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SPOKEN LANGUAGE PARSING BASED ON INCREMENTAL DISAMBIGUATION

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ABSTRACT

Towards a real-time spoken dialogue system, several incremental parsing methods have been proposed so far. They constructs syntactic structures for an initial fragment of an input sentence. However, they have a problem that the structures do not necessarily represent the syntactic relation correctly. The problem is caused by the ambiguity of initial fragments. This paper proposes an incremental disambiguation method, which decides correct structures at an stage where the entire input is not completed. The method finds the structures which are correct independently of the remaining input. When correct structures cannot be decided, the method delays the decision. Since the disambiguation is executed for every word input, the method can find correct structures at an early stage.

1. INTRODUCTION

It is important for a spoken dialogue system to communicate with the user smoothly. Responding to the user immediately, the system is required to understand spoken language at least incrementally [1, 5], that is, to analyze input sentences from left to right and acquire the semantic content.

Several incremental parsing methods have been proposed so far. For example, Matsubara et al. has proposed a chart-based parsing for context free grammar[3]. Milward has proposed a parsing based on categorial grammar[6]. The methods can construct syntactic structures for initial fragments of input sentences. However, they have a problem that the structures do not necessarily represent the syntactic relation correctly. The problem is caused by the ambiguity of initial fragments. It cannot be ignored, because a dialogue system may misunderstand the user's utterance if the system interprets the utterance depending on an incorrect structure. Therefore, the system is required to make the correctness of structures clear.

This paper proposes an incremental disambiguation method, which decides correct structures at an stage where the entire input is not completed. The method finds the structures which are correct independently of the remaining input. Since the initial fragment does not have the information enough to resolve the ambiguity, the method utilizes a part of the input which follows the fragment. When correct structures cannot be decided, the method delays the decision. The disambiguation is executed by utilizing the following two information: undecided parts in syntactic structures and subsumption relation between structures. Since the disambiguation is executed for every word input, the method can find correct structures for an initial fragment at an early stage.

input: $w_1 w_2 \cdots w_n$
output: *chart*
$chart := \{(0, 0, [?]_s)\}$;
for $i = 1$ **to** n **begin**

  1)consulting dictionary:
    if the category of w_i is x
      then add $(i-1, i, [w_i]_x)$ to *chart*

  2)applying grammar rule:
    for each $(i-1, i, [\cdots]_{x_1}) \in chart$ and
      each grammar rule $a \rightarrow x_2 y \cdots z$
      if $x_1 = x_2$
        then add $(i-1, i, [[\cdots]_{x_1}[?]_y \cdots [?]_z]_a)$ to *chart*

  3)replacing term:
    for each $(0, i-1, \sigma), (i-1, i, [\cdots]_x) \in chart$
      if the category of $lut(\sigma)$ is x
        then add $(0, i, rep(\sigma, [\cdots]_x))$ to *chart*
end

Figure 1: Algorithm of incremental chart parsing

This paper is organized as follows: The next section explains incremental chart parsing shortly. Section 3 discusses the ambiguity in incremental chart parsing. Section 4 describes the incremental disambiguation method.

2. INCREMENTAL CHART PARSING

2.1. Chart

Incremental chart parsing records parsing results in a graph called a *chart* [2]. The edge is labeled a syntactic structure called a *term*, which is denoted by $[\alpha]_x$, where x is a category and α is a word, a special symbol '?' or a list of terms. The term $[?]_x$ is called an *undecided term* and represents that the part has not been inputed yet. The leftmost occurrence of an undecided term in a term σ is called a *leftmost undecided term* in σ, which is denoted by $lut(\sigma)$. If an edge is labeled a term which includes an undecided term, it is called *active*, otherwise *inactive*.

s	→ np vp $	pron	→ I / her
np	→ pron	det	→ the / her
np	→ det n	n	→ aunt / telescope
np1	→ det n pp	p	→ with
pp	→ p np	vi	→ saw
vp	→ vi	vt	→ saw
vp	→ vt np pp	$	→ .
vp	→ vt np1		

Figure 2: Grammar

2.2. Parsing Algorithm

Figure 1 shows the incremental parsing algorithm[3]. Here, an edge with a label σ between nodes j and k is denoted by (j, k, σ). The result of replacing the leftmost undecided term in σ with τ is denoted by $rep(\sigma, \tau)$. The incremental chart parsing introduces two new operations to the standard bottom-up chart parsing[2]. One is the application of grammar rules to an active edge and the other is the replacement of the leftmost undecided term with the term of an active edge. The operations enable the parsing to necessarily construct syntactic structures of initial fragments of input sentences.

As an example, let us consider parsing the following sentence using context free grammar shown in Figure 2:

$$\text{I saw her aunt with the telescope.} \quad (1)$$

Table 1 shows the process of chart construction for the sentence (1).

When "saw" is inputed, by consulting a dictionary and applying grammar rules, the following terms for "saw" are constructed:

$$[[saw]_{vi}]_{vp} \quad (2)$$

$$[[saw]_{vt}[?]_{np}[?]_{pp}]_{vp} \quad (3)$$

$$[[saw]_{vt}[?]_{np1}]_{vp} \quad (4)$$

The parsing replaces the leftmost undecided term in #2 with the terms (2), (3) and (4) respectively, so that it constructs terms #3, #4 and #5 for the initial fragment "I saw". These terms, at least, represent the relation that a pronoun "I" is the subject of the verb "saw". This example shows that the incremental chart parsing is capable of constructing terms of initial fragments for every word input.

3. AMBIGUITY IN INCREMENTAL PARSING

Before describing the ambiguity of initial fragments, we give some definitions about terms.

Definition 1 (subsumption relation) *Let σ and τ be terms. Then we write $\sigma \rhd \tau$, if $rep(\sigma, \theta) = \tau$, for some term θ.*

Let $\rhd^*$ be the reflexive transitive closure of $\rhd$. We say that σ subsumes τ, if $\sigma \rhd^* \tau$. □

That σ subsumes τ means that τ is constructed by application of replacement operation to σ. Figure 3 shows the subsumption relation between the terms constructed for the sentence (1).

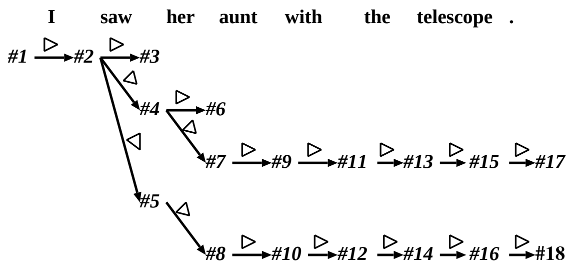

Figure 3: subsumption relation between terms

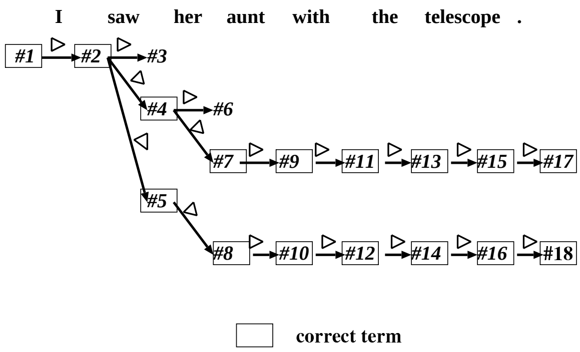

Figure 4: correct terms

If a term for an initial fragment represents syntactic relation correctly, the term subsumes some final complete terms. We call such a term *correct*. The correctness of a term is defined as follows:

Definition 2 (correct term) *Let σ be a term and $w_1 \cdots w_n$ be an input sentence. We say that σ is correct for $w_1 \cdots w_n$ if some term τ satisfies the following conditions:*

1. *τ is a term for $w_1 \cdots w_n$.*
2. *τ does not include undecided terms.*
3. *$\sigma \rhd^* \tau$.* □

For example, the term #4 is correct for the sentence (1), because the term #17 for the sentence (1) does not includes undecided terms and #4 $\rhd^*$ #17. On the other hand, the term #3 is not correct for (1). Figure 4 shows the correct terms for the sentence (1).

The previous section has illustrated the construction of terms for initial fragment in incremental chart parsing. Here, note that the constructed terms are not necessarily correct. It is caused by the syntactic ambiguity of initial fragments.

As an example, let us consider the fragment "I saw her". A word "her" is syntactically ambiguous in the sense that it has two part-of-speeches. The incremental chart parsing constructs the terms #6 #7 and #8 for the fragment "I saw her". #6 is the term in which "her" is "pron" and #7 and #8 are the ones in which "her" is "det". The ambiguity of the fragment "I saw her" produces the incorrect term. For instance, the term #6 is not correct, when the entire input sentence is "I saw her aunt with the telescope.".

Table 1: Incremental parsing process of "I saw her aunt with the telescope ."

word	chart		
	#	loc	term
	1	0-0	$[?]_s$
I	2	0-1	$[[[I]_{pron}]_{np}[?]_{vp}[?]_{\$}]_s$
saw	3	0-2	$[[[I]_{pron}]_{np}[[saw]_{vi}]_{vp}[?]_{\$}]_s$
	4	0-2	$[[[I]_{pron}]_{np}[[saw]_{vt}[?]_{np}[?]_{pp}]_{vp}[?]_{\$}]_s$
	5	0-2	$[[[I]_{pron}]_{np}[[saw]_{vt}[?]_{np1}]_{vp}[?]_{\$}]_s$
her	6	0-3	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{pron}]_{np}[?]_{pp}]_{vp}[?]_{\$}]_s$
	7	0-3	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[?]_n]_{np}[?]_{pp}]_{vp}[?]_{\$}]_s$
	8	0-3	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[?]_n[?]_{pp}]_{np1}]_{vp}[?]_{\$}]_s$
aunt	9	0-4	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[aunt]_n]_{np}[?]_{pp}]_{vp}[?]_{\$}]_s$
	10	0-4	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[aunt]_n[?]_{pp}]_{np1}]_{vp}[?]_{\$}]_s$
with	11	0-5	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[aunt]_n]_{np}[[with]_p[?]_{np}]_{pp}]_{vp}[?]_{\$}]_s$
	12	0-5	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[aunt]_n[[with]_p[?]_{np}]_{pp}]_{np1}]_{vp}[?]_{\$}]_s$
the	13	0-6	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[aunt]_n]_{np}[[with]_p[[the]_{det}[?]_n]_{np}]_{pp}]_{vp}[?]_{\$}]_s$
	14	0-6	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[aunt]_n[[with]_p[[the]_{det}[?]_n]_{np}]_{pp}]_{np1}]_{vp}[?]_{\$}]_s$
telescope	15	0-7	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[aunt]_n]_{np}[[with]_p[[the]_{det}[telescope]_n]_{np}]_{pp}]_{vp}[?]_{\$}]_s$
	16	0-7	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[aunt]_n[[with]_p[[the]_{det}[telescope]_n]_{np}]_{pp}]_{np1}]_{vp}[?]_{\$}]_s$
.	17	0-8	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[aunt]_n]_{np}[[with]_p[[the]_{det}[telescope]_n]_{np}]_{pp}]_{vp}[.]_{\$}]_s$
	18	0-8	$[[[I]_{pron}]_{np}[[saw]_{vt}[[her]_{det}[aunt]_n[[with]_p[[the]_{det}[telescope]_n]_{np}]_{pp}]_{np1}]_{vp}[.]_{\$}]_s$

4. INCREMENTAL DISAMBIGUATION

Our purpose is to develop a disambiguation framework to make the correctness of terms clear at an early stage.

In general, it is impossible to know whether a term for a fragment is correct or not, from only the fragment. Because the correctness of the terms depends on the entire input sentence. For example, in the case where the entire input sentence is "I saw her.", #6 is correct and #7 and #8 are not correct. On the other hand, if the entire input sentence is "I saw her aunt with the telescope.", #6 is not correct but #7 and #8 are correct.

By utilizing a part of the input which follows the fragment, it becomes possible to decide correct terms. For example, it turns out that a word "her" in the fragment "I saw her" is "det", if the next word is "aunt". It means that the term #6 is not correct.

Our method delays the decision to utilize a part of the input which follows an initial fragment, if necessary. Only if a term is correct independently of the remaining input, the method decides the term to be correct.

4.1. The Algorithm

Our method utilizes the terms constructed in incremental parsing. The terms have the syntactic information of the fragment which has been already inputed. They can be obtained for every word input. Therefore, the disambiguation is easy to be executed at an early stage. For every word input, our method decides whether the terms constructed before the input is correct, if possible.

The method utilizes an undecided part of a term and subsumption relation between terms. First, we describe an undecided part of a term.

Definition 3 (undecided part of term)
Let $\tau_1, \ldots, \tau_m$ be undecided terms which occur in a term σ in this order. Furthermore, let X_i be the category of τ_i.

Table 2: undecided part of terms

word	term	upt
	#1	*s*
I	#2	*vp* \$
saw	#3	\$
	#4	*np pp* \$
	#5	*np*1 \$
her	#6	*pp* \$
	#7, #8	*n pp* \$
aunt	#9, #10	*pp* \$
with	#11, #12	*np* \$
the	#13, #14	*n* \$
telescope	#15, #16	\$
.	#17, #18	

We call the sequence $X_1 \cdots X_m$ an undecided part of σ and denote it by $upt(\sigma)$. □

Let $w_1 \cdots w_n$ be an input sentence and σ be a term for an initial fragment $w_1 \cdots w_i (i \leq n)$. $upt(\sigma) = X_1 \cdots X_m$ means that σ becomes correct in the case where $w_{i+1} \cdots w_n$ satisfies $X_1 \cdots X_m \stackrel{*}{\Rightarrow} w_{i+1} \cdots w_n$. [1] For example, $upt(\#4)$ ="*np pp* \$" and "*np pp* \$"$\stackrel{*}{\Rightarrow}$ "her aunt with the telescope.". Therefore, #4 is correct for the sentence (1). Table 2 shows the undecided part of the terms constructed for the sentence (1).

Furthermore, let σ' be a term for the initial fragment $w_1 \cdots w_i$. When $upt(\sigma) = upt(\sigma')$, the correctness of σ and σ' is identical. Because both σ and σ' are correct if and only if $upt(\sigma) \stackrel{*}{\Rightarrow} w_{i+1} \cdots w_n$. For example, since $upt(\#7) = upt(\#8)$ ="*n pp* \$", the correctness of #7 and #8 is identical. When $upt(\sigma) = upt(\sigma')$, we write $\sigma \equiv \sigma'$.

Now, we describe the disambiguation method proposed in

[1] The definition of $\stackrel{*}{\Rightarrow}$ is as follows: Let β and γ be sequences of categories and words. Furthermore, let A be a category. If a grammar rule $A \rightarrow \alpha$ exists, then we write $\beta A \gamma \Rightarrow \beta \alpha \gamma$. $\stackrel{*}{\Rightarrow}$ is the reflexive and transitive closure of $\Rightarrow$.

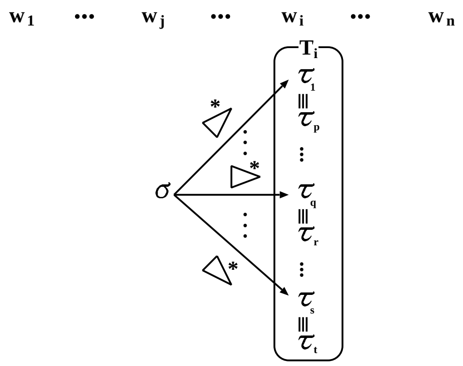

Figure 5: Decision of correct term

Table 3: correct terms

word	correct term
	#1
I	#2
saw	
her	#4
aunt	#5, #7, #8, #9, #10
with	#11, #12
the	#13, #14
telescope	#15, #16
.	#17, #18

this paper.

Theorem 4 *Let $w_1 \cdots w_n$ be an input sentence and σ be a term for an initial fragment $w_1 \cdots w_j (j \leq n)$. Furthermore, let T_i be a set of terms for an initial fragment $w_1 \cdots w_i (j \leq i \leq n)$. σ is correct for $w_1 \cdots w_n$ if σ satisfies the following condition for all $\tau \in T_i$:*

- *There exists a term $\tau' \in T_i$ such that $\sigma \rhd^* \tau'$ and $\tau' \equiv \tau$.* □

When σ satisfies the condition as shown in Figure 5, σ is correct for $w_1 \cdots w_n$. The proof is as follows: Some term $\tau_c \in T_i$ is correct for $w_{i+1} \cdots w_n$(otherwise $w_{i+1} \cdots w_n$ is not accepted by the grammar). When σ satisfies the condition, there exists some term $\tau' \in T_i$ such that $\sigma \rhd^* \tau'$ and $\tau' \equiv \tau_c$. Since τ_c is correct and $\tau' \equiv \tau_c$, τ' is correct. Therefore, σ is also correct, because $\sigma \rhd^* \tau'$.

Furthermore, it should be noted that the correctness of σ is independent of $w_{i+1} \cdots w_n$. It means that correct terms can be decided when the word w_i is inputed.

4.2. An Example

This section gives an example of the disambiguation. Table 3 shows the correct terms, which are found by the proposed method, for the sentence (1).

When "saw" is inputed, the terms #3, #4 and #5 are constructed for the initial fragment "I saw". It cannot be decided whether the terms are correct or not. When "her" is inputed, the parsing constructs terms #6, #7 and #8. *upt*(#6) ="*pp* \$" and *upt*(#7) = *upt*(#8) ="*n pp* \$". The correctness of the terms #6, #7 and #8 is not clear.

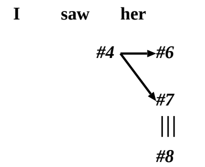

Figure 6: Finding correct term #4

However, it turns out that the term #4 is correct. Because #4 satisfies the condition in Theorem 4, as shown in Figure 6. When "aunt" is inputed, the terms #9 and #10 are constructed. #9 $\equiv$ #10 and #9 $\rhd^*$ #9. Therefore, the term #9 is correct. In the same way, the term #10 is correct.

This example shows that the proposed method can find correct terms at an early stage.

5. CONCLUSION

This paper has proposed a method of deciding correct syntactic structures, which are constructed in incremental parsing. The method can decide correct structures at an early stage. We can expect that the disambiguation method enables a dialogue system to interpret the user's utterance correctly at an early stage.

We intend to apply the method proposed in this paper to incremental spoken language translation [4].

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