Integration of Morphological and Syntactic Analysis based on LR Parsing Algorithm

Tanaka Hozumi,† Tokunaga Takenobu† and Aizawa Michio††

Morphological analysis of Japanese is very different from that of English, because no spaces are placed between words. This is also the case in many Asian languages such as Korean, Chinese, Thai and so forth. In the Indo-European family, some languages such as German have the same phenomena in forming complex noun phrases. Processing such languages requires the identification of the word boundaries in the first place. This process is often called segmentation. Segmentation is a very important process, since the wrong segmentation causes fatal errors in the later stages such as syntactic, semantic and contextual analysis. However, correct segmentation is not always possible only with morphological information. Syntactic, semantic and contextual information are also necessary to resolve the ambiguities in segmentation. This paper proposes a method to integrate the morphological and syntactic analysis based on LR parsing algorithm. An LR table derived from grammar rules is modified on the basis of connectabilities between two adjacent words. The modified LR table reflects both the morphological and syntactic constraints. Using the LR table and the generalized LR parsing algorithm, efficient morphological and syntactic analysis is available.

KeyWords: Generalized LR parsing, Morphological analysis, Syntactic analysis

1 Introduction

Morphological analysis of Japanese is very different from that of English, because no spaces are placed between words. This is also the case in many Asian languages such as Korean, Chinese, Thai and so forth. In the Indo-European family, some languages such as German have the same phenomena in forming complex noun phrases. Processing such languages requires the identification of the word boundaries in the first place. This process is often called segmentation. Segmentation is one of the most important tasks of morphological analysis for these languages, since the wrong segmentation causes fatal errors in the later stages such as syntactic, semantic and contextual analysis. However, correct segmentation is not always possible only with morphological information. Syntactic, semantic and contextual information are also necessary to resolve the ambiguities in segmentation.

Over the past decades a number of studies have been made on the morphological and

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syntactic analysis of Japanese. From the viewpoint of two kinds of integration, description of constraints and processing, they would be classified into the following three approaches. The relation of these approaches is illustrated in Figure 1.

Figure 1 Relation of approaches

**Cascade:** Separate the morphological and syntactic analysis and execute them in a cascade manner. The morphological and syntactic constraints are represented separately.

**Interleave:** Separate the morphological and syntactic analysis and execute them interleavingly. The morphological and syntactic constraints are represented separately.

**Single Framework:** Represent both the morphological and syntactic constraints in a single framework such as context free grammars (CFGs) and make no distinction between the two analysis.

Representing the morphological and syntactic constraints separately as in the first two approaches, Cascade and Interleave, makes maintaining and extending the constraints easier. This is an advantage of these approaches. Many natural language processing systems have used these two approaches. For example, Mine et al. proposed a method to represent the morphological constraints in regular grammar and the syntactic constraints in CFG, and interleave the morphological and syntactic analysis (Mine, Taniguchi, and Amamiya 1991). Most other systems use a connection matrix instead of regular grammar (Miyazaki 1984; Sugimura, Akasaka, Kubo, and Matsumoto 1988). The main drawbacks of these approaches would be summarized as follows:

- It may require two different algorithms for each analysis.
- It must retain all ambiguities from the morphological analysis until the syntactic anal-
ysis begins. This wastes memory space and computing time.

On the other hand, from a viewpoint of processing, it is preferable to integrate the morphological and syntactic analysis into a single framework, since some syntactic constraints are useful for morphological analysis and vice versa. The last approach fulfills this requirement. There have been several attempts to develop CFG that covers both the morphological and syntactic constraints (Kita 1992; Sano and Fukumoto 1992). However, it is empirically difficult to describe both constraints by using only CFG. In order to have CFG rules include morphological constraints, nonterminal symbols have to bear the morphological attributes which are used for checking connectabilities between morphemes. In other words, nonterminals should be more precisely subcategorized. This increases the number of nonterminals and thus that of grammar rules.

![Figure 2 Connectability check by CFG](image)

Using augmented context free grammar (ACFG) instead of CFG may remedy this problem. However, this may cause the delay of connectability checking. For example, in Figure 2, in order to check the connectability between adjacent words, \( w_i \) and \( w_{i+1} \), the morphological attributes of each word should be propagated up to their mother nodes B and C, and the check is delayed until the application of the rule \( A \rightarrow BC \).

By using connection matrices for morphological analysis as in the Cascade/Interleave approaches, connectability checks between adjacent words is performed very easily. Therefore, it is desirable to represent the morphological and syntactic constraints separately as in Cascade/Interleave, and to integrate the execution of both analysis into a single process as in Single Framework. Our method has captured these advantages by representing the morphological constraints in connection matrices and the syntactic constraints in CFGs, then compiling both constraints into an LR table (Aho, Ravi, and Ullman 1986). The already existing efficient LR parsing algorithms would be used with minor modifications, enabling us to utilize both the morphological and syntactic constraints at the same time. Our approach, called MSLR (Morpho-Syntactic LR), locates at the right bottom of the map in Figure 1, which is the most preferable position.

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In the next section, we first give a brief introduction to Japanese morphological analysis using an example sentence. In section 3, we describe the method of generating an LR table from a connection matrix and CFG rules, then in section 4 we explain the parsing algorithm. Our algorithm is principally the same as Tomita’s generalized LR parsing algorithm (Tomita 1986). The only difference is that the input is not a sequence of preterminals, but a sequence of characters.

## 2 Morphological analysis of Japanese

A simple Japanese sentence consists of a sequence of postpositional phrases (PPs) followed by a predicate. The PP consists of a noun phrase (NP) followed by a postposition which indicates the case role of the NP. The predicate consists of a verb or an adjective, optionally followed by a sequence of auxiliary verbs (Morioka 1987)).

We illustrate the Japanese morphological analysis with an example sentence “かおるにあいます (meet Kaoru).” We use a simple Japanese dictionary shown in Figure 3, and a connection matrix shown in Figure 4 which gives us the connectabilities between adjacent morphological categories (mcat). For example in Figure 4, the symbol “o” at the intersection of row 2 \((p_1)\) and column 3 \((vs_k)\) indicates that the morphological category \(vs_k\) can immediately follow the morphological category \(p_1\).

<table>
<thead>
<tr>
<th>entry</th>
<th>cat</th>
<th>mcat</th>
<th>meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>かお</td>
<td>n</td>
<td>(n_1)</td>
<td>face</td>
</tr>
<tr>
<td>かおる</td>
<td>n</td>
<td>(n_1)</td>
<td>person’s name</td>
</tr>
<tr>
<td>にあ</td>
<td>p</td>
<td>(p_1)</td>
<td>(dative)</td>
</tr>
<tr>
<td>きい</td>
<td>vs</td>
<td>(vs_k)</td>
<td>open</td>
</tr>
<tr>
<td>いく</td>
<td>ve</td>
<td>(ve^2_k)</td>
<td>(connect to verb)</td>
</tr>
<tr>
<td>あい</td>
<td>ve</td>
<td>(ve^3_k)</td>
<td>(connect to nominal)</td>
</tr>
<tr>
<td>つく</td>
<td>vs</td>
<td>(vs_w)</td>
<td>meet</td>
</tr>
<tr>
<td>きっ</td>
<td>ve</td>
<td>(ve^2_w)</td>
<td>(connect to verb)</td>
</tr>
<tr>
<td>くる</td>
<td>ve</td>
<td>(ve^3_w)</td>
<td>(connect to nominal)</td>
</tr>
<tr>
<td>かお</td>
<td>vs</td>
<td>(vs_r)</td>
<td>smell sweet</td>
</tr>
<tr>
<td>おり</td>
<td>vs</td>
<td>(ve^2_r)</td>
<td>(connect to verb)</td>
</tr>
<tr>
<td>つる</td>
<td>ve</td>
<td>(ve^3_r)</td>
<td>(connect to nominal)</td>
</tr>
<tr>
<td>ます</td>
<td>ax</td>
<td>(ax_1)</td>
<td>(polite form)</td>
</tr>
<tr>
<td>た</td>
<td>ax</td>
<td>(ax_2)</td>
<td>(past form)</td>
</tr>
</tbody>
</table>

Figure 3 An example of Japanese dictionary
Using only the dictionary, we would obtain the following twelve candidates of segmentation for the sentence “かおるにあります。”

<table>
<thead>
<tr>
<th>かおるにあります</th>
<th>かおるにあります</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(9)</td>
</tr>
<tr>
<td>(2)</td>
<td>(10)</td>
</tr>
<tr>
<td>(3)</td>
<td>(11)</td>
</tr>
<tr>
<td>(4)</td>
<td>(12)</td>
</tr>
<tr>
<td>(5)</td>
<td></td>
</tr>
<tr>
<td>(6)</td>
<td></td>
</tr>
<tr>
<td>(7)</td>
<td></td>
</tr>
<tr>
<td>(8)</td>
<td></td>
</tr>
</tbody>
</table>

By also referring to the connection matrix, we would be able to filter out illegal segmentations. From the examples above, we find (1)–(4) violate the connectability between “かお (n₁)” and “る (ve₃)”,” and that (5)–(8) violate the connectability between “る (ve₃)” and “に (p₁)”.

Also (9) and (11) violate the connectability between “い (ve₂)” and “ます (ax₁)”,” and (11) violates the connectability between “かおる (vsₖ)” and “い (ve₂)”.” Thus by eliminating the illegal candidates we obtain the morphologically correct candidate, (12). A long input sentence generally gives ambiguities which need to be resolved in later stages using syntactic, semantic and contextual information.
3 Generating LR table

Connection matrices and CFG rules have been used for morphological analysis and syntactic analysis respectively by most Japanese processing systems. Because CFG rules were mainly used for syntactic analysis and connection matrices for morphological analysis, they have been developed independently of each other.

In this section, we propose a method to integrate morphological and syntactic constraints in the framework of LR parsing algorithm, and thus capturing the advantages of Cascade/Interleave and Single Framework described in section 1.

In order to combine connection matrices and CFG rules, the first step we have to take is to extend the CFG rules by relating the syntactic categories in the CFG rules with the morphological categories in a connection matrix. This is realized by adding CFG rules called morphological rules each of which is a unit production rule with a syntactic category in the LHS and a morphological category in the RHS.

\[
\begin{align*}
    s &\rightarrow v \quad (1) &
    v &\rightarrow vs\ ve \quad (4) \\
    s &\rightarrow v\ ax \quad (2) &
    pp &\rightarrow n\ p \quad (5) \\
    s &\rightarrow pp\ s \quad (3)
\end{align*}
\]

Figure 5 An example of CFG for Japanese

\[
\begin{align*}
    n &\rightarrow n_1 \quad (6) &
    ve &\rightarrow ve_{w}^{2} \quad (14) \\
    p &\rightarrow p_1 \quad (7) &
    ve &\rightarrow ve_{w}^{2t} \quad (15) \\
    vs &\rightarrow vs_{k} \quad (8) &
    ve &\rightarrow ve_{w}^{3} \quad (16) \\
    vs &\rightarrow vs_{w} \quad (9) &
    ve &\rightarrow ve_{r}^{2} \quad (17) \\
    vs &\rightarrow vs_{r} \quad (10) &
    ve &\rightarrow ve_{r}^{2t} \quad (18) \\
    ve &\rightarrow ve_{k}^{2} \quad (11) &
    ve &\rightarrow ve_{r}^{3} \quad (19) \\
    ve &\rightarrow ve_{k}^{2i} \quad (12) &
    ax &\rightarrow ax_{1} \quad (20) \\
    ve &\rightarrow ve_{k}^{3} \quad (13) &
    ax &\rightarrow ax_{2} \quad (21)
\end{align*}
\]

Figure 6 A morphological rules derived from the dictionary in Figure 3

Let us take an example CFG rules shown in Figure 5. From the dictionary shown in Figure 3, we would extract a set of new CFG rules as shown in Figure 6, which are simply added to the CFG rules in Figure 5 to get an extended set of CFG rules.

We would generate an LR table as shown in Figure 7 from the extended CFG rules (1) through (21) from Figure 5 and 6. Note that the extended CFG rules do not include any information about connectability represented in the connection matrix in Figure 4. For example, rules (4), (10) and (14) allow the structure \([v\ [vs\ vs_{r}],[ve\ [ve_{w}^{2}]])\] which violates the connectability between \(vs_{r}\) and \(ve_{w}^{2}\) with respect to Figure 4.
The second step is to introduce the constraints on connectability into the LR table by deleting illegal reduce actions. This is carried out by modifying the LR table with the procedure shown in Figure 8.

Figure 7 LR table generated from rules (1)–(21)
For each reduce action $\mathbf{A}$ with a morphological rule in the LR table {
    if (Not $\text{Connect}(\text{RHS}(\text{Rule}(\mathbf{A})), \text{LA}(\mathbf{A}))$) {
        delete $\mathbf{A}$ from the entry;
    }
}
where each function is defined as follows:

$\text{Rule}: \text{action} \rightarrow \text{rule};$
returns a rule used by the reduce action.

$\text{LA}: \text{action} \rightarrow \text{symbol};$
returns a look ahead symbols of the action.

$\text{Connect}: \text{symbol} \times \text{symbol} \rightarrow \{T, F\};$
returns true or false with respect to the connectability of the two symbols.

$\text{RHS}: \text{rule} \rightarrow \text{symbol};$
returns a right hand side symbol of the rule.

Figure 8 A procedure to modify an LR table

Deleting reduce actions by applying the above procedure prohibits the application of morphological rules which violates the connectability between two adjacent words, namely the current scanned word and its lookahead word. Note that given an LR table and a connection matrix, this procedure can be performed automatically without human intervention.

It is possible to incorporate this procedure into the LR table generation process, however, it is better to keep them separate. Since this procedure is applicable to any type of LR table, separating this process from LR table generation enables us to use the already existing LR table generation program.

For example, in Figure 7, the reduce action $\mathbf{r8}$ in state 7 and column $\nu_e^3$ is deleted, since the connection between $\nu_s$, the RHS of rule (8), and $\nu_e^3$, the lookahead symbol, is prohibited with respect to the connection matrix in Figure 4. Similarly, reduce action $\mathbf{r8}$ in state 7 and column $\nu_e^2$ will be deleted and so forth. The reduce actions which should be deleted is enclosed in Figure 7. The overview of generating a modified LR table is shown in Figure 9.

Generally speaking, the size of the LR table is on the exponential order of the number of rules in the grammar. Introducing the morphological rules into the syntactic rules can cause an increase in the number of states in the LR table, thereby exponentially increasing the size of the overall LR table in the worst case. In our method, the increase of the number of states
is equal to that of the morphological rules introduced. Suppose we add a morphological rule
\( X \rightarrow x \) to the grammar. Only the items in the form of \( [A \rightarrow \alpha \cdot X\beta] \) would produce a single
new item \( [X \rightarrow \cdot x] \) from which only a single new state \( \{[X \rightarrow \cdot x]\} \) would be created. Thus
the increase of the number of the states is equal to that of the morphological rules introduced,
and the size of the LR table will not grow exponentially.

![Diagram](image)

Figure 9 Outline of generating a modified LR table

4 Algorithm

The LR parsing algorithm with the modified LR table is principally the same as Tomita’s
generalized LR parsing algorithm. The only difference is that Tomita’s algorithm assumes a
sequence of preterminals as an input, while our algorithm assumes a sequence of characters.
Thus the dictionary reference process needs to be slightly modified. Figure 10 illustrates the
outline of our parsing algorithm.

In Figure 10 the stage number (CS) indicates how many characters have been processed.
The procedure begins at stage 0 and ends at stage N, the character length of an input sen-
tence. In stage 0, the stack is initialized and only the node with state 0 exists (step (1)). In
the outer-most loop (2)–(14), each stack top in the current stage is selected and processed.
In step (4), the dictionary is consulted and look-ahead symbols are obtained. An important
point here is that look-ahead symbols may have different character lengths. A new node is
introduced by a shift action at step (8) and is placed into a stage which is ahead of the current
stage by the length of the look-ahead word.
Figure 10 Outline of the parsing algorithm

5 A worked example

The following example well illustrates the algorithm in Figure 10. The input sentence is “かおるにあります$” (meet Kaoru). We assign position numbers between adjacent characters.

Input: かおるにあります$
Position: 0 1 2 3 4 5 6 7 8 9

In the following trace, the numbers in circles denote state numbers, and the numbers in squares denote the subtree number. The symbols enclosed by curly brackets denote a look ahead symbol followed by the next applicable action, separated by a slash (/). The stage numbers are shown below the stacks.

Stage: 0

Dictionary reference:

\[ n_1, \text{“かお”} \] at 0–2
\[ vs_r, \text{“かお”} \] at 0–2
\[ n_1, \text{“かある”} \] at 0–3

We find three look ahead symbols, \( n_1 \), \( vs_r \), and \( n_1 \) by consulting the dictionary in Figure 3. A shift action is applied for each of them according to the LR table in Figure 7.
After the shift actions, three new nodes are created at stage 2 or stage 3 depending on the length of look ahead words. At the same time subtrees $1 \rightarrow 3$ are constructed. The current stage is updated from 0 to 2, since there is no node in stage 1. The look ahead symbols are unknown at this moment.

Stage: 2

Dictionary reference:

$[ve_3^r, \text{"る"}]$ at 2–3

Dictionary reference gives one look ahead symbol from position 2. Since the current stage number is 2, only the first two stack tops are concerned at this stage. No action is taken of the first stack, because the LR table has no action in the entry for state 6 and a look ahead symbol $ve_3^r$. As the result, the first stack is rejected. The reduce action ($r10$) is taken for the second stack.

After $r10$, a shift action ($s23$) is carried out for the first stack.

Stage: 3

Dictionary reference:

$p_1$, “い” at 3–4

We obtain symbol $p_1$ by consulting the dictionary. Because the first stack can take no more action, it is rejected. The reduce action ($r6$) is then applied to the second stack.
The shift action \((s25)\) is applied to the following stack.

After the shift action \((s25)\), new nodes are created in stage 4.

**Stage: 4**

Dictionary reference:

\([vs_k, \text{“"}}\] at 4–5

\([vs_w, \text{“"}}\] at 4–5

Dictionary reference provides two look ahead symbols for the next word.

After the two reduce actions \((r7)\), we get two nodes with the same state 24, and they would be merged. This is possible because these two reduce actions give the same structure as well. If the structures are different, we would not able to merge the stacks. We would see such an example later at stage 5.

The process in stage 4 continues as follows.
Stage: 5

Dictionary reference:

\[
[ve_k^2, "v"] \quad \text{at 5–6}
\]
\[
[ve_w^2, "v"] \quad \text{at 5–6}
\]

We have two look ahead symbols for each stack top. The reduce actions \((r8 \text{ and } r9)\) are performed.

Note that we are not able to merge the stack tops even with the same state \(4\) since the structure of \(12\) and \(13\) are different. If two stack tops are merged here and then different shift actions \((s16 \text{ and } s18)\) are carried out, we might have invalid combinations of structure such as \((12, 15)\) and \((13, 14)\).

After the shift actions \((s16 \text{ and } s18)\), we proceed to stage 6.

Stage: 6

Dictionary reference:

\[
[ax_1, "ます"] \quad \text{at 6–8}
\]

The process in stage 6 proceeds as follows.
Stage: 8

Dictionary reference:
“$” at 8–9

The input sentence is automatically segmented and accepted, giving a final parse result 21 as shown in Figure 11.

6 Conclusion

We have proposed a method representing the morphological constraints in connection matrices and the syntactic constraints in CFGs, then compiling both constraints into an LR table. The compiled LR table enables us to make use of the already existing, efficient generalized LR parsing algorithms through which integration of both morphological and syntactic analysis is obtained.
Advantages of our approach would be summarized as follows:

- Morphological and syntactic constraints are represented separately, and it makes easier to maintain and extend them.
- The morphological and syntactic constraints are compiled into a uniform representation, an LR table. We can use the already existing efficient algorithms for generalized LR parsing for the analysis.
- Both the morphological and syntactic constraints can be used at the same time during the analysis.

We have implemented our method using the EDR dictionary with 300,000 words (EDR 1993) from which 437 morphological rules are derived. This means only 437 new states are introduced to LR table and this does not cause an explosion in the size of the LR table. The method proposed in this paper is also applicable to integrate phonological and syntactic analysis. The detail is described elsewhere (Tanaka, Li, and Tokunaga 1994).

Reference


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