Hybrid Transfer in an English-French Spoken Language Translator

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Abstract

The paper argues the importance of high-quality translation for spoken language translation systems. It describes an architecture suitable for rapid development of high-quality limited-domain translation systems, which has been implemented within an advanced prototype English to French spoken language translator. The focus of the paper is the hybrid transfer model which combines unification-based rules and a set of trainable statistical preferences; roughly, rules encode domain-independent grammatical information and preferences encode domain-dependent distributional information. The preferences are trained from sets of examples produced by the system, which have been annotated by human judges as correct or incorrect. An experiment is described in which the model was tested on a 2000 utterance sample of previously unseen data.

1 Introduction

During the last five years, people have started to believe there is a serious possibility of building practically useful spoken language translators for limited domains. There are now a number of high-profile projects with large budgets, the most well-known being the German Verbmobil effort. At the moment, the best systems are at the level of advanced prototypes; making projections from current performance, it seems reasonable to hope that these could be developed into commercially interesting systems within a time-scale of five to ten more years.

This paper will describe work carried out on one such advanced prototype, the Spoken Language Translator (SLT) system (Rayner et al., 1993; Agnès et al., 1994). SLT can translate spoken English utterances from the domain of air travel planning (ATIS: (Hemphill et al., 1990)) into spoken Swedish or French, using a vocabulary of about 1200 stem entries. The Swedish version has been operational since June 1993, and has been publicly demonstrated on numerous occasions. The French version became operational fairly recently; the language-processing component was demoed for the first time at the CeBIT trade fair at Hannover in March 1995. The Swedish and French versions have approximately equivalent levels of performance (Rayner et al., 1994b). SLT incorporates modules for speech recognition, speech synthesis and translation. In the paper, we will focus on the last of these. All examples given will refer to the French version.

One of the most important differences between spoken language translation and text translation is that there are much stronger demands on quality of output. If output is not good enough, people frequently have difficulty understanding what has been said. There is no possibility of the pre- or post-editing which nearly all text translation systems rely on. Quite apart from the problem of generating natural-sounding speech, it is also necessary to ensure that the translated text sent to the speech synthesizer is itself of sufficient quality. A high-quality translation must fulfill several criteria: in particular, it should preserve the meaning of the original utterance, be grammatical, and contain correct wordChoices.

The basic design philosophy of the SLT project has been to build a framework which is theoretically clean, on the usual grounds that this makes for a system that is portable and easy to scale up. We have attempted to subsume as much of the system as possible under two standard paradigms: unification-based language processing and the noisy-channel statistical model. The unification-based part of the system encodes domain-independent grammatical rules; for each source-language word or grammati-
The simplest examples of transfer rules are those used to translate individual words; here it is immediately clear that many words can be translated in several ways, and thus that more than one rule will often apply. For instance, the English preposition “on” can be translated as any of the French prepositions “avec” (fly to Boston on Delta → aller à Boston avec Delta); “sur” (information on ground transportation → des renseignements sur les transports publics); “à bord de” (a meal on that flight → un repas à bord de ce vol); “pour” (the aircraft which is used on this flight → l’avion qu’on utilise pour ce vol); or omitted and replaced by an implicit temporal adverbial marker (leave on Monday → partir le lundi). In each of these cases, the correct choice of translation is determined by the context.

To take a slightly more complex case, which involves some grammar, there are a number of transfer rules that list possible ways of realizing the English compound nominal construction in French. Among these are adjective + noun (economy flight → vol économique); noun + PP (arrival time → heure d’arrivée; Boston ground transportation → transports publics à Boston); or in special cases simply a compound noun (Monday morning → lundi matin). Again, the individual lexical items and the context determine the correct rule to use.

Experience has shown that it is relatively simple to write the context-independent rules which list sets of choices like the ones above. It is however much more difficult to use rules to specify the context in which each particular choice is appropriate. Moreover, the correct choice is frequently domain-dependent; thus the rules will need to be rewritten if the system is ported to a new application. For these reasons, statistically trained machine translation architectures have recently been receiving a great deal of attention. Some researchers (notably those in the IBM CANDIDE project, Brown et al., 1990) have even gone so far as to claim that statistical techniques are sufficient on their own. Our view is that this is at best unnecessary. Since many aspects of language (for instance, agreement and question-in formation in French) appear to be regular and readily describable by rules, it seems more logical to use a mixture of rules and statistics; it is in this sense that we have a hybrid transfer model (cf. Carbonell and Grishman and Kosaka, 1992).

The rest of the paper describes the system in more detail, focusing on the question of how rules and statistics are combined in the translation component. Section 2 describes the overall architecture of SLT. Section 3 gives examples of typical non-trivial translation problems from the English/French ATIS domain, and the way they are dealt with. Finally, Section 4 summarizes the current implementation status of the project, and presents the results of tests carried out on a recent version of the prototype.

2 The SLT system

The SLT system consists of a set of individual processing modules, linked together in a pipelined fashion. The input speech signal is processed by the SRI DECIPHER(TM) recognizer (Murveit et al., 1993), and an N-Best list of hypotheses is passed to the source language processor, a copy of the SRI Core Language Engine (CLE; Alshawi (ed.), 1992)) loaded with an English grammar and lexicon. The CLE produces for each speech hypothesis a set of possible analyses in Quasi Logical Form, and uses trainable preference methods to select the most plausible hypothesis and analysis (Alshawi and Carter, 1994; Rayner et al., 1994a).

The QLF analysis selected as most plausible is passed to the transfer component, which first annotates it with extra information in a rule-based pre-transfer phase. Next, a set of possible target-language QLFs is created, using the unification-based transfer rules (Alshawi et al., 1991). The target QLFs are stored in a “packed” form (Tomita, 1985) to avoid a combinatoric explosion when many transfer choices are non-deterministic. A rule-based post-transfer phase then performs some simple rewriting of the transferred QLFs, following which a second set of trained statistical preferences extract the most plausible transferred QLF and “unpack” it into a normal representation. The selected target-language QLF is passed to a second copy of the CLE, loaded with a target-language grammar and lexicon, which generates a surface string using the Semantic Head-Driven algorithm (Shieber et al., 1990). Finally, the target-language string is passed to a speech synthesizer and converted into output speech.

Most of this processing has already been covered in detail in (Agnäs et al., 1994), with reference to the Swedish version. The rest of this section will describe the new functionalities added since then: trainable transfer preferences, transfer packing, and the use of pre- and post-transfer phases. The final sub-section briefly summarizes the main features of
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new candidate transfer is now defined to be a real

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the noisy-channel statistical model of translation de-

fer component. A human judge marks each transfer

of possible output sentences produced by the trans-

ing of a set of utterances, each paired with a list

allowably adapted for the transfer task; a brief summary

follows. W e start with a training corpus, consist-

mentioned in (Alshawi and Carter, 1994) and (Rayner et al., 1994a), suit-

2.1 T rainable transfer preferences

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structure. It would in principle have been possible

transfer component between pre- and post-transfer

found it necessary to bracket the unification-based

rules and trainable transfer preferences constituted

2.2 Pre- and post-transfer

ideally, we would like to say that unification-based

rules and trainable transfer preferences constituted

the whole transfer mechanism. In fact, we have

found it necessary to bracket the unification-based

transfer component between pre- and post-transfer

phases. Each phase consists of a small set of rewrit-

ing rules, which are applied recursively to the QLF

structure. It would in principle have been possible

to express these as normal unification-based trans-

fer rules, but efficiency considerations and lack of

implementation time persuaded us to adopt the cur-

rent solution.

The pre-transfer phase implements a simple treat-

ment of reference resolution or coercion, which at

present only deals with a few cases important in the

ATIS domain. Most importantly, QLF constructs
representing bare code expressions used as NPs are

the French language description.

The basic preference model and training method for
transfer preferences is the one described in (Alshawi
and Carter, 1994) and (Rayner et al., 1994a), suit-
ably adapted for the transfer task; a brief summary
follows. In line with

the noisy-channel statistical model of translation de-

described in (Brown et al., 1990), the plausibility of a

new candidate transfer is now defined to be a real
number, calculated as a weighted sum of two con-

tributions: the transfer rule score, and the target
language model score. The first of these represents
the relative plausibility of the rules used to make the
transfer, and the second the plausibility of the target
QLF produced.

The transfer rule score and the target language
model score are computed using the same method; for
clarity, we first describe this method with reference
to transfer rules. The transfer rule score for the
bag of transfer rules used to produce a given target
QLF is a sum of the discriminant scores for the in-

dividual transfer rules. The discriminant score for a
rule $R$ is calculated from the training corpus, and
summarizes the reliability of $R$ as an indicator that
the transfer is correct or incorrect. The intent is that
transfer rules which tend to occur more frequently in

correct transfers than incorrect ones will get posi-
tive scores; those which occur more frequently in

incorrect transfers than correct ones will get nega-
tive scores.

More formally, we define the discriminant score
for $R$, $d(R)$, as follows. We find all possible 3-tuples
$(S, T_1, T_2)$ in the training corpus where

- $S$ is a source language utterance,
- $T_1$ and $T_2$ are possible transfers for $S$, exactly
  one of which is correct,
- The transfer rule $R$ is used in exactly one of $T_1$
  and $T_2$.

If $R$ occurs in the correct hypothesis of the pair
$(T_1, T_2)$, we call this a “good” occurrence of $R$; oth-

wise, it is a “bad” one. Counting occurrences over
the whole set, we let $g$ be the total number of good
occurrences of $R$, and $b$ be the total number of bad

occurrences. $d(R)$ is then defined as

$$d(R) = \begin{cases} 
\log_2(2(g+1)/(g+b+2)) & \text{if } g < b \\
0 & \text{if } g = b \\
-\log_2(2(b+1)/(g+b+2)) & \text{if } g > b 
\end{cases}$$

This formula is a symmetric, logarithmic transform
of the function $(g+1)/(g+b+2)$, which is the ex-
pected a posteriori probability that a new $(S, T_1, T_2)$
3-tuple will be a good occurrence of $R$, assuming
that, prior to the quantities $g$ and $b$ being known,
this probability has a uniform a priori distribution
on the interval $[0,1]$.

The target language model score is defined simi-
larly. The first step is to extract a bag of “semantic
triples” (Alshawi and Carter, 1994) from each pos-
sible transferred QLF in the training corpus, follow-

ing which each individual triple is assigned a dis-

criminant score using the method above. Semi-
tic triples encode grammatical relationships between
head-words; we have generalized the original defi-
nition from (Alshawi and Carter, 1994) to include
relationships involving determiners, since these are
important for transfer. Thus for example the normal
reading of the English sentence

Show flights with a stop.

would include the triples

(show, obj, flight) (show, obj, bare_plur)
(bare_plur, det, flight) (flight, with, stop)
(flight, with, a) (a, det, stop)

In Section 3 below, we will present examples il-

rating how the two components of the transfer
preference model combine to solve some non-trivial
transfer problems.
annotated with the type of object the code refers to. Code expression are frequent in ATIS, and the type of referent is always apparent from the code’s syntactic structure. The extra information is necessary to obtain a good French translation: flight codes must be prefaced with le vol (e.g. C O one three three → le vol C O cent trente-trois) while other codes are translated literally.

The post-transfer phase reduces the transferred QLF to a canonical form; the only non-trivial aspect of this process concerns the treatment of nominal and verbal PP modifiers. In French, PP modifier sequences are subject to a strong ordering constraint: locative PPs should normally be first and temporal PPs last, with other PPs in between. In the limited context of the ATIS domain, this requirement can be implemented fairly robustly with a half-dozen simple rules, and leads to a marked improvement in the quality of the translation.

2.3 Transfer packing
As already indicated, the basic philosophy of the transfer component is to make the transfer rules more or less context-independent, and let the results be filtered through the statistically trained transfer preferences. The positive side of this is that the transfer rules are robust and simple to understand and maintain. The negative side is that non-deterministic transfer choices multiply out, giving a combinatoric explosion in the number of possible transferred QLFs.

To alleviate this problem, transferred QLFs are packed, in the sense of (Tomita, 1986); lexical transfer ambiguity is left “unexpanded”, as a locally ambiguous structure in the target QLF. It is possible to compute preference scores efficiently on the packed QLFs, and only unpack the highest-scoring candidates; this keeps the transfer phase acceptably efficient even when several thousand transferred QLFs are produced.

The following example illustrates how transfer packing works. The source utterance is

flights on Monday

and the packed transferred QLF (in slightly simplified form) is:

\[
\text{elliptical_np(}
\text{term(1,[def_plur,}
\text{indef_plural,}
\text{bare_plur]),}
\text{C^[and,}
\text{[vol1,C],}
\text{form(temporal_np,}
\text{term(def_sing,}
\text{E^[lundi1,E]))])}
\]

This contains three lexical transfer ambiguities, reflecting the different ways of translating the bare singular and bare plural determiners, and the preposition “on”. In this case, the transfer preferences determine that the best choices are to realise English bare plural as French definite plural, English bare singular as French definite singular, and “on” as an implicit temporal NP marker. Substituting these in, the preferred unpacked QLF is

\[
\text{elliptical_np(}
\text{term(def_plur,}
\text{C^[and,}
\text{[vol1,C],}
\text{form(temporal_np,}
\text{term(def_sing,}
\text{E^[lundi1,E]))])}
\]

producing the French surface output

\[\text{les vols le lundi}\]

2.4 French language description
The French language description is a straightforward adaptation of the general unification-based CLE grammar and lexicon for English (Pulman, 1992). It covers most important French constructions, including all those occurring frequently in the ATIS domain. The most significant divergences compared to the English language description are in the treatment of clitic pronouns, which will be reported in detail elsewhere. Very briefly, however, a approach analogous to the standard idea of “gap-threading” has been implemented, which uses difference lists to “move” the clitics from their surface position next to the verb to their notional positions (usually, but not necessarily, as verb complements).

A fairly complete treatment of French inflectional morphology has been implemented, based on (Bouillon and Tovena, 1991). The French lexicon currently contains about 750 stem entries (excluding proper nouns), which is adequate to provide good coverage of the ATIS domain in the English to French direction. Of these entries, about half are for function words and the remainder for content words.

3 Examples of non-trivial translation problems
This section will give examples of non-trivial translation problems from the ATIS domain, and describe
Embedded questions constitute another good example of a mainly grammatical problem. Just as in English, French embedded questions normally have the uninverted word-order, e.g.

**Tell me when these flights arrive in Boston**
→ *Dites-moi quand ces vols arrivent à Boston*

However, if the main verb is *être* with an NP complement, the inverted word-order is obligatory, e.g.

**Tell me what the cheapest fares are**
→ *Dites-moi quels sont les tarifs les moins chers*

In ATIS, embedded questions occur in about 1% of all corpus sentences; this makes them too frequent to ignore, but rare enough that a pure statistical model will probably have difficulties finding enough training examples to acquire the appropriate regularities. The relevant facts are however quite easy to state as grammatical rules. Moreover, they are domain-independent, and can thus be reused in different applications.

In contrast, there are many phenomena, especially involving word-choice, which are hard to code as rules and largely domain- and application-dependent. As mentioned earlier in Section 1, the translation of prepositions and determiners is most frequently determined on collocational grounds; in our framework, this means that the information used to decide on an appropriate translation is primarily supplied by the transfer preferences. We will now describe in more detail how the idea works in practice.

Recall that the preference score for a given transfer candidate is a weighted sum of a channel contribution (discriminants on transfer rules) and a target language model score (discriminants from target language semantic triples). The transfer rule discriminants make transfer rules act more or less strongly as defaults. If a transfer rule *R* is correct more often than not when a choice arises, it will have a positive discriminant, and will thus be preferred if there is no reason to avoid it. If use of *R* produces a strong negative target-language discriminant, however, the default will be overridden.

Let us look at some simple examples. The English indefinite singular article *a* can be translated in several ways in French, but most often it is correct to realise it as an indefinite singular (*un* or *une*),
“une”). The discriminant associated with the transfer rule that takes indefinite singular to indefinite singular is thus fairly strongly positive. There are however several French prepositions which have a strong preference for a bare singular argument; for instance, “flights without a stop” is almost always better translated as “les vols sans escale” than “les vols sans une escale”. In cases like these, the a-to-un rule will be wrong, and the less common rule that takes indefinite singular to bare singular will be right. So if enough training examples are available, the negative discriminant associated with the semantic triple (vol, sans, indef_sing) will have a higher absolute value than the positive discriminant associated with a-to-un, and can override it.

Similar considerations apply to prepositions. In the ATIS domain, most prepositions have several possible translations, none of which are strongly preferred. For example, the channel score discriminants associated with the transfer rules on-to-sur and on-to-avec both have low absolute values; the first is slightly negative, and the second slightly positive. Target language triples associated with these prepositions are however in general more definite: the triples (aller avec <airline>) (renseignement sur transports) are both strongly positive, while (aller sur <airline>) (renseignement avec transports) are strongly negative. The net result is that the target language contribution makes the decision, and as desired we get “fly on Delta” and “information on flights” going to “aller avec Delta” and “des renseignements sur les vols” rather than “aller sur ...” and “des renseignements avec ...”.

In general, a combination of rules and collocational information is needed to translate a construction. A good example is the English implicit singular mass determiner, which is common in ATIS. Grammatical rules are used to decide that there is a singular mass determiner present, following which the correct translation is selected on collocational grounds. An elementary French grammar will probably say that the normal translation should either be the French partitive singular determiner, e.g.

\[
\text{I like cheese} \\
\rightarrow \text{J’aime le fromage}
\]

In the ATIS domain, it happens that the nouns which most frequently occur with mass singular determiner are “transportation” and “information”, both of which are conventionally singular in English but plural in French. Because of this, neither of the standard rules for translating mass singular gets a strong positive discriminant score, and once again the target language model tends to make the decision. For instance, if the head noun is “transportation”, it is most often correct to translate the mass singular determiner as a definite plural, e.g.

\[
\text{Show me transportation for Boston} \\
\rightarrow \text{Indiquez-moi les transports pour Boston}
\]

This is captured in a strong positive discriminant score associated with the target language triple (def_plur, det, transport)

\[
\text{Is there transportation in Boston?} \\
\rightarrow \text{Y a-t-il des transports à Boston?} \\
\rightarrow \text{*Y a-t-il les transports à Boston?}
\]

4 Implementation status and results

So far, the French version of SLT has consumed about eleven person-months of effort over and above the effort expended on the original English/Swedish SLT project. Of this, about seven person-months were spent on the French language description, two on transfer rules, and two on other tasks. The small quantity of effort required to develop a good French language description underlines the extent to which its structure overlaps with that of the original English grammar and lexicon.

We now describe preliminary experiments designed to test the performance of the system. A set of 2000 ATIS utterances was used, randomly selected from the subset of the ATIS corpus consisting of A or D class utterances of length up to 15 words, which had not previously been examined during the

\[\text{2This means roughly that the sentence represented a valid inquiry to the database, either alone or in the context in which it was uttered.}\]
development of the French version of SLT. Utterances were supplied in text form, i.e. the speech recognition part of the system was not tested here.

Each utterance was analysed using the English language version of the CLE, and for the 1847 sentences where at least one QLF was produced the most plausible QLF was selected using the preference methods described in (Alshawi and Carter 1994). This was then submitted to the transfer phase, and a set of transfer candidates produced. A simple set of hand-coded transfer preferences was applied, and one French surface string was generated for each of the five highest-scoring transfer candidates. A native French speaker fluent in English judged each generated string as being either an acceptable or an unacceptable translation of the source utterance. Translations were only regarded as acceptable if they were fully grammatical, preserved the meaning of the source utterance, and used a stylistically natural choice of words. The judging process took approximately eight hours, averaging three seconds per source/target pair.

The annotated N-best transfer corpus was then used to train a new set of preferences using the method described in Section 2.1; the corpus was divided into five equal pieces, each fifth being held out in turn as test data with the remaining four-fifths used as training. Finally, the derived preferences were tested for accuracy. Of the 1847 transfer sets, there were 1374 for which at least one acceptable transfer was in the top five candidates. The trained transfer preferences selected an acceptable candidate in 1248 of these 1374 cases (91%); in contrast, random choice among the top five gave a baseline score of 826 acceptable transfers, or 60%. We regard this as a promising initial result, and intend soon to repeat the experiment with a larger set of 5000–10000 sentences. We also anticipate significant improvements over the next few months from planned extensions and refinements to the French language description.

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