scripts, Plans, and Knowledge, *Proc. 4IJCAI*, Tiblisi, Georgia, 1975.

[9] Schank,R.C. and Rieger, C.T.: MARGIE: Memory, Analysis, Response Generation, and Inference on English, *Proc. 3IJCAI*, Stanford, 1973.

[10] Okada, N. and Tamati, T.: Interpretation of the Meaning of Picture Patterns and its Description in Natural Language—Primitive Picture Recognition and Syntactic Analysis, Trans. IECE, Japan, J59-D, 5, p.323-330(May 1976).

[11) Okada, N. and Tamati, T.: Interpretation of the Meaning of Moving Picture Patterns and its Description in Natural Language—Semantic Analysis, Trans. IECE, Japan, J59-D, 5, p.331-338(May 1976).

[12] Okada, N.: SUPP: Understanding Moving Picture Patterns Based on Linguistic Knowledge, *Proc. 6IJCAI*, Tokyo, 1979.

[13] Evans, T.G.: A Program for the Solution of Geometric Analogy Intelligence-Test Questions, in Minsky, M.(ed.): "Semantic Information Processing," The M.I.T. Press, Cambridge, Mass., 1968.

[14] Katz, J.J. and Fodor, J.A.: The Structure of a Semantic Theory, *Language*, 39, 2, p.170-210(1963).