Russian - a challenge to METAL ? Some Difficulties of Russian-German Machine Translation

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1 Introduction

The fundamental political changes in Europe during the last five years have promoted interest in East European languages. The increasing co-operation of the Federal Republic of Germany with Russia and other East European countries in various fields of economy, science and culture has also made it necessary to communicate more comprehensively and speedily in such "exotic" languages as Russian. In this political context a group of linguists and information scientists working in Berlin began to develop a Russian-German MT system based on the METAL software from Sietec Systemtechnik GmbH.

The developers (formerly staff members of the former East German Academy of Sciences) had designed and implemented an experimental German-Russian MT system named VIRTEX in the late 1980s, which was presented at COLING-90 in Helsinki. VIRTEX focused on the translation of German verbal groups which implied the treatment of such complex problems as the interrelation of aspect, tense and modality. At present a demonstration version of this system is being used for training students at Bonn University. Meanwhile the development team of VIRTEX, together with other former colleagues, have found shelter under the roof of a small industrial company, GMS (Gesellschaft für Multilinguale Systeme mbH).

When the development of the new Russian-German system - funded by two German government agencies - started at the end of 1991, the only systems translating from Russian to German were SUSY and CAT2 developed at the university of Saarbrücken. While the development of SUSY written in FORTRAN was stopped in 1989, work on CAT2 is still going on. The latter is a pure research project based on unification formalism and working with a lexicon comprising, up to now, about 5000 full forms. Only recently MT News International reported that the two commercial PC systems STYLUS and PARS have taken up the development of the language-pair German-Russian.

The investigations of the GMS team in the field of Russian-German started with the intention of proving that Russian, though in many respects different from the METAL languages tested so far (namely English, French, German, Danish and Spanish), could nevertheless be integrated into this system.

2 The prototype

As mentioned above, the team worked closely together with Sietec and therefore was able to exploit the existing METAL software. METAL is transfer-based and organised on a modular basis. That means that existing analysis and synthesis modules can be reused for new language pairs. Thus, for Russian-German, "only" the Russian analysis grammar and the Russian-German transfer grammar had to be developed. Besides, the corresponding lexicons had to be built: a Russian monolexicon and a transfer lexicon for Russian-German. Figure 12 - 1 gives an overview of the whole system:

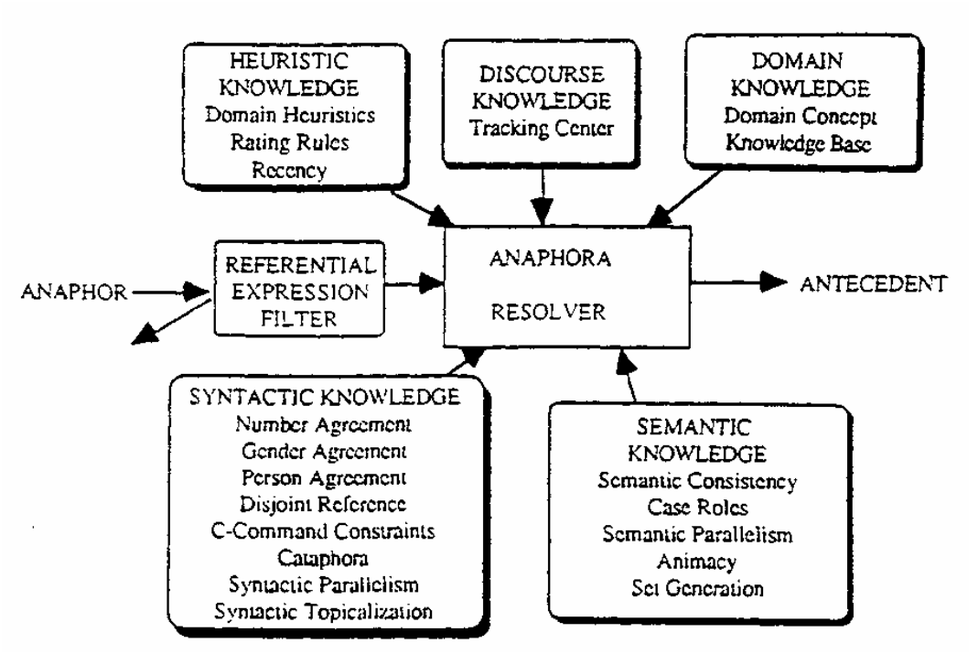

Figure 12 – 1: System overview

During the period of development the German generation component along with a lexicon of about 50,000 entries was at the disposal of the research team.
The result of the investigations was a prototype, presented to the public in Berlin this spring, which will be developed into a commercial system within the next two years. The performance of the prototype was demonstrated with texts from two domains, nuclear power and aeronautics. With some 7,000 entries, it had a set of lexicons considerably larger than is usual for a prototype. Meanwhile the size of the lexicons has reached nearly 10,000 entries.

Unfortunately, we are unable to show our system at this conference, because it does not run on a PC and therefore is difficult to install without our bringing along our own hardware. The hardware basis used so far is a Sun Sparc station. We hope that the sample texts at the end of this paper will convey an impression as to what extent the grammatical complexity of the language pair is covered.

3 Peculiarities of Russian

The system already handles most of the grammatical constructions typical of Russian, though in many cases only as parts of simple structures or not yet to their full extent. Speakers of both Russian and German will certainly be aware of several phenomena which may complicate Russian analysis or are difficult to handle in transfer. In the following, we will describe in more detail some of the major grammatical obstacles we had to cope with. The first barrier to overcome was the Cyrillic character set. This presented a problem for integration with other METAL

components, as the original METAL software was not suited to Cyrillic. Meanwhile METAL has become able to process Cyrillic characters as well as a special Latin transliteration developed for them. (For typographic reasons, all Russian examples of this paper are transliterated[1]).

Other problems resulted from the rich inflectional system of Russian and a variety of syntactic phenomena, unknown in Germanic languages, such as

- a zero copula in the present tense
- subjectless main clauses
- homography of passive and reflexive constructions with the particle '-sya'
- interrelation of aspect and tense
- numerals dominating noun phrases
- high complexity of noun phrases
- missing articles.

3.1 Morphological analysis

Russian has a huge number of inflectional forms, many more than German and all other languages treated so far by METAL:

- nouns and adjectives have six cases for each number
- adjectives, moreover, mark the gender in the singular and have different forms for attributive and predicative use
- verbs mostly have different stems depending on the verbal aspect (perfect or imperfect), as well as a large number of inflectional forms varying with person, number and tense and various participial forms
- cardinal numbers are inflected like nouns.

A rich morphology has both advantages and disadvantages for analysis: On the one hand, there are fewer ambiguous forms than in languages with few morphological forms. On the other hand, if a form is ambiguous, it often has more than two grammatical meanings, e.g. 'knigu' (book) is always accusative singular, whereas 'knigi' (books) is genitive singular or nominative plural or accusative plural. During morphological analysis the words to be analysed are compared with the Russian lexicon and split into stems and endings (provided there are endings) and the endings are supplied with all possible grammatical meanings. Before calling the word rules, a morphological filter is activated, which consists of a matrix with all possible sequences of word segments. If the word forms have more than one meaning at the morphological level, they have to be disambiguated by syntactic analysis. In case the syntactic analysis is not successful, the corresponding sentence has more than one interpretation, all of which can be displayed on the screen.

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[1] Editors' note: The transliteration into Latin characters is usually in accordance with the phonetic rules of German.

3.2 Syntactic analysis

Before discussing problems of syntactic analysis, we think it necessary to give a short overview of the analysis phase and the structures built by METAL. The translation units in METAL are sentences. The system is based on an augmented phrase-structure grammar. During analysis, according to a version of X-bar theory, tree structures for every phrase or clause are built . Except for conjunctions and prepositions, these structures consist of three levels for each category. The basic structure looks as follows:

Basic structure

X" → NP

| |

X' → N

| |

X → NST

These structures are called MIR structures (MIR = Metal Interface Representation). The representation and decoration of tree structures is standardised for all METAL languages. This is one of the major prerequisites for the modularity of analysis and generation modules. If possible, MIR structures are built already during analysis; otherwise necessary adaptations are made during structural transfer.
The syntactic function of the nodes in analysis tree structures is characterised by means of function values like FUNC HEAD, FUNC MOD(ifier), FUNC SPEC(ifier), FUNC COMPL(ementizer). (Figure 12 - 2)

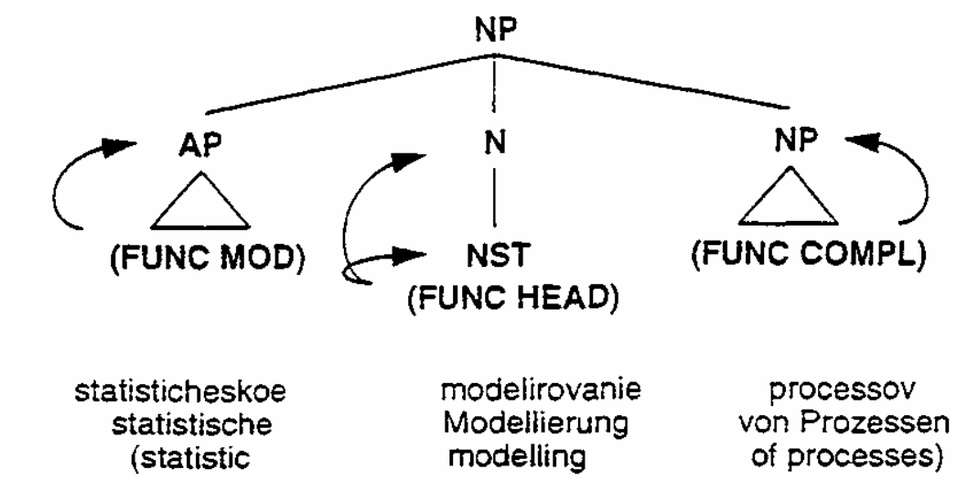

Figure 12 – 2: Modification

Example of a modification:

As a result of sentence analysis the verbal arguments are assigned syntactico-semantic roles, e.g. a NP in the instrumental case (=5th case) can be assigned one of the roles "agents of a passive sentence", "subject complement", "object complement", "indirect object" or "instrument". This is done by a procedure called Framing, which checks whether the slot fillers found in the clause match the verbal frame coded in the lexicon. In this connection, the characteristic Russian phenomenon of the zero copula in the present tense is a challenge to an analysis centred around the verb.

3.3 Zero Copula

According to our understanding of subject and predicate as the core of a sentence, there occur regular sentences in Russian where the subject and/or predicate are not expressed. The missing constituents must be reconstructed during analysis in order to represent their structures. A predicate form never expressed by a word form is the present tense of the copula 'bytj' (sein/ to be):

(1) 'On naw direktor' --> He (is) our director.

In English or German missing predicates are exceptions, not occurring in normal sentences, but in headings or signs, like 'Fahrstuhl defekt', 'heute kein Ausschank', 'mortgages available'. The question was how to check the structure of a clause the predicate of which is missing. To the right and to the left of the non-existing copula there may be different phrases: NP and NP, NP and AP etc. Altogether there are more than twelve combinations, which may also occur adjacently in clauses with verbs. Therefore, it is necessary to block multiple analyses by checking the immediate context as early as possible. The missing predicate node is inserted during analysis and assigned all lexical feature-value pairs as well as information from the sentence context, thus ensuring that zero copula phrases can pass framing without failure.

At first sight analysis seems to be easier if the copula in the present tense is expressed, namely by means of "-", the dash (in Russian: 'tire'), which is considered a verb form of 'bytj':

(2) 'Nomografiya - oblastj matematiki.' --> Die Nomografie ist ein Gebiet der Mathematik. (Nomography is a field of mathematics.)

Unfortunately, the dash is highly ambiguous. It is a punctuation mark designating appositions, and it may also function as a dummy predicate in elliptic structures in order to avoid repeating the main verb. As the following example (3) shows, analysis even has to cope with combinations of these functions:

(3) 'Chetyre kolesa - dva perednix i dva zadnix - upravlyaemye.' --> Vier Räder - zwei vordere und zwei hintere - werden angetrieben. (Four wheels - two front and two rear ones - are driven.)

Both dashes mark the apposition within the sentence, and in addition the second dash functions as a zero copula. The solution of these problems will not be feasible without further fundamental investigation.

3.4 Subjectless Clauses

In German and English, main clauses are considered complete if there is a (nominal) subject. Normally, except for the imperative clauses, cf. 'Schreib(t)!' (Write!), it has to be expressed on the surface. Note, however, that the polite form of the imperative in German has an explicit subject: 'Schreiben Sie!' In addition to imperative clauses Russian has a number of other clause patterns

where the subject is missing: impersonal, indefinite-personal and indirect-personal clauses. In impersonal clauses the correlate (verbal precursor) is not expressed on the surface.

(4) 'Temno'. --> Es ist dunkel. (It is dark.)

(5) 'Interesno, chto russkie voijska okonchateljno pokinuli Germaniyu.' --> Es ist interessant, daß die russischen Truppen endgültig Deutschland verlassen haben. (It is interesting that the Russian Forces have left Germany for good.)

As can be seen, there is neither a correlate nor a copula in the present tense. Analysis makes the gapped constituents overt, thus enriching the analysis result in order to prepare correct transfer. Indefinite-personal clauses have a verb form expressing the 3rd person plural:

(6) 'Govoryat, chto Boris Eljcin budet obespechivatj mir.' --> Man sagt, daß Boris Jelzin den Frieden gewährleisten wird. (They say that Boris Yelzin will guarantee peace.)

As a result of analysis the construction is marked "indefinite-personal", and in transfer the empty subject node is lexically filled, depending on the voice chosen for the target language sentence, cf. 'man sagt' vs. 'es wird gesagt' ('they say' vs. 'it is said').

The indirect personal clauses are not really subjectless but contain a noun phrase in the dative, which semantically functions as a subject:

(7) 'Studentu mozhno primenyatj ehti metody.' --> Der Student darf diese Methoden anwenden. (The student is allowed to use these methods.)

In this case, analysis has to check whether the dative NP is the subject of the given sentence or an indirect object. In example (7) it can only be the subject because the modal predicative 'mozhno' binds a dative subject and the verb 'primenyatj' does not attach any indirect object. Such a construction can be ambiguous if the verbal frame contains a slot for a dative object, e.g.,

(8) 'Studentu mozhno peredatj knigu.'

Here the NP 'studentu' may be either the subject or the indirect object. Hence, METAL delivers two interpretations, the second of which reconstructs the missing subject. Dative object and dative subject may occur together in a sentence, cf.

(9) 'Studentu mozhno peredatj knigu direktoru.' --> Der Student darf das Buch dem Direktor geben. (The student is allowed to give the book to the director.)

Both in English and in Russian there are various types of subclauses where the first valency of a verb or adjective, e.g., the subject, cannot be expressed on the surface. They include

infinitive subclauses

subclauses each formed with a gerund

pre- and postpositional participle clauses and

postpositional adjectival clauses.

All these zero-subjects are made overt during Russian analysis no matter whether the result is necessary for the translation into German or not. The necessity of reconstructing such gapping elements results from the aim to make the METAL interface structure (MIR) a real deep-semantic structure, which contains all the pieces of information needed for transfer into different target

languages, especially in cases of structural non-correspondences between source and target language. One example of non-correspondences are gerund constructions, which are widely used in Russian, but are unknown - or at least unusual - in German:

(10) Chitaya knigu, on sidit sa stolom. --> (literally, not the METAL translation:) *Lesend Buch, er sitzt am Tisch. (See figure 12 - 3.)

Gerund constructions are analysed as subclauses without conjunctions, which function as adverbials. During analysis a copy of the subject of the matrix clause is inserted into the gerundial clause.

The structural transfer determines the tense of the subclause and the conjunction to be inserted later during generation. This depends on various factors like the type of gerund (expressing simultaneity or anteriority), the tense of the matrix clause and the position of the gerund clause (before or after the matrix clause). In example (10) the present tense gerund is in front of the matrix clause which itself is in the present tense. This yields the following translation:

--> Während er ein Buch liest, sitzt er am Tisch. (Reading a book, he is sitting at the table.)

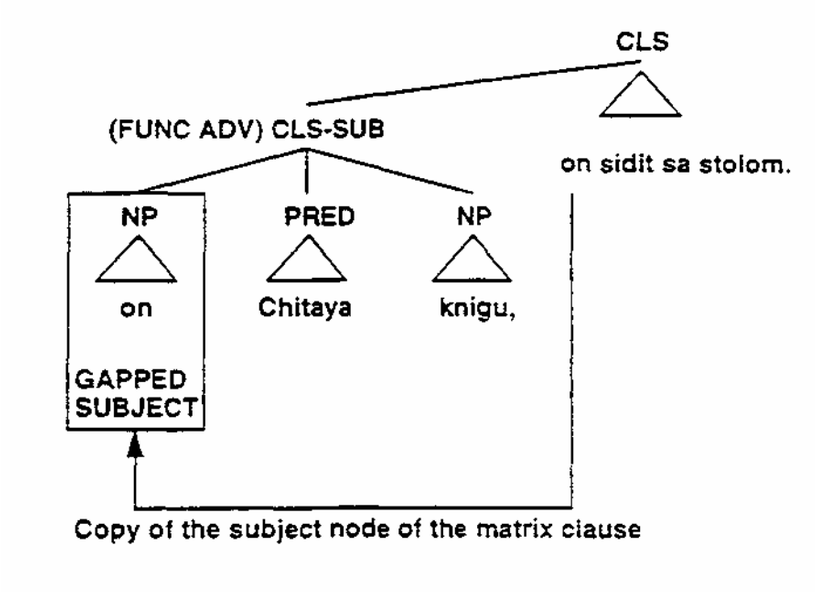

Figure 12 - 3 Analysis structure of a gerundial clause

When translating from Russian into English, the reconstruction of the zero-subject is not so compelling, thanks to the structural correspondences. This may be one of the reasons why, in the Russian-English MT system ETA-3, the zero subjects are so far generally not made visible in the so-called "normalised" structure which more or less corresponds to the MIR structure, since it is the basis for transfer. However, even when translating into English, one cannot dispense with zero-subject reconstruction if one wants to seriously tackle the problem of anaphora resolution. For this purpose it is an important prerequisite to make the gapping constituents overt, in

particular, if the zero subject functioning as an antecedent of a personal or reflexive pronoun has no controller within the sentence.

In METAL Russian-German the anaphora problems are resolved as far as the above mentioned constructions are concerned. Besides, the antecedents of the relative pronouns of participle, adjectival and, of course, of "normal" relative clauses are identified.

In contrast to German and English, Russian has four types of participles (two active and two passive ones) the long forms of which may be left or right modifiers of noun phrases:

prenominal use:

(11) 'rabotayuqie v institute studenty'--> die im Institut arbeitenden Studenten (literally: *working at the institute students)

postnominal use:

(12) 'studenty, rabotayuqie v institute,...' --> Studenten, die im Institut arbeiten, ... (students working at the institute)

From a morphological point of view participles are treated as adjectives which are derived from verbs. But during syntactic analysis they are expanded to relative clauses by inserting the zero subject /object depending on the voice of the respective participle. The German translation of (11) does not show the expanded analysis structure (approximately like this: *'kotorye rabotayuqie v institute studenty'), because the relative clause is changed into a participle during German generation.

This approach has two advantages: First, with reconstructed constituents, participle clauses can pass the framing procedure, thus avoiding misinterpretations. The following examples illustrate structure disambiguation by framing:

(13) 'piwuqie studenty' (SUBJECT) --> schreibende Studenten (writing students)

(14) *'piwuqie knigi' (DIRECT OBJECT) --> *schreibende Bücher (*writing books)

(15) 'studenty, piwuqie knigi (DIRECT OBJECT),...' --> Studenten, die Bücher schreiben,...

(students writing books)

(16) 'piwuqie knigi (DIRECT OBJECT) studenty (SUBJECT)' --> Bücher schreibende ....Studenten (students writing books)

In (14) no interpretation is found, because 'knigi' cannot be the subject of the verb 'pisatj' (write). If this construction is embedded into a sentence, it can be part of two correct structures. In example (15) it is a right modifier of 'studenty', in example (16) it is a left modifier.

The second advantage is that regular transfer tests and transformations coded in the transfer lexical entry of the verbs likewise apply for their participles. This is not only of use for anaphora resolution, but also for lexical disambiguation. The past passive participle of the verb 'sostavlyatj' has many equivalents in German, which can only be disambiguated on the basis of the slot fillers of the verb:

'sostavlennyij protokol' --> aufgenommenes Protokoll (protocol taken down)

'sostavlennoe pisjmo' --> aufgesetzter Brief (drawn up letter)

'sostavlennyij proekt' --> entworfenes Projekt (planned project).

3.5 Interrelation of aspect and tense

A peculiarity of Russian is the grammatico-semantic category of aspect, which expresses various temporal references in relation to the time of speech. It has the values "imperfective" and "perfective". As aspect has no direct correspondence in German, its meaning has to be extracted and, if necessary, expressed by adequate lexical and/or morphological means. Incomplete knowledge of the meanings of the Russian verbal aspect can cause serious misunderstandings. The following sample sentences contain the same verb of locomotion 'prixoditj/priijti' kommen (to come) but which differs in aspect:

(17) 'On priwel' (perfective aspect) --> Er ist gekommen. (He has come.)

(18) 'On prixodil.' (imperfective aspect) --> Er war gekommen. (He had come.)

Whereas (17) means that the person in question is still there, (18) means that he was there but went away. Here the use of different aspect forms results in almost opposite meanings. Such extreme contrasts normally only occur with verbs of locomotion. In other cases aspect may influence the selection of lexical equivalents:

(19) 'On sdal ehkzamen.' (perfective aspect) --> Er hat die Prüfung bestanden.

(He has passed the examination.)

(20) 'On sdaval ehkzamen.' (imperfective aspect) --> Er hat die Prüfung abgelegt.

(He has taken the examination.)

Whereas (19) says that the person passed the examination, sentence (20) leaves it open.

Further problems arise in connection with verbal phrase interpretation. For instance, Russian subjunctive has only one morphological form consisting of the verb in the past tense and the particle 'by'. Sometimes the aspect form is sufficient for disambiguating tense:

(21) 'On pisal by doklad, esli by ...' (imperfective aspect) --> Er würde den Vortrag schreiben,

wenn ... (He would write the paper, if ...)

(22) 'On napisal by doklad, esli by (perfective aspect) --> Er hätte den Vortrag geschrieben, wenn

(He would have written the paper, if ...)

If the aspect form does not differ, temporal adverbials may help to find the correct tense for the German verbal phrase:

(23) 'On napisal by otchet vchera.' --> Er hätte den Bericht gestern geschrieben.

(He would have written the paper yesterday.)

(24) On napisal by otchet zavtra.' --> Er würde den Bericht morgen schreiben.

(He would write the paper tomorrow.)

3.6 Numeral Phrases

The treatment of numeral phrases is always a difficult field in Machine Translation. Russian numerals have two properties which further complicate analysis. First, they inflect like nouns in six cases; second, (with the exception of the numeral 'odin' (eins/one), they control case and number of the following noun. The numbers (as ciphers or lexicalized) behave as follows:

2 to 4 govern the genitive singular.

5 to 19, 20, 30,...,100, 1000 etc. govern the genitive plural.

Each of the numerals mentioned above has just one corresponding lexeme. In the case of complex numbers the last lexeme governs the following NP. The rules of governing as stated above, however, only apply, if the whole phrase is in the nominative or accusative case, e.g

(25) 'On sostavil dva (nom./acc.) novyx (gen. pl) proekta (gen. sing.).' --> Er entwarf zwei neue Projekte.

(He planned two new projects).

As can be seen by the example, the nominative or accusative case can only be identified on the basis of information on the numeral node.

In all other morphological cases the numeral phrase and the noun phrase agree in case:

(27) 'On govoril s dvumya (instr.) matematikami (instr.). --> Er sprach mit zwei Mathematikern. (He spoke with two mathematicians.)

3.7 Complexity of Noun Phrases

Russian NPs can be very complex. Insiders know that there can be more than five attributes (especially in the genitive) to the right of a head noun. This nominal style can pose serious problems even for the human translator, when striving for a readable German translation. A non-trivial problem of analysis is the so-called "interrupted genitive". Normally, a Russian NP in the genitive directly follows the NP it modifies. However, it is not rare for the modified noun (usually adverbal noun) to be separated from its modifier by a phrase which also modifies the head noun. The interrupting modifier can be the agent in the instrumental case, an adverbial phrase (often a temporal or local one), or an indirect object as illustrated by the following example:

(28) 'peredacha direktoru Instituta geologii v Moskve dokumentacii o ...' --> die Übergabe einer

Dokumentation über ... an den Direktor des Instituts für Geologie in Moskau

(giving the documentation on ... to the director of the Institute of Geology in Moscow)

As (28) shows, the interrupting modifier itself can have right attributes. In the lexicon nouns must be assigned detailed information on their government properties owing to the fact that analysis has to identify the right "border" and the type of the interrupting phrase (subtree). This is a prerequisite for generating correct word order within such a complex NP.

3.8 Missing Articles

The generation of the German article is a rather complicated problem, as Russian like many other Slavonic languages has no articles and must use other means for expressing definiteness or indefiniteness. Although all the other METAL languages have articles, there are not always one-to-one correspondences between the articles of the source and the target language. When translating , for instance, from English or Spanish into German, METAL treats such non-correspondences in the following way. First, German nouns can be provided with information whether they occur always with or always without an article.

Examples:

never with article: Übersee (overseas), Dur (major), Hochwürden (Reverend Sir)

always with article: die Schweiz (Switzerland), die Relativitätstheorie (theory of relativity)

The examples show that such unique features only hold for a very limited number of nouns like geographic names, proper names or titles. Second, all nominal phrases pass a procedure in the German generation which decides according to the kind of NP, whether it does not need an article (e.g., pronouns, dates, phrases with attributive numerals) or whether the German article has already been fixed. If the NP leaves the procedure without a decision, it must pass another procedure testing certain target language conditions for inserting articles.

For the translation from languages without articles this approach is not sufficient. On the one hand, the German generation procedure has to be further developed. On the other hand, it should be possible to use information from the source text during transfer, e.g., the theme-rheme relations. Especially, the inversion of surface subject and predicate, which often occurs in Russian sentences, points to the indefiniteness of the NP. This kind of inversion is often encountered in passive sentences:

(29) Provodyatsya raboty, kotorye neobxodimy dlya povyweniya bezopasnosti

AS --> Es werden Arbeiten (no article = indefinite) durchgeführt, die für die Erhöhung der Sicherheit von AKW erforderlich sind.

(They did some work necessary for increasing the safety of nuclear power stations.)

These ideas could only be partly implemented, as the problem requires further investigation. Information beyond sentence boundaries, necessary for recognising something previously mentioned, is not yet available in METAL. What has been done so far is restricted to local occurrences which can be treated in the structural transfer. In most of these cases the choice of the German article (TL-Det(erminer) in the examples) is connected with certain structural changes. The examples show two types of constructions where the kind of article is fixed as indefinite in the first case and as definite in the second case:

(30) sudno dlinoij v 30 m --> Schiff mit einer Länge von 30 m (a ship with a length of 30 m)

(TL-Det indef.)

(31) nekotorye iz knig --> einige der Bücher (some of the books)

(TL-Det def.)

German nouns like 'Art' (kind), 'Sorte'(sort), 'Typ' (type) attach the genitive attribute in the plural by the preposition 'von' (of) and the noun of the attribute must have zero-article:

(32) tipy ballisticheskix raket --> Typen von ballistischen Raketen

(types of ballistic missiles)

(TL-Det zero)

As the category of determiner does not exist in Russian, other word classes can fulfil this function, e.g., adjectives like 'mnogie' (many), 'otdeljnyij' (individual) et al. If they occur in an attributive function, the value of zero-article is fixed in transfer.

Another possibility of influencing article insertion is offered by lexical transfer. About ten different transfer procedures allow the determination of the target language articles of verbal arguments and complements of nouns, adjectives or prepositions and likewise of individual nouns. With but one exception all the nouns in the examples below have zero-article, other examples are rare.

Verbal argument: 'vxoditj v silu' --> in Kraft treten (come into effect)

Noun complement: 'konec aprelya' --> Ende April (at the end of April)

Complement of adjective:

'gotov(yij) k demonstracii' --> bereit zur Vorführung (ready for demonstration)

Complement of preposition: 'na yug' --> nach Süden (southward)

Individual noun: 'na bortu' --> an Bord (aboard)

'Rossiijskaya Federaciya' --> die Russische Föderation (the Russian Federation)

"Föderation" in the last example can be used with the definite as well as with the indefinite article. However, as a proper name in connection with "russisch" the definite article has always to be used.

4 Outlook

The results of the work in the field of Russian analysis and Russian-German transfer obtained so far have made evident which linguistic phenomena need further investigation. Other major tasks to be tackled in the near future are - in addition to substantial lexicon extension - clause co-ordination (so far co-ordination has been restricted to constituent level), the treatment of multi-words and the implementation of a lexicon coding tool for the user. By developing the Russian-German prototype into a commercial system Russian will serve as a testing ground with regard to the future integration of other Slavonic languages into METAL.

Sample Translation

Matematicheskie modeli nadezhnosti

Metody, ispoljzuemye dlya postroeniya matematicheskix modeleij nadezhnosti, dolzhny uchityvatj vse otmechennye osobennosti. Vybor metoda dolzhen opredelyatjsya tochnostjyu isxodnoij informacii, a takzhe zhelaemoij tochnostjyu poluchaemyx reweniij. Dlya postroeniya matematicheskix modeleij nadezhnosti slozhnyx texnicheskix sistem ispoljzuyutsya analiticheskie algoritmy i metod statisticheskogo modelirovaniya.

V daljneijwem ukazyvayutsya nekotorye iz analiticheskix metodov, igrayuqix vazhnuyu rolj v teorii nadezhnosti. Pri ehtom, kak pravilo, ispoljzuyutsya metody, baziruyuqiesya na apparate markovskix processov.

Mathematische Zuverlässigkeitsmodelle

Die Methoden, die zum Aufbau der mathematischen Zuverlässigkeitsmodelle verwendet werden, müssen alle erwähnten Besonderheiten berücksichtigen. Die Auswahl der Methode muß von der Genauigkeit der Ausgangsinformationen sowie von der gewünschten Genauigkeit der erhaltenen Lösungen bestimmt werden. Zum Aufbau der mathematischen Modelle der Zuverlässigkeit der komplizierten technischen Systeme werden die analytischen Algorithmen und die Methode der statistischen Modellierung verwendet.

Nachfolgend werden einige der analytischen Methoden aufgeführt, die eine wichtige Rolle in der Zuverlässigkeitstheorie spielen. Dabei werden die Methoden in der Regel verwendet, die auf dem Apparat der Markovschen Prozesse basieren.

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