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Structural Translation with Synchronous Rewriting Systems

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Abstract[1]

In the VERBMOBIL project, a dialogue in English between two non–native speakers of English can be assisted on demand by the VERBMOBIL translation system. In this situation, we propose to apply Synchronous Rewriting Systems (SRSs) *for a transfer step of varying depth (Anytime–approach). In an SRS, each rule of the source grammar and its corresponding rule in the target grammar are pairwise related. Futhermore the recursion operation is restricted to take place in parallel only in linked nodes. For a structural transfer, German and English syntactic constructions are directly related. The size of a rule can vary from word level up to a whole dialogue contribution. We propose this kind of processing as appropriate to early interruptions and conventionalized speech acts.*

1 Motivation

In the *VERBMOBIL project* (see, e.g., [Wahlster 93]), a machine translation system is developed for the following situation. A dialogue in English of two non–native speakers of English can be assisted on demand by the VERBMOBIL translation system. A main emphasis lies on the requirement of realtime processing in order to make the system naturally integratable in an ongoing communication. In VERBMOBIL, realtime processing is realized by *Anytime constructions* (see, e.g., [Dean & Boddy 88]), i.e., processes can be interrupted at any time cutting off time–intensive tasks but always providing more or less preliminary results.

In the following, we demonstrate how to apply *Synchronous Rewriting Systems (SRSs)* for this task. Two Rewriting Systems (e.g., two TAGs as outlined in [Shieber & Schabes 90]) are synchronized in the following way. Individual rules in the so called source and target grammar are specified as pairs in order to express structural correspondencies. Additionally, such pairs can contain links between nonterminals. Such links restrict the recursion operation to take place in linked nodes in parallel. Finally, the two inserted structures must belong to the same rule pair.

In the VERBMOBIL scenario, we apply SRSs with respect to flat transfer and early Anytime interruptions. In both cases, structural descriptions in German/Japanese and English are pairwise related. In the first case of flat transfer, a direct translation of simple constructions is provided (e.g., conventional

[1]Also appeared in '3e Colloque International sur les grammaires d'Arbres Adjoints (TAG+3)'. Technical Report TALANA-RT-94-01, TALANA, Universite' Paris 7, 1994.

speech acts as outlined in Figure 1 in Section 3). In the second case of an early interruption, they allow for rudimentary translations. A main advantage of such behaviour instead of detailed processing is that a result is always provided (interrupts). Furthermore, simple constructions do not waste time (realtime processing).

In the next section, we introduce the formal definition of an SRS. Furthermore, we discuss in general which formalisms can be related in an SRS. Then we focus on an adequate combination for our task. Especially, we present our experiences with a prototypical implementation using Synchronous Tree Adjoining Grammars (S-TAGs). Finally future work is mentioned.

2 Definition of Synchronous Rewriting Systems

A formal definition of *synchronicity* was given by Shieber and Schabes for TAGs (*S–TAGs*) [Shieber & Schabes 90] to express the related representations of semantics and syntax in natural–language description. In this section, we generalize this idea to *Synchronous Rewriting Systems*.

Definition 1 *A* **rewriting system** *S (***RS***) is a pair $S = (A(S), P(S))$ where $A(S)$ is a finite alphabet which consists of* the set of nonterminals *$N(S)$ and* the set of terminals *$T(S)$ ($A(S) := N(S) \cup T(S)$, $N(S) \cap T(S) = \emptyset$). $P(S) \subseteq A(S)^* N(S)^+ A(S)^* \times A(S)^*$ is the finite set of* productions.

Definition 2 *Let $S = (A(S), P(S))$ be an RS and $w, v \in A(S)^*$.*
v is called **directly derivable** *from w ($w \models v$) iff there exist words $u_1, u_2, p, q \in A(S)^*$ with $w = u_1\ p\ u_2$ and $v = u_1\ q\ u_2$ and $(p, q) \in P(S)$.*
Furthermore, v is called **derivable** *from w ($w \vdash v$) iff there exists a sequence of words $w = w_0, w_1, ..., w_r = v$ with $r \in \mathbb{N}$, $w_i \in A(S)^*$ ($0 \leq i \leq r$) and $w_i \models w_{i+1}$ ($0 \leq i \leq r\text{-}1$).*

Definition 3 *A* **synchronous rewriting system** *S (abbreviated as* **SRS***) consists of two rewriting systems G_1 and G_2 and a set of links L. Each rule in $P(G_1)$ is related to a corresponding rule in $P(G_2)$. A link ($\in L$) is defined between a nonterminal of the right–hand side of a rule in $P(G_1)$ and a nonterminal of the right–hand side of the related production in $P(G_2)$.*

Definition 4 *Let $S = (G_1, G_2)$ be a synchronous rewriting system.*
The terms **directly derivable** *and* **derivable** *are restricted to hold in parallel in both synchronously linked rewriting systems in the following sense. The two*

nodes where the recursion operations take place must be linked. The applied rules must be related.

Obviously, our definition is general enough to synchronize different formalisms (*mixed synchronization*). To some degree, the less powerful formalism can serve as an additional memory for the more powerful one. For instance, a TAG combined with a context–free grammar (CFGs)[2] allows for pushing a characterization of adjoinings which have taken place up to now. Each pop operation can be combined with a specific adjoining in the source grammar. This additional control allows, e.g., for the production of a^n b^n c^n d^n e^n where d and e alternate.

Beside this master–slave mode, mixed synchronization is advantageous in cases where tasks of different complexity have to be managed in parallel. For instance, if a computer program can be specified in natural language, an at least mildly context–sensitive formalism is required. An aspired representation in terms of a programming language (as target language) can be specified, e.g., in terms of a synchronized context–free grammar.

Linguistically interesting are decidable formalisms which are further restricted to allow only for linear growth during the derivation process and for polynomial parsing results (e.g., Tree Adjoining Grammars (TAG) [Joshi 85]). The class of *linear context–free rewriting systems* thus characterized was introduced by [Vijay-Shanker et al. 87] to allow generalizations of the definition of context–free grammars to manipulate any structure, e.g., strings, trees or graphs. Thus restricted formalisms are the basis for our further considerations.

3 Structural Transfer with S-TAGs

In the VERBMOBIL scenario, we apply Synchronous Rewriting Systems in Anytime processing in the following two respects. Synchronously linked structures in German/Japanese and English allow for rudimentary translations in the case of an early interruption of the system (e.g., quick and dirty translation of keywords). Consequently, a broad coverage of the language must be represented in the synchronous framework. On the other hand, direct translation of simple constructions (e.g., conventional speech acts as outlined in Figure 1) by synchronously related structures speeds up the system allowing more time for the processing of difficult phenomena in the source utterance. In this case, the final translation result is completely processed in the synchronous framework, certainly for a sublanguage.

[2]This means, grammars of the form $G = (N(G), T(G), S(G), P(G))$ where $P(G) \subseteq N(G) \times (N(G) \cup T(G))^*$).

Especially in the second case, an elaborate structural representation is necessary to be able to integrate synchronously produced phrases into — loosely speaking — "freely" generated phrases in order to form a correct utterance. This consideration rules out an approach on the basis of "flat" templates in favor of a "deep" grammatical representation.

Currently, we have implemented a flat translation system for conventionalized speech acts as salutations based on Synchronous TAGs. One basic reason for that is the well known fact that syntactic descriptions in the source (German and Japanese) and in the target language (English) can adequately be described by TAGs ([Joshi 85]). Another main reason is that this system should be able to exchange structures with the TAG–based generator in VERBMOBIL.

Figure 1[3] exemplifies flat transfer rules for *((wunder-)* schönen) Tag (Herr Miller)* and *Hello (Mister Miller) How are you*, respectively.

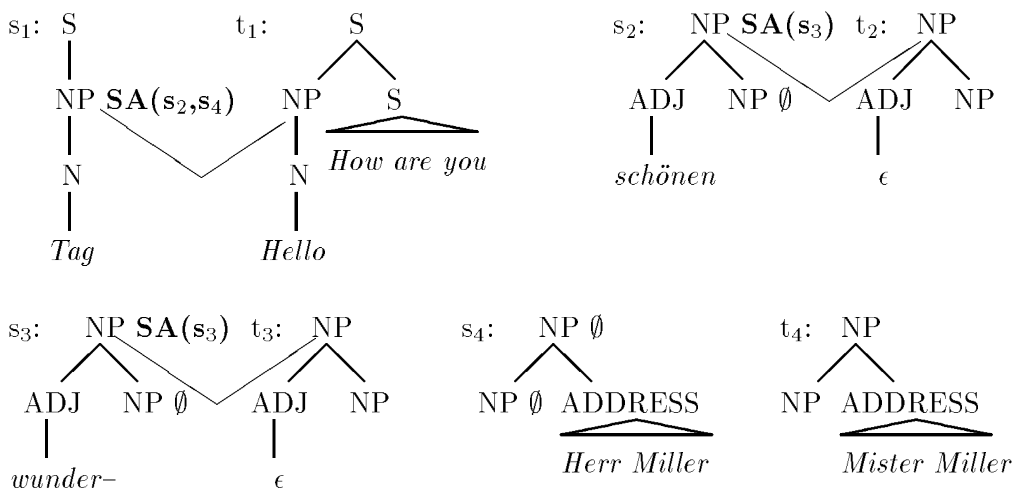

Figure 1: Example trees in a Synchronous TAG (with Constraints).

The system uses an analysis component based on the TAG parser of Peter Poller ([Poller 94]) which is based on the Earley algorithm and which works in a two–level mode. First, a context–free analysis for the source grammar is done. In the resulting item lists, all TAG readings are iteratively computed by searching for the current innermost trees, i.e. trees where no adjoining has taken place or where all adjoinings have already been eliminated.

[3]We allow for so called ϵ *trees*, i.e., auxiliary trees where all leaves are labelled with the empty string "ϵ" in the target grammar.

In order to realize synchronous adjoining, the step of identifying a complete elementary tree is extended to produce a building instruction of the synchronously corresponding rule in the target grammar. As a precondition it is checked whether there exists a link between the applied node in the source rule and in the target rule where the adjunction described in the building instruction should take place. Furthermore, in the target rule the label of the linked node and the label of the root node of the currently identified tree to be adjoined there must be the same.

During the iteration the individual building instructions are combined in a similar way as derivation trees for TAGs are specified in order to share subdescriptions efficiently. For reasons of even more efficiency, all building instructions remain uninstantiated until the iteration has terminated. At the end of this step only the complex building instructions for complete readings are evaluated in the target language. They represent the output of the overall component, i.e. the translation result.

A main advantage of using a two–level analysis approach — where the identification of adjoinings follows the derivation definition in an inverse manner — is that the system always operates on related subresults so that the regular expressions are only extended but never revised. Furthermore, the filtering by the corresponding derivation in the target language can immediately rule out readings in the source language. Another feature of our system allows switching between source and target languages, i.e. the system is *reversible* as long as no ϵ trees occur in the selected source grammar. Obviously, the grammar in Figure 1 is not reversible.[4] Currently, the system works with a grammar of about 500 rules. In the average case, a structural transfer step takes 0.5 sec on a SYMBOLICS MACIVORY machine.

4 Future Work

In general, it is difficult to decide whether two TAGs are the right formalisms for synchronization in order to express structural correspondences. Since the analysis and the generation task require more than context–free formalisms we propose the following possibilities to realize some additional power which remains below the complexity of S–TAGs. The synchronization of two CFGs comes up with the problem of the determination of the content of a rule because restrictions

[4] Reversibility is an overall goal in VERBMOBIL. However, the analysis is realized by another formalism than TAG. Over the long–term, a synchronization between this formalism and TAG is planned so that the Anytime mode can run interleaved with "free" analysis. As mentioned above for the generation, this is an important reason which determines the selected formalisms. Obviously, this combination can be stated by a mixed synchronization, although the complexities should be just the same here.

for analysis must be expressed in the target grammar. For the more powerful mixed synchronization of a source TAG with a target CFG we see difficulties for expressing, e.g, idioms in the target language.

For the application in VERBMOBIL, ambiguities with respect to source and target grammar must be resolved. One considerable strategy is to define probabilities for the individual readings.
If a sublanguage is described by a Synchronous Rewriting System the combination with "freely" generated fragments becomes necessary. We argue for a mixed mode on shared structures.

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