FUDR-based MT, head switching and the lexicon

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Abstract

We present an MT-approach which does transfer at the level of *flat underspecified discourse representation structures*. It allows for natural definitions of notoriously difficult structural divergencies between source and target, like *head switching*, by exploiting the formal means of semantic scope. The corresponding expressive lexicon formalism allows for a lexically driven, co-descriptive transfer architecture where the items of the lexicon are assigned transfer equivalents which carry the correct constraints about their incorporation into the target structure. This keeps the built-in transfer modules lean and easy to maintain, as they can be restricted to global transfer (and generation) routines which are independent of lexical pecularities (as presented by the treated structural mismatches). As a consequence this enables economic system development and maintenance.

Keywords: MT-methodology, lexicon encoding

1 Introduction

Most existing analytical, transfer-based Machine Translation systems distribute the transfer knowledge into relatively simple (conditioned) equivalence statements between source and target words, stored in the bilingual lexicon, and relatively fine-grained transfer knowledge about structural change, stored in the transfer module(s) proper. Some even renounce completely a bilingual lexicon and put all transfer knowledge in a transfer grammar. [a] Upgrading the system continuously is a very important task, which, as experience shows, is mostly a question of enlarging the lexica and the transfer knowledge respectively, given that source- (analysis-) and target- (generation-) grammars are normally relatively stable and complete from the first release on. The problem of such architectures with, say 'weak' bilingual lexica is that upgrading means upgrading the lexicon **and** the transfer grammar, which means that the lexicographer (very often a human translator) must be familiar with the transfer module/grammar and must maintain the transfer routines, or that there is someone permanently in charge of this. Neither alternative is desirable.

[a] For an overview to MT and its difficulties compare (D.J.Arnold et al., 1994), (Arnold, 2000), for an evaluation of (commercial) systems compare for instance (Hess and Volk, 1999), also (Seewald-Heeg, 1995); (Wahlster, 2000) describes a recent research prototype; w.r.t to transfer, in particular, compare (Dorna and Emele, 1996)

Costs and instability are minimized, if the lexicographer can use an expressive formalism which allows him or her, to formulate most types of structural change lexically, such that the underlying transfer routine can remain stable. With regard to system architecture, this is the co-descriptive correspondance-based approach, where the source lexical items *co-describe* the corresponding target structure informations.

This approach is rather traditional and so far approved (see (Kaplan et al., 1989), (Zajac, 1990), (Dalrymple et al., 1995) and others). However, it is known that correspondance-based approaches can run into problems in case of structural divergencies between source and target, mainly with so called *head switching*-phenomena, as in (1):

(1) *a. Le bébé vient de tomber.*
b. Das Baby ist gerade herunter gefallen.
b. The baby just fell.

Given that *venir* translates into *gerade/just*, the translation of the head of (a) is an adjunct of the head of (b), which is the translation of a complement of (a). Two elements exchange their positions in the structural hierarchy for each other, and thus destroy the homomorphic picture between source and target (see (Kaplan et al., 1989) for the example). There is an ongoing discussion about this problem (see (Sadler and Thompson, 1991), (Kaplan and Wedekind, 1993), (Butt, 1994) and others). Common assumption is that the co-description approach using function-application and equality must fail when faced with embedded head switching structures (like *Peter thought that the baby just fell*), if formulated for the level of *syntactic* representation, including abstract syntactic descriptions like LFG's f-structures. This is so, because, at such descriptive levels, circular structures, or, to the same effect, contradictory path descriptions are unavoidable w.r.t. such cases, except one assumes unintuitive restriction operations. [1]

2 Towards solutions of the head switching translation mismatch

Commonly, in the research community, there are seen two ways out of this problem: On the syntactic level, the transfer function/relation is reformulated as a term- or graph rewriting system, which permits specific constellations to override the transfer assumptions of more general ones. This means a transfer relation B:TB overrides the assumptions of a relation A:TA, where B is a set of tems representing a structure with *venir (de)*, where TB is the corresponding head switching target description and where A is B without the *venir (de)*-contribution. In turn, the statement B:TB will be overridden by C:TC, where C, in addition, represents an embedding of the switching structure (that is: $A \subseteq B \subseteq C$, or $C \rightarrow B \rightarrow A$), see (Dorna and Emele, 1996), (Dorna et al., 1998)). In the light of what has been said above, the disadvantage of such suggestions is that they do not treat the mismatch in the lexicon, but define structural correspondences in the transfer module proper. Also, by separating the transfer knowledge from the lexical entries and by making the translation dependent on the specificity of the matching source sides of the rewriting definitions of the transfer module, stalemates (with several concurrent, equally specific transfer statements) can arise which do not in the co-description case. Also, the computation of the specificity relation is rather costly, even when executed at system compilation time, at least if large transfer data bases are considered which are permanently upgraded.

Alternatively, it is suggested to put the translation task to the semantic level, assuming that the problem of structural divergency disappears at this more abstract level (see (Butt, 1994), (Dorna et al., 1998)). For the case at hand, this means to assume that *venir de* and *gerade/just* indeed have the same semantics. But do they? Since long one knows that the correct translation of tense and aspect presupposes the analyses of the temporal relations of the text, see (Kamp and Rohrer, 1983), (Kamp and Rohrer, 1985), (Eberle et al., 1992). Therefore, the Davidsonian style event representation (which provides discourse referents for events), is an important feature for semantic representation based transfer systems. On the basis of this, one can argue that these items cannot have the same semantics, because the one, the verb, introduces an event variable on its own right, whereas the other, the adverbe, just describes a relation to the perspective time. If this is true, for the critical cases considered, the semantic representations of source and target cannot be identified generally as one and the same term of a semantic interlingua. Instead, depending on the design purposes of the representation language, we may be confronted with the critical switching constellation and must find transfer solutions for it also at the abstract semantic level.

With regard to commercial systems, a third approach is even more frequent: Postprocessing routines are defined (mostly figuring as part of the transfer grammar) which structurally modify the output of the lexical transfer (see (McCord, 1989a)). This is disadvantageous under the objective of autonomously encoding the lexicon and also because it contradicts a principle-based treatment of transfer, by reason of the output of the lexical mapping being neither a defined source- nor a defined target structure in this case (with *gerade/just* syntactically heading *fallen/fall*), and vice versa with respect to the opposite translation task).

There are several reasons that transfer at the level of semantic representation should be preferred to transfer of syntactic structures. We mentioned the correct translation of tense and aspect (see also (Eberle, 2000) for a motivation). Of course, another reason is that the structural differences between the semantic representations of source and target can be expected to be less significant, when compared to syntactic analysis.

A third reason is that the cyclicity problem changes into a question of semantic scope at the level of semantic representation, such that concepts like the *restriction operator* of (Kaplan and Wedekind, 1993), which are somehow artificial when formulated for syntactic representations (see also (Butt, 1994)), on the semantic level, can be formulated quite naturally as constraints about the relative scope of operators (see section 5). This result is important also insofar as it legitimates the lexically-driven co-descriptive architecture, which, because of its advantages with respect to modularity, ergonomy and preference logic takes it over the graph rewriting approaches, including those which suggest rewriting of semantic descriptions (see (Dorna et al., 1998), compare also section 5).

However, the arguments for a semantics based transfer approach are practically validated only if the system can maximally avoid multiplying out those lex-

[1] Note that the value of the sentential complement of the *thinking*, which is the *falling*-structure in the source, should be the translation of the adverb in the target, which should subsume the translation of the *falling*-structure, but **without** the adverbial substructure. However, there is no natural syntactic formal means which would allow for hierachically structuring the analysis into a sufficiently fine-grained set of substructures.

ical and structural ambiguities which are irrelevant to translating the sentence. In other words the representations must be *underspecified* and must allow for dynamic semantic evaluation triggered by the transfer needs. The system that we present in the following meets these requirements. [2]

3 Architecture

The system parses sentences into so called *slot grammar*-analyses (for the dependency oriented *slot grammar* theory and formalism see (McCord, 1989b)). From these syntactic analyses, the system constructs *flat underspecified discourse representation structures* (FUDRSs), which are augmented by information from the syntax-semantics interface. We call these decorated FUDRs *dependence structures*. They define the level of transfer. [3] The transfer routine runs through the dependence structure, guided by the (semantic) ordering constraints of the sentence representation, translating the node structures by the specifications of the bilingual lexicon. (Basically, this means that the translation of (the flat semantics of) a non-deterministically chosen subcategorized slot or adjunct is chosen to be a modifier of the present argument translation, provided there is no other slot or adjunct which is known to have narrow scope w.r.t. the first one–where the order of the modifiers is preserved, except there is some constraint, like a change of type, which requires different structuring, like percolating the narrow scope modifiers down into some local domain of the new argument). From the target dependence structure, the generation grammar constructs the target string, where this grammar (as well as the just described recursive transfer) may use source surface information and also may refine the semantic interpretation in order to obtain correct output. [4]

Figure 1 renders this architecture, where the use of the LFG-typical projection names ϕ and σ should demonstrate the relative similarity to the LFG-approach (see (Kaplan and Bresnan, 1982), (Dalrymple et al., 1995)). However, recall that the dependence structure is a semantic representation, in contrast to LFG's f-structure. Therefore, in our approach, σ (triggered by lexical instructions and generation) is not a mapping between structures of different types, but a relation between structures of the same (semantic) type, but different semantic granularity. This is advantageous.

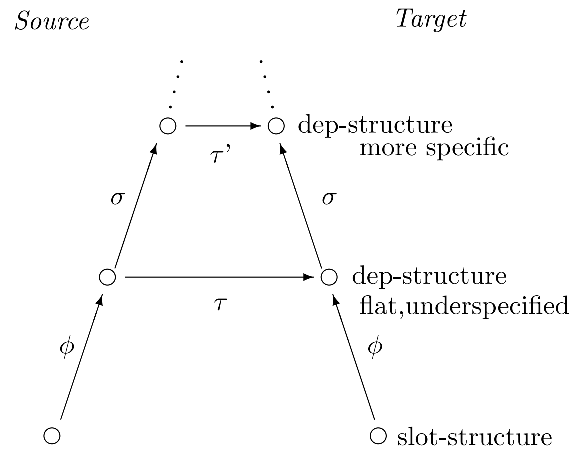

Figure 1: Relations

4 Recursive transfer

Basically, in slot grammar, a sentence is analysed into a head (the verb node), which is assigned a number of (subcategorized) *slots* (the verb complements) and, possibly, one or more adjunct modifiers (like subordinated clauses, adverbials, etc.). Given the sentence (2), (2.syn) renders the corresponding analysis:

(2) *Pierre a donné Fido à Marie.*
Pierre has given Fido to Marie.

(2.syn)
$$\text{AVOIR}\begin{bmatrix} \text{subj(n): PIERRE} & \\ \text{aux(i): DONNER} & \begin{bmatrix} \text{obj(n): FIDO} \\ \text{iobj(n): MARIE} \end{bmatrix} \end{bmatrix}$$

Here AVOIR, PIERRE, ... are the analyses of the corresponding words in (2), this, mainly, is surface position information (node number) connected to common syntactic and morphologic information. From (2.syn), the dependence structure (2.dep) evolves by flat semantic construction (which interpretes the auxiliary complex of sentences with analytic tense forms as tense and aspect information about an introduced event description and the like, see (Eberle, 2000)).

[2]It has been implemented (starting in 1996) and is part of the *Personal Translator* product line, whose technology has its roots in the LMT project (McCord, 1989c).

[3]FUDRSs have been introduced in (Eberle, 1997) mainly to complete Reyle's UDRT-approach (cf. (Reyle, 1993)) by an event semantics component, this is by an account of the quality and temporal structure of the sentence event(s) with regard to quantification, modalization and Aktionsart. *Flat* means among other things, that the lexical items are not analyzed further than into their predicate argument structure at first, but are connected to possibly more analytic disambiguated representations. Instead of the partial representations of UDRT, FUDRT uses functions from representations into representations and interpretes the order constraints dynamically as stipulations about the order of application.

[4]Similar to approaches like *VerbMobil* (see (Kay et al., 1994) for an overview), we assume that semantic evaluation, since costly, should be guided by transfer needs, instead of generally and globaly refining the underspecified basic dependence structures into readings of the sentences. Therefore the instruction formalism that we will sketch in section (5) allows for constraints containing elements which trigger such dynamic semantic evaluation.

(2.dep)

$$\underline{\text{donner}} \left\{ \begin{array}{ll} \text{subj(n):} & \underline{\text{pierre}}, \\ \text{obj(n):} & \underline{\text{fido}}, \\ \text{iobj(n):} & \underline{\text{marie}} \end{array} \right\} \text{\& OC}$$

(2.dep) has to be read as follows: donner, pierre, ... are the *flat* semantic representations of the corresponding words in the sentence (that is: decorated by relevant distinguished referents, tense and aspect information, if any, and connected to a range of more specific interpretations, if any). The elements of the set are semantic functors with respect to the object heading the set, where a specific semantic interpretation (a DRS) can be constructed by applying the functors in accordance with the scope constraints of *OC* and where the type of application or composition is identified by the name of the corresponding grammatical function, subj(n), obj(n) etc., via using information from the syntax-semantics interface. (In case the set of order constraints *OC* is empty, the order of the applications is not further determined). On the basis of this, it is easy to see, how the transfer routine τ should work by default: τ applied to (2.dep) should result into the target dependence structure (2.tdep).

(2.tdep)

$$\tau_n(\underline{\text{donner}}) \left\{ \begin{array}{ll} \tau_s(\text{subj(n)}): & \tau_n(\underline{\text{pierre}}), \\ \tau_s(\text{obj(n)}): & \tau_n(\underline{\text{fido}}), \\ \tau_s(\text{iobj(n)}): & \tau_n(\underline{\text{marie}}) \end{array} \right\} \text{\& OC}$$

where τ_n is the transfer relation between nodes, that is the translation of flat word semantics, basically the relation between source and target word, and where τ_s is the transfer relation between application types as designated by the grammatical functions, translating for instance de-complements of nouns, *ncomp(p(de))*, *le mari de la femme*, into noun complements of case genitive, *ngen*, *der Mann der Frau*. The relative scope order, *OC*, should be preserved.[5]

Summarizing, the basic default transfer algorithm we use can be sketched by the following formula:

$$\tau(\text{Mother} \left\{ \begin{array}{ll} \text{slot}_1: & \text{Daughter}_1, \\ \vdots & \\ \text{slot}_n: & \text{Daughter}_n \end{array} \right\} \text{\& OC})$$

$$:= \tau_n(\text{Mother}) \left\{ \begin{array}{ll} \tau_s(\text{slot}_1): & \tau(\text{Daughter}_1), \\ \vdots & \\ \tau_s(\text{slot}_n): & \tau(\text{Daughter}_n) \end{array} \right\} \text{\& OC}$$

[5]Note that the reverse of the slot analysis hierarchy defines the initial constraints about the order of semantic application (and composition, to be precise), where the order of applying the daughter representations to the head representation is completely unspecified. It might be constrained by transfer and generation however.

This allows for translating source sentences into target sentences, which, w.r.t. the level of dependence structure, are isomorphic.

5 τ-Instructions

The formal means that we suggest in the following extend the basic settings of the LMT lexicon formalism (see (Bernth, 1992)). A relevant (economic) feature of this is that saying nothing about the translation of a specific slot, slot_i, of an item means: translate it by default, this is by $\tau_s(\text{slot}_i)$. A prerequesite of this is to keep track of positional information. For this reason, we deviate slightly from the description style of (2.dep), (2.tdep) by rendering the set of subcategorized modifiers as ordered set, that is as a list. Next to the source setting (of the thus revised type (2.dep)), marked by •, and the corresponding target setting, τ, the considered part of a bilingual lemma, as a third component, may contain conditions, C, which restrict the acceptance of the presented translation to source structures satisfying C. For the example (2), therefore, we will write:

• $\underline{\text{donner}}^{\text{[subj(n),obj(n),iobj(n)]}}$
C: true
τ : $\underline{\text{geben}}$

This means that *donner* has a 3-place reading which is translated into *geben*, without further preconditions, where the slots are translated isomorphically according to τ_s, with values as defined by the corresponding lexical entries and the source dependence representation. From this isomorphic default case, we can deviate by combinations of the following local and non-local τ-instruction types.

5.1 Local τ-instructions

We assume the following basic local instruction types:

T1 τ modifies the function of a slot: $\tau(\text{slot}_i) \neq \tau_s(\text{slot}_i)$

T2 τ suppresses a slot: $\tau(\text{slot}_i)=$ e

T3' τ introduces a slot: item(slot_name,slot_descr$_{2-4}$)

item has at least two arguments, where the first defines the new slot and the second its value (the new word and its relation to the semantic argument). Additionally semantic type information about the new item may be given. Finally, in recursive manner, slots and adjuncts of the new item may be defined. Therefore, via *item*, descriptions of entire (V-, N-, A-...) **phrases** can be introduced.

The local instruction types also include the following generalization to adjuncts and paths (over adjuncts and subcategorized modifiers):

T3 τ introduces an adjunct:
item(adjct_name,adjct_descr$_{2-4}$)

T4 τ shifts a s-dpath into a t-dpath:
tp(s-dpath,t-dpath)

Path shifting statements of type T4 are restricted to downward paths (*d*, designating (modifiers of) modifiers) including the empty path (*e*) at the target position. Instead of illustrating these means by corresponding examples we turn directly to the more relevant non-local instructions and to the considered structural difficulties and their definitions which will make use of the types T1-T4 also.

5.2 Non-local τ-instructions

Non-local instructions speak about positions which are outside the structure which is (syntactically) dominated by the lexical item considered. One of these instructions allows for *upward path shifts* which are renamings and redefinitions of the role the value plays w.r.t. its semantic argument in the target structure:

T4' τ shifts a s-upath into a t-upath:
tp(u(s-mod),u(t-mod))

(3) exemplifies this: the role played by the adjective changes in transfer.

(3) *Un médecin auxiliaire*
Ein Hilfsarzt
An assistant doctor

The target value is not an adjectival attribute of the head noun (*nadj*), but a compound of it (*ncompound*). We could render this change within the entry of *médecin*, via a T4 *tp(d(nadj),d(ncompound))*-statement. However, since the change does not really depend on the head noun, but is rather an intrinsic quality of *auxiliaire*, we prefer incorporating it into the entry of the adjective, as follows:

• $\underline{\text{auxiliaire}}$ []
C: u(nadj) - f
τ : $\underline{\text{ui('Hilfs-')}}$ [tp(u(nadj),u(ncompound))]

There are 3 other types of non-local instructions:
Provided N names a (source) structure (directly or via a path description), and M the lexical entry:

T5 τ uses a structure which is coreferent to τ(N):
$\ldots\tau(\mathrm{N})\ldots$

T6 τ uses the translation of a substructure of N in the scope of M, $N^{\not\succeq M}$:
$\ldots\tau(N^{\not\succeq M})\ldots$

T7 τ constrains a distant node:
τ(N): τ_constraints

More precisely, T6 takes up a dependence structure N where M figures as a semantic functor (slot or adjunct) and chooses a substructure $N^{\not\succeq M}$ of N for which there is a linearization of the OC-constraints of N, according to which $N^{\not\succeq M}$ is the argument of M. This means the functors of $N^{\not\succeq M}$ have narrow scope with respect to M according to OC, or allow to have and are constrained accordingly by the σ-evaluation which must accompany the choice of the argument $N^{\not\succeq M}$ of the T6 τ-application.

Types T5 and T7 allow the treatment of the *verb to adverb* switching case ('a' to 'b' in (1)):

• $\underline{\text{venir}}$ [subj(n),obj1(infde)]
C: mtv(M,TF,a) & d(obj)-w(V)
τ: τ(V) &
V: $\begin{bmatrix}\text{item(vadv,gerade,temploc\_adv),}\\ \text{tp(u-d(adjt),d(adjt))}\end{bmatrix}$
& mtv(M,perf(TF),a)

This means: given the obj(infde) of *venir* is *V* and *venir* has mood *M* (infinitival, finite,...), tense features TF and voice *a*ctive, we translate *venir* into the translation of V, where this translation obtains a new adverbial modifier *gerade*, takes over the adjuncts of *venir*, if any, and inherits the mtv-features of *venir*, with TF replaced by its perfective variant.

We use type T6, in order to specify the opposite case of switching ('b' to 'a' in (1)):

• $\underline{\text{gerade}}$
C: u(vadv) - f & dst(temploc_adv)
τ: $\underline{\text{venir}}$ $\begin{bmatrix}\text{item(subj(n),}\tau\text{(u-d(s\_subj)),}\\ \text{item(obj(infde),}\tau(u^{\not\succeq id}))\end{bmatrix}$

This means that *gerade* is translated into *venir*, provided it modifies a verb *V* and *can be shown by default semantic evaluation* – this is the meaning of 'dst' – to be a temporal modifier in the actual context, where the subject of *venir* will be the translation of the (surface) subject of the modified verb and where the object of *venir* is the translation of a structure, which syntactically is headed by *V* (and which is the value of the path *u*) and which, semantically, does not omit a functor which is known to have narrow scope with respect to *gerade*. (*id* designates the node of the item considered). In addition, this translation comes as infinitival complement. Its subject, which is coreferent to the matrix subject, is not realized on the surface. We repeat that this type of τ-instruction requires refinement of the OC of the structure containing *id* as a modifier and we emphasize that this σ-evaluation may influence the translation of functors concerned.

These non-local means are very powerful and allow for specifying nearly all types of structural divergency. Of course, the lexicographer might define templates for frequently used complex τ-statements and write them into a normalization data base. For instance, when defining the template D1 as below, in the *gerade* entry above, he/she can replace the τ-statement by the following shorter one:

τ: $\underline{\text{venir}}^{advtoverb(infde)}$.

D1

advtoverb(infde) := [item(subj(n),τ(u-d(s_subj))), item(obj(infde),$\tau(u^{\not\geq id})$)]

As a side-effect of the lexically driven recursive transfer strategy, we obtain a default logic which is more specific than common inheritance systems which base on the criterion of specificity of information only, since it can prefer default information from a node A to (conflicting, equally specific) default information of a node B also, if, according to the dependency hierarchy of the analysis, A is more specific than B. For example think of the following bilingual informations about the French preposition *à*:

- <u>aller</u>

C: true

τ: <u>gehen</u>[tp(d(prep(à)-st(COUNTRY),d(prep(nach))]

- <u>États Unis</u>

C: true

τ: <u>Vereinigte Staaten</u> [tp(u(prep(à)-st(MOTIONV),u(prep(in))]

The first definition is part of the entry of the verb *aller* and stipulates that an *à*-adjunct of an *aller*-VP is translated into German *nach* in the context *C1*: *aller* **à** COUNTRY. The second definition presents the translation of *Etats Unis* and triggers a specific translation of à, *in*, in the context *C2*: MOTIONV **à** *Etats Unis*. Given a corresponding sentence where both constraints are satisfied, the translation *in* will be preferred, because it stems from the more specific node and overrides the conflicting information of the higher node. Neither *C1* nor *C2* being more specific than its competitor, under the graph rewriting approach, where *C1* and *C2* define source descriptions of transfer pairs relating to the translation of *à*, the example presents a stalemate. Note that in large-scale systems such stalemates are rather frequent and even unavoidable, if the descriptions are too weak to prevent that the relevant contexts overlap. We emphasize that, for reasons of efficiency, weak descriptions are necessary on principle and also cannot be avoided in practice.

6 Conclusion

We have presented a FUDR-based transfer system which uses an expressive formalism for transfer statements which allows for describing most of the frequent and relevant types of structural mismatches lexically, including head switching. This frees the lexicographer from engineering tasks and contributes to efficient system development and maintenance.

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