Using Hybrid Methods and Resources in Semantic-based Transfer

BIANKA BUSCHBECK-WOLF & MICHAEL DORNA

University of Stuttgart

Abstract

This paper presents ongoing work on the development of the semantic transfer component of the multi-lingual speech-to-speech MT system Verb*mobil*. It focuses on the use of symbolic and statistical methods for the acquisition of semantic transfer rules, the disambiguation of translational ambiguities and the selection of appropriate rule candidates at runtime.

1 Introduction

Verb*mobil* (Wahlster 1993) is a multi-lingual speech-to-speech MT system that is applied to the task of translating spoken language in the domain of appointment scheduling and travel planning. Currently, the system includes modules for German, English and Japanese. In this paper we describe how a combination of different methods and resources is used for the development of the transfer component of Verb*mobil* (Dorna & Emele 1996b).

Over the last decades, neither pure stochastic approaches to machine translation (MT), such as the statistical approach (Brown et al. 1990) or example-based MT (Sato & Nagao 1990, Sumita et al. 1990), nor pure symbolic methods, as pursued in METAL (Slocum et al. 1987), SYSTRAN (Wheeler 1987) or LOGOS (Schmid & Gdaniec 1996), turned out to be sufficient for high quality translation. A reasonable, task-specific combination of different techniques seems to be the most promising solution (Carbonell et al. 1992, Lehmann & Ott 1992, Brown & Frederking 1995).

With our semantic transfer approach, we present ongoing research on the integration of successful methods from different paradigms. We focus on the combination of stochastic and symbolic methods in both the *acquisition of bilingual semantic transfer lexicons* and the *disambiguation of translational ambiguities*.

In large MT projects, such as Verb*mobil*, the linguistic resources, representations and tools for analysis and generation are developed in parallel with the translation component. Hence, one has to think of a strategy for isolating transfer from ongoing changes during the project by reducing the dependencies between different components. For this reason, we have developed *templates for transfer rules* that cope with classes of translation patterns in a systematic way and minimise necessary adaptations for actual representations.

Another well-known problem in MT is the selection of appropriate rule candidates at runtime if there are alternatives among applicable transfer rules. We introduced the *specificity principle* in Dorna & Emele (1996a) which we have extended for processing different translation alternatives in parallel.

This paper is organised as follows: in Section 2, we describe our semantic transfer approach together with the semantic representation language. Section 3 outlines the extraction of semantic transfer knowledge from a pool of bilingual resources. In Section 4, we show the exploitation of symbolic and statistical disambiguation techniques and illustrate the idea of *disambiguation on demand* with a series of examples. Finally, Section 5 gives some technical details of the transfer rule compiler and the runtime system.

2 Semantic-based transfer

2.1 *Our approach*

In Verb*mobil*, we took a semantic-based transfer approach similar to Copestake (1995), i.e., the transfer module maps source language (SL) semantic representations to target language (TL) semantic representations (Dorna & Emele 1996b). Beside the bilingual mapping module, our transfer component includes several cascaded modules. Among them, there is a monolingual refinement module (see Section 2.3) and a tense resolution module (Schiehlen 1997).

The input to the transfer module is a semantic representation (see Section 2.2) which is produced by a semantic construction module (Bos et al. 1996). The transfer obtains additional information from a semantic evaluation component that keeps track of the dialogue history and provides discourse information, such as dialogue acts (Alexandersson et al. 1997). Apart from this symbolic evaluation module, a statistical evaluation component allows the transfer to access information about TL co-occurrences (see Section 4). The transfer module reports its TL semantic representations to the generator which maps them to TL expressions (Kilger & Finkler 1995). Figure 1 shows the Verb*mobil* architecture from a transfer point of view.

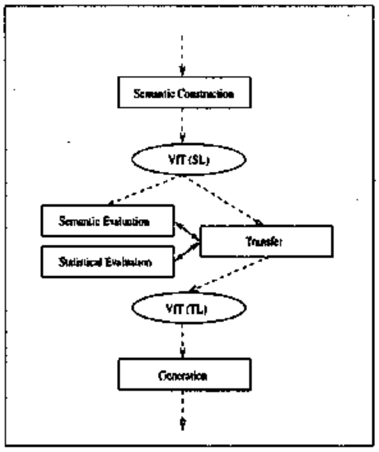

Fig. 1: *Interaction of the transfer component*

2.2 *Semantic representation*

The semantic representation together with additional information, such as sortal and prosodic information, number, tense, aspect, dialogue acts, etc., is represented in a multi-dimensional data structure called Verb*mobil* Interface Term (VIT) (Dorna 1996). This uniform data structure serves as an interface representation for all components that operate on semantic structures, i.e., transfer, semantic evaluation and generation.

In the following, we describe only the part of a VIT which contains the set of semantic predicates. Each semantic predicate has a unique label `l` which is used as an address for linking information within and between multiple levels of a VIT. Besides their label, referential predicates introduce an instance `i`. Argument roles and modifier relations are represented in a Neo-Davidsonian way (Parsons 1991). Semantic operators, like quantifiers, modals or scopal adverbs, take extra label arguments for referring to other elements which are in the relative scope of these operators.[1] The semantic predicates containing labels and instances encode a recursive representation in a flat set-oriented list structure. This data structure proved to be convenient for the specification of transfer operations.

Consider example (1a) and its favourable English translation (1b).

[1] If the scope is underspecified, explicit subordination constraints are fixed in the scope slot of the VIT. The exact details of subordination are beyond the scope of this paper; see (Frank & Reyle 1995) and (Bos et al. 1996) for implementations.

(1) a. Wir wollten das Gespräch doch vorziehen?
b. We wanted to schedule the meeting earlier, didn't we?

The SL utterance (1a) is assigned a representation in (2). The relative scope of the sentence mood operator `ynq(l0,l1)` (yes-no question), the control verb `wollen(l1,i1)`, `arg1(l1,i1,i2)`, `arg3(l1,i1,l2)` and the pragmatic adverb `doch(l2,l3)` has been resolved by using the explicit labels of other predicates, these are l1, l2 and l3.

(2)
```
ynq(l0,l1), wollen(l1,i1), arg1(l1,i1,i2),
arg3(l1,i1,l2), doch(l2,l3), vorziehen(l3,i3),
arg1(l3,i3,i2), arg3(l3,i3,i4),
pron(l4,i2,speaker_hearer), def(l5,i4,l6),
gespraech(l6,i4)
```

2.3 *Abstraction*

It is well known that the more abstract the representation to be transferred, the easier the transfer mapping (Vauquois 1975). Since semantic representations abstract away from language-specific morpho-syntactic peculiarities, they allow transfer rules to be specified in a rather compact way. However, our domain-specific task allows for more abstraction. With lexicons for each language of about 5000 words which are used to express rather similar things it is reasonable to introduce language-neutral representations for synonymous expressions. They are produced in a refinement step which precedes the actual translation mapping.

Apart from the mapping of synonymous expressions to meaning abstractions, this module also resolves ambiguities of prepositions and decomposes complex predicates into language-independent semantic primitives. Thus, the information encoded in the abstract predicate can also be used for the resolution of translational ambiguities in the actual transfer mapping. This allows contextual restrictions to be specified in a compact way.

The output of transfer is a partial language-neutral representation that allows the generator to produce paraphrases. Abstraction leads to a reduction of the number of transfer rules to the necessary minimum and to lower costs for introducing new languages (Kay et al. 1994).

2.4 *Transfer knowledge bases*

The primary knowledge bases of our transfer component are a set of monolingual refinement and restructuring rules (see Section 2.3) and a database of bilingual transfer equivalences which we consider in the following.

The general form of a transfer rule is shown in (3). It establishes the equivalence between sets of SL semantic predicates `SL_Sem` and sets of TL semantic predicates `TL_Sem`. The operator `TauOp` indicates in which direction a rule is applied, i.e., bi-directional (`<->`) or uni-directional (`->` or `<-`).[2]

(3)
```
SL_Sem # SL_Cond TauOp TL_Sem # TL_Cond.
```

Some simple transfer rules for the unambiguous predicates in (2) are presented below.[3]

(4)
```
ynq(L,I) <-> ynq(L,I).
def(L,I,L1) <-> def(L,I,L1).
wollen(L,I) <-> want(L,I).
pron(L,I,R) <-> pron(L,I,R).
```

The capitalised symbols `L`, `I`, `R`, etc. stand for logical variables which are bound to concrete values when applying a rule to a given input.

To resolve translational ambiguities, the rules are optionally provided with a condition part (`SL_Cond` and `TL_Cond`) which restricts their application to the relevant context. The condition part contains only tests (see also Morimoto et al. (1992)). The `#` sign separates the transfer mapping from the rule restriction.[4] Splitting the mapping from the condition part leads to smaller translation units. Thus, problems with the interaction of rules can be minimised.

Rule (5) shows a mapping of the ambiguous predicate `vorziehen` to `prefer` under the condition that its theme argument `arg3` is of sort `time` (see also Section 4).

(5)
```
vorziehen(L,I) # arg3(L,I,I1), sort(I1,time) ->
prefer(L,I).
```

2.5 *Templates for transfer rules*

For building the transfer rule base, templates for transfer rules have been developed (Buschbeck-Wolf 1998). They considerably simplify the rule writing and cope with classes of translation patterns in a systematic way. Templates turned out to be also advantageous in the way they allow systematic adaptation of changes in the input and output representations.

---

[2] A rule application reduces the SL input by the set of semantic predicates in `SL_Sem` if they form a matching subset of the input. On the other hand, the TL semantic predicates `TL_Sem` are added to the TL output (see Dorna & Emele (1996a) for details).

[3] The transfer formalism provides a single metarule which can be used instead of mappings for identical predicates on SL and TL side.

[4] The condition to the left of `TauOp` restricts the application direction `->`, and vice versa.

Templates are defined for transfer equivalences and also for frequently used conditions. The calls of *rule templates* are prefixed by an @ operator. Template calls (6) correspond to rules (4).

(6)
```
@mood(ynq, ynq).
@quant(def, def).
@verb(wollen, want).
@noun(pron, pron).
```

A template definition for transferring quantifiers is shown in (7). Its usage is restricted to the semantic type the predicate belongs to. In our case it is qua for quantifiers. The variables SL and TL are replaced by the incoming quantifier names when calling the template.

(7)
```
quant(qua(SL), qua(TL)) := SL(L,I,L1) <-> TL(L,I,L1).
```

While this is a very simple case, templates are more useful for capturing systematic changes in the semantic structure of the involved languages (Dorr 1994).

(8)
```
predicativeTOarg1verb(adx(SL), verb(TL)) :=
support(L,I,L1), SL(L1,I1) <-> TL(L,I), arg1(L,I,I1).
```

The definition of the predicativeTOarg1verb template (8) covers the switch of a predicative into a verbal construction, as it is relevant for the translation of *einverstanden sein* into *agree*. The SL predicate support which represents the copula together with its predicative of the type adx (adjectival/adverbial modifier) is substituted by the TL verb. The instance of the SL predicative I1 becomes arg1 of the verb. By applying (8), the translation correspondence between *einverstanden sein* and *agree* can be established in a simple way (9).

(9)
```
@predicativeTOarg1verb(einverstanden, agree).
```

Condition templates are applied in the rule's condition part in order to state frequently occurring restrictions more efficiently. They are used to express, e.g., that a predicate is of a specific sort or semantic type, is modified, is quantified or is embedded in a certain way, etc. Condition template calls are prefixed with a + operator. As a result, the conditioned rule (5) can be expressed by (10).

(10)
```
# +arg3_sort(I,time) -> true
@verb(vorziehen,prefer,_,I).
```

The verb template is combined with a rule where only the condition on the SL side is specified. true on the TL side stands for any predicate. The rule and the template are merged at compile time (see Section 5.1.1).

3 Transfer rule development

In this section, we show how we exploit existing resources for the acquisition of initial bilingual transfer lexicons. These are domain-specific bilingual corpora of spoken material as well as on-line dictionaries, thesauri and off-line resources.

3.1 *Extraction of translation candidates*

MT is still most successful in restricted application domains because the number of translational ambiguities can be kept small. Unfortunately, for such specific domains neither dictionaries nor parallel corpora of a sufficient size are available. This applies especially to spoken language resources. It is not yet clear whether or how knowledge extracted from large general corpora, e.g., mono- and bilingual co-occurrence frequencies (Kitamua & Matsumoto 1996) or learned translation rules (Almuallim et al. 1994), can be used in smaller domains. Moreover, domain specific readings and transfer mappings are not covered by models trained on the basis of unspecific resources.

In Verb*mobil* we work in a restricted domain with a limited vocabulary constraint by the speech recognizer. Hence, we have no problems with unknown words, but the arbitrary word combinations cause different readings of the same words. Again, the usual on-line resources such as thesauri do not always cover domain specific readings and thus can hardly be used for automatic disambiguation of word senses.[5]

In this situation, it is more reasonable to stick to a symbolic approach concerning the overall architecture of an MT system and involve statistical methods wherever possible. So we still use mono- and bilingual annotation, alignment and extraction tools only for preparing the contrastive data for the rule writer. At the moment, this seems to be the only way to ensure translation quality in the domain of spoken language dialogues. See Section 3.3 for future directions.

[5] The techniques for stochastic word sense disambiguation are getting better all the time, see, e.g., Almuallim et al (1994) or Dorr & Jones (1996). But there is no hope to get word sense models without large corpora which are manually tagged with such senses (Ng 1997).

3.2 *Combining existing resources and tools*

In the following, we sketch the derivation of transfer rule skeletons using existing tools and resources at IMS. The process itself is mainly independent of the tools in use. However, the quality of the results reflects the precision of the tools.

Taggers (Schmid 1994), lemmatisers and/or morphological analysers (for German (Schiller 1995, Schulze 1996)) are used to annotate independently the monolingual parts of parallel bilingual corpora. After sentence and word alignment (Eisele 1997), the data is prepared for off-line and interactive corpus queries (Christ 1995). For each word to be covered by transfer rules, these tools can produce parallel subcorpora containing all occurrences and translations found in the data.

Extracted translation correspondences are annotated with frequencies of their occurrence in monolingual corpora and in bilingual domain-specific corpora. This information is used to guide the manual rule definition and refinement to achieve a rapidly growing coverage combined with a good quality of the transfer output.

3.3 *Automatic acquisition of semantic transfer rules*

Future research concerns the automation of transfer rule acquisition for symbolic transfer approaches. Robust parsers (Abney 1997) already produce syntactic chunks which are used to construct partial semantic analyses (Light 1996).

The quality of the chunks is getting better with the availability of larger resources which cover syntactic and semantic restrictions on argument bindings. Ongoing projects at IMS successfully develop corpora extraction techniques, e.g., for finding syntactic subcategorisation frames (Eckle & Heid 1996) in combination with word sense clusters (Rooth 1994) to produce huge on-line lexicons including morphological, syntactic and semantic knowledge.

Given all these annotation and preparation steps for both languages in a parallel corpus, an alignment on different linguistic levels, such as words, phrases or even semantic fragments is possible by using similarity measures (see, e.g., Kitamua & Matsumoto (1996)). This alignment and co-occurrence information will be used to compute mappings to transfer templates (see Section 2.5). Subsequently, these templates are enriched by further contextual conditions that constrain the transfer mappings if there is more than one correspondence (see Section 4 below).

4 Disambiguation

Since spoken language is highly ambiguous, disambiguation is of major importance to achieve an acceptable translation quality. In order to choose between alternative translation correspondences, we consider contexts in which the one TL expression or the other is used. For the resolution of many translational ambiguities the local VIT context is sufficient. It allows the formulation of restrictions on the sort or the semantic type of a predicate, on its structural embedding, mood, number, tense, etc. (Buschbeck-Wolf 1998) as well as on prosodic information (Lieske et al. 1997). However, there are cases in which the transfer component needs information from a broader context to choose the appropriate TL correspondence, e.g., information about the antecedent of an anaphor or an ellipsis, domain-specific world knowledge, speech act and discourse stage information and also information about the pragmatic function of discourse particles. To obtain this kind of information we have developed the concept of *resolution on demand* (Buschbeck-Wolf 1997). By anchoring specific requests to the semantic and statistical evaluation components (see Figure 1) in the transfer rules, transfer triggers inference processes whenever more information is needed to solve a particular translation task.

4.1 *Symbolic disambiguation*

Let us illustrate the disambiguation of translational ambiguities with sentence (1) of Section 2.2 which is repeated in (11).

(11) a. Wir wollten das Gespräch doch vorziehen?
b. We wanted to schedule the meeting earlier, didn't we?

(11a) includes three ambiguous words: *i*) the pragmatic particle *doch* which, among others, is translated into *after all* or into a question tag, but it can also be dropped in the translation, *ii*) the verb *vorziehen* which means either *prefer* or *schedule earlier*, and *iii*) the noun *Gespräch* which corresponds in our domain to *meeting*, *discussion* or *conversation*. Let us consider some contexts in which the translation of these words differs.

(12) a. Wir wollten uns *doch* am Montag treffen?
b. We wanted to meet on Monday, *didn't we?*

(13) a. Dann würde das *DOCH* gehen.
b. Then, it would be possible, *after all*.

(12) and (13) illustrate the two major readings of the particle *doch* if it does not occur not in a sentence-initial position. It might signal the speaker's

return to a previously made arrangement (12). The speaker reminds the hearer of a scheduled meeting and expects his approving response. Similarly, in (11), the speaker reminds the hearer of their agreement to schedule the meeting earlier. With a prosodically marked *doch* the speaker refers to a previous dialogue stage (13). Something that was impossible before turned out to be feasible at the utterance time.

These two readings of *doch* need to be translated differently, i.e., the transfer problem consists of identifying meanings that can be captured in terms of pragmatic functions. Stede & Schmitz (1997) developed a classification of discourse functions for particles. They consider *doch* to be either a coherence marker which should not be translated or a pointer to something previously uttered (`particle(L,given)`). In case the latter function is appropriate, the translation of *doch* seems to differ wrt. sentence mood and prosodic accent. If it occurs unstressed (`not(accent(L))`) in yes-no questions (`mood(ynq)`), it is expressed by a question tag in English. In declarative or imperative sentences (`mood(decl;imp)`), it is rendered by *after all* if it bears prosodic accent (`accent(L)`). Transfer rules (14)–(15) integrate these kinds of restrictions in their condition parts.

(14) `# not(initial(L)), particle(L,given), mood(ynq), not(accent(L))`
`-> true @particle(doch,quest_tag,L).`

(15) `# not(initial(L)), particle(L,given), mood(decl;imp), accent(L)`
`-> true @particle(doch,after_all,L).`

Now let us consider the verb *vorziehen*. Sentences (16)–(18) show some contexts in which its mapping to one of its equivalents is quite obvious.[6]

(16) a. Ich würde **den Dienstag** *vorziehen*.
b. I would *prefer* Tuesday.

(17) a. Wir **sollten** das Treffen *vorziehen*.
b. We should *schedule* the meeting *earlier*.

(18) a. Ich würde es *vorziehen*, **am Montag** zu kommen.
b. I would *prefer* to come on Monday.

If a theme argument is a time expression, *prefer* is the only correspondence (16). This is captured by (19) which we know already as (10) from Section 2.5. A translation with *schedule earlier* is not feasible here, because it would require an object movable in time in the **arg3** role. In contrast, and times, such as Tuesday, are fixed.

(19) `# +arg3_sort(I,time) -> true`
`@verb(vorziehen,prefer,L,I).`

[6] The contextual trigger is marked in bold face.

Vorziehen is an attitude verb. If it is embedded by a modal verb that also expresses an attitude, it cannot have an attitude reading itself (17). This excludes *prefer* as correspondence (20).[7]

(20)
```
# +modal(_,L2), L =< L2 -> true
@verb(vorziehen,schedule,L,I)
@add_compadx(early,I).
```

If *vorziehen* has a propositional arg3 realisation (18), *prefer* is the appropriate equivalent (21).[8]

(21)
```
# +proposit_arg3(I) -> true
@verb(vorziehen,prefer,_,I).
```

However, these rules are not sufficient to cope with the ambiguity of *vorziehen*. If its arg3 belongs to the sort `situation` (22a) and it does not occur in one of the mentioned contexts (16)–(18), the local semantic context does not allow a choice to be made between (22b) and (22c).

(22) a. Ich würde **das Treffen** am Montag *vorziehen*.
b. I would *prefer* the meeting on Monday.
c. I would *schedule* the Monday meeting *earlier*.

To resolve this ambiguity, the semantic evaluation component, which provides more information on the actual dialogue situation, is consulted by an `eval` call for resolving the particular reading of *vorziehen*, (23) or (24).

(23)
```
# +arg3_sort(I,sit), eval(L,vorziehen_pref) -> true
@verb(vorziehen,prefer,L,I).
```

(24)
```
# +arg3_sort(I,sit), eval(L,vorziehen_move) -> true
@verb(vorziehen,schedule,L,I)
@add_compadx(early,I).
```

Concerning our example sentence (11a), rules (6), (14) and (20) have been applied so far in order to get translation (11b).

4.2 *Statistical disambiguation*

Finally, the noun *Gespräch* has to be mapped onto its contextual appropriate correspondence. In contrast to verbal and modificational predicates, the disambiguation of nominal predicates is notoriously difficult, since it is impossible to state manually all contexts in which one translation or the other

[7] The template `modal` checks the semantic type of the incoming verbs. The equation says *vorziehen* is in the scope of the modal verb. The template `add_compadx` introduces a modifier and a comparative predicate for it.

[8] The template `proposit_arg3` tests the propositional argument realisation.

is preferred. For this task it is reasonable to rely on statistical information (Kameyama et al. 1993).

Consider the German noun *Gespräch*. It corresponds to *meeting* or *discussion* when it is a kind of organised event, while the other equivalent *conversation* denotes a more casual event or refers to its course. There are several contexts which force the interpretation or the other. Co-occurring with verbs, such as *organise, plan* or *prepare, meeting* or *discussion* seem to be appropriate translations, while in other contexts *conversation* is used (Table 1). Similarly, modifiers can identify one of the alternatives (Table 2).

sich in ein *Gespräch* **einschalten**	**join** a *conversation*
ins *Gespräch* **kommen**	**get into** a *conversation*
ein *Gespräch* **fortsetzen**	**continue** a *conversation*
ein *Gespräch* **vorbereiten**	**prepare** a *meeting/discussion*
ein *Gespräch* **organisieren**	**organise** a *meeting/discussion*
ein *Gespräch* **planen**	**plan** a *meeting/discussion*

Table 1: *Co-ocurrences of* Gespräch *with verbal predicates*

ein **stockendes** *Gespräch*	a **faltering** *conversation*
ein **nettes** *Gespräch*	a **nice** *conversation*
ein *Gespräch* **unter vier Augen**	a **private** *conversation*
ein **angesetztes** *Gespräch*	a **scheduled** *meeting/discussion*
ein **vertagtes** *Gespräch*	a **postponed** *meeting/discussion*
ein **dringendes** *Gespräch*	an **urgent** *meeting/discussion*

Table 2: *Co-ocurrences of* Gespräch *with modifiers*

To extract the correct translation (Gale et al. 1992), we regard the TL contexts in which the TL correspondences of the ambiguous word occur. If they are close to the input context (Almuallim et al. 1994) the statistical evaluation component validates the corresponding transfer rule (Eisele 1997). The one that is relevant for our example (11) is shown in (25). In the context of *schedule*, the "official event" interpretation of *Gespräch* is appropriate, i.e., *meeting* or *discussion* are the translations. Concerning the choice between them, *meeting* is more likely to be used in the domain of meeting scheduling.

(25)
```
# stat_eval(discussion;meeting,I) -> true
@noun(gespraech,meeting,I).
```
(26)
```
# stat_eval(conversation,I) -> true
@noun(gespraech,conversation,I).
```

5 Processing of transfer rules

The IMS transfer system consists of a transfer rule compiler (trc) and a transfer runtime system (trs). The trc version described in Dorna & Emele (1996a) was extended by a template preprocessor. Furthermore, we have refined the specificity principle which guides the rule selection at runtime. This gives us a selection criterion when trs computes several transfer alternatives in parallel.

5.1 *Compile time processing*

5.1.1 *Template expansion*

Rule and condition templates (see Section 2.5) are expanded before any further compilation takes place. All parts of a rule found during a template expansion are merged, i.e., sets of semantic predicates and rule conditions are united, respectively. Additionally, the direction of possible rule applications is determined. A bi-directional operator (<->) will be overridden by a uni-directional operator (<- or ->) if a template definition or the rule itself contains this operator. If no overriding takes place, the application of a rule is always possible in both directions. The result of this preprocessing is a regular transfer rule (see Section 2.4).

5.1.2 *Rule compilation*

Transfer rules are always part of a module where each side of a rule belongs to a specific language. trc uses this information to check the compatibility of semantic predicates wrt. language specific on-line lexicons. The lexicons are part of an ADT package for the VIT (Dorna 1996).

The semantic predicates in transfer rules are sets of terms and trc partially orders these sets. The results are sequences (lists) which are used to collapse rules with the same prefix. Then trc builds an index over the prefixes for quickly accessing applicable rules when matching rules against the input at runtime (Dorna & Emele 1996a).

The compiled rules form a kind of transducer which takes a set of SL semantic predicates as its input and produces a TL representation.

5.2 *Runtime processing*

trs works incrementally on linguistically motivated segments of different sizes. The segment size may vary from words over constituents to sentences depending on the output of the recogniser and linguistic analysis components. Robustness is achieved by handling all sizes of segments. As expected, the quality of transfer output is improving with the length of segments.

At runtime, transfer solves a problem which can be reduced to a set covering problem. trs looks for the minimal number of subsets covering an input set. The subsets are defined by semantic predicates found in the SL matching parts (SL_Sem) of transfer rules. trs tries to find the most specific rules which cover the largest subsets. The *specificity principle* defined in Dorna & Emele (1996a) ensures a rule selection which is locally optimal. If, at a particular processing state, one such rule is found, all other candidates are blocked. This nonmonotonic behaviour does not always give the optimal solution. Sometimes we find the most specific rule but not always the most specific sequence of rule applications (derivation).

Currently, we are working on a parallel approach which looks for potential transfer results and selects those which are derived using a minimal number of rule applications. The minimal number of rule application is equivalent to the problem of finding the minimal number of subsets which was mentioned above. Therefore, this behaviour ensures a global optimum relating the input with the most appropriate rules designed for it.

Techniques for a possible realisation of parallel transfer are, e.g., chart processing (Amtrup 1995) or lemma table proof procedures (Johnson & Doerre 1995).

6 Summary

We have presented the semantic transfer approach of the speech-to-speech MT system Verb*mobil*. Transfer is regarded to be a central component in Verb*mobil* which triggers inferences in analysis and resolution components on demand. The results are used for solving certain translation problems.

To cope with the multi-lingual scenario, we integrated a special refinement step that introduces language-independent elements into the language-specific semantic representation. A template mechanism was developed to capture generalisations and to ensure the adaptation and reusability of transfer rules independently of the concrete input and output of transfer.

We exploited different bi- and monolingual resources for building the transfer rule base, i.e., for extracting translation correspondences. We illustrated the combination of symbolic and statistical methods for choosing between translation alternatives. Finally, the compilation of templates and transfer rules was sketched and the selection of appropriate transfer results in a parallel transfer approach was presented.

Acknowledgements. This work was funded by the German Federal Ministry of Education, Science, Research and Technology (BMBF) in the framework of the Verb*mobil* project under grant 01 IV 701 N3. The work presented here is strongly influenced by discussions with our colleagues of the Verb*mobil* subproject TP 3 "Translation", namely A. Eisele, M. Emele and M. Schiehlen. We would also like to thank G. Carroll, R. Vaughan and the anonymous reviewers of the RANLP'97 conference for helpful comments. The responsibility for the contents of this article lies with the authors.

REFERENCES

Abney, S. 1997. "The SCOL Manual". Technical Report. SfS, Univ. of Tübingen, Germany. URL: `http://www.sfs.nphil.uni-tuebingen.de/~abney/scol.ps.gz`.

Alexandersson, J., B. Buschbeck-Wolf, T. Fujinami, E. Maier, N. Reithinger, B. Schmitz & M. Siegel. 1997. "Dialogue Acts in Verb*mobil*-2". Verb*mobil* Report 204. DFKI GmbH, Saarbrücken, Univ. of Stuttgart, Technical Univ. of Berlin, Univ. of Saarland, Saarbrücken, Germany. URL: `http://www.ims.uni-stuttgart.de/verbmobil/vm-reports/report-204-97.ps.gz`

Almuallim, H., Y. Akiba, T. Yamazaki, A. Yokoo & S. Kaneda. 1994. "Two Methods for Learning ALT-J/E Translation Rules from Examples and a Semantic Hierarchy". *Proceedings of the 15th International Conference on Computational Linguistics (COLING'94)*, 57-63. Kyoto, Japan.

Amtrup, Jan W. 1995. "Chart-based Incremental Transfer in Machine Translation". *Proceedings of the 6th International Conference on Theoretical and Methodological Issues in Machine Translation (TMI'95)*, 188-195. Leuven, Belgium.

Bos, J., B. Gambäck, C. Lieske, Y. Mori, M. Pinkal & K. Worm. 1996. "Compositional Semantics in Verbmobil". *Proceedings of the 16th International Conference on Computational Linguistics (COLING'96)*, 131-136. Copenhagen, Denmark.

Brown, R. & R. Frederking. 1995. "Applying Statistical English Language Modeling to Symbolic Machine Translation". *Proceedings of the 6th International Conference on Theoretical and Methodological Issues in Machine Translation (TMI'95)*. Leuven, Belgium.

——, J. Cocke, S. Della Pietra, V. Della Pietra, J. Jelinek, F. A. Lafferty, R. Mercer & P. Roossin. 1990. "A Statistical Approach to Machine Translation". *Computational Linguistics* 16:2.79-85.

Buschbeck-Wolf, B. 1997. "Resolution on Demand". Verb*mobil* Report 196, IMS, Univ. of Stuttgart. URL: `http://www.ims.uni-stuttgart.de/verbmobil/vm-reports/report-196-97.ps.gz`

——. 1998. "Using Templates to Encode Transfer Rules". Verb*mobil* Report 229. IMS, Univ. of Stuttgart. URL: `http://www.ims.uni-stuttgart.de/verbmobil/vm-reports/report-229-96.ps.gz`

Carbonell, J. G., T. Mitamura & E. H. Nyberg 3rd. 1992. "The KANT Perspective: A Critique of Pure Transfer (and Pure Interlingua, Pure Statistics, ...)". *Proceedings of the 4th International Conference on Theoretical and Methodological Issues in Machine Translation (TMI'92)*, 225-237. Montreal, Canada.

Copestake, A. 1995. "Semantic Transfer in Verbmobil". Verb*mobil* Report 93, IMS, Univ. of Stuttgart, Germany & CSLI, Stanford Univ., Stanford, Calif., U.S.A. URL: `http://www.ims.uni-stuttgart.de/verbmobil/vm-reports/report-93-95.ps.gz`

Dorna, M. & M. C. Emele. 1996a. "Efficient Implementation of a Semantic-based Transfer Approach". *Proceedings of the 12th European Conference on Artificial Intelligence (ECAI'96)*, 567-571. Budapest, Hungary.

—— & M. C. Emele. 1996b. "Semantic-based Transfer". *Proceedings of the 16th International Conference on Computational Linguistics (COLING'96)*, 316-321. Copenhagen, Denmark.

——. 1996. "The ADT-Package for the Verb*mobil* Interface Term". Verb*mobil* Report 104, IMS, Univ. of Stuttgart, Germany. URL: `http://www.ims.uni-stuttgart.de/verbmobil/vm-reports/report-104-96.ps.gz`

Dorr, B. J. 1994. "Machine Translation Divergences: a Formal Description and Proposed Solution". *Computational Linguistics* 20:4.597-633.

—— & D. Jones. 1996. "Acquisition of Semantic Lexicons: Using Word Sense Disambiguation to Improve Precision". *Proceedings of Breadth and Depth of Semantic Lexicons, Special Interest Group on the Lexicon of the ACL (SIGLEX-96)*, 42-50. Santa Cruz, Calif., U.S.A.

Eckle, J. & U. Heid. 1996. "Extracting Raw Material for a German Subcategorisation Lexicon from Newspaper Text". *Proceedings of the 4th International Conference on Computational Lexicography.* Budapest, Hungary.

Eisele, A. 1997. "IMS Alignment Tool Box". Software. IMS, Univ. of Stuttgart, Germany.

Frank, A. & U. Reyle. "Principle Based Semantics for HPSG". *Proceedings of the 7th Conference of the European Chapter of the Association for Computational Linguistics (EACL'95)*, 9-16. Dublin, Ireland.

Gale, W. A., K. W. Church & D. Yarowsky. 1992. "Using Bilingual Materials to Develop Word Sense Disambiguation Methods". *Proceedings of the 4th International Conference on Theoretical and Methodological Issues in Machine Translation (TMI'92)*, 101-113. Montreal, Canada.

Johnson, M. & J. Dörre. 1995. "Memoization of Coroutined Constraints". *Proceedings of the 33rd Annual Meeting of the Association for Computational Linguistics (ACL'95)*, 100-107. Cambridge, Mass., U.S.A.

Kameyama, M., S. Peters & H. Schütze. 1993. "Combining Logic-Based and Corpus-Based Methods for Resolving Translation Mismatches". *Working Notes of the AAAI Spring Symposium Series*, 86-92. Berkeley, Calif., U.S.A.

Kay, M., M. Gawron & P. Norwig. 1994. *Verbmobil: a Translation System for Face-to-Face Dialogs.* (= *CSLI Lecture Notes* 33). Stanford, Calif.: CSLI Press, Stanford University.

Kilger, A. & W. Finkler. 1995. "Incremental Generation for Real–Time Applications". Research Report RR-95-11, DFKI GmbH, Saarbrücken, Germany.

Kitamua, M. & Y. Matsumoto. 1996. "Automatic Extraction of Word Sequence Correspondances in Parallel Corpora". *Proceedings of the 4th Workshop on Very Large Corpora.* Copenhagen, Denmark.

Lehmann, H. & N. Ott. 1992. "Translation Relations and the Combination of Analytical and Statistical Methods in Machine Translation". *Proceedings of the 4th International Conference on Theoretical and Methodological Issues in Machine Translation (TMI'92)*, 237-249. Montreal, Canada.

Lieske, C., J. Bos, M. Emele, B. Gambäck & C.J. Rupp. 1997. "Giving Prosody a Meaning". *Proceedings of the 5th European Conference on Speech Communication and Technology (Eurospeech'97).* Rhodes, Greece.

Light, M. 1996. "CHUMP: Partial Parsing and Underspecified Representations". *Proceedings of the European Conference on Artifical Intelligence (ECAI'96) Workshop: Corpus-Oriented Semantic Analysis.* Budapest, Hungary.

Morimoto, T., M. Suzuki, T. Takezawa, G. Kikui, M. Nagata & M. Tomokiyo. 1992. "A Spoken Language Translation System: SL-TRANS2". *Proceedings of the 15th International Conference on Computational Linguistics (COLING'92)*, 1048-1053. Nantes, France.

Ng, H.T. 1997. "Getting serious about word sense disambiguation". *Proceedings of the International Conference on Applied Natural Language Processing (ANLP-97) Workshop "Tagging Text with Lexical Semantics: Why, What, and How?"*. Washington, D.C.

Parsons, T. 1991.*Events in the Semantics of English.* Cambridge, Mass.: MIT Press.

Rooth, M. 1994. "Two-dimensional Clusters in Grammatical Relations". Unpublished manuscript.

Sato, S. & M. Nagao. 1990. "Towards Memory-Based Translation". *Proceedings of the 13th International Conference on Computational Linguistics (COLING'90)*, 247-252. Helsinki, Finland.

Schiehlen, M. 1997. "Eine Untersuchung zur Tempusresolution in der Verbmobil-domäne [in German]". Verb*mobil* Memo 130. IMS, Univ. of Stuttgart, Germany.

Schiller, A. 1995. "DMOR: Entwicklerhandbuch und Benutzeranleitung [in German]". Unpublished manuscript. IMS, Univ. of Stuttgart, Germany.

Schmid, P. & C. Gdaniec. 1996. "Evolution of the Logos Grammar: System Design and Development Methodology". *Proceedings of the 2nd Conference of the Association for Machine Translation in the Americas (AMTA-96)*. Montreal, Canada.

Schmid, H. 1994. "Probabilistic Part-of-Speech Tagging Using Decision Trees". *International Conference on New Methods in Language Processing*, 86-95. Manchester, U.K. URL: `ftp://ftp.ims.uni-stuttgart.de/pub/corpora/tree-tagger1.ps.gz`

Schulze, B. M. 1996. "GERMLEX – ein Lemmatisierer für deutsche Textcorpora [in German]". Unpublished manuscript. IMS, Univ. of Stuttgart, Germany.

——— & O. Christ. 1995. "The XKWIC User's Manual". Technical Report. IMS, Univ. of Stuttgart, Germany.

Slocum, J., W. S. Bennet, J. Bear, M. Morgan & R. Root. 1987. "METAL: The LRC Machine Translation System". *Machine Translation Today: The State of the Art* ed. by S. Michaelson et al., 111-134. Edinburgh, U.K.: Edinburgh University Press.

Stede, M. & B. Schmitz. 1997. "Discourse Particles and Routine Formulas in Spoken Language Translation". *Proceedings of the Annual Meeting of the Association for Computational Linguistics (ACL/EACL'97) Workshop on Spoken Language Translation*. Madrid, Spain.

Sumita, E., H. Iida & H. Kohyama. 1990. "Translating with Examples: A New Approach to Machine Translation". *Proceedings of the 3th International Conference on Theoretical and Methodological Issues in Machine Translation (TMI '90)*, 203-213. Austin, Texas.

Vauquois, B. 1975. *La Traduction Automatique á Grenoble*. Paris: Dunod.

Wahlster, W. 1993. "Verbmobil — Translation of Face-to-Face Dialogs". *Proceedings of the 4th Machine Translation Summit*. Kobe, Japan.

Wheeler, P. J. 1987. "Systran". *Machine Translation Today: The State of the Art* ed. by M. King. Edinburgh, U.K.: Edinburgh University Press.