Noun-Noun Compound Machine Translation: 
A Feasibility Study on Shallow Processing

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Abstract

The translation of compound nouns is a major issue in machine translation due to their frequency of occurrence and high productivity. Various shallow methods have been proposed to translate compound nouns, notable amongst which are memory-based machine translation and word-to-word compositional machine translation. This paper describes the results of a feasibility study on the ability of these methods to translate Japanese and English noun-noun compounds.

1 Introduction

Multiword expressions are problematic in machine translation (MT) due to the idiomativity and overgeneration problems (Sag et al., 2002). Idiomativity is the problem of compositional semantic unpredictability and/or syntactic markedness, as seen in expressions such as kick the bucket (= die) and by and large, respectively. Overgeneration occurs as a result of a system failing to capture idiosyncratic lexical affinities between words, such as the blocking of seemingly equivalent word combinations (e.g. many thanks vs. *several thanks). In this paper, we target the particular task of the Japanese→English machine translation of noun-noun compounds to outline the various techniques that have been proposed to tackle idiomativity and overgeneration, and carry out detailed analysis of their viability over naturally-occurring data.

Noun-noun (NN) compounds (e.g. web server, car park) characteristically occur with high frequency and high lexical and semantic variability. A summary examination of the 90m-word written component of the British National Corpus (BNC, Burnard (2000)) unearthed over 400,000 NN compound types, with a combined token frequency of 1.3m;¹ that is, over 1% of words in the BNC are NN compounds. Moreover, if we plot the relative token coverage of the most frequently-occurring NN compound types, we find that the low-frequency types account for a significant proportion of the type count (see Figure 1²). To achieve 50% token coverage, e.g., we require coverage of the top 5% most-frequent NN compounds, amounting to roughly 70,000 types with a minimum token frequency of 10. NN compounds are especially prevalent in technical domains, often with idiosyncratic semantics: Tanaka and Matsuo (1999) found that NN compounds accounted for almost 20% of entries in a Japanese-English financial terminological dictionary.

Various claims have been made about the level of processing complexity required to translate NN compounds, and proposed translation methods range over a broad spectrum of processing complexity. There is a clear division between the proposed methods based on whether they attempt to interpret the semantics of the NN compound (i.e. use deep processing), or simply use the source language word forms to carry out the translation task (i.e. use shallow processing). It is not hard to find examples of semantic mismatch in NN compounds to motivate deep translation methods: the Japanese idobata-kaigi “(lit.) well-side meeting”, e.g., translates most naturally into English as “idle gossip”, which a shallow method would be hard put to predict. Our interest is in the relative occurrence of such NN compounds and their impact on the performance of shallow translation methods. In particular, we seek to determine what proportion of NN compounds shallow translation translation methods can reasonably translate and answer the question: do shallow methods perform well enough to preclude the need for deep processing? The answer to this question takes the form of an estimation of the upper bound on translation performance for shallow translation methods.

In order to answer this question, we have selected the language pair of English and Japanese, due to the high linguistic disparity between the two languages. We consider the tasks of both English-to-Japanese (EJ) and Japanese-to-English (JE) NN compound translation over fixed datasets of NN compounds, and apply representative shallow MT methods to the data.

¹Results based on the method described in § 3.1.

²The graph for Japanese NN compounds based on the Mainichi Corpus is almost identical.

³With all Japanese NN compound examples, we explicitly segment the compound into its component nouns through the use of the “-” symbol.
2 Methods for translating NN compounds

Two basic paradigms exist for translating NN compounds: memory-based machine translation and dynamic machine translation. Below, we discuss these two paradigms in turn and representative instantiations of each.

2.1 Memory-based machine translation

Memory-based machine translation (MBMT) is a simple and commonly-used method for translating NN compounds, whereby translation pairs are stored in a static translation database indexed by their source language strings. MBMT has the ability to produce consistent, high-quality translations (conditioned on the quality of the original bilingual dictionary) and is therefore suited to translating compounds in closed domains. Its most obvious drawback is that the method can translate only those source language strings contained in the translation database.

There are a number of ways to populate the translation database used in MBMT, the easiest of which is to take translation pairs directly from a bilingual dictionary (dictionary-driven MBMT or MBMT_{DICT}). MBMT_{DICT} offers an extremest solution to the idiomaticity problem, in treating all NN compounds as being fully lexicalised. Overgeneration is not an issue, as all translations are manually determined.

As an alternative to a precompiled bilingual dictionary, translation pairs can be extracted from a parallel corpus (Fung, 1995; Smadja et al., 1996; Ohnori and Higashida, 1999), that is a bilingual document set that is translation-equivalent at the sentence or paragraph level; we term this MT configuration alignment-driven MBMT (or MBMT_{ALIGN}). While this method alleviates the problem of limited scalability, it relies on the existence of a parallel corpus in the desired domain, which is often an unreasonable requirement.

Whereas a parallel corpus assumes translation equivalence, a comparable corpus is simply a crosslingual pairing of corpora from the same domain (Fung and McKeown, 1997; Rapp, 1999; Tanaka and Matsuo, 1999; Tanaka, 2002). It is possible to extract translation pairs from a comparable corpus by way of the following process (Cao and Li, 2002):

1. extract NN compounds from the source language corpus by searching for NN bigrams (e.g. 機械 翻訳 kikai-ho'nyuku "machine translation")

2. compositionally generate translation candidates for each NN compound by accessing translation templates; example JE translation templates for source Japanese string [N₁ N₂] are [N₁ N₂]_{E} and [N₂ of N₁]_{E}, where the numeric subscripts indicate word coindexation between Japanese and English (resulting in, e.g., machine translation and translation of machine)

3. use empirical evidence from the target language corpus to select the most plausible translation candidate

We term this process word-to-word compositional MBMT (or MBMT_{COMP}). While the coverage of MBMT_{COMP} is potentially higher than MBMT_{ALIGN} due to the greater accessibility of corpus data, it is limited to some degree by the coverage of the simplex translation dictionary used in Step 2 of the translation process. That is, only those NN compounds whose component nouns occur in the bilingual dictionary can be translated.

Note that both MBMT_{ALIGN} and MBMT_{COMP} lead to a static translation database. MBMT_{COMP} is also subject to overgeneration as a result of dynamically generating translation candidates.

2.2 Dynamic machine translation

Dynamic machine translation (DMT) is geared towards translating arbitrary NN compounds. In this paper, we consider two methods of dynamic translation: word-to-word compositional DMT and interpretation-driven DMT.
Word-to-word compositional DMT (or \( \text{DMT}_{\text{COMP}} \)) differs from MBMT\(_{\text{COMP}}\) only in that the source NN compounds are fed directly into the system rather than extracted out of a source language corpus. That is, it applies Steps 2 and 3 of the method for MBMT\(_{\text{COMP}}\) to an arbitrary source language string.

Interpretation-driven DMT (or \( \text{DMT}_{\text{INTERP}} \)) offers the means to deal with NN compounds where strict word-to-word alignment does not hold. It generally does this in two stages:

1. use semantics and/or pragmatics to carry out deep analysis of the source NN compound, and map it into some intermediate (i.e. interlingual) semantic representation (Copestake and Lascarides, 1997; Barker and Szpakowicz, 1998; Rosario and Hearst, 2001)

2. generate the translation directly from the semantic representation

DMT\(_{\text{INTERP}}\) removes any direct source/target language interdependence, and hence solves the problem of overgeneration due to crosslingual bias. At the same time, it is forced into tackling idiomaticity head-on, by way of interpreting each individual NN compound. As for MBMT\(_{\text{COMP}}\), DMT\(_{\text{INTERP}}\) suffers from undergeneration.

With DMT\(_{\text{INTERP}}\), context must often be called upon in interpreting NN compounds (e.g. apple juice seat (Levi, 1978; Bauer, 1979)), and minimal pairs with sharply-differentiated semantics such as colour/group photograph illustrate the fine-grained distinctions that must be made. It is interesting to note that, while these examples are difficult to interpret, in an MT context, they can all be translated word-to-word compositionally into Japanese. That is, apple juice seat translates most naturally as アップルジュース・の・席 appurujuusu-no-seki "apple-juice seat",\(^4\) which retains the same scope for interpretation as its English counterpart; similarly, colour photograph translates trivially as カラー・写真 karaa-shashin "colour photograph" and group photograph as 団体・写真 daNta-shashin "group photograph". In these cases, therefore, DMT\(_{\text{INTERP}}\) offers no advantage over DMT\(_{\text{COMP}}\), while incurring a sizeable cost in producing a full semantic interpretation.

3 Methodology

We selected the tasks of Japanese-to-English and English-to-Japanese NN compound MT for evaluation, and tested MBMT\(_{\text{DICT}}\) and DMT\(_{\text{COMP}}\) on each task. Note that we do not evaluate MBMT\(_{\text{ALIGN}}\) as results would have been too heavily conditioned on the makeup of the parallel corpus and the particular alignment method adopted. Below, we describe the data and method used in evaluation.

3.1 Testdata

In order to generate English and Japanese NN compound testdata, we first extracted out all NN bigrams from the BNC (90m word tokens, Burnard (2000)) and 1996 Mainichi Shimbun Corpus (32m word tokens, Mainichi Newspaper Co. (1996)), respectively. The BNC had been tagged and chunked using fnTBL (Ngai and Florian, 2001), and lemmatised using morph (Minnen et al., 2001), while the Mainichi Shimbun had been segmented and tagged using ALT-JAWS.\(^5\) For both English and Japanese, we took only those NN bigrams adjoined by non-nouns to ensure that they were not part of a larger compound nominal. In the case of English, we additionally measured the entropy of the left and right contexts for each NN type, and filtered out all compounds where either entropy value was < 1.\(^6\) This was done in an attempt to, once again, exclude NNs which were embedded in larger MWEs, such as service department in social service department.

We next extracted out the 250 most common NN compounds from the English and Japanese data, and from the remaining data, randomly selected a further 250 NN compounds of frequency 10 or greater (out of 20,748 English and 169,899 Japanese NN compounds). In this way, we generated a total of 500 NN compounds for each of English and Japanese. For the Japanese NN compounds, any errors in segmentation were post-corrected. Note that the top-250 NN compounds accounted for about 7.0% and 3.3% of the total token occurrences of English and Japanese NN compounds, respectively; for the random sample of 250 NN compounds, the relative occurrence of the English and Japanese compounds out of the total token sample was 0.5% and 0.1%, respectively.

We next generated a unique gold-standard translation for each of the English and Japanese NN compounds. In order to reduce the manual translation overhead and maintain consistency with the output of MBMT\(_{\text{DICT}}\) in evaluation, we first tried to translate each English and Japanese NN compound automatically by MBMT\(_{\text{DICT}}\). In this, we used the union of two Japanese-English dictionaries: the ALTDIC dictionary and the on-line EDICT dictionary (Breen, 1995). The ALTDIC dictionary was compiled from the ALT/J/E MT system (Ikehara et al., 1991), and has approximately 400,000 entries including more than 200,000 proper nouns; EDICT has approximately 150,000 entries. In the case that multiple translation candidates were found for a given NN compound, the most appropriate of these was selected manually, or in the case that the dictionary translations were considered

\(^4\)Here, no is the genitive marker.

\(^5\)http://www.kecl.ntt.co.jp/icl/mtg/resources/altjaws.html

\(^6\)For the left token entropy, if the most-probable left context was the, a or a sentence boundary, the threshold was switched off. Similarly for the right token entropy, if the most-probable right context was a punctuation mark or sentence boundary, the threshold was switched off.
to be sub-optimal or inappropriate, the NN compound was put aside for manual translation. Finally, all dictionary-based translations were manually checked for accuracy.

The residue of NN compounds for which a translation was not found were translated manually. Note that as we manually check all translations, the accuracy of MBMT is less than 100%. At the same time, we give MBMT full credit in evaluation for containing an optimal translation, by virtue of using the dictionaries as our primary source of translations.

### 3.2 Upper bound accuracy-based evaluation

We use the testdata to evaluate MBMT and DMT. Both methods potentially produce multiple translation candidates for a given input, from which a unique translation output must be selected in some way. So as to establish an upper bound on the feasibility of each method, we focus on the translation candidate generation step in this paper and leave the second step of translation selection as an item for further research.

With MBMT, we calculate the upper bound by simply checking for the gold-standard translation within the translation candidates. In the case of DMT, rather than generating all translation candidates and checking among them, we take a predetermined set of translation templates and a simplex translation dictionary to test for word alignment. Word alignment is considered to have been achieved if there exists a translation template and set of word translations which lead to an isomorphic mapping onto the gold-standard translation. For example, alignment is achieved through the word-level translations 領土・問題 ryou-do-moNdai “territorial dispute”, for which the mapping conforms to the [N1 N2] ⇒ [Adj, N2] translation template. It is thus possible to translate by way of DMT. Note here that derivational morphology is used to convert the nominal translation of *territory* into the adjective *territorial*.

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### 3.3 Learning translation templates

DMT relies on translation templates to map the source language NN compound onto different constructions in the target language and generate translation candidates. For the JE task, the question of what templates are used becomes particularly salient due to the syntactic diversity of the gold standard English translations (see below). Rather than assuming a manually-specified template set for the EJ and JE NN compound translation tasks, we learn the templates from NN compound translation data. Given that the EJ and JE testdata is partitioned equally into the top-250 and random-250 NN compounds, we cross-validate the translation templates. That is, we perform two iterations over each of the JE and EJ datasets, taking one dataset of 250 NN compounds as the test set and the remaining dataset as the training set in each case. We first perform word-alignment on the training dataset, and in the case that both source language nouns align leaving only closed-class function words in the target language, extract out the mapping schema as a translation template (with word coincidences). We then use this extracted set of translation templates as a filter in analysing word alignment in the test set.

A total of 23 JE and 3 EJ translation templates were learned from the training data in each case, a sample of which are shown in Table 1. Here, the count for each template is the combined number of activations over each combined dataset of 500 compounds.

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7 The reason that we used Genius here is that, as an edited dictionary, Genius has a more complete coverage of translations for simple words.

8 For the 3 EJ templates learned on each iteration, there was an intersection of 2, and for the 23 JE templates, the intersection was only 10.
### 4.2 Word-to-word compositional DMT

In order to establish an upper bound on the performance of DMT\textsubscript{COMP}, we word-aligned the source language NN compounds with their translations, using the extracted translation templates as described in § 3.3. The results of alignment are classified into four mutually-exclusive classes, as detailed below:

(A) **Completely aligned** All component words align according to one of the extracted translation templates.

(B) **No template** The translation does not correspond to a known translation template (irrespective of whether component words align in the source compound).

(C) **Partially aligned** Some but not all component words align. We subclassify instances of this class into: C1 compounds, where there are unaligned words in both the source and target languages; C2 compounds, where there is an unaligned word in the source language only; and C3 compounds where there are unaligned words in the target language only.

(D) **No alignment** No component words align between the source NN compound and translation. We subclassify D instances into: D1 compounds, where the translation is a single word; and D2 compounds, where no word pair aligns.

The results of alignment are shown in Table 3, for each of the top-250, random-250 and combined 500-element datasets. The alignment was carried out using both the basic ALTDIC and ALTDIC+ (ALTDIC with 178 manually-added simplex entries). Around 40% of the data align completely using ALTDIC+ in both translation directions. Importantly, DMT\textsubscript{COMP} is slightly more robust over the random-250 dataset...
In this section, we offer qualitative analysis of the unaligned translation pairs (i.e., members of classes B, C and D in Table 3) with an eye to improving the coverage of DMT\textsubscript{COMP}. We make a tentative step in this direction by suggesting one extension to the basic DMT\textsubscript{COMP} paradigm based on synonym substitution.

5.1 Analysis of unaligned translation pairs

We consider there to be 6 basic types of misalignment in the translation pairs, each of which we illustrate with examples (in which underlined words are aligned and **boldface words** are the focus of discussion). In listing each misalignment type, we indicate the corresponding alignment classes in §4.2.

(a) **Missing template (B)** An example of misalignment due to a missing template (but where all component words align) is:

(a1) **kesshou** “advancement to finals”

Simply extending the coverage of translation templates would allow DMT\textsubscript{COMP} to capture examples such as this.

(b) **Single-word translation (C2,D1)** DMT\textsubscript{COMP} fails when the gold-standard translation is a single word:

(b1) **jouhou** “information disclosure” ⇒ **dislosure**

(b2) **shunou-kaidaN** “(lit.) leader meeting” ⇒ **summit**

(b3) **interest rate** ⇒ **利率 ritsu**

In (b1), the misalignment is caused by the English *dislosure* default-encoding *information*; a similar case can be made for (b2), although here *summit* does not align with **kaN**. DMT\textsubscript{COMP} could potentially cope with these given a lexical inference module interfacing with a semantically-rich lexicon (particularly in the case of (b1) where translation selection at least partially succeeds), but DMT\textsubscript{INTERP} seems the more natural model for coping with this type of translation. (b3) is slightly different again, in that **ritsu** can be analysed as a two-character abbreviation derived from **riN** “interest” and **ritsu** “rate”, which aligns fully with *interest rate*. Explicit abbreviation expansion could unearth the full wordform and facilitate alignment.

(c) **Synonym and association pairs (C1)** This class contains translation pairs where one or more pairs of component nouns does not align under exact translation, but are conceptually similar:

(c1) **budget deficit** ⇒ **財政赤字 zaisei-akaji** “finance deficit”
(c2) 加盟 kamei-koku “affiliation state” ⇒ member state  

In (c1), although 財政 zaisai “finance” is not an exact translation of budget, they are both general financial terms. It may be possible to align such words using word similarity, which would enable DMT \( C_{\text{COMP}} \) to translate some component of the C1 data. In (c2), on the other hand, 加盟 kamei “affiliation” is lexically-associated with the English membership, although here the link becomes more tenuous.

(d) Mismatch in semantic explicitness (C1) This translation class is essentially the same as class (b) above, in that semantic content explicitly described in the source NN compound is made implicit in the translation. The only difference is that the translation is not a single word so there is at least the potential for word-to-word compositionality to hold:

(d1) 州知事選挙 shuuchigi-seNkyo “(lit.) state-governor election” ⇒ state election  

(e) Concept focus mismatch (C1-2,D2) The source NN compound and translation express the same concept differently due to a shift in semantic focus:

(e1) 就職・活動 shuushoku-katsudou “(lit.) activity for getting new employment” ⇒ job hunting.  

Here, the mismatch is between the level of directed participation in the process of finding a job. In Japanese, 活動 katsudou “activity” describes simple involvement, whereas hunting signifies a more goal-oriented process.

(f) Lexical gaps (C3,D2) Members of this class cannot be translated compositionally as they are either non-compositional expressions or, more commonly, there is no conventionalised way of expressing the denoted concept in the target language:

(f1) 議員 zoku-giiN “legistors championing the causes of selected industries”  

These translation pairs pose an insurmountable obstacle for DMT \( C_{\text{COMP}} \).

Of these types, (a), (b) and (c) are the most realistically achievable for DMT \( C_{\text{COMP}} \), which combined account for about 20% of coverage, suggesting that it would be worthwhile investing effort into resolving them.

5.2 Performance vs. translation fan-out  

As mentioned in § 5.1, there are a number of avenues for enhancing the performance of DMT \( C_{\text{COMP}} \). Here, we propose synonym-based substitution as a means of dealing with synonym pairs from class (c).

The basic model of word substitution can be extending simply by inserting synonym translations as well as direct word translations into the translation templates. We test-run this extended method for the JE translation task, using the Nihongo Goi-taikei thesaurus (Ikehara et al., 1997) as the source of source language synonyms, and ALTDIC+ as our translation dictionary. The Nihongo Goi-taikei thesaurus classifies the contents of ALTDIC into 2,700 semantic classes. We consider words occurring in the same class to be synonyms, and add in the translations for each. Note that we test this configuration over only C1-type compounds due to the huge fan-out in translation candidates generated by the extended method (although performance is evaluated over the full dataset, with results for non-C1 compounds remaining constant throughout).

One significant disadvantage of synonym-based substitution is that it leads to an exponential increase in the number of translation candidates. If we analyse the complexity of simple word-based substitution to be \( O(n^2) \) where \( n \) is the average number of translations per word, the complexity of synonym based substitution becomes \( O((m^2 + 1)n^2) \) where \( m \) is the average number of synonyms per class.

Table 5 shows the translation performance and also translation fan-out (average number of translation candidates) for DMT \( C_{\text{COMP}} \) with and without synonym-based substitution (± sim) over the top 6 and 13 translation templates (TTs). As baselines, we also present the results for MBMT \( \text{DICT} \) (MBMT \( \text{DICT (orig)} \)) and DMT \( C_{\text{COMP}} \) (DMT \( C_{\text{COMP (orig)}} \)) in their original configurations (over the full 23 templates and without synonym-substitution for DMT \( C_{\text{COMP}} \)). From this, the exponential translation fan-out for synonym-based substitution is immediately evident, but accuracy can also be seen to increase by over 4 percentage points through the advent of synonym substitution. Indeed, the accuracy when using synonym-substitution over only the top 6 translation templates is greater than that for the basic DMT \( C_{\text{COMP}} \) method, although the number of translation candidates is clearly greater. Note the marked difference in fan-out for MBMT \( \text{DICT} \) vs. the various incarnations of DMT \( C_{\text{COMP}} \), and that considerable faith is placed in the ability of translation selection with DMT \( C_{\text{COMP}} \).

While the large number of translation candidates produced by synonym-substitution make translation selection appear intractable, most candidates are meaningless word sequences, which can easily be filtered out based on target language corpus evidence. Indeed, Tanaka (2002) successfully combines synonym-substitution with translation selection and
achieves appreciable gains in accuracy.

6 Conclusion and future work

This paper has used the NN compound translation task to establish performance upper bounds on shallow translation methods and in the process empirically determine the relative need for deep translation methods. We focused particularly on dictionary-driven MBMT and word-to-word compositional DMT, and demonstrated the relative strengths of each. When cascaded these two methods were shown to achieve 95%+ coverage and potentially high translation accuracy. As such, shallow translation methods are able to translate the bulk of NN compound inputs successfully.

One question which we have tactfully avoided answering is how deep translation methods perform over the same data, and how successfully they can handle the data that shallow translation fails to produce a translation for. We leave these as items for future research. Also, we have deferred the issue of translation selection for the methods described here, and in future work hope to compare a range of translation selection methods using the data developed in this research.

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