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Hokkai-Gakuen Organization of Knowledge Ubiquitous through Gaining Archives.

Automatic Acquisition of Bilingual Translations Using Recursive Chain-link-type Learning from a Parallel Corpus

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Abstract

This paper describes an automatic acquisition method of bilingual translations (bilingual pairs of words or phrases) based on the learning algorithm that we call Recursive Chain-link-type Learning. The system with Recursive Chain-link-type Learning automatically acquires many bilingual translations from various bilingual sentences without requiring any analytical knowledge or a large number of similar bilingual sentences. In this learning method, bilingual translations and bilingual templates are reciprocally acquired like a linked chain. A bilingual template is a bilingual pair of generalized sentences that the system acquires by replacing bilingual translations with variables. By using collocations based on variables and their adjoining words in acquired bilingual templates, the system automatically acquires new bilingual translations from various bilingual sentences. In the experimental results, the correct acquisition rate for all nouns and noun phrases in a parallel corpus was 74.9%. Moreover, the acquisition rate of the correct equivalent for unknown words in the commercial English-to-Japanese machine translation system was 78.4%. These results show that the learning ability of the system with Recursive Chain-link-type Learning is high and the automatic acquisition method for bilingual translations using Recursive Chain-link-type Learning is effective.

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1. Introduction

In the field of machine translation, there are several studies based on corpus-based methods. The advantage of corpus-based approaches is that it is possible to deal with various linguistic phenomena by using corpora. Areas of studies using corpora are grouped as follows:

- Automatic sentence alignment[1, 2]
- Word-sense disambiguation[3, 4, 5]
- Automatic acquisition of bilingual translations[6, 7, 8, 9, 10]
- Finding bilingual collocations[11, 12]
- Estimating parameters for statistics-based machine translation[13]
- Automatic acquisition of translation knowledge in learning-based machine translation [14, 15, 16]]

For a machine translation system, it is important to develop a system that can flexibly improve bilingual dictionaries because the machine translation system often faces linguistic phenomena that appear for the first time like unknown words. In this paper, we describe a new method to acquire bilingual translations (bilingual pairs of words or phrases) from bilingual sentences, that are pairs of source language (SL) sentences and target language (TL) sentences.

Most studies for the acquisition of bilingual translations use static linguistic knowledge or large amounts of corpora[6, 7, 8, 9, 10]. However, in the case of using static linguistic knowledge, the system becomes adhoc because it is difficult for developers to give complete linguistic knowledge to the system beforehand. Moreover, the system cannot acquire bilingual translations using the other language because it depends on specific language. Even in the case of using large amounts of corpora, the system requires some linguistic knowledge, e.g., information of parts-of-speech. Therefore, the system which uses large amounts of corpora also becomes adhoc and cannot also acquire bilingual translations from bilingual sentences using other language. On the other hand, there are several studies based on learning algorithms that do not depend on static linguistic knowledge[14, 15, 16]. However, these methods require a large number of similar bilingual sentences.

To overcome these problems of the existing works, it is necessary to develop a learning-based method that can automatically acquire bilingual translations without using any linguistic knowledge beforehand and can efficiently acquire many bilingual translations from sparse bilingual sentences without requiring a large number of similar bilingual sentences. Therefore, we propose an automatic acquisition method for bilingual translations using Recursive Chain-link-type Learning[17] [18] as a new method. In the system with Recursive Chain-link-type Learning, bilingual translations and bilingual templates are reciprocally acquired from various bilingual sentences without requiring any linguistic knowledge. In this paper, a bilingual translation is a bilingual pair of words or phrases that are extracted from the SL parts and the TL parts of bilingual sentences. A bilingual template is a bilingual pair of sentences generalized by replacing bilingual translations with variables. All bilingual templates have position information to extract bilingual translations from various bilingual sentences. By using collocations based on variables and their adjoining words in bilingual templates, the system decides the parts that it extracts from the SL parts and the TL parts of bilingual sentences. Moreover, all bilingual translations have information to acquire bilingual templates. The system acquires bilingual templates by replacing the same parts as bilingual translations with variables.

Based on this process, the system reciprocally acquires bilingual translations and bilingual templates. This means that the system can efficiently acquire bilingual translations and bilingual templates from various bilingual sentences without any linguistic knowledge and without a large number of similar bilingual sentences. For example, when the bilingual translation **A** exists in the dictionary, the system can automatically acquire the bilingual template **B** by using the bilingual translation **A** from a bilingual sentence. Moreover, by using the acquired bilingual template **B**, the system can automatically acquire the bilingual translation **C** from the other bilingual sentence. Such a process of acquisition of bilingual translations and bilingual templates is like a chain where each ring is linked. Therefore, we call this mechanism Recursive Chain-link-type Learning (RCL). The details of this process are described in Section 3 and Section 5.2.2. As a result of evaluation experiments using the system with RCL, the correct acquisition rate of all nouns and noun phrases in the parallel corpus used as evaluation data was 74.9%. Moreover, we confirmed that the system with RCL is effective to solve the problem of unknown words in a machine translation system. In our evaluation experiments, the system with RCL could acquire 29 correct equivalents for 37 unknown words in the translation results outputted from a commercial English-to-Japanese machine translation system. Therefore, the acquisition rate of the correct equivalents for unknown words was 78.4%. From these results, we confirmed that the system with RCL can efficiently many bilingual translations because the learning ability of it is high.

2. Related Works in Acquisition of Bilingual Translations

Kupiec[6] proposes an algorithm for finding noun phrases from bilingual corpora. In this algorithm, noun phrase candidates are extracted from tagged and aligned parallel texts using a noun phrase recognizer. As a result, the accuracy of about 90% has been attained for the hundred highest ranking correspondences. However, this algorithm requires a large number of parallel texts to obtain high accuracies. Moreover, the system requires tagger and NP recognizer as large-scale linguistic knowledge. Kumano and Hirakawa[7] propose a method for finding compound nouns and unknown words from parallel texts. This method utilizes both statistical information and linguistic information to obtain corresponding words or phrases in parallel texts. As a result, over 70% of accurate translations of compound nouns and over 50% of unknown words have been attained from small Japanese-English parallel texts. However, this method also requires various static linguistic knowledge, e.g., machine translation bilingual dictionary and NP recognizer.

There have been many studies that acquire bilingual translations from non-parallel texts in recent years. Rapp[8] proposes a method based on the assumption that there is a correlation between the patterns of word co-occurrences in texts of different languages. Fung[9] proposes a pattern matching method based on a statistical algorithm for coupling a bilingual translation of nouns and proper nouns from non-aligned, noisy parallel texts. However, the outputs in these methods are just word-word correspondences. Moreover, these studies require large amounts of corpora to obtain high accuracies and information of parts-of-speech as linguistic knowledge to identify nouns or words. Tanaka[10] pro-

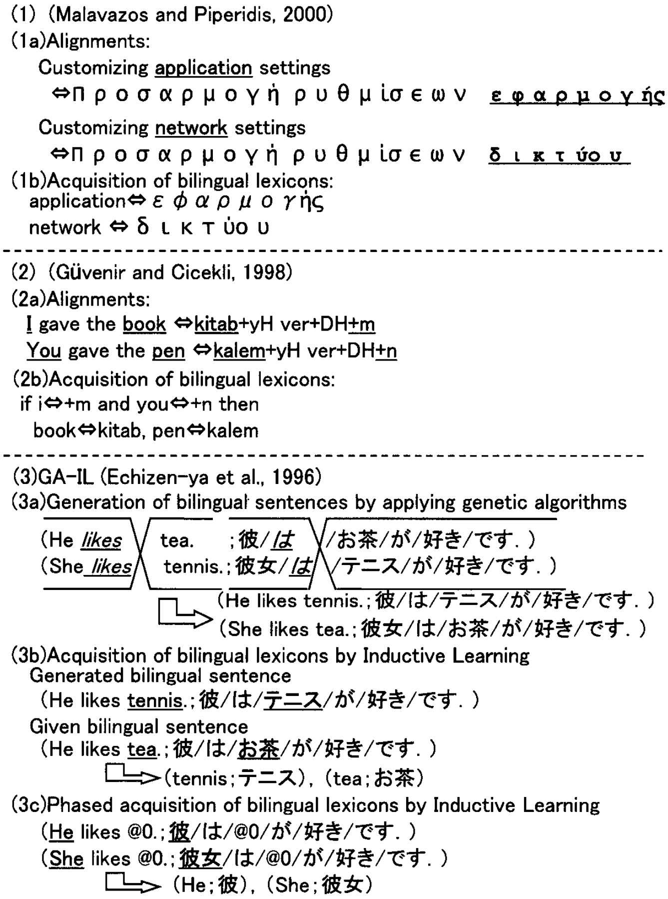

Figure 1 Related works based on learning algorithms.

poses a method for extracting compound noun translations from non-parallel corpora by using a bilingual dictionary and thesaurus. As a result, the accuracy of about 58% has been attained for compound noun translations. In that case, this method requires large-scale static linguistic knowledge like the other methods. Existing works have been proposed on the premise of using some static linguistic knowledge. However, it is difficult to give complete linguistic knowledge to the system beforehand. Therefore, the system is very adhoc because the developers must add new linguistic knowledge whenever the system faces linguistic phenomena that appear for the first time. Moreover, the system cannot acquire bilingual translations from bilingual sentences using the other language because it depends on specific language.

On the other hand, there are several studies using learning algorithms that acquire bilingual translations only from bilingual sentences without requiring static linguistic knowledge. Malavazos and Piperidis[14] propose a method based on analogical reasoning. In two bilingual sentences, this method can acquire bilingual translations only when the number of different parts between two SL sentences is just one and the number of different parts between two TL sentences is also just one as shown in (1) of Fig. 1. This means that the condition of acquisition of bilingual translations is very strict. Güvenir and Cicekli[15] propose a method that can acquire bilingual translations even when the number of different parts between two SL sentences is more than two and the number of different parts between two TL sentences is also more than two as shown in (2) of Fig. 1. However, the number of different parts between two SL sentences must be the same as the number of different parts between two TL sentences. Therefore, this method also means that the condition of acquisition of bilingual translations is strict. We propose a method using Inductive Learning with Genetic Algorithms (GA-IL)[16]. This method automatically generates two bilingual sentences in which the number of different parts between two SL sentences is just one and the number of different parts between two TL sentences is also just one by applying genetic algorithms as shown in (3) of Fig. 1. However, after all, this method also requires similar bilingual sentences as the condition of acquisition of bilingual translations. Therefore, these methods based on learning algorithms require a large number of similar bilingual sentences to acquire many bilingual translations although they do not need any static linguistic knowledge beforehand. The system with RCL can solve the problems of the existing works because it uses the method based only on learning ability, not like the methods based on static linguistic knowledge, and it efficiently acquires bilingual translations from each bilingual sentence without comparing two bilingual sentences, not like the other methods based on learning algorithms.

3. Basic Idea

RCL has an ability to extract corresponding parts from corresponding pairs of objects. In this paper, we applied RCL to bilingual sentences. Therefore, by using RCL, many bilingual translations are efficiently acquired from various bilingual sentences without any linguistic knowledge. Figure 2[1] shows the schema in the process of acquisition of bilingual translations and bilingual templates using RCL.

Figure 2 shows the process where the bilingual template **B**, the bilingual translation **C**,

[1]In Fig. 2, the use of a Greek character means that all language characters correspond to unknown character strinhs for a computer when any linguistic knowledge is not given at all.

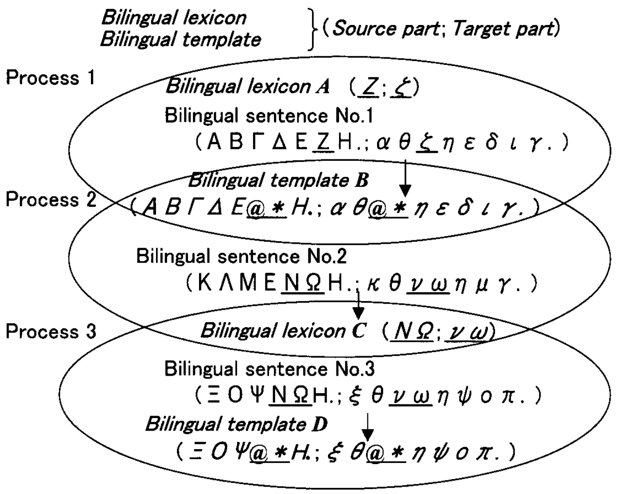

Figure 2 Schema in process of acquisition of bilingual lexicons and bilingual templates using RCL.

and the bilingual template **D** are acquired one after another by using RCL when the bilingual translation **A** exists in the dictionary. In the system with RCL, bilingual translations and bilingual templates are reciprocally acquired. This means that the chain reaction is caused in the acquisition of bilingual translations and bilingual templates. In this paper, a bilingual translation is a pair of source part and target part, and a bilingual template is also a pair of source part and target part. The source parts are the parts acquired from the SL parts of bilingual sentences, and the target parts are the parts acquired from the TL parts of bilingual sentences. In process 1 of Fig. 2, the bilingual translation **A** has information to acquire bilingual templates. By using the bilingual translation **A**, the system extracts "Z" from the SL parts of bilingual sentences and "ξ" from the TL parts of bilingual sentences. Therefore, in process 1, the system can automatically acquire the bilingual template **B** by replacing "Z" and "ξ" with the variables "@*".

Moreover, the acquired bilingual template **B** has position information to extract bilingual translations from bilingual sentences. By using collocations based on "E @*H" in the source part and "θ@*η" in the target part of the bilingual template **B**, the system extracts the parts from the right of "E" to the left of "H" in the SL parts of bilingual sentences, and extracts the parts from the right of "θ" to the left of "η" in the TL parts of bilingual sentences. Therefore, in process 2, by using the bilingual template **B**, the system can automatically acquire the bilingual translation **C** (NΩ ; νω) as the corresponding parts to the variables in the bilingual template **B** from the bilingual sentence No.2. In process 3, by using the bilingual translation **C**, the system can acquire the bilingual template **D** from the bilingual sentence No.3. In summary, the system with RCL can automatically acquire bilingual translations from various bilingual sentences by focusing not only on the whole of bilingual sentences but also on the parts of bilingual sentences, not like GA-IL or the other learning-based methods. Moreover, the system with RCL has the ability to decide common parts and different parts in character strings as a primitive ability like Inductive Learning[19] that the performs phased extraction of different parts and common parts. In this paper, a common part and a different part mean a word or a part that is composed of more than one word.

On the other hand, bilingual translations or bilingual templates that are used as starting points in the acquisition process of new bilingual translations and new bilingual templates, like the bilingual translation **A** in Fig. 2, are acquired by using GA-IL which is the method based on learning ability. The reason for using GA-IL is that our system can acquire bilingual translations based only on learning ability without any static linguistic knowledge. In this paper, the system with RCL means the system that uses both RCL and GA-IL. The system with RCL can efficiently acquire many bilingual translations based only on learning ability from various bilingual sentences as shown in Fig. 2.

4. Outline

Figure 3 shows the outline of the system with RCL to acquire bilingual translations from bilingual sentences. First, a user inputs a bilingual sentence. In the feedback process, the system evaluates bilingual translations and bilingual templates in the dictionary. In that case, the system automatically decides by using given bilingual sentences whether bilingual translations and bilingual templates are correct or not. This means that it is unnecessary for the user to directly evaluate bilingual translations and bilingual templates. In this paper, correct bilingual translations and correct bilingual templates mean that the source parts and the target parts correspond to each other. In the learning process, bilingual translations and bilingual templates are automatically acquired by using two learning algorithms, i.e., RCL and

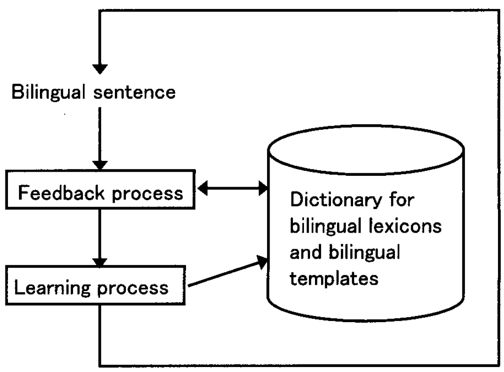

Figure 3 Process flow.

GA-IL. In this paper, the system with RCL acquires English-Japanese bilingual translations from bilingual sentences that are pairs of English sentences and Japanese sentences.

5. Process

5.1 Feedback Process

In the feedback process, first, the system generates the bilingual sentences, in which the English parts have the same character strings as the English parts of the given bilingual sentences, by combining bilingual templates with bilingual translations. Figure 4 shows an example of this process. In Fig. 4, (He is my friend. ; 彼/は/わたし/の/友達/です.[2] [*Kare wa watashi no tomodachi desu.*[3]]). The system selects the bilingual translations and the bilingual templates from the dictionary. The selected bilingual translations and bilingual templates are the ones in which the source parts, except the variables, have the same character strings as the parts in the English parts of the given bilingual sentences. In Fig. 4, three bilingual templates and one bilingual translation are selected. Moreover, the system chooses (He is my @0. ; 彼/は/わたし/の/@0/です. [*Kare wa watashi no @0 desu.*]) because the source part of this bilingual template is the closest to the English part of the given bilingual sentence in three selected bilingual templates. As a result, the system can

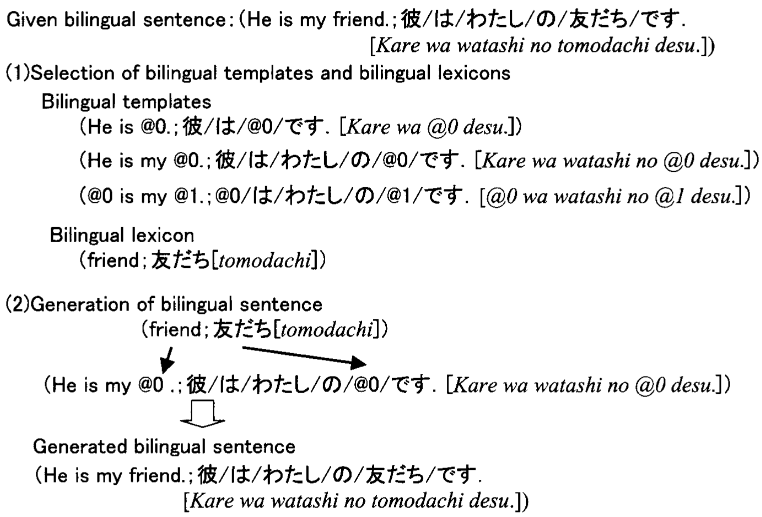

Figure 4 Example of generation of bilingual sentence.

[2]"/"in Japanese sentences are inserted after each morpheme because Japanese is an agglutinative language. This process is automatically performed by using the system based only on its learning method[19] without requiring any static linguistic knowledge.

[3]Italics express the pronunciation in Japanese.

generate the bilingual sentence, in which the English part has the same character strings as the English part of the given bilingual sentence, by combining the chosen bilingual template (He is my @0. ; 彼/は/わたし/の/@0/です. [*Kare wa watashi no @0 desu.*]) with the bilingual translation (friend;友だち [*tomodachi*]).

Next, the system compares the Japanese parts of the generated bilingual sentences with the Japanese parts of the given bilingual sentences. The bilingual translations and the bilingual templates used to generate the bilingual sentences are decided as correct when the Japanese parts of the generated bilingual sentences have the same character strings as the Japanese parts of the given bilingual sentences. As a result, the system adds one point to the correct frequency of the used bilingual translations and the used bilingual templates. On the other hand, the bilingual translations and the bilingual templates used to generate the bilingual sentences are decided to be an error when the Japanese parts of the generated bilingual sentences have different character strings from the Japanese parts of the given bilingual sentences. As a result, the system adds one point to the erroneous frequency of the used bilingual translations and the used bilingual templates. In the case of Fig. 4, the system adds one point to the correct frequency of (He is my @0. ; 彼/は/わたし/の/@0/です. [*Kare wa watashi no @0 desu.*]) and (friend ; 友だち [*tomodachi*]) because the Japanese part of the generated bilingual sentence has the same character strings as the Japanese part of the given bilingual sentence. By using correct frequency and erroneous frequency, the system calculates Correct Rate (CR) for the used bilingual translations and the used bilingual templates. CR is defined as follows:

$$\mathrm{CR}(\%) = \frac{\text{Correct frequency}}{\text{Correct frequency} + \text{Erroneous frequency}} \times 100.0$$

The system automatically evaluates bilingual translations and bilingual templates using CR. However, this evaluation method for bilingual translations and bilingual templates is not enough because there is sometimes the case that correct bilingual sentences are generated by combining erroneous bilingual translations and erroneous bilingual templates. As a result, the system adds one point to the correct frequency of the used erroneous bilingual translations and the used erroneous bilingual templates. For example, (friend ; わたし/の/友だち [*watashi no tomodachi*]) and (He is my @0. ; 彼/は/@0/です. [*Kare wa @0 desu.*]) are the erroneous bilingual translation and the erroneous bilingual template respectively because the source parts and the target parts do not correspond to each other. In this case, "friend" in English means "友だち [*tomodachi*]" in Japanese, not "わたし/の/友だち [*watashi no tomodachi*]", and "He is my @0." in English means "彼/は/わたし/の/@0/です. [*Kare wa watashi no @0 desu.*]" in Japanese, not "彼/は/@0/です. [*Kare wa @0 desu.*]". However, by combining this bilingual translation and this bilingual template, the bilingual sentence (He is my friend. ; 彼/は/わたし/の/友だち/です. [*Kare wa watashi no tomodachi desu.*]), in which the Japanese part has the same character strings as the Japanese part of the given bilingual sentence, is generated. As a result, the system adds one point to the correct frequency of the erroneous bilingual translation (friend ; わたし/の/友だち [*watashi no tomodachi*]) and the erroneous bilingual template (He is my @0. ; 彼/は/@0/です. [*Kare wa @0 desu.*]) respectively. This means that the evaluation method based on the result of combinations of bilingual translations and bilingual templates is not enough. Therefore, the system should focus on the process of combinations of bilingual translations and bilingual templates. From this point of view, we propose an evaluation method based on the process of combinations of bilingual translations and bilingual templates. We reserve the detail of this evaluation method in another paper[20].

5.2 Learning Process

5.2.1 Inductive Learning with Genetic Algorithms (GA-IL)

In this paper, GA-IL described in Section 2 is utilized for acquiring the bilingual translations and the bilingual templates that are used as starting points in RCL. By using GA-IL, the system with RCL can acquire bilingual translations based only on learning ability from bilingual sentences. In GA-IL, similar bilingual sentences are automatically generated by applying a crossover process of genetic algorithm[21]. In that case, the crossover positions are common parts between two bilingual sentences.

In (3a) of Fig. 1, "likes" is the crossover position in the English sentences and "は" [*wa*] is the crossover position in the Japanese sentences. Therefore, one-point crossover is performed by using these crossover positions. The system replaces the word following "likes" in the English sentences, and replaces the words following "は" [*wa*] in the Japanese sentences. As a result, (He likes tennis. ; 彼/は/テニス/が/好き/です. [*Kare wa tenisu ga suki desu.*]) and (She likes tea. ; 彼女/は/お茶/が/好き/です. [*Kanojo wa ocha ga suki desu.*]) are generated as new bilingual sentences. By this process, two bilingual sentences, in which the number of different parts between two SL sentences is just one and the number of different parts between two TL sentences is also just one, are automatically generated. Moreover, by using Inductive Learning, from the generated bilingual sentences and the given bilingual sentences, the system acquires bilingual translations by extracting different parts between two bilingual sentences, and it acquires bilingual templates by replacing different parts with variables. In (3b) of Fig. 1, from the generated bilingual sentence (He likes tennis. ; 彼/は/テニス/が/好き/です. [*Kare wa tenisu ga suki desu.*]) and the given bilingual sentence (He likes tea. ; 彼/は/お茶/が/好き/です. [*Kare wa ocha ga suki desu.*]), (tennis ; テニス [*tenisu*]) and (tea ; お茶 [*ocha*]) are acquired as the bilingual translations because they are the different parts between the two bilingual sentences. (He likes @0. ; 彼/は/@0/が/好き/です. [*Kare wa @0 ga suki desu.*]) is acquired as the bilingual template by replacing the different parts with the variables "@0". Moreover, from two acquired bilingual templates, new bilingual translations are acquired by performing phased extraction of different parts using Inductive Learning. In (3c) of Fig. 1, from (He likes @0. ; 彼/は/@0/が/好き/です. [Kare wa @0 ga suki desu.]) and (She likes @0. ; 彼女/は/@0/が/好き/です. [*Kanojo wa @0 ga suki desu.*]), (He ; 彼 [*kare*]) and (She ; 彼女 [*kanojo*]) are acquired as the new bilingual translations.

5.2.2 Recursive Chain-link-type Learning (RCL)

In RCL, bilingual translations and bilingual templates are reciprocally acquired. We first describe the process of acquisition of bilingual translations using bilingual templates. The details are as follows :

(1) The system selects bilingual sentences that have the same parts as the parts which adjoin variables in bilingual templates.

(2) The system acquires bilingual translations by extracting the parts that adjoin the common parts, which are the same parts as the parts in bilingual templates, from bilingual sentences. This means that the parts extracted from bilingual sentences correspond to variables in bilingual templates. In the extraction process, there are three patterns from the view of the position of variables and their adjoining words in bilingual templates:

- Pattern 1: In the case that the common parts exist both on the right side and the left side of variables in the source parts or the target parts of bilingual templates, the system extracts the parts between two common parts from the SL parts or the

TL parts of bilingual sentences.

- Pattern 2: In the case that the common parts exist only on the right side of variables in the source parts or the target parts of bilingual templates, the system extracts the parts between the words at the beginning and the words to the left of the common parts in the SL parts or the TL parts of bilingual sentences.

- Pattern 3: In the case that the common parts exist only on the left side of variables in the source parts or the target parts of bilingual templates, the system extracts the parts between the words to the right of the common parts and the words at the end in the SL parts or the TL parts of bilingual sentences.

(3) The system gives CR that is the same as the used bilingual templates to the acquired bilingual translations. This means that the bilingual translations acquired by using the bilingual templates that have high CR also have high CR.

Figure 5 shows an example of acquisition of a bilingual translation using a bilingual template. In Fig. 5, "My" and "is" adjoin the variable "@0" in the source part of the bilingual template, and they are the common parts with the parts in the English part "My job is walking the dog." of the bilingual sentence. Moreover, "の [*no*]" and "は [*wa*]" adjoin the variable "@0" in the target part of the bilingual template, and they are the common parts with the parts in the Japanese part "ぼく/の/仕事/は/犬/を/散歩/さ/せる/こと/です. [*Boku no shigoto wa inu o sanpo sa seru koto desu.*]" of the bilingual sentence. Therefore, the system acquires (job ; 仕事 [*shigoto*]) as the bilingual translation by extracting "job" from the right of "My" to the left of "is" in the English part of the bilingual

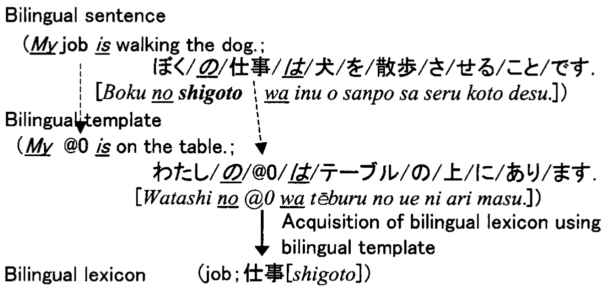

Figure 5 Example of acquisition of bilingual lexicons using bilingual templates.

sentence, and extracting "仕事 [*shigoto*]" from the right of "の [*no*]" to the left of "は [*wa*]" in the Japanese part of the bilingual sentence.

Moreover, we describe the process of acquisition of bilingual templates using bilingual translations. The details are as follows:

(1) The system selects bilingual translations in which the source parts have the same character strings as parts in the SL parts of bilingual sentences, and in which the target parts have the same character strings as parts in the TL parts of bilingual sentences.

(2) The system acquires bilingual templates by replacing the common parts which are the same parts as bilingual translations with variables, with the SL parts and the TL parts of bilingual sentences.

(3) The system gives CR that is the same as the used bilingual translations to the acquired bilingual templates. This means that the bilingual templates acquired by using the bilingual translations that have high CR also have high CR.

Figure 6 shows an example of the acquisition of a bilingual template using a bilingual translation. In Fig. 6, the source part "job" of the bilingual translation (job ; 仕事 [*shigoto*]) has the same character strings as the part in the English part "What's your job?" of the bilingual sentence, and the target part "仕事 [*shigoto*]" of the bilingual translation (job ; 仕事 [*shigoto*]) has the same character strings as the part in the Japanese part "あなた/の/仕事/は/何/です/か? [*Anata no shigoto wa nan desu ka?*]" of the bilingual sentence. Therefore, the system acquires (What's your @0? ; あなた/の/@0/は/何/です/か? [*Anata no @0 wa nan desu ka?*]) as the bilingual template by replacing "job" and "仕事 [*shigoto*]" with the variables "@0", with the bilingual sentence (What's your job? ; あなた/の/仕事/は/

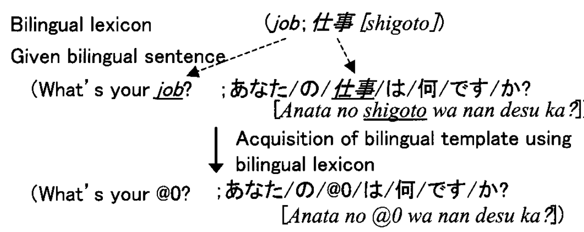

Figure 6 Example of acquisition of bilingual templates using bilingual lexicons.

何/です/か? [*Anata no shigoto wa nan desu ka?*]).

6. Experiments for Performance Evaluation

6.1 Experimental Procedure

In order to evaluate the system with RCL, 2,856 bilingual sentences that are pairs of English sentences and Japanese sentences were used as experimental data. These bilingual sentences were taken from textbooks for first[22] and second[23, 24, 25, 26] grade junior high school students. The total number of characters of the 2,856 bilingual sentences is 142,592. The average number of words in English sentences in the 2,856 bilingual sentences is 6.0. All bilingual sentences are processed by the system based on the outline described in Section 4 and on the process described in Section 5. Initial condition of the dictionary is empty.

6.2 Evaluation Standard

In this paper, we evaluated all acquired bilingual translations that correspond to nouns and noun phrases. The reason that we evaluated only nouns and noun phrases is because it is possible to correctly evaluate them. In nouns and noun phrases, the relation between English and Japanese are much clearer than other parts-of-speech like verbs that have complicated conjugation. The acquired bilingual translations are ranked when several different equivalents are gotten for the same source parts. In that case, the bilingual translations are sorted so that the bilingual translations which have the highest CR described in Section 5.1 are ranked at the top. Among the ranked bilingual translations, three bilingual translations ranked from No.1 to No.3 are evaluated.

6.3 Experimental Results

In the evaluation data, there are 463 kinds of nouns and noun phrases. The number of all nouns is 437 kinds and the number of all noun phrases is 26 kinds. Table 1 shows the correct acquisition rate of the system with RCL in the evaluation data. In Table 1, the values in () mean the number of the correct bilingual translations acquired by the system with RCL. Moreover, we performed the evaluation experiment using the system with only GA-IL. Table 2 shows the correct acquisition rate of the system with only GA-IL.

In Table 1 and Table 2, the correct acquisition rate improved from 58.7% to 74.9% by using RCL. On the other hand, the correct acquisition rate of the system with RCL was 66.1% when only one bilingual translation ranked as No.1 was evaluated. The correct acquisition rate of the system with only GA-IL was 50.3% when only one bilingual translation ranked as No.1 was evaluated. Table 3 shows examples of the acquired correct bilingual translations.

Table 1 Correct acquisition rate of the system with RCL.

Correct acquisition rate	Detail	
	nouns	noun phrases
74.9%(347)	75.5%(330)	65.4%(17)

Table 2 Correct acquisition rate of the system with only GA-IL.

Correct acquisition rate	Detail	
	nouns	noun phrases
58.7%(272)	60.4%(264)	30.8%(8)

Table 3 Examples of acquired correct bilingual lexicons.

Examples of acquired correct nouns	
English	Japanese
boomerang	ブーメラン [*bumeran*]
science	科学 [*kagaku*]
monorail	モノレール [*monoreru*]
reservation	指定/居住/地 [*shitei kyoju chi*]
指定/居住/地[*shitei kyoju chi*] means a place where the aborigines live.	
watch	時計 [*tokei*]
museum	博物館 [*hakubutsukan*]
Shakespeare	シェイクスピア [*sheikusupia*]
Saturn	土星 [*dosei*]
machine	機械 [*kikai*]
sumo	すもう [*sumo*]
すもう [*sumo*] means Japanese traditional sport.	
fool	愚か/な/人 [*oroka na hito*]
愚か/な/人 [*oroka na hito*] means a foolish person.	
Examples of acquired correct noun phrases	
gift shop	みやげ/品/店 [*miyage hin ten*]
Statue of Liberty	自由/の/女神 [*jiyu no megami*]
Alice in Wonderland	不思議/の/国/の/アリス [*fushigi no kuni no arisu*]
electric guitar	エレキ/・/ギター [*ereki gita*]
ball point pen	ボールペン [*boru pen*]

6.4 Discussions

6.4.1 Correct Acquisition Rate and Learning Ability of Recursive Chain-link-type Learning (RCL)

From the experimental results, we confirmed that the system with RCL can acquire many bilingual translations based only on learning ability without requiring static linguistic knowledge. The correct acquisition rate of 74.9% shows that the learning ability of the system with RCL is very high.

Moreover, we confirmed that the system with RCL can acquire bilingual translations without requiring a large number of the frequency of appearances of bilingual translations. Figure 7 shows the change of the correct acquisition rates of the system with RCL and the system with only GA-IL for every one hundred bilingual translations that correspond to nouns and noun phrases in the 2,856 bilingual sentences used as evaluation data. 463 bilingual translations that correspond to noun and noun phrases are sorted in the sequence of appearances in Fig. 7.

In Fig. 7, the dotted line shows the average of the frequency of appearances of bilingual translations for every one hundred bilingual translations that correspond to nouns and noun phrases in the evaluation data. The average of the frequency of appearances of bilingual translations between No.1 and No.100 is high because such bilingual translations appear in many other bilingual sentences. The average of the frequency of appearances of bilingual translations between No.1 and No.100 is 13. For example, the sequence of appearances of (basketball ; バスケットボール [*basukettobōru*]) is No.10, and (basketball ; バスケットボール

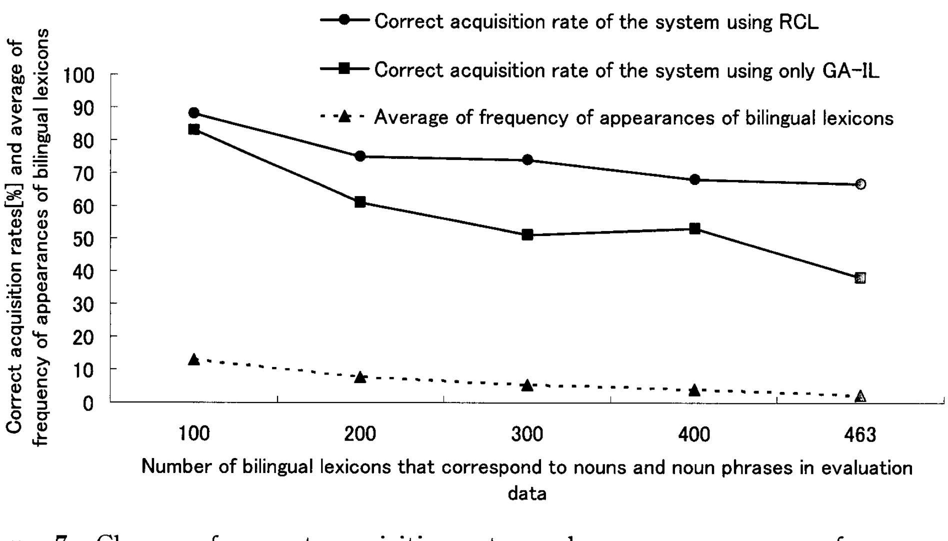

Figure 7 Change of correct acquisition rates and average appearance frequency of acquired bilingual lexicons.

[*basukettobōru*]) appears in No.19 bilingual sentences for the first time. This means that the frequency of appearances of (basketball ; バスケットボール [*basukettobōru*]) can be high because 2,837 bilingual sentences, except 19 bilingual sentences from the 2,856 bilingual sentences, are given to the system after (basketball ; バスケットボール [*basukettobōru*]) appears in the evaluation data for the first time. The total frequency of appearances of (basketball ; バスケットボール [*basukettobōru*]) is 14. It is easy for the system to acquire the bilingual translations when the frequency of appearances of them is high because the chances that the system can acquire them increase. As a result, the correct acquisition rate of bilingual translations between No.1 and No.100 is higher than the ones in the other parts in Fig. 7.

On the other hand, the average of the frequency of appearances of bilingual translations between No.401 and No.463 is low because such bilingual translations do not appear in any other bilingual sentences. The average of the frequency of appearances of bilingual translations between No.401 and No.463 is 2.43. For example, the sequence of appearances of (ball point pen ; ボールペン [*bōru pen*]) is No.442, and (ball point pen ; ボールペン [*bōru pen*]) appears in No.2,583 bilingual sentences for the first time. This means that the frequency of appearances of (ball point pen ; ボールペン [*bōru pen*]) is low because only 273 bilingual sentences, except 2,583 bilingual sentences from the 2,856 bilingual sentences, are given to the system after (ball point pen ; ボールペン [*bōru pen*]) appears in the evaluation data for the first time. The total frequency of appearances of (ball point pen ; ボールペン [*bōru pen*]) is only one. It is difficult for the system to acquire the bilingual translations when the frequency of appearances of them is low because the chances that the system can acquire them decrease.

In Fig. 7, the correct acquisition rate of the system with only GA-IL decreases rapidly as the frequency of appearances of bilingual translations gets lower. In contrast, the correct acquisition rate of the system with RCL is almost flat except between No.1 and No. 100. In the system with RCL, the decrement of the correct acquisition rate is only 9 points between No.101 and No.463. In the system with only GA-IL, the decrement of the correct acquisition rate is 23 points between No.101 and No.463. This result shows that the system with RCL can efficiently acquire many bilingual translations without requiring a large number of the frequency of appearances of bilingual translations because it possesses a high learning ability. In Table 2, the correct acquisition rate of 30.8% of noun phrases is very low in the system with only GA-IL. The reasons is that the frequency of appearances of most noun phrases is low. The average of the frequency of appearances of noun phrases is 2.35. In the system with RCL, the correct acquisition rate of noun phrases is 65.4% in Table 1. This result also shows that the system with RCL can efficiently acquire many bilingual translations without requiring a large number of the frequency of appearances of bilingual translations.

6.4.2 Acquired Bilingual Translations and Acquired Bilingual Templates

By using RCL, both the number of the acquired bilingual translations and the number of the acquired bilingual templates increased. Therefore, the correct acquisition rate of the system with RCL improved more than the correct acquisition rate of the system with only GA-IL. In the 2,856 bilingual sentences used as evaluation data, by using RCL, the number of the acquired bilingual translations increased 2,449 more, the number of the acquired bilingual templates increased 20,541 more than the ones in the system with only GA-IL. Figure 8 shows that the change of the increased number of the acquired bilingual translations and the acquired bilingual templates for every one hundred bilingual sentences in the evaluation data.

In Fig. 8, we can confirm that the increase in number of the acquired bilingual translations and the acquired bilingual templates expands as the number of the bilingual sentences increases. In the 2,856 bilingual sentences used as evaluation data, any similar bilingual sentences do not exist. This means that the system with only GA-IL cannot

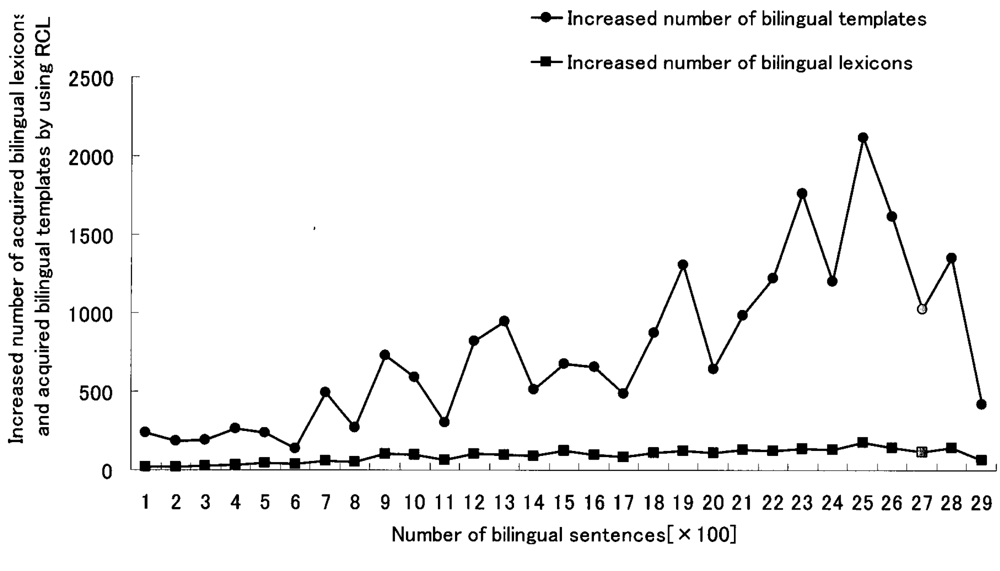

Figure 8 Change of increased number of acquired bilingual lexicons and acquired bilingual templates.

acquire any bilingual translations and bilingual templates as the number of the bilingual sentences increases because it requires a large number of similar bilingual sentences to acquire many bilingual translations and bilingual templates. In contrast, the system with RCL can efficiently acquire bilingual translations and bilingual templates from sparse bilingual sentences without requiring a large number of similar bilingual sentences. Therefore, in Fig. 8, the margin in the increased number of the acquired bilingual translations and the acquired bilingual templates expands between the system with RCL and the system with only GA-IL.

However, the system with RCL acquires not only correct bilingual translations and correct bilingual templates but also erroneous bilingual translations and erroneous bilingual templates. As it was mentioned in Section 5.1, erroneous bilingual translations and erroneous bilingual templates mean that the source parts and the target parts do not correspond to each other. We investigated the precision of the acquired bilingual translations and the acquired bilingual templates. As a result, we confirmed that the precision of the acquired bilingual translations was 47.3%. This precision is not enough because 52.7% of the erroneous bilingual translations were acquired at the same time. The acquisition of erroneous bilingual translations is, in most cases, caused by the difference of structure between bilingual templates and bilingual sentences. For example, from the bilingual template (He is @0. ; 彼/は/@0/です. [Kare wa @0 desu.]) which is the affirmative sentence and the bilingual sentence (Who is this boy? ; この/少年/は/誰/です/か? [*Kono shōnen wa dare desu ka?*]) which is the interrogative sentence, (this boy ; だれ [*dare*]) is acquired as the erroneous bilingual translation because "this boy" corresponds to the variable "@0" by the collocations between "<u>is</u> @0" in the source part of the bilingual template and "<u>is</u> this boy" in the English part of the bilingual sentence, and "だれ [*dare*]" corresponds to the variable "@0" by the collocations between "<u>は</u>/@0/<u>です</u> [<u>*wa*</u> *@0* <u>*desu*</u>]" in the target part of the bilingual template and "<u>は</u>/だれ/<u>です</u> [<u>*wa*</u> *dare* <u>*desu*</u>]" in the Japanese part of the bilingual sentence. However, this acquired bilingual translation (this boy ; だれ [*dare*]) is the erroneous bilingual translation because "this boy" in English means "この/少年 [*kono shōnen*]" in Japanese, not "だれ [*dare*]". On the other hand, the precision of the acquired bilingual templates was 54.6%. This precision is also not enough because 45.4% of the erroneous bilingual templates were acquired at the same time. However, in the feedback process described in Section 5.1, the system with RCL can evaluate these bilingual translations as erroneous bilingual translations. The rate that the system could decide as the erroneous bilingual translations for the acquired erroneous bilingual translations was 69.2%. In that case, the erroneous bilingual translations decided by the system mean the acquired bilingual translations whose CR is under 50.0%.

6.4.3 Acquisition of Correct Equivalents for Unknown Words

We confirmed that the system with RCL is effective to solve the problem of unknown words in a commercial machine translation system. We gave the English parts of the 2, 856 bilingual sentences used as evaluation data to the commercial English-to-Japanese machine translation system. As a result, 37 unknown words were included in the Japanese translation results generated by the commercial machine translation system. In that case, their unknown words appear as alphabets in the Japanese translation results because the commercial machine translation system cannot translate them at all. The system with RCL acquired 29 correct equivalents for the 37 unknown words. Therefore, the acquisition rate of the correct equivalents for unknown words is 78.4%. On the other hand, the system with only GA-IL acquired 23 correct equivalents for the 37 unknown words. Therefore, the acquisition rate of the correct equivalents for unknown words is 62.2% in the system with only GA-IL. The acquisition rate of the correct equivalents for unknown words improved from 62.2% to 78.4% by using RCL. These results show that the system with RCL is effective to solve the problem of unknown words in the machine translation system. Table 4 shows examples of the acquired correct equivalents for unknown words. All unknown words in 2,856 English sentences were proper nouns.

Table 4 Examples of acquired correct equivalents for unknown words.

English	Japanese
Rika	りか[*rika*]
りか[*rika*] means a Japanese name.	
Shinkansen	新幹線[*shinkansen*]
新幹線[*shinkansen*] means a Japanese transportation like train.	
Lake Biwa	琵琶湖[*biwa ko*]
琵琶湖[*biwa ko*] means a famous lake in Japan.	
Ishikari River	石狩川[*ishikari gawa*]
石狩川[*ishikari gawa*] means a famous river in Japan.	
Mt. Asama	浅間山[*asama yama*]
浅間山[*asama yama*] means a famous mountain in Japan.	

6.4.4 Advantage of Recursive Chain-link-type Learning (RCL)

By using RCL, a lot of bilingual translations and a lot of bilingual templates can be efficiently acquired from various bilingual sentences. This reason is that the system with RCL causes the chain reaction in acquisition of new bilingual translations and new bilingual templates. Figure 9 shows an example of the chain reaction in the acquisition of bilingual translations and bilingual templates using RCL.

In Fig. 9, (Statue of Liberty ; 自由/の/女神 [*jiyu no megami*]) is eventually acquired as the bilingual translation. First, the bilingual translation (boy ; 少年 [*shonen*]) that is used as starting point in RCL is acquired by GA-IL in (1) of Fig. 9. The acquired bilingual translation (boy ; 少年 [*shonen*]) has information that the system can extract "boy" from the SL parts of bilingual sentences and can extract "少年 [*shonen*]" from the TL parts of bilingual sentences. Therefore, by using the bilingual translation (boy ; 少年 [*shonen*]), the system can acquire (The @0 is shouting. ; @0/が/叫ん/で/い/ます. [*@0 ga saken de i masu.*]) as the bilingual template from the bilingual sentence (The boy is shouting. ; 少年/が/叫ん/で/い/ます. [*Shonen ga saken de i masu.*]) in (2) of Fig. 9. The acquired bilingual

(1) Acquisition of bilingual lexicons using GA-ILMT
(Who is that girl?; あの/女の子/は/だれ/です/か? [*Ano* ***onna no ko*** *wa dare desu ka?*]) → (girl; 女の子[*onna no ko*])
(Who is that boy?; あの/少年/は/だれ/です/か? [*Ano* ***shōnen*** *wa dare desu ka?*]) → (boy; 少年[***shōnen***])
(2) Acquisition of bilingual template using the bilingual lexicon
(boy; 少年[***shōnen***])
(The boy is shouting.; 少年/が/叫ん/で/い/ます. [***Shōnen*** *ga saken de i masu.*])
→ (The @0 is shouting.; @0/が/叫ん/で/い/ます. [***@0*** *ga saken de i masu.*])
(3) Acquisition of bilingual lexicon using the bilingual template
(*The* @0 is shouting.; @0/が/叫ん/で/い/ます. [***@0*** *ga saken de i masu.*])
(*The* wind is very strong.; 風/が/とても/強い. [***Kaze*** *ga totemo tsuyoi.*]) → (wind; 風[***kaze***])
(4) Acquisition of bilingual template using the bilingual lexicon
(wind; 風[***kaze***])
(The wind is always blowing.; 風/は/いつも/吹い/て/い/ます. [***Kaze*** *wa itsumo fui te i masu.*])
→ (The @0 is always blowing.; @0/は/いつも/吹い/て/い/ます. [***@0*** *wa itsumo fui te i masu.*])
(5) Acquisition of bilingual lexicon using the bilingual template
(*The* @0 is always blowing.; @0/は/いつも/吹い/て/い/ます. [***Kaze*** *wa itsumo fui te i masu.*])
(*The* moon is smaller than the earth.; 月/は/地球/より/小さい. [***Tsuki*** *wa chikyū yori chīsai.*]) → (moon; 月[***tsuki***])
(6) Acquisition of bilingual template using the bilingual lexicon
(moon; 月[***tsuki***])
(The moon was first visited in 1969.; 月/は/1969/年/に/最初/に/訪れ/られ/まし/た. [***Tsuki*** *wa senkyūhyakurokujūkyū nen ni saisho ni otozure rare mashi ta.*])
→ (The @0 was first visited in 1969.; @0/は/1969/年/に/最初/に/訪れ/られ/まし/た. [***@0*** *wa senkyūhyakurokujūkyū nen ni saisho ni otozure rare masih ta.*])
(7) Acquisition of bilingual lexicon using the bilingual template
(*The* @0 was first visited in 1969.; @0/は/1969/年/に/最初/に/訪れ/られ/まし/た. [***@0*** *wa senkyūhyakurokujūkyū nen ni saisho ni otozure rare mashi ta.*])
(*The* Statue of Liberty was given to the United States in 1884.; 自由/の/女神/は/1884/年/に/アメリカ合衆国/に/与え/られ/まし/た. [***Jiyū no megami*** *wa senhappyakuhachijūyo nen ni amerika gasshūkoku ni atae rare mashi ta.*])
→ (Statue of Liberty; 自由/の/女神[***Jiyū no megami***])

Figure 9 Example of process of acquisition of bilingual lexicons using RCL.

template (The @0 is shouting. ; @0/が/叫ん/で/い/ます. [*@0 ga saken de i masu.*]) has position information to extract bilingual translations from bilingual sentences. By using collocations based on "The @0 is" in the source part and "@0/が [*@0 ga*]" in the target part of the bilingual template (The @0 is shouting. ; @0/が/叫ん/で/い/ます. [*@0 ga saken de i masu.*]), the system can extract the part from the right of "The" to the left of "is" in the SL parts of bilingual sentences, and can extract the part between the words at the beginning and the words to the left of "が" in the TL parts of bilingual sentences. Therefore, in (3) of Fig. 9, by using the bilingual template (The @0 is shouting. ; @0/が/叫ん/で/い/ます. [*@0 ga saken de i masu.*]), the system automatically acquires (wind ; 風 [*kaze*]) as the bilingual translation from (The wind is very strong. ; 風/が/とても/強い. [*Kaze ga totemo tsuyoi.*]). This means that "wind" and "風 [*kaze*]" in the bilingual sentence (The wind is very strong. ; 風/が/とても/強い. [*Kaze ga totemo tsuyoi.*]) correspond to the variables "@0" in the bilingual template (The @0 is shouting. ; @0/が/叫ん/で/い/ます. [*@0 ga saken de i masu.*]). Moreover, (The @0 is always blowing. ; @0/は/いつも/吹い/て/い/ます. [*@0 wa itsumo fui te i masu.*]) as the bilingual template in (4) of Fig. 9, (moon;月 [*tsuki*]) as the bilingual translation in (5) of Fig. 9, (The @0 was first visited in 1969. ; @0/は/1969/年/に/最初/に/訪れ/られ/まし/た. [*@0 wa senkyūhyakuroku-jūkyū nen ni saisho ni otozure rare mashi ta.*]) as the bilingual template in (6) of Fig. 9, and (Statue of Liberty ; 自由/の/女神 [*jiyū no megami*]) as the bilingual translation in (7) of Fig. 9 are acquired one after another. Figure 9 shows that the chain reaction is caused in the acquisition of bilingual translations and bilingual templates. In the system with RCL, the acquired bilingual translations and the acquired bilingual templates have information to extract new bilingual translations and new bilingual templates from various bilingual sentences. Therefore, the system with RCL causes the chain reaction in the acquisition of bilingual translations and bilingual templates.

7. Conclusion

In this paper, we proposed the automatic acquisition method of bilingual translations using Recursive Chain-link-type Learning (RCL). In the system with RCL, bilingual translations and bilingual templates are reciprocally acquired like a linked chain. The system with RCL automatically acquires bilingual translations by using collocations based on variables and their adjoining words in bilingual templates. Moreover, the system with

RCL automatically acquires new bilingual templates by replacing the parts that have the same character strings as the acquired bilingual translations with variables, with bilingual sentences. Therefore, the system with RCL can reciprocally acquire bilingual translations and bilingual templates like a linked chain. This means that the system with RCL can efficiently acquire many bilingual translations from sparse bilingual sentences based only on learning ability without requiring any static linguistic knowledge or a large number of similar bilingual sentences, not like existing approaches.

From evaluation experiments, the correct acquisition rate of all nouns and noun phrases in the parallel corpus used as evaluation data was 74.9%. The correct acquisition rate of all nouns and noun phrases of the system with only GA-IL was 58.7%. Therefore, by using RCL, the correct acquisition rate of all nouns and noun phrases improved from 58.7% to 74.9%. Moreover, the acquisition rate of the correct equivalents for unknown words in the commercial English-to-Japanese machine translation system was 78.4%. The acquisition rate of the correct equivalents for unknown words of the system with only GA-IL was 62.2%. Therefore, by using RCL, the acquisition rate of the correct equivalents for unknown words improved from 62.2% to 78.4%. These results show that RCL is very effective to acquire bilingual translations.

In the future, we will go on with the evaluation experiments using practical data, and will confirm that the system with RCL can acquire bilingual translations from bilingual sentences using the other languages. This means that the system with RCL is a learning method that does not depend on specific language. Moreover, we will apply RCL to the other natural language processing systems, i.e., a dialog system, to confirm the effectiveness of RCL.

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