sentence sequence.[2] Finally, we can obtain all necessary grammatical resources (a), (b), and (c), and CCG-based deep parsing is established.

This methodology relies on a source treebank that will be converted into CCG derivations. The most common resource for parsing research in English is the Penn Treebank [Marcus et al. 1993], which is used as well for the development of the English CCGbank [Hockenmaier and Steedman 2007]. A critical issue to address is the absence of a Japanese counterpart to PTB. We only have chunk-based dependency corpora, and their relationship to CCG analysis is not clear (see Figure 10).

Our solution is to first integrate multiple dependency-based resources and convert them into a phrase structure treebank that is independent of CCG analysis (Step 1). Next, we translate the treebank into CCG derivations (Step 2). The idea of Step 2 is similar to what has been done with the English CCGbank, but obviously we have to address language-specific issues. We will describe these two steps in detail in the following.

3.1. From Dependencies to Phrase Structure Trees

We first integrate and convert available Japanese corpora—namely, the Kyoto corpus, NAIST text corpus, and JP corpus—into a phrase structure treebank, which is similar in spirit to PTB. As explained in Section 2, the Kyoto corpus provides morphological information and chunk-based syntactic dependencies, while the NAIST and JP corpora provide annotations of syntactic/semantic roles on top of the Kyoto corpus dependencies. Our approach is to convert the dependency structures of the Kyoto corpus into phrase structures then augment them with syntactic/semantic roles from the other two corpora.

The conversion involves two steps: 1) recognizing the chunk-internal structures and (2) converting interchunk dependencies into phrase structures. For (1), we do not have any explicit information in the Kyoto corpus. The corpus only provides word segmentations and their attributes, although each chunk has internal structures in principle [Vadas and Curran 2007; Yamada et al. 2010]. The lack of a chunk-internal structure makes the dependency-to-constituency conversion more complex than a similar procedure by Bos et al. [2009], which converts an Italian dependency treebank into constituency trees, since their dependency trees are annotated down to the level of each word. For the current implementation, we abandon the idea of identifying exact structures and instead basically rely on the following generic rules (Figure 11).

Nominal chunks. Form each compound noun as a right-branching phrase then attach post-positions to the phrase.

Verbal chunks. Form left-branching structures for verbal chunks.

These rules amount to assuming that all but the last word in a compound noun modify the head noun (the last word) and that a verbal chunk is typically in the form $V\,A_1 \ldots A_n$, where V is a verb (or other predicative word) and A_is are auxiliaries (see Figure 11). We chose the left-branching structure as default for a verbal chunk in order to form a similar structure to the CCG derivations in Bekki's analysis. For both cases, phrase symbols are percolated upward from the right-most daughters of the branches

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[2] This rule was designed for treatment of sentence sequences that frequently appear in direct quotes in Japanese. For example, a direct quote in a sentence “彼は「変更については聞いていない。これから確認する」と言った。” (He said “I haven’t heard about the change. I will confirm it.”) consists of two sentences.

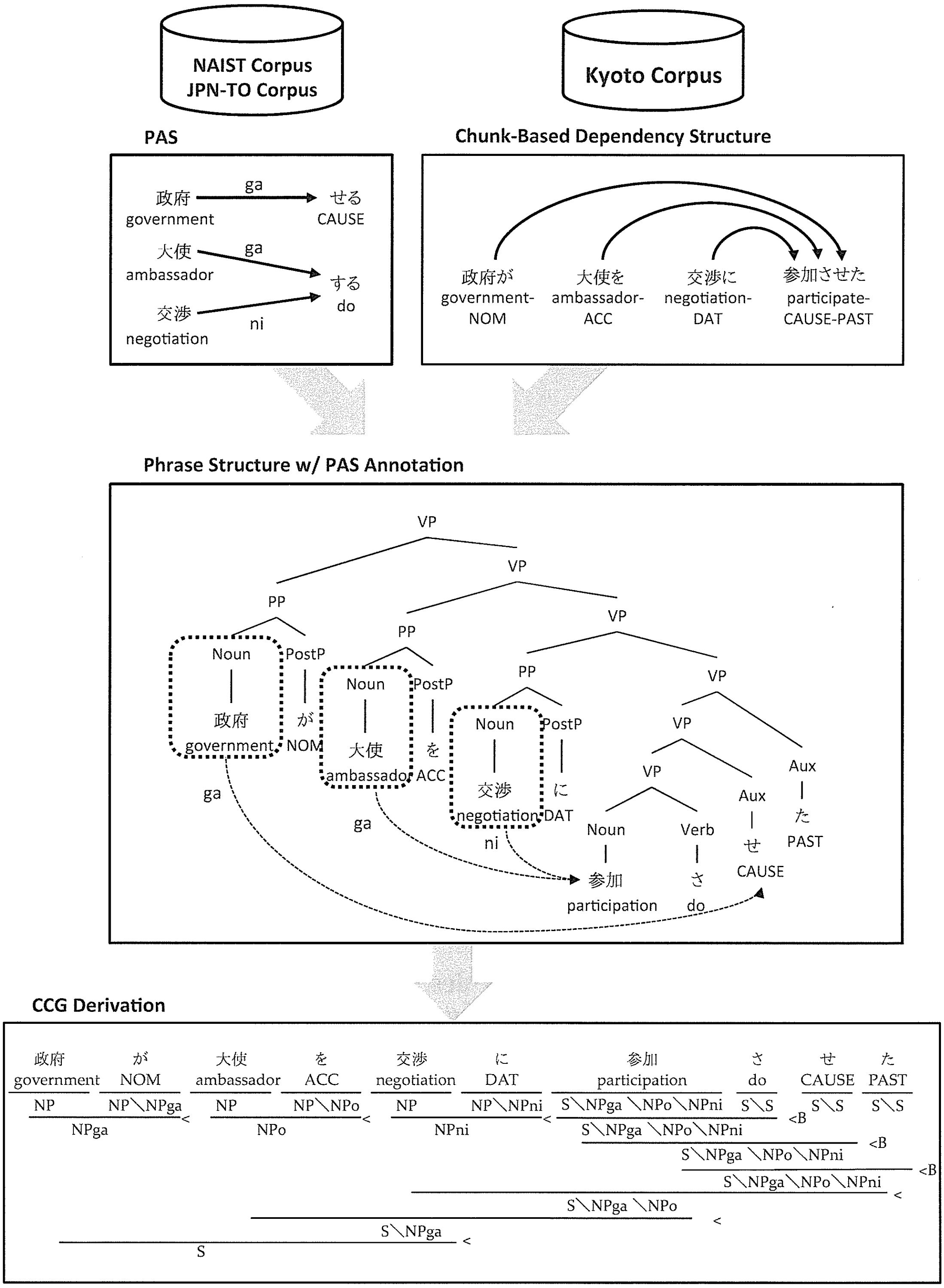


Fig. 10. Conversion from dependency relations to a CCG derivation.

(except for a few cases like punctuation) because in almost all cases the syntactic head of a Japanese phrase is the right-most element.

In practice, we have found several patterns of exceptions to these rules. We implemented exceptional patterns as small CFGs and determined the chunk-internal

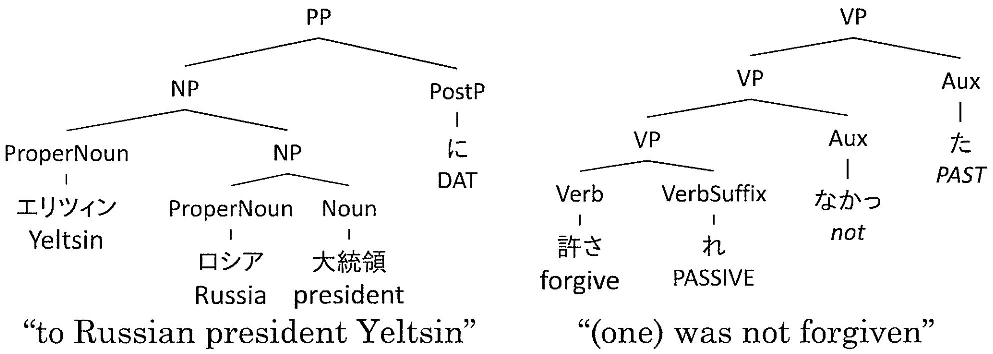


Fig. 11. Internal structures of a nominal chunk (left) and a verbal chunk (right).

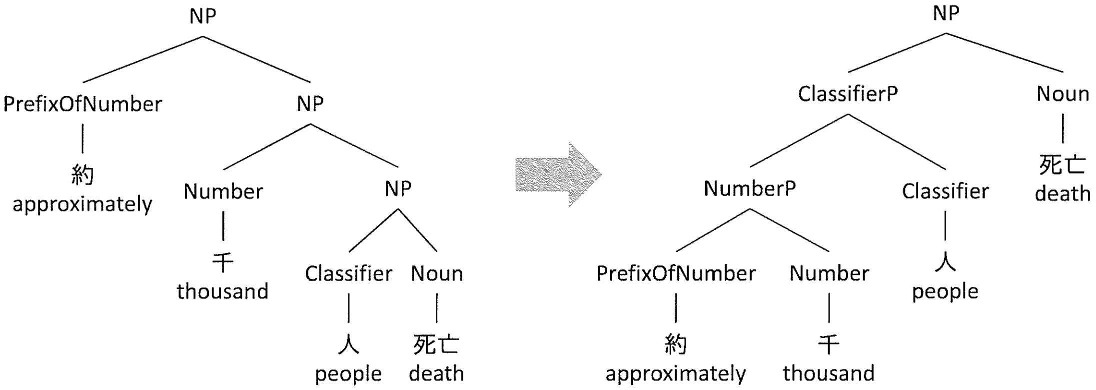


Fig. 12. Improvement of a phrase structure for "deaths of approximately one thousand people" by additional pattern rules.

structures by deterministic parsing with the generic rules and the CFG. For example, two of the rules we came up with are

rule A: Number → PrefixOfNumber Number and
rule B: ClassifierPhrase → Number Classifier

in the precedence: rule A > B > generic rules. Using these rules, we bracket a compound noun "約千人死亡" meaning *deaths of approximately one thousand people*, as in Figure 12. We can improve chunk-internal structures to some extent by refining the CFG rules. However, accurate identification of the chunk-internal structure inherently involves the understanding of meanings, and a complete solution, such as the manual annotation by Vadas and Curran [2007], is left for future work.

The conversion of interchunk dependencies into phrase structures may sound trivial, but it is not necessarily easy when the dependency annotation only partially specifies the word-to-word dependency relations. In actuality, the Kyoto Corpus specifies only the dependency structures among *chunks*. Hence, we cannot know only from the annotation, which word in the head chunk the modifier chunk depends on. This in turn means that we cannot fully determine the phrase structure of the sentences only by the annotation in the Kyoto Corpus.

Setting this uncertainty aside, thanks to the strictly head-final nature of Japanese, we can formulate the process of combining two subtrees (one for a modifier chunk and the other for a head chunk) as follows. First, given two subtrees as shown in Figure 13, we select a node from $Y_0, Y_1, \ldots, Y_n$ in the head subtree, which are the nodes on the leftmost path from the root and hence visible from the modifier tree. Let Y_k be the selected node, which means the modifier tree syntactically depends on the

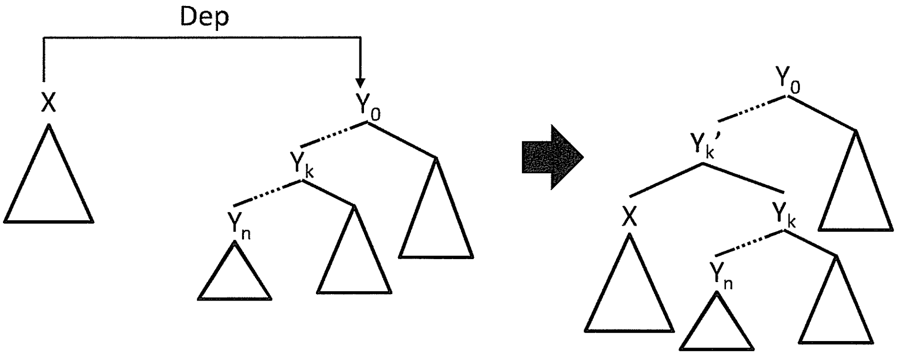


Fig. 13. Combining a modifier subtree and a head subtree.

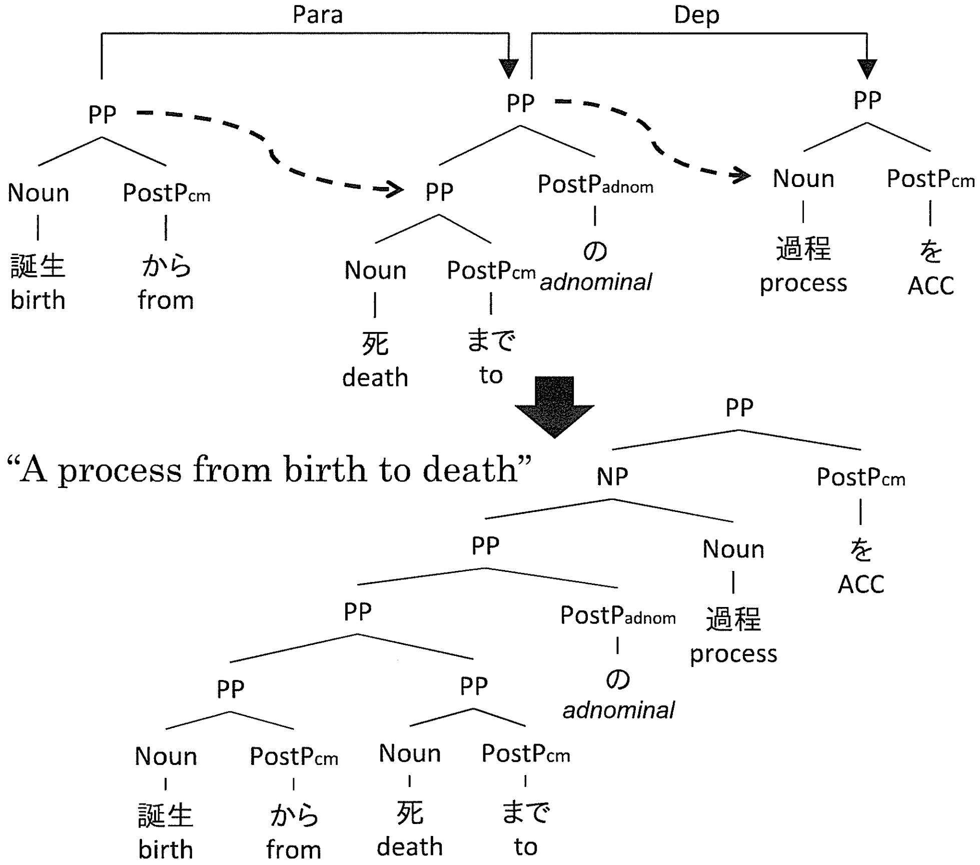


Fig. 14. From interchunk dependencies to a tree.

lexical head of the subtree rooted at Y_k. We insert a new node Y'_k above Y_k and combine the modifier subtree and Y_k. The phrase symbol of the new node Y'_k can be determined by percolating the phrase symbol of its head daughter, Y_k.

Figure 14 shows a concrete example. In Figure 14, three chunks are in the dependency relation indicated by the solid arrows on the top. The dotted arrows point to the nodes to which the subtrees should be attached. By recursively applying the combining operation in Figure 13, we have the phrase structure shown at the bottom of Figure 14.

The remaining problem is how to choose the sister node for a modifier subtree (how to select Y_k in Figure 13). Without any additional annotations, we cannot always correctly determine it. Therefore, as a compromise, we implement approximate heuristic rules to do this. Table III lists examples of such rules. Each row defines a precedence list

Table III. Example of Rules to Determine a Node to Combine with a Subtree

Dep-type	Modifier-type	Head-type
Para	(から, PostP_{cm})	(まで, PostP_{cm}) > (*, Verb|Aux|Adj) > (*, Noun) > (*, *)
Dep	(*, PostP_{cm})	(*, Verb|Aux|Adj) > (*, Noun) > (*, *)
Dep	(*, $\text{PostP}_{\text{adnom}}$)	(*, Noun) > (*, Verb|Aux|Adj) > (*, *)

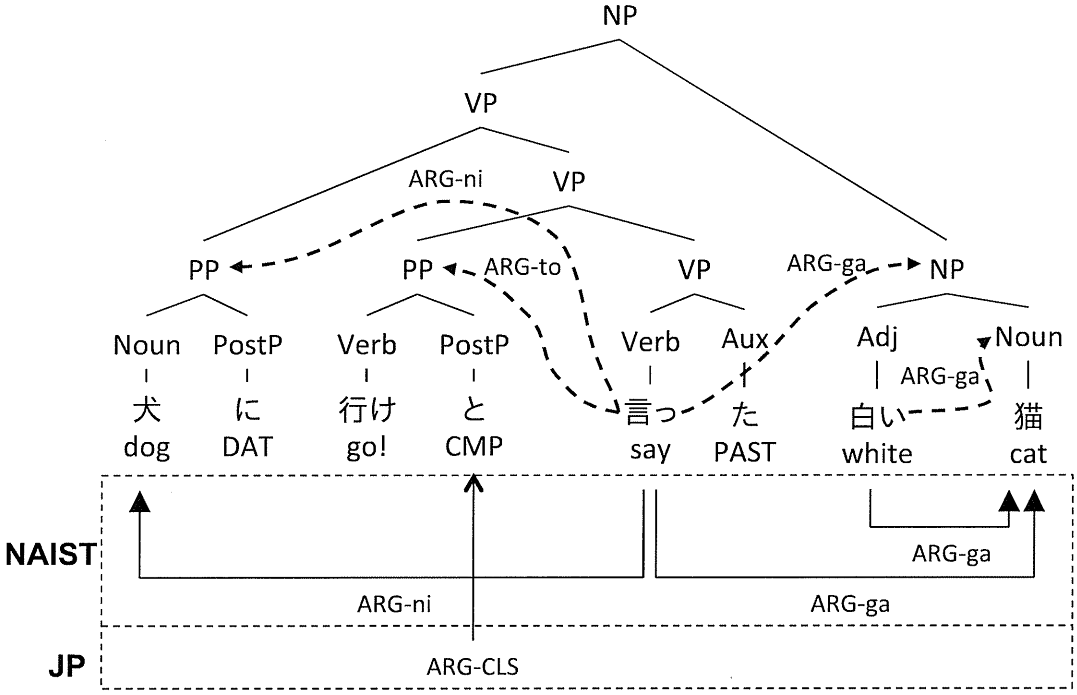


Fig. 15. Overlay of predicate-argument structure annotation ("The white cat who said "Go!" to the dog.").

of patterns on the sister node for a certain type of modifier tree (Modifier-type) and for each dependency relation type (Dep-type). We have four dependency relation types that are used in the Kyoto Corpus: apposition (A), argument cluster (I), coordination (Para), and any other dependency types (Dep). Since the syntactic property of a subtree is largely determined by its lexical head, we classify the modifier subtrees and their sisters using a pair of patterns (w, t), where w is a pattern on the word form of the lexical head and t is a pattern on its POS tag.

To select the sister node for the leftmost subtree in Figure 14, for example, we look up the rule table using the dependency type, Para, and the lexical head of the modifier subtree, "から/PostP_{cm}", as the key. We thus find the precedence list (まで, PostP_{cm}) > (*, Verb|Aux|Adj) > (*, *) in the first row of Table III. Using the precedence list, we select the PP-node on the middle subtree pointed by the dotted arrow because its lexical head (the right-most word) "まで/PostP_{cm}" matches the first pattern in the list. In general, we try to find a matching node for each pattern (w, t) in the precedence list in descending order until we find the first match. When a pattern matches more than one node, we select the one at the highest position.

After constructing phrase structures, we augment the trees with predicate-argument annotations from the NAIST and JP corpora. The semantic annotation given in the two corpora is overlaid on the phrase structure trees with slight modifications (Figure 15). In the figure, the annotation given in the two corpora is shown inside the dotted box at the bottom. We converted the predicate-argument annotations given as labeled word-to-word dependencies into the relations between the predicate words and their argument *phrases*. The results are thus similar to the annotation style of

PropBank [Palmer et al. 2005] (see dotted arrows in Figure 15). In the NAIST corpus, each predicate-argument relation is labeled with the argument-type (ga/o/ni) and a flag indicating that the relation is mediated by either a syntactic dependency or a zero anaphora. For a relation of a predicate w_p and its argument w_a in the NAIST corpus, the boundary of the argument phrase is determined as follows.

(1) If w_a precedes w_p and the relation is mediated by a syntactic dependency, select the maximum PP that is formed by attaching one or more postpositions to the NP headed by w_a.
(2) If w_p precedes w_a or the relation is mediated by a zero anaphora, select the maximum NP headed by w_a that does not include w_p.

In Figure 15, "犬/dog に/DAT" is marked as the ni-argument of the predicate "言っ/say" (Case 1), and "白い/white 猫/cat" is marked as its ga-argument (Case 2). Case 1 is for the most basic construction, where an argument PP precedes its predicate. Case 2 covers the relative clause construction, where a relative clause precedes the head NP, the modification of a noun by an adjective, and the relations mediated by zero anaphora.

The JP corpus provides only the function label to each particle "to" in the text as the label ARG-CLS in Figure 15. For the "to" particles labeled as ARG-NOM (a marker on a nominal argument) or ARG-CLS (a marker on a clausal argument) in the corpus, we determined the argument phrases marked by the "to" particles labeled as (nominal or clausal) argument-markers in a similar manner to Case 1 and identified the predicate words as the lexical heads of the phrases to which the PP_{to} phrases attach.

3.2. From Phrase Structures to CCG Derivations

The latter half of the corpus conversion translates augmented phrase structures to CCG derivations. This step consists of three substeps (Figure 16).

(1) Add constraints on categories of tree nodes according to detected constructions and assign a combinatory rule to each branching.
(2) Apply combinatory rules to all branching and obtain CCG derivations.
(3) Add feature constraints to terminal nodes.

3.2.1. Local Constraints on Derivations. According to the phrase structures, the first procedure in Step 2 imposes restrictions on the resulting CCG derivations. To describe the restrictions, we focus on some of the notable constructions and illustrate the restrictions for each.

Phrases headed by case marker particles. A phrase of this type must be either an argument (Figure 17, upper) or a modifier (Figure 17, lower) of a predicative. Distinction between the two is made based on the predicate-argument annotation of the predicative. If a phrase is found to be an argument, (1) category NP is assigned to the corresponding node, (2) the case feature of the category is given according to the particle (in the case of the upper part of Figure 17, *ni* for dative), and (3) the combinatory rule *backward function application rule* (<) is assigned to the branch that combines the particle and the predicative phrase. Otherwise, a category T/T is assigned to the corresponding modifier node and the rule will be *forward function application* (>).

Auxiliary verbs. As described in Section 2.2, an auxiliary verb is always given the category $S\backslash S$ and is combined with a verbal phrase via < or <B (Figure 18). Furthermore, we assign the *form* feature value of the returning category S according to the inflection form of the auxiliary. In the case shown in the figure, $S_{base}\backslash S$ is assigned for "た/PAST-BASE" and $S_{cont}\backslash S$ for "なかっ/not-CONT". As a result of this restriction, we

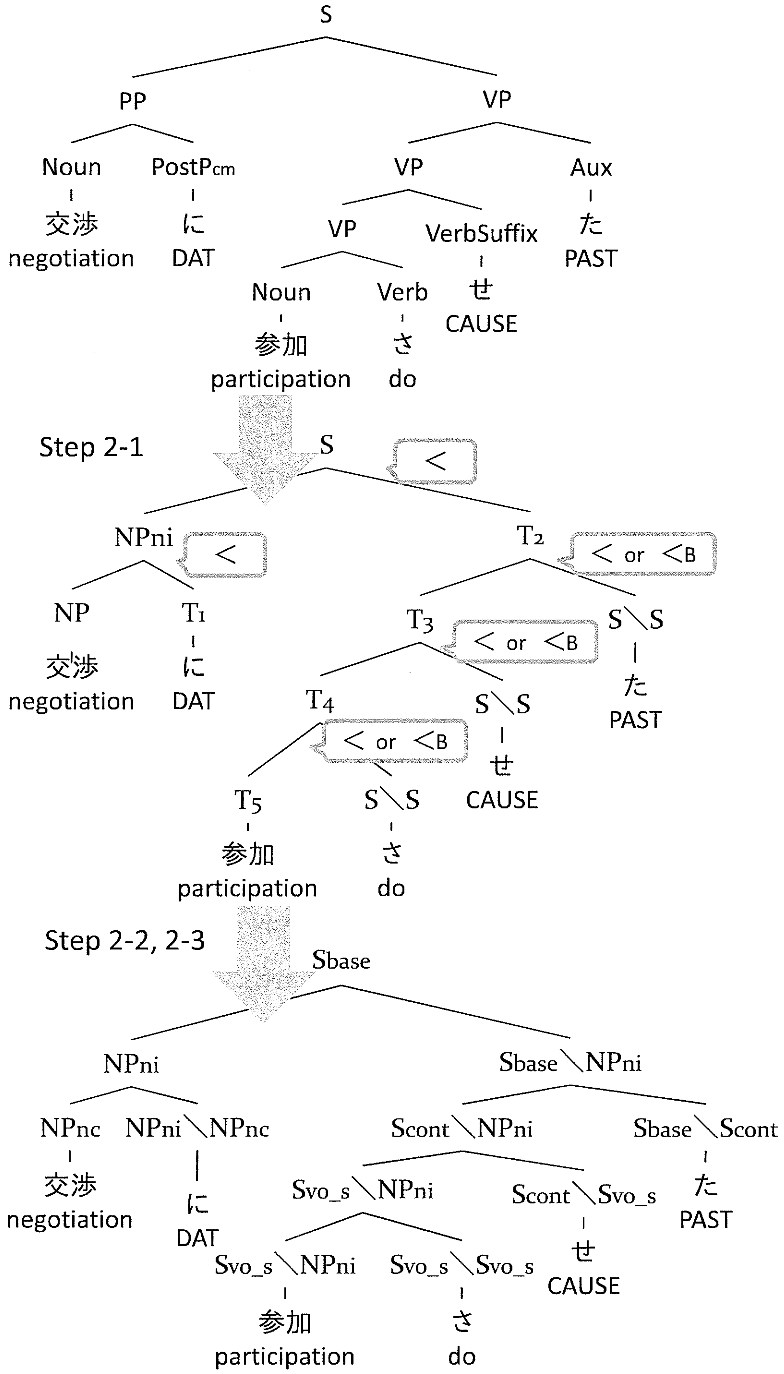
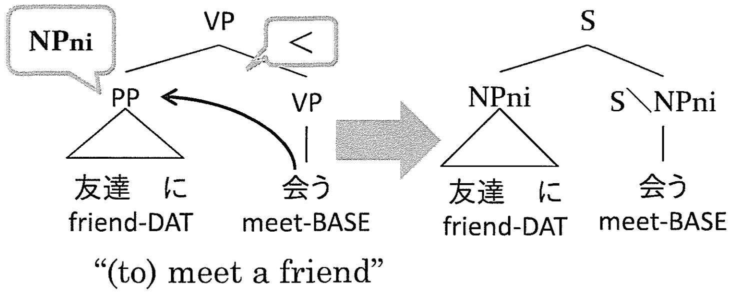


Fig. 16. From a phrase structure to a CCG derivation.

can obtain conditions for every auxiliary agglutination because the two *form* values in $S\backslash S$ are both restricted after applying the combinatory rules (Section 3.2.2).

Case alternations. In addition to the illustrated argument/adjunct distinction a process is needed for an argument phrase if the predicate involves case alternation. Such predicates are either causative (see Figure 19) or passive verbs and can be detected by voice annotation from the NAIST corpus. For an argument of that type of verb, its *deep* case (*ga* for Figure 19) must be used to construct the semantic representation, namely the PAS. As well as assigning the shallow case value (*ni* in Figure 19) to the



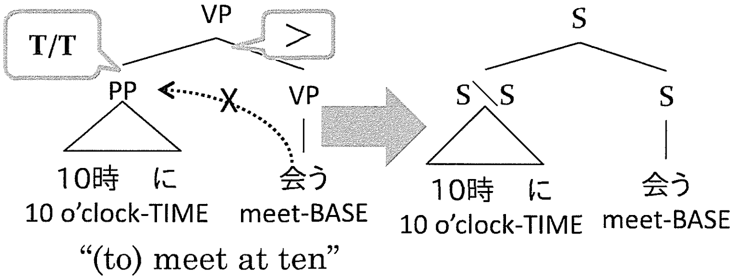


Fig. 17. An argument post particle phrase (PP) (upper) and an adjunct PP (lower).

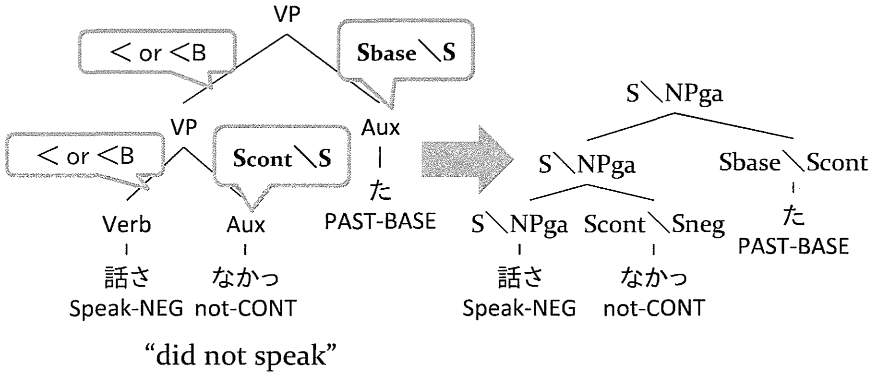


Fig. 18. An auxiliary verb and its conversion.

argument's category NP, as usual, we assign a restriction to the PAS of the verb so that the semantic argument corresponding to the deep syntactic case is co-indexed with the argument NP. These restrictions are then used for the PAS construction discussed in Section 3.2.3.

Relative clauses. A relative clause can be detected as a subtree that has a VP as its left child and an NP as its right child, as shown in Figure 20. Its conversion consists of, (1) inserting a node on the top of the left VP (see the right-hand side of Figure 20) and (2) assigning the appropriate unary rule to make the new node. The difference between candidate rules RelExt and RelIn (Figure 5) is whether the right-hand NP is an obligatory argument of the VP, which can be determined by the predicate-argument annotation on the predicate in the VP. In the upper example in Figure 20, RelIn is assigned because the right NP "book" is annotated as an accusative argument of the predicate "buy" in the left tree. In contrast, RelExt is assigned in the lower side in the figure (note that restriction for the nodes is different from the upper example) because the right NP "store" is not annotated as an argument for the predicate "buy".

Continuous clauses. Conversion for a continuous clause is similar to that for a relative clause. A continuous clause can be detected as a subtree with a VP of continuous

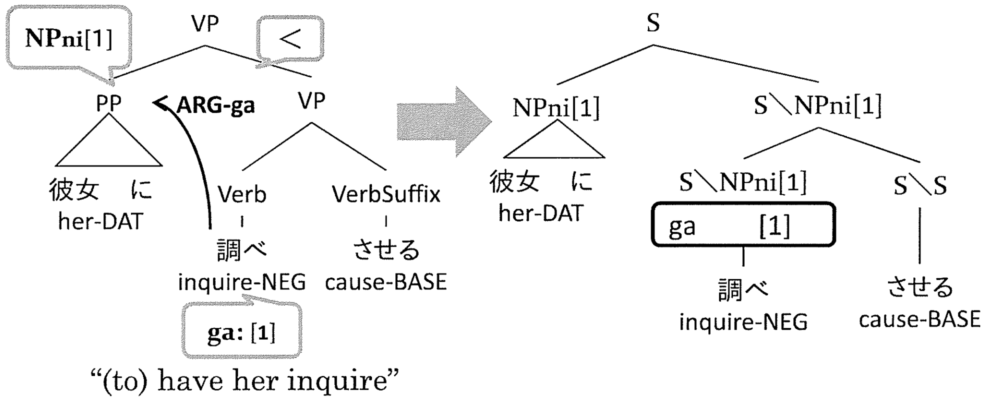


Fig. 19. A causative construction. Restriction for a PAS is represented in the rounded box.

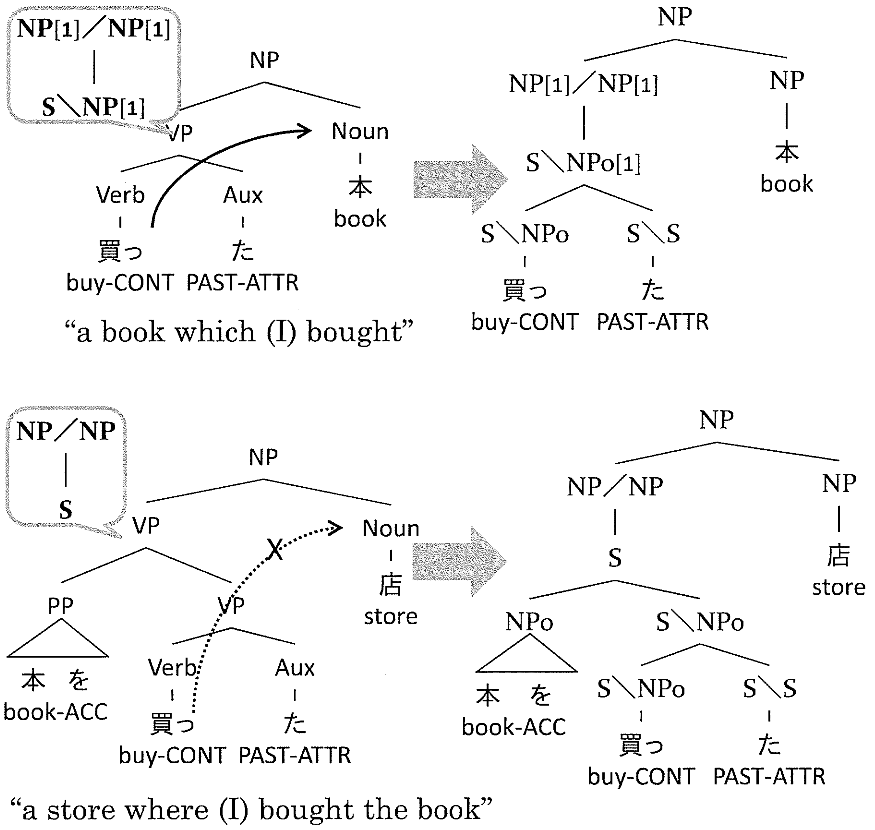


Fig. 20. A relative clause with/without argument extraction (upper/lower, respectively).

form as its left child and a VP as its right child. Its conversion is similar to that of a relative clause, and only differs in that the candidate rules are Con and ConCoord. ConCoord generates a continuous clause that shares arguments with the main clause while Con produces one without shared arguments. Rule assignment is done by comparing the predicate-argument annotations of the two phrases (an example of a shared argument as shown in Figure 21). Since a nominative "彼は / he-NOM" is shared by the predicates of the main clause "歌った / sang-BASE" and that for the continuous clause "踊って / danced-CONT", unary rule ConCoord is assigned.

3.2.2. Inverse Application of Combinatory Rules. After assigning local constraints on the trees, combinatory rules are inversely applied. This begins with assigning a category

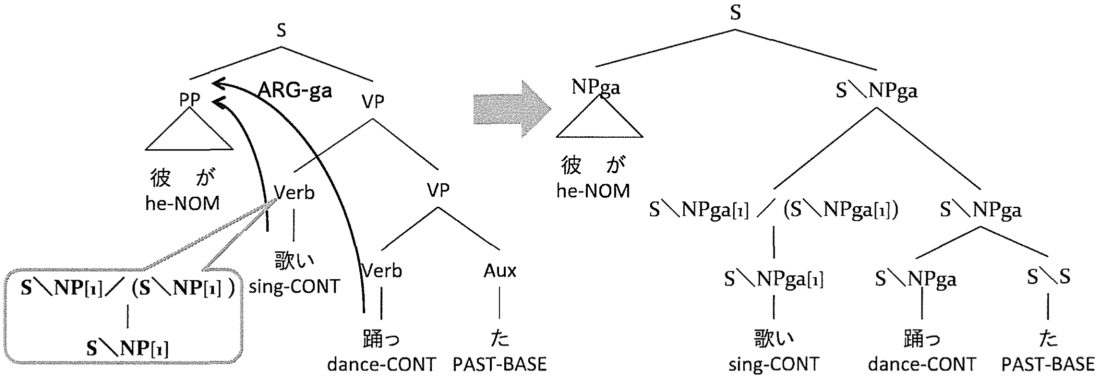


Fig. 21. A continuous clause with a shared argument.

S to the root node. A combinatory rule assigned to each branching is then applied inversely so that the constraint assigned to the parent transfers to the children. In the upper part of Figure 17, given constraints on the tree "(I) meet a friend" are the category NP_{ni} for the left child and the backward application rule, as illustrated on the left-hand side. After S is given to the root and the combinatory rule is applied, the category for the right child is determined as $\mathrm{S}\backslash\mathrm{NP}_{ni}$. If multiple combinatory rules are assigned in Procedure 3.2.1, the applicable rule with the highest priority is chosen.[3] For the subtree in Figure 18, if the category $S\backslash NP_{ga}$ is given to the top node, the only applicable rule is the *crossed composition rule*, while the assignment mentioned in Section 3.2.1 also allows *backward function application*. By applying the rule, we obtain $S_1\backslash NP_{ga}$ and $S_{base}\backslash S_1$ as the children's categories. The same process can be applied to the left subtree. We then obtain three concrete categories for the terminal, *e.g.*, $S_{neg}\backslash NP_{ga}$, $S_{cont}\backslash S_{neg}$, and $S_{base}\backslash S_{cont}$ for "speak-NEG", "not-CONT", and "past-BASE", respectively.

3.2.3. Constraints on Terminal Nodes. The final process consists of, (a) imposing restrictions on the terminal category in order to instantiate all the feature values and (b) constructing a PAS for each verbal terminal. An example of process (a) includes setting the *form* features in the verb category, such as $\mathrm{S}\backslash\mathrm{NP}_{ni}$ and $\mathrm{S}\backslash\mathrm{NP}_{ni}\backslash\mathrm{NP}_{ga}$, according to the voice and inflection form of the verb. For example, if a category $S\backslash\mathrm{NP}_{ni}$ is obtained for a verb "会う/meet-BASE", the value *base* is set as S's form feature based on the inflection form of the verb. For (b), arguments in a PAS are given according to the category and partial restriction. For example, if a category $\mathrm{S}\backslash\mathrm{NP}_{ni}$ is obtained for "調べ/inquire" (Figure 19), the PAS for "inquire" is unary because the category has one argument category (NP_{ni}), and the category is coindexed with the semantic argument *ga* in the PAS, due to the partial restriction depicted in Section 3.2.1. However, the case for the argument is nominative *ga*, according to the deep case annotation. As a result, the lexical entry is obtained as 調べ $\vdash \vdash \mathrm{S}\backslash\mathrm{NP}_{ni}[1]$: inquire([1]).

3.3. Lexical Entries

Finally, each of the obtained lexical entries is reduced to canonical form. Since words in the corpus (especially verbs) often involve inflection, pro-drop, and scrambling, there are many obtained entries that have slightly varied categories yet share a PAS. We assume that an obtained entry is a variation of the canonical one and register the canonical entries in the lexicon. After collecting canonical entries available from the

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[3] The priority is defined in advance. For example, <B has priority over <.

Table IV. Statistics of Input Linguistic Resources

	Training	Develop.	Test
Sentences	24,283	4,833	9,284
Chunks	234,685	47,571	89,874
Words	664,898	136,585	255,624

Table V. Statistics of Corpus Conversion

	Training		Development		Test	
	Step 1	Step 2	Step 1	Step 2	Step 1	Step 2
Sentences	24,283	24,116	4,833	4,803	9,284	9,245
Converted	24,116	22,852	4,803	4,560	9,245	8,769
Conversion rate	99.3	94.8	99.4	94.9	99.6	94.9

corpora, new lexical entries for inflection, pro-drop, and scrambling are systematically produced from the canonical ones and are added to the lexicon.

Inflection basically changes the value of the *form* feature of the obtained category. For instance, if a category $\mathrm{S}_{cont}\backslash\mathrm{NP}_{ga}$ is extracted from “歩き / walk-CONT”, continuative form of verb “歩く”, it is regarded as derived from the non-inflected category $\mathrm{S}_{stem}\backslash\mathrm{NP}_{ga}$.

For pro-drop, we now treat only subject deletion because there is not sufficient information to judge the deletion of other arguments. As described in Section 2.2, almost any argument phrase can be dropped in Japanese. To make the issue more complicated, a verb with multiple senses is supposed to have a different set of semantic arguments for each sense. Therefore, if a category $\mathrm{S}\backslash\mathrm{NP}_{o}$ is obtained from a verb occurrence in the corpus, whether the original category is $\mathrm{S}\backslash\mathrm{NP}_{ga}\backslash\mathrm{NP}_{o}$ (subject deletion) or $\mathrm{S}\backslash\mathrm{NP}_{ga}\backslash\mathrm{NP}_{o}\backslash\mathrm{NP}_{ni}$ (subject and dative deletion) cannot be decided without sense disambiguation and the argument set for the sense. As there is no such annotation available for the text used for now; only the subject drop can be treated.

Scrambling is simply treated as permutation of arguments in the current implementation. Therefore, a canonical form of a verb category is assumed to have canonically ordered arguments.

As a result of the preceding lexical treatment, category $\mathrm{S}_{cont}\backslash\mathrm{NP}_{ni}$ is reduced to $\mathrm{S}_{stem}\backslash\mathrm{NP}_{ga}\backslash\mathrm{NP}_{ni}$, and the reduced form is registered in the lexicon.

4. EVALUATION

We used the following for the implementation of our resources: Kyoto corpus version 4.0,[4] NAIST text corpus version 1.5,[5] and JP corpus version 1.0.[6] The integrated corpus is divided into training, development, and final test sets following the standard data split in previous work on Japanese dependency parsing [Kudo and Matsumoto 2002]. The details of these resources are listed in Table IV.

4.1. Corpus Conversion and Lexicon Extraction

Table V shows the number of successful conversions done with our method.[7] In total, we obtained 22,852 CCG derivations from 24,283 sentences (in the training set), resulting in a total conversion rate of 94.1%. The table shows we lost more sentences in Step 2 than in Step 1. This is natural because Step 2 imposes more restrictions on

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[4] http://nlp.ist.i.kyoto-u.ac.jp/EN/index.php?Kyoto\%20University\%20Text\%20Corpus

[5] http://cl.naist.jp/nldata/corpus/

[6] https://alaginrc.nict.go.jp/resources/tocorpus/tocorpusabstract.html

[7] The figures are slightly improved over those previously reported [Uematsu et al. 2013].

Table VI. Frequent Causes for Sentence Loss in Step 2 (Counted in Randomly Sampled 100 Sentences)

Freq.	Description
39	Improper handling of irregular structures corresponding to functional expressions
17	Incorrect conversion in Step 1
11	POS tag errors
7	Relative clauses not covered by RelExt, RelIn
4	Mistaken decision between verbal nouns acting as nouns and ones acting as verbs

resulting structures and therefore detected more discrepancies including compounding errors. Our conversion rate is about 5.5 points lower than the English counterpart [Hockenmaier and Steedman 2007], which suggests that there is room for improvement in the current conversion.

Among the failures in Step 1, a very small number of sentences (0.04% in the training set) failed to be converted because of the non-projective dependencies in them. Except for those cases, most of the failures in Step 1 were due to errors in the input corpora such as data format bugs, inconsistent annotations, and annotation errors in various levels (word segmentation, POS tagging, chunk segmentation, and dependency annotation).

In Step 2, 94% of sentence loss occurred in the phase described in Section 3.2.2 due to the contradiction between the local restrictions assigned in Section 3.2.1. We randomly sampled 100 sentences from those 1185 sentences and manually investigated the cause of the contradictions. Table VI shows the most frequent causes. Thirty-nine of the 100 sentences were lost due to inappropriate treatment of certain functional expressions and 17 were triggered by conversion mistakes in Step 1, such as errors in recognizing coordinated phrases. A function expression is a multiword expression working as one function unit and often accompanies an irregular phrase structure. Examples include "(((VP-base こと/expletive noun) なし/adjective) に/PostP) /without doing (something)" and "((VP$_1$-base よう/expletive noun) VP$_2$) /VP$_2$ so that (one can) VP$_1$." Handling function expressions is difficult partly because many of the expressions occur within one chunk and are not marked in the original annotations. Fortunately, three types of function expressions, including the examples above, consist of mostly errors concerning function expressions. Therefore we can expect improvement of the conversion quality by adding rules for the major function expressions (as least when converting the Kyoto corpus.)

For the lexicon extraction from the CCGbank, we obtained 699 types of lexical categories from 616,305 word tokens. After lexical reduction, the number of categories decreased to 454, which in turn produced 5342 categories by lexical expansion including scrambling. The average number of categories for a word type was 11.68 as a result.

4.2. Evaluation of Obtained Derivations

To estimate the quality of the obtained derivations, 50 derivations were randomly sampled from the Japanese CCGbank and manually investigated. We assumed a gold-standard derivation for each of the sampled sentences, compared it to the obtained derivation, and investigated the causes of the differences if any. When comparing derivations, we focused on their unlabeled structures and the lexical categories. Structure comparison as unlabeled trees was included because the goal of our conversion (especially in Step 1) was to build phrase structures usable for grammar development in other formalisms. Table VII summarizes the results. Forty of the 50 obtained derivations had the same structure as the gold standards, but thirteen of the forty derivations included incorrect lexical categories. The total number of incorrect lexical categories was 37, which accounted for 2.6% of all the lexical categories in the samples.

Table VII. Comparison of 50 Sampled Derivations to Gold-Standard Derivations

	Structure	LCs	# sentences	# LCs	# incorrect LCs
A	matched	matched	27	619	0
B	matched	w\ error	13	492	19
C	w\ error	matched	2	57	0
D	w\ error	w\ error	8	274	18
Total	-	-	50	1442	37

We further investigated the incorrect lexical categories obtained from derivations that had correct structures (B in Table VII) and structure discrepancies (C and D in the table). For B, 12 of the 19 erroneous categories were caused due to annotation errors in various levels such as POS tags and arguments missing in PASs. Therefore, correction of existing annotations is an important factor in improving accuracy of the obtained lexical categories. The other errors were verb categories with missing arguments due to, for example, mistakes in argument vs. adjunct decisions (see Section 3.2.1.) Some can be fixed by simply improving the algorithm, but others need correcting annotations or resolving discrepancies between the annotations from different corpora. Among ten sentences with structure discrepancy (C and D), annotation errors were not the major cause of the difference. The discrepancies in eight derivations originated in the phase converting interchunk dependencies to phrase structure (see Section 3.1), that is, each of the derivations has a subtree corresponding to a chunk connecting to a wrong point. To obtain more accurate structures, manually correcting the tree structure may be an option as well as improving the conversion rules.

To summarize, 80% of the sampled derivations had the same structure as the gold standards, and 97% of the obtained lexical entries were correct. For the derivations with correct forms, annotation correction is expected to improve the quality of the lexical categories. To decrease structure discrepancy, we need to manually correct the tree structure as well as improve the conversion rules.

4.3. Evaluation of Coverage

Following the evaluation criteria in Hockenmaier and Steedman [2007], we measured the coverage of the grammar on unseen texts. First, we obtained CCG derivations for evaluation sets by applying our conversion method and then used these derivations as the gold standard. Lexical coverage indicates the number of words to which the grammar assigns a gold-standard category. Sentential coverage indicates the number of sentences in which all words are assigned gold-standard categories. Since a gold derivation can be logically obtained if gold categories are assigned to all words in a sentence, sentential coverage means that the obtained lexicon has the ability to produce exactly correct derivations for those sentences.

Tables VIII and IX list the evaluation results.[8] Lexical coverage was 99.4% with rare word treatment by using a tag dictionary [Clark and Curran 2007], which is at the same level as the case of the English CCG parser. The columns for "Uncovered" show that most of the uncovered words result from unseen combinations of seen words and seen categories. We also measured sentential coverage in a weak sense, which means the number of sentences that are given at least one analysis (not necessarily correct) by the obtained grammar. This number was 99.4%, and it was 99.3% for the development and test sets, respectively, which is sufficiently high for wide-coverage parsing of real-world texts. In fact, this number is 3.5% higher than the coverage of the Japanese HPSG lexicon [Yoshida 2005].

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[8] The figures improved slightly over those previously reported [Uematsu et al. 2013].

Table VIII. Sentential Coverage

	Covered	Uncovered	Coverage (%)
Develop.	3,924	636	86.1
Test	7,628	1,141	87.0

Table IX. Lexical Coverage

	Words	Covered pair	Uncovered			
			combi.	cat.	word	both
Develop.	127,183	126,428	681	74	0	0
Test	238,038	236,674	1,227	137	0	0

Note: Uncovered combination refers to a word in the test set whose correct category is not in the lexicon as a combination, *i.e.*, an unseen combination of a seen word and a seen category. Uncovered category is for a word in the test set whose category did not appear in the training.

Table X. Parsing Accuracy

	LP	LR	LF	UP	UR	UF	Lex. Cov.	Cat.
Devel.	85.1	84.7	84.9	90.9	90.5	90.7	99.4	92.3
Test	85.2	84.6	84.9	91.0	90.4	90.7	99.4	92.3
C&C	88.34	86.96	87.64	93.74	92.28	93.00	99.63	94.32

Note: LP, LR, and LF refer to labeled precision, recall, and F-score, respectively. UP, UR, and UF are for unlabeled. Cat. column shows the rate of correct lexical categories in output derivations.

4.4. Evaluation of Parsing Accuracy

Finally, we evaluated parsing accuracy. We employed the parser and supertagger of Miyao and Tsujii [2008], specifically, its generalized modules for lexicalized grammars. We trained log-linear models in the same way as Clark and Curran [2007], using the training set as training data. Feature sets were borrowed from an English parse[9] [Miyao and Tsujii 2008]; no tuning was performed. We used the gold morphological information from the annotated corpora described in Section 2.3 and input it into the parser according to the conventions of the research on Japanese dependency parsing. Following Clark and Curran [2007], the evaluation measures were precision and recall over dependencies, where a dependency is defined as a 4-tuple: a head of a functor, functor category, argument slot, and head of an argument. A labeled dependency is correct if the four elements match the gold standard. An unlabeled dependency is correct if the heads of the functor and the argument appear together in the gold standard. We assumed that the dependencies derived from the CCG derivations converted from unseen sentences were correct, and used the dependencies as the gold standard in the evaluation.

Table X shows the parsing accuracy on the development and test sets.[8] The row C&C shows the performance of the English CCG parser [Clark and Curran 2007] on the English CCGbank. While our coverage was almost the same as Clark and Curran [2007], the performance of our parser was 2–3% lower. One possible approach to improving the performance is tuning disambiguation models for Japanese. Comparing the parser's performance with previous work on Japanese dependency parsing is difficult because our figures are not directly comparable to theirs. For example, our category dependency includes more difficult problems, such as whether a subject PP

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[9] While the English parser is not a CCG parser, the features used were naturally translatable to CCG and our feature set as a whole was comparable to one used in the normal-form model of Clark and Curran [2007], besides language difference.

is shared by coordinated verbs, while dependency parsers simply ignore the relation between PP and the former verb. Sassano and Kurohashi [2009] reported the accuracy of their parser as 88.48 and 95.09 in unlabeled chunk-based and word-based F1, respectively. Our score of 90.7 in unlabeled category dependency seems to be lower than their word-based score. Thus, our parser is expected to be capable of real-world Japanese text analysis, but there is room for improvement by tuning the disambiguation model for Japanese.

5. CONCLUSION

In this article, we proposed a method to induce wide-coverage Japanese resources based on CCG, which will lead to deeper syntactic analysis for Japanese and we presented the results of empirical evaluation of the corpus conversion, the coverage of the obtained lexicon, and the parsing accuracy. Although our work is basically in line with CCGbank, in which the conversion of phrase structure trees into CCG derivations is key, the application of the method to Japanese is not trivial due to the fact that the relationship between a chunk-based dependency structure and a CCG derivation is not obvious.

Our method integrates multiple dependency-based resources to convert them into an integrated phrase structure treebank. The obtained treebank is then transformed into CCG derivations. Because the treebank is fairly independent of our CCG implementation, the treebank itself can be utilized as a resource and its quality can be improved with additional resources in parallel to the treebank-CCG conversion. The empirical evaluation in Section 4 shows that our corpus conversion successfully converts 94% of the corpus sentences and that the coverage of the lexicon is 99.4%, which is sufficiently high for analyzing real-world texts. A comparison of the parsing accuracy with obtained grammar with that of previous works on Japanese dependency parsing and English CCG parsing indicates that our parser can analyze real-world Japanese texts fairly well and that there is room for improvement in disambiguation models.

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Review Article

Pattern Classification in Kampo Medicine

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Pattern classification is very unique in traditional medicine. Kampo medical patterns have transformed over time during Japan's history. In the 17th to 18th centuries, Japanese doctors advocated elimination of the Ming medical theory and followed the basic concepts put forth by Shang Han Lun and Jin Gui Yao Lue in the later Han dynasty (25–220 AD). The physician Todo Yoshimasu (1702–1773) emphasized that an appropriate treatment could be administered if a set of patterns could be identified. This principle is still referred to as "matching of pattern and formula" and is the basic concept underlying Kampo medicine today. In 1868, the Meiji restoration occurred, and the new government changed its policies to follow that of the European countries, adopting only Western medicine. Physicians trained in Western medicine played an important role in the revival of Kampo medicine, modernizing Kampo patterns to avoid confusion with Western biomedical terminology. In order to understand the Japanese version of traditional disorders and patterns, background information on the history of Kampo and its role in the current health care system in Japan is important. In this paper we overviewed the formation of Kampo patterns.

1. Introduction

The globalization of health care has not left traditional medicine behind. The World Health Organization (WHO) took the initiative for globalization of traditional medicine by founding the Division of Traditional Medicine in 1972 [1]. In 1978, the Alma-Ata Declaration on Primary Health Care called on countries and governments to include the practice of traditional medicine in their primary health care approach [2]. Thirty years later, traditional medicine is widely available, affordable, and commonly used in many parts of the world.

WHO is presently updating its International Classification of Diseases from the 10th (ICD-10) to 11th edition (ICD-11) [3, 4] and plans to incorporate traditional medicine into this new version. International experts from China, Korea, Japan, Australia, the US, and the EU are involved in this project. The ICD-11 alpha version was released in 2011, and the beta version was released in May 2012, with a version also available on the web [5].

The ICD-11 beta version contains 2 sections on traditional medicine: "traditional disorders" and "patterns" (zheng in Chinese). China and Korea referred to their own national standards to develop these sections. China used the 1995 classification and codes of traditional disorders and patterns of traditional Chinese medicine (GB95) as a national standard. The third edition of the Korean Classification of Diseases of Oriental Medicine (KCDOM3) was incorporated into the Korean modification of ICD-10 (KCD-6) in 2010. KCD-6 was groundbreaking because it was the first publication in which Western biomedicine and traditional medicine shared a common platform in terms of medical statistics.

For Japan's contribution to this edition, the Committee for Terminology and Classification of the Japan Society for Oriental Medicine (JSOM) was responsible for organizing the section on Kampo classification. Kampo covers a wide variety of traditional Japanese medicine including acupuncture and moxibustion, existing before Western medicine was introduced to Japan. In contrast to China and Korea, Japan did not have national standards for reference. To understand the Japanese version of traditional disorders and patterns, background information on the history of Kampo and its role in the current health care system in Japan is important.

2. History of Kampo Medicine

Medicines were brought from ancient China to Japan via the Korean peninsula in the 5th or 6th century. While Japanese medicine originally followed the ways of ancient Chinese medicine, Japan adopted Chinese knowledge to suit its own climate and race [6]. Also because not all materials were available, Japan replaced the material to the Japanese herbs and minerals. The first Japanese medical book, "Daidoruijuho," was a collection of Japanese traditional therapies written in 808.

Further modifications of Japanese traditional medicine occurred during the Edo period (1603–1867) [7, 8]. The medicine of Ming-China was introduced at the beginning of this period and spread widely (Gosei school). During this time, Japanese doctors advocated the elimination of Ming Chinese medicine, instead following the basic concepts of Shang Han Lun and Jin Gui Yao Lue introduced during the later Han dynasty (25–220 AD). The physician Todo Yoshimasu promoted his perspective on these classic texts and rejected the theory developed later in China. His approach emphasized that an appropriate treatment could be administered if a set pattern could be identified, a practice still referred to today as "matching of pattern and formula" (Koho school). Later in the Edo period, another school which integrated both Koho style and Gosei style occurred (Setchu school).

Among these three schools, Koho school influenced most the current Kampo practice in Japan.

In the 18th century, European medicine was introduced in Japan. Modern anatomy was first studied in 1754 by Toyo Yamawaki, a famous Kampo doctor who had acquired an anatomy book from Europe. Toyo Yamawaki respected Yoshimasu, who also knew European medicine. Yoshimasu may have tried to reform Kampo medicine to harmonize it with European medicine.

This trend was followed by other doctors like Seishu Hanaoka (1761–1835), who performed the first surgery with general anesthesia in 1804. This event occurred 42 years before William T. G. Morton successfully performed surgery using ether as a general anesthetic. Hanaoka combined Kampo and European medicines, using Kampo mainly for internal medicine and European medicine for surgery.

The Meiji restoration occurred in 1868, and the new government decided to modernize Japan introducing European culture including medicine. With the passing of the 1874 Medical Care Law, the German model was adopted as the national health care system, and all Kampo-related systematic education was stopped. Kampo practitioners were no longer recognized as official medical professionals; for those interested in becoming physicians, the only option available was to study Western medicine and pass a national examination. Thereafter, the practice of Kampo drastically declined.

After difficult years, physicians like Kyushin Yumoto (1876–1941), Keisetsu Otsuka (1900–1980), and Domei Yakazu (1905–2002) played a key role in reviving Kampo medicine. For Kampo medicine to survive, these physicians had to transform it into a more practical form that the new generation of physicians would also find useful. The modern form of Kampo medicine lost much of its theoretical origin, and emphasis was now being placed on proper prescription of Kampo formulas for treating symptoms. These changes made Kampo conceptually easier to understand for the new generation of physicians trained only with Western medicine. Moreover, the "matching of pattern and formula" methodology made the clinical use of Kampo a more appealing form of treatment.

The result of these efforts was that, by 1967, the first 4 Kampo formulas were approved by the government for coverage under the national insurance system.

3. Current Status of Kampo Medicine in Japan

Recent research shows that about 90% of physicians in Japan use Kampo medicines in daily practice, even for cancer patients [9–11]. For women's health, nearly 100% of Japanese obstetrics/gynecology doctors use Kampo medicine [12–14]. Physicians even use Kampo medicine in the university hospital along with high-tech techniques such as organ transplantation or robotic surgery. Physicians often use Kampo medicines along with chemotherapy or radiation therapy for cancer patients. These examples show the magnificent integration of modern Western biomedicine and traditional medicine [15, 16].

Kampo medicine has government-regulated prescription drugs, and now 148 formulas are listed on the Japanese Insurance Program. Kampo practitioners can also use decoctions, selecting several herbs among 243 types covered by the insurance system [17]. In 2001, the Ministry of Education, Culture, Sports, Science and Technology decided to incorporate Kampo medical education into the core curriculum of medical schools. There are 80 medical schools in Japan, all of which now provide Kampo medical education.

4. How the "Kampo Medical Classification" Developed Recently in Japan

The Japan Society for Oriental Medicine (JSOM) was founded in 1950 and is the largest academic association for Kampo medicine. The JSOM Committee for Terminology and Classification decided not to use traditional names for disorders in Kampo classification because many of them overlap with Western biomedical terms. Traditional names for disorders are primarily symptoms, such as "headache" or "watery diarrhea." In contrast, in Western medicine, disease names are based on pathological causes, such as cholera or malaria. Since these diseases have existed for a long time, traditional medicine recognizes these diseases. However, the pathologies of these diseases were unknown when the names were given and so are not reflected in the disease names in traditional medicine. Therefore, it is difficult to map traditional disorder names and biomedical disease names. Sometimes, symptomatic traditional names for disorders are broad and can be mapped to multiple biomedical disease names. Because the restoration of Kampo medicine in Japan was led by physicians, Western biomedical terms were often used instead of the traditional Kampo terms to avoid confusion.

Organ system patterns are very important in medicine in China and Korea. However, Kampo experts in the Meiji (1868–1912), Taisho (1912–1925), and Showa (1926–1989) eras chose not to use organ systems to avoid overlap with biomedical terms. As a result, Kampo medicine is sometimes criticized because of the relative lack of terms to describe patients' conditions. The pathogenesis rather than host reaction is most important in Western biomedicine. In contrast, the host's reaction to the pathogen is the most important factor in traditional medicine. In this regard, Kampo medicine has been developed in harmony with Western biomedicine.

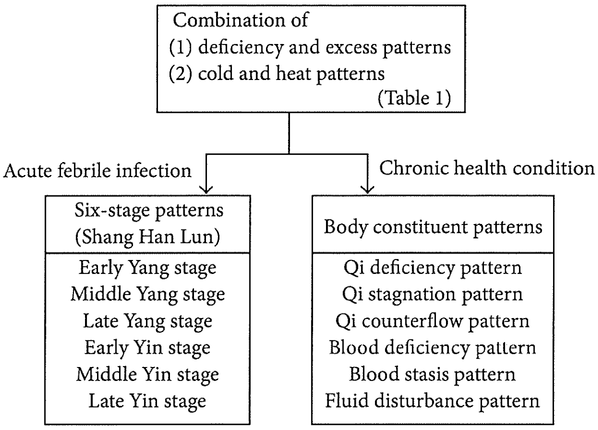

FIGURE 1: Diagnostic flow used in Kampo medicine. All patients are assigned a specific category as described in Table 1 and then divided into 2 groups according to whether they have acute febrile infectious disease or chronic disease. For acute febrile disease, the 6 stages of Shang Han Lun are very important. For chronic diseases, the host body constituent patterns are very important.

5. Kampo Medicine Patterns

Kampo patterns were reconstructed logically according to the ICD principles, which are both jointly exhaustive and mutually exclusive. Several parameters are used for determining Kampo patterns: yin-yang, deficiency-excess, cold-heat, 6 stages of acute febrile diseases, and qi-blood-fluid [18]. Of these, yin-yang, deficiency-excess, cold-heat, and interior-exterior belong to the 8 principles used in Chinese medicine. In China, each component is used in combination with the others to define the pattern, such as "liver yin deficiency pattern," and is not usually used independently. Among 8 principles, yin-yang is a polysemic word. Sometimes it is used for the sensible temperature in Japan. Under international harmonization, yin-yang is usually a high-level concept of deficiency-excess, cold-heat, and interior-exterior. To avoid confusion, we decided not to use yin-yang for the sensible temperature.

Kampo patterns are determined for all patients according to the flow charts shown in Table 1 and Figure 1. Patient conditions are divided into 2 groups: acute febrile infectious conditions and chronic conditions (Figure 1). A 6-stage pattern, based on Shang Han Lun, is used for describing acute febrile infectious diseases like influenza. Qi-blood-fluid patterns are mainly used for describing chronic diseases.

One issue raised regarding Kampo patterns concerns the "between deficiency and excess" pattern. The deficiency and excess pattern is usually based on the strength of the pathogen. However, in Japan, deficiency and excess patterns are primarily based on the patient's condition. The ancient textbook of Huangdi Neijing (Former Han dynasty; 220 AD to 8 AD) explains that "when the foreign pathogen is strong, it is called as excess, and when body energy is weakened, it is called as deficiency." The problem with this statement is that deficiency is defined by the strength of foreign pathogens, and deficiency is defined by the energy of the host. Many traditional medical terms are polysemic, mainly due to their long history. However, the deficiency-excess terms are originally polysemic; this has created much confusion.

In Japan, deficiency-excess was originally determined by the strength of the foreign pathogen in the case of acute febrile infectious diseases and by the strength of the body energy in the case of chronic diseases. Additionally, Kampo medicine was used extensively for acute febrile infectious diseases before antibiotics were developed, where the strength of the foreign pathogen was very important. Since the development of antibiotics, Kampo medicine has been used more often for chronic diseases, in which the strength of the body energy is more important. In the modern version of Kampo, the host condition is assigned a high value, while the foreign pathogen is addressed by Western biomedicine. Therefore, the host energy is of greater importance. The need thus arose for the option to designate the body energy level as "neutral" rather than just "deficient" or "excessive." This issue was raised by Tokaku Wada (1743–1803), a physician in the Edo period [19]. His clinical wisdom was described in "Dosui Sagen" which was published in 1805. In this book, "between deficiency and excess" was described in the type of edema. This idea is thought to have influenced Kazuo Tatsuno (1905–1976) [20, 21] and other physicians in the Showa era. For example, a patient with impaired glucose tolerance appears normal according to the older Kampo designations, even though Kampo medicine is indicated for this condition. In such cases, the "neutral" designation enables acknowledgment of a condition that lies between deficiency and excess.

6. Formula Pattern

The formula pattern is also very unique in Kampo medicine. While traditional Chinese medicine (TCM) prescriptions are individualized at the herbal level, Kampo medicine is individualized at the formula level. This practice may have started during the Edo period, as usage of different amounts of herbs was described in a book by Kaibara in 1712 [22]. According to this book, the amount of each herb used in Japan was 1/5 to 1/3 that used in China. Kaibara explained that one of the reasons for this practice was the difficulty in importing herbs from China. Even though alternative herbs available in Japan were used, some had to be imported from

Table 1: Combinations of deficiency-excess and cold-heat patterns.

Components	Cold	Heat	Between cold and heat	Tangled cold and heat
Deficiency	Cold, deficiency	Heat, deficiency	Between cold and heat, deficiency	Tangled cold and heat, deficiency
Excess	Cold, excess	Heat, excess	Between cold and heat, excess	Tangled cold and heat, excess
Between deficiency and excess	Cold, between deficiency and excess	Heat, between deficiency and excess	Between cold and heat, between deficiency and excess	Tangled cold and heat, between deficiency and excess

Regardless of acute or chronic health conditions, all patients are classified into 1 of these 12 combinations. Very limited combinations are used for acute diseases. Between deficiency and excess; neutral in "deficiency and excess"; between cold and heat; neutral in "cold and heat"; tangled cold and heat; mixture "cold and heat," for example, cold foot and hot flush on face.

China. These differences in the amounts of herbs used are still prevalent. This may explain why Kampo medicine is individualized at the formula level. During the Edo period, doctors carefully studied the roles of formulas and decided the characteristics of each formula. This practice led to Yoshimasu's idea of "matching of pattern and formula."

Physicians continue to follow this principle today. Clinical trials have been conducted using the same Kampo formula used previously for a specific disease, determining the appropriate Kampo formula based on host patterns. "Matching of pattern and formula" has thus been shown to be a sophisticated approach.

By 1967, the first 4 Kampo formulas were approved by the government for coverage under the national insurance system, and 148 are now listed.

The acceptance of Kampo formulas into the national health insurance system marked the start of the exponential growth of Japan's market in Kampo medicines. Between 1976 and 1992, the sales of Kampo medicine grew more than 10-fold in Japan (Japan Kampo Medicine Manufacturers Association, 2007) [23].

With such a rapid increase in the number of Kampo drug products sold, the government and pharmaceutical industry needed to ensure that high standards were maintained. In 1987, the government established the Good Manufacturing Practice (GMP) law to ensure safety in manufacturing processes, including the production of Kampo formulas. The stringent manufacturing process for Kampo medicine has increased the legitimacy of this modality, as people can now expect uniformity and high quality from the different formulas. This facilitates "matching of pattern and formula," because if the formulas are not stable, it is very difficult to consistently match pattern to formula.

7. Future Challenges

Even though all 80 medical schools in Japan have incorporated Kampo medical courses into their curricula, the number of such courses is very small compared to that of Western biomedicine courses. Postgraduate and continuous Kampo medical education have not been established. Statistics indicate that Kampo formulas are used in daily practice by 90% of physicians, which represents over 260,000 physicians. However, the number of Kampo experts certified by the JSOM is only 2150. This great discrepancy means that most physicians use Kampo formulas based on Western biomedical disease diagnoses without deep consideration of patterns. Further education is necessary for the users of Kampo formulas.

Another concern for the future is the coding rule used for the qi-blood-fluid pattern. Deficiency, excess, and between deficiency and excess are mutually exclusive. Likewise, cold-heat and the 6 stages are mutually exclusive in the same category. However, several abnormalities in qi-blood-fluid may exist in 1 patient. We conducted a small clinical trial without establishing any coding rules. Some doctors provided only 1 code for the qi-blood-fluid pattern, while others provided 4 codes. For more accurate statistics, coding rules should be developed and training in coding should be imparted.

In terms of international comparisons, Kampo patterns are too simple compared to TCM and traditional Korean medicine (TKM). Organ system patterns are particularly lacking in Japan. However, in ICD-11, all the patterns will be presented on the common platform of Western biomedicine. Some organ system patterns can be linked to Western biomedicine disease codes, even though they do not map one-to-one. ICD 11 has terminology that is novel to ICD. This allows ontology software precisely describe the content of each term and links the different codes to each other. The next stage of ICTM development will be field testing. We expect that the international field test will allow for international comparisons.

8. Conclusion

Kampo patterns are rather unique compared to Chinese or Korean patterns. There are 2 explanations for this difference. First, Kampo medicine was separated from the theory of the Ming dynasty and then reestablished based on Shang Han Lun theory during the Edo period. Second, Kampo medicine is used in combination with Western biomedicine by licensed doctors in Japan. Kampo terminology was redeveloped in order to avoid confusion with Western biomedicine.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.