Advances in Machine Translation Research in IBM

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Abstract

IBM is engaged in advanced research and development projects on various aspects of machine translation, between several language pairs. The activities reported on here are all parts of a rather large-scale, international effort, following Michael McCord’s LMT approach. The paper focuses on seven selected topics: recent enhancements made in the Slot Grammar formalism and the specific analysis components; specification of a semantic type hierarchy and its use for verb sense disambiguation; incorporation of statistical techniques in the translation process; anaphora resolution; linkage of target morphology modules; methods for the construction of large MT lexicons; and interactive disambiguation.

1 Introduction

This paper reports on a set of advanced research and development projects, coordinated under one international framework, being carried out in various IBM centers in Europe and the USA. The projects tackle various aspects of machine translation, and the achievements are demonstrated by working prototypes. The presentation of this work in MT Summit III will include examples from our three major prototypes at this time: English-German, German-English, and English-Spanish. (Work is also underway on five other language pairs.)

The overall LMT architecture is described in detail elsewhere [McCord 85, 89a,b]. Here we concentrate on a few selected topics, representing interesting recent enhancements to the original LMT design.

The one central guideline we follow is to maintain a reasonable balance between advanced research goals and practical possibilities. Thus, while we seek solid methodological grounds and linguistic motivation, we do not neglect issues such as coverage, performance, and an open software design. It is our belief that in an extremely complex area such as MT the only way to produce significant results is to have a comprehensive, long-term, perhaps even ambitious research plan, implemented in small steps in practical, working prototypes.

2 New Features in Slot Grammar

Source analysis in this project is done with Slot Grammar (SG) [McCord 80, 90]. SG is characterized by (a) the systematic use of slots (grammatical relations) and slot frames in the lexicon and the grammar rules, and (b) a rather large language-general shell dealing with coordination, extraposition, punctuation and parse evaluation. No phrase structure rules are used. Instead, grammar rules are divided modularly into slot filler rules, slot ordering rules, and obligatory slot rules, plus some minor types of rules dealing with language-specific aspects of constructions treated in the shell, such as coordination. The parser is basically a bottom-up chart parser and uses the (numerical) parse evaluation rules to prune the parse space (during parsing).

*The authors represent larger groups in the IBM centers in the United States, Germany, Spain and Israel, collaborating on this effort. Credit for contributions is due to G. Arrarte, E. Bentur, A. Bernt, B. Bläser, B. Carranza, I. Dagan, S. Lappin, H. Leass, M. Neff, U. Rackow, T. Redondo, D. Segev (Ben-Ari), A. Storrer and I. Zapatia. Specific references are made in the paper to major individual contributions. The mail address of the technical leader of the coordinated projects is: Mori Rimon, IBM Scientific Center, the Technion City, Haifa 32000, Israel. E-mail: rimon@haifasc3.vnet.ibm.com
In the current paper we comment on a number of recent improvements.

(1) Or-slots. There is a systematic treatment of slots with parameters that are formally disjunctions of symbols representing syntactic characteristics of the filler. The SGs for English, German, and Danish, and their lexicons, have been revised to use or-slots. This allows greater expressive power in the lexicon.

(2) Lexical erasure rules. Such rules are used in a pre-parse pass to heuristically remove (probably) incorrect lexical analyses, based on local context.\(^1\)

(3) Pre-editing facilities. The user can mark the input string selectively with brackets \(< \ldots \>\) (to any degree) to force parsing choices and disambiguate the input. “User” in this context can also apply to tools (such as the interactive disambiguator described in Section 8), which may introduce such marks in their output.

(4) Fail-soft parse facility. A method for producing “fitted parses” for unparsable inputs (similar to that in [Jensen/Heidorn 82]) has been developed for SG. The translation phases which follow source analysis can handle such pieced-together analyses.

(5) Flexible format of analysis output. A network representation of the source analysis output (created after the parse, and stored as a set of Prolog unit clauses) allows easy exploration of the entire data structure, sometimes needed for target word selection and other translation tasks.

(6) Large lexicons. The English SG is interfaced to the UDICT lexicon [Byrd 83], [Klavans/Wacholder 89], which has over 60,000 lemmas, by heuristics that convert UDICT’s feature bundles into SG-style entries. The Spanish SG has a similar interface and heuristics for a lexicon which combines information from the Collins Spanish-English Lexical Data Base and from a project of Spanish document verification and composition [Casajuana et al. 87], [Rodriguez et al. 90]; when completed, it will contain about 40,000 lemmas. Similar volumes are now available for German-English. For lexicons and lexicon tools in this project, see Section 7.

(7) Inferential lexical disambiguation. We use techniques from a more general research program, reported in [Berth/Lappin 91], to resolve word sense ambiguities based on inference from world knowledge. (The ambiguity and the resolution are in terms of target word selection.) In that program, meaning postulates are expressed in pseudo-natural language, containing variable symbols for sub-phrases. Parsed forms of the rules are then used in an inference system.

(8) Treatment of idioms. Idioms are stored in the lexicon as pseudo-natural language strings, containing variable symbols much as in item (7) above. These strings are parsed during lexical preprocessing and used to build patterns and transformations which "normalize" the idiom, in a post-parse step. Transfer rules refer to the normalized trees, (Work in progress by Schwall, McCord. and Neff).

Slot Grammars are available (at different levels of coverage) for English, German, and Danish; work has started on Spanish and Hebrew versions.

3 Semantic Types

One of the problems for MT consists in the fact that there are no one-to-one correspondences between source and target lexical units, even when morpho-syntactic ambiguities have been resolved. The sense representation required for target word selection has to be seen as a special issue in the field of semantic ambiguity representation: sense mappings are language-pair specific. Also, the sense disambiguation required for purposes other than target word selection can require finer distinctions than needed here. For the purpose of sense disambiguation in the specific context of target word selection, the LMT system incorporates a facility to formulate selectional restrictions over complements (slots) or heads as conditional tests. (In fact, the facility is more general, allowing examination and tests of any part of the parse.) These tests are called during transfer, only when the translation-relevant ambiguity is identified.

The selectional restrictions for verbal slots are formulated by means of semantic types that are hierarchically related. The SemType hierarchy [Breidt 90], inspired by [Dahlgren 88], was constructed; Dahlgren's hierarchy is supposed to reflect the "everyday knowledge" of ordinary people (folk taxonomy) and is not intended to capture scientific structuring of the world. Our SemType hierarchy has been created in a combined inductive-deductive process: starting with a preliminary hierarchy (mainly based on [Dahlgren 88] and [Zelinsky-Wibbelt 88]), then enriching it with concepts necessary for selectional restrictions, as found by an investigation of the most frequent German-English vocabulary. In its current version, the hierarchy consists of 42 types and allows for formulation of strong restrictions by the method of multiple attachment and cross classification. The experiences with this SemType hierarchy have shown good practical results so far; we will soon start an intensive evaluation phase, and will also study the adaptability to specific text domains.

As an example for the use of the type hierarchy for target word selection, consider the transitive form of the German verb abreißen. It can be translated into English as tear off or tear down (or pull down). This ambiguity can be resolved by a rather rough formulation of selectional restrictions. The first reading allows a subject of the semantic type non-stationary or real-event, and a direct object which is non-selfmove (this implies non-stationary). The second reading selects a physical or a sentient subject and a direct object with the

\(^1\) Cf. [Marshall 83], [Herz/Rimon 91], about the disambiguation power of local constraints in general.

\(^2\) Work done in the Heidelberg center.
cross classified type stationary & lion-living. This is demonstrated by the following sentences:

“The secretaryin hat das alte Kalenderblatt abgerissen.”
“The secretary has torn off the old calendar page.”

“The company hat die Theodor-Heuss-Brücke abgerissen.”
“The company has torn down the Theodor Heuss Bridge.”

As can be seen from this verb example, the selectional restrictions will not give a definite and unambiguous semantic description of the complements themselves: the type assigned to a complement will remain as coarse as possible in order to capture a target verb ambiguity. The advantage of cross classification, as demonstrated by the direct object requirement of the second reading of abgereissen, is that instead of introducing new concepts, atomic concepts can be combined to complex categories. Lower structure and domain-specific concepts can be added easily.

In case of collocational or idiomatic use of complements, the SemType approach does not apply; here the treatment of idioms described in Section 2 comes in. The combination of both approaches yields good results for the compositional and non-compositional translation of constructions.

4 Statistical Considerations

Natural language processing techniques, based on statistics drawn from large corpora, have received considerable attention in the last few years. In our approach, statistics is a valuable source for enhancements of linguistic considerations; it does not replace linguistics. We use statistics for various types of disambiguation, as an alternative or a complement to semantic methods, in cases where such methods require too much coding of knowledge. The use of corpus information also helps in tuning an MT system to prefer common interpretations found in real texts.

One type of useful data is statistics on lexical relations, i.e. co-occurrences of specific words in certain syntactic relations (such as subject-verb, verb-object, adjective-noun, etc.). The usefulness of such data for the problem of target word selection is demonstrated in the following example of translation from German into English, taken from the current German press:

“Es wurde auch die Vorstellung begraben, man könne mit den Ideen und Ideologien des 19. Jahrhunderts die ganz anderen Probleme des 20. Jahrhunderts lösen.”

This sentence contains three ambiguous words that have more than one possible translation into English: Vorstellung, begraben and lösen. Without having information

which is the right translation for each word in this context, one would get alternative translations for the sentence, such as:

“But also the idea/picture/performance/presentation was abandoned/relinquished/buried/ended that one could solve/resolve/remove/cancel the totally different problems of the 20th Century with the ideas and ideologies of the 19th Century.”

The statistical data on the frequency of lexical relations in very large English corpora (tens of millions of words) enable us to select automatically the correct translation for the three cases (see [Dagan/Itai/Schwall 91]). The words idea and abandon were selected because they occurred in the ‘verb-object’ relation significantly more times than all other alternative combinations; similarly for the verb solve, which appears frequently with the noun problem in the ‘verb-object’ relation.

A large-scale experiment was conducted to test the performance of the statistical method, selecting the English translation for 105 ambiguous Hebrew words taken arbitrarily from the broad domain of foreign news in the Israeli press. The results of the experiment are very promising, as the statistics were applicable for about 70% of the ambiguous words, and the selection was then correct for 92% of the cases.

The statistics on lexical relations is also used successfully to resolve ambiguous references of the pronoun ‘it’ [Dagan/Itai 90]. Similarly, we intend to use these statistics on lexical relations for syntactic disambiguation, preferring parse trees which correspond to frequent relations.

A different kind of statistical data relates to the frequency of various syntactic structures. This data is used to estimate the probabilities of production rules in a probabilistic model of grammar, and by that to select the most probable parse (and intermediate partial parses) for a sentence. (Cf. similar work for Context Free Grammars such as [Fujisaki et al. 89].) We have started to develop and implement a probabilistic model for Slot Grammar in order to capture also this kind of information and improve the current ranking mechanism of the parser.

5 Anaphora Resolution

Previous sections described considerations based on syntax, semantics and statistics. The anaphora resolution component demonstrates how different levels of processing can act together in an effective way.

The multi-strategy approach for resolution of anaphora in this project focuses on two cases: pronomin al reference and interpretation of definite noun phrases.

The core of this component is a discourse-based procedure, RAP [Leiss/Schwall 91]. Discourse History is built up in the course of processing a text; it contains entities introduced in the text, as well as assertions about them. Indefinite descriptions invoke new entities, as do definite descriptions for which no antecedent can be found. A salience weight is associated with each entity, providing
a measure of its level of foregrounding. No inferences relying on world or domain knowledge are made here.

For resolution of pronominal reference, we first filter out antecedents not compatible with the pronoun morphologically (number and gender agreement) or syntactically. This deterministic procedure is based on a syntactic filter, operating at a sentence level on SG parse output [Lappin/McCord 90]. It contains three algorithms, of which we currently use the first two. One algorithm identifies the set of pronoun-NP pairs in a sentence, for which coreference is syntactically excluded. The second algorithm identifies the possible NP antecedent binders for reflexive pronouns and reciprocal noun phrases. The third algorithm generates interpretations for a central class of elliptical verb phrase structures.

Following the deterministic filtering, a heuristic procedure is applied. First, based on a salience threshold and constraints imposed by selectional restrictions on verbal complements, the search space is further reduced. Empirically and linguistically motivated heuristics (such as recency, subject emphasis, accusative object emphasis, matrix clause preference, etc.) then serve to rank candidates and, when possible, to select the most appropriate referent in the list. If no candidate is found, the search is repeated without a salience threshold.

For interpretation of definite noun phrases, we use constraining information on their modifiers (e.g. adjectives and relative clauses). The semantic type hierarchy and selectional restrictions on verbal complements described in section 3 provide further constraints. Salience weighting and the search heuristics are used in a similar way as in the case of pronominal reference resolution. If no referent is found for a definite noun phrase, a new entity is created.

The third dimension of anaphora resolution (in addition to the deterministic filtering and the discourse-based heuristics) is statistical. The idea here is to evaluate the list of candidates which RAP produces using methods described in section 4 above, and to generate weighted plausibility measures. The integration of the statistical considerations with RAP is underway at this time (joint work by the Haifa and Heidelberg centers). When completed, it will add a dimension that is usually missing in comprehensive anaphora resolution packages (cf. [Carter 87], [Carbonell/Brown 88], for example).

6 Linkage of Target Morphology Modules

Being a basic building block in all natural language processing applications, modules that handle morphology (analysis and/or generation) are available for many languages. Since morphology can be quite complex, it makes economical sense to reuse such modules for new applications.

In this project we took advantage of a comprehensive effort of classification and specification of Spanish words, undertaken in the Madrid center in the period 1983-88. The idea behind that effort is that, although Spanish has a complex, irregular morphology, it is possible to define a simple set of rules governing the inflection of words according to a system of inflection models (paradigms). In the framework of that project\(^1\), such morphological classes were defined and a large number of Spanish words were classified accordingly. After slightly restructuring this classification according to the logic of LMT, a final set of 183 word classes (paradigms) was defined - for verbs (105 classes), nouns (50) and adjectives (28).

The open design for LMT lexical organization allows for various methods of hooking in target morphology modules. In the case of Spanish, we found it best to include morphology markers in the bilingual lexicon. Thus, when a target word is selected in the transfer phase, it is passed to the generation module along with this marker, telling its paradigm class, and the morphological features (tense, mode, person, number, gender, etc.). This method is simple, efficient, flexible (e.g. allows easy handling of cases where the same target lemma may have different morphological characteristics depending on its sense), and it reduces the number of lexicons in the system. It can be described as Lexicon Driven Morphology\(^2\).

In another situation, when translating from English into Hebrew, it was found more convenient to keep an already available morphological module as-is, and interface to it through a simple set of Prolog predicates.

7 Construction of Large MT Lexicons

The construction of lexicons for multilingual MT systems constitutes a major challenge. It is an extremely labor- and cost-intensive task, requiring significant (multilingual) linguistic skill. Therefore, special attention is being paid in the framework of our project to methodologies for (a) reducing the cost of developing lexicons, (b) increasing reliability, (c) allowing the use of the lexical data in different versions of prototypes or even in various syntactic systems, and (d) reusing the MT lexicon information for Machine Assisted Human Translation tools. Significant progress has been made in the automatic access of available machine readable dictionaries, both monolingual and bilingual. The bilingual Collins dictionaries English-German, German-English, and English-Spanish have been converted to the corresponding Lexical Data Bases using a separately developed general-purpose Dictionary Entry Parser. The English-German LMT system has been augmented by an access module (COLLEG) which supplements the coverage of hand-coded lexicons with real-time access to the lexical data base (converting data stored in such data bases to the required lexical entry formal, on the fly). The access module includes a language-pair independent shell component COLLXY, that makes it easily adaptable for other language pairs for which a machine readable dictionary is available. The shell together with modified versions of the English-German access rules provide

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\(^1\) A system for verification and composition of Spanish documents, which contains a ground dictionary for Spanish as well as morphological and synonym modules [Casajuana et al. 87], [Rodríguez et al. 90].

\(^2\) Although this method was applied first to generation morphology, it is now being extended to analysis morphology in the Spanish Slot Grammar.
real-time access also for the German-English (COLLEG) and English-Spanish (COLLES) systems. A background batch dictionary generation option of the COLLXY access program allows the data from the lexical data base to be loaded as an auxiliary lexicon in LMT format and accessed directly by the translation system.\footnote{This paragraph summarizes an application of ongoing research in machine-readable dictionaries and lexical data bases (Mary Neff, Hawthorne Research Center). See [Neff/Bryd/Rizk 88] for a general description of the Collins-based dictionary and Entry Parser; [Neff/McCord 90] for COLLEG. The English-German and German-English Lexical Data Bases and COLLXY software were developed at Hawthorne; COLLEGE and COLLIES resulted from collaborative efforts between the Hawthorne lab and the Heidelberg and Madrid centers, respectively. The English-Spanish Lexical Data Bases were built at the Madrid center, and work continues there on COLLES; both efforts are partly for the PhD dissertation of Isabel Zapata in the Universidad Complutense, Madrid. Work was also done in the Heidelberg center - see [Bläser/Schwall/Storrer 90].}

However, lexical information derived from machine readable dictionaries is, in many cases, neither complete nor sufficient for MT purposes. Therefore, and with the objectives set above in mind, an additional set of lexicon tools was developed\footnote{Work done in the Heidelberg center - see [Bläser/Schwall/Storrer 90].}. This set of tools, LOLA (Linguistic-oriented Lexical Database Approach), provides (a) a relational bilingual database managed via a database management system; (b) a convenient user interface for hand-coding and modification; (c) a conversion program for loading Lexical Data Base entries into the relational system in the required format; and (d) purpose-specific generation tools. The information from the machine readable dictionaries is first loaded into the lexicon database of LOLA, where, in a second step, it can be modified and augmented through a convenient user interface. Then the generation program converts the content of the database into the lexical entry format used in the translation system. This separation helps avoid notational mistakes, typical for hand-coding, as well as undesirable strong dependency between the general lexical data and the specific (and changing) format of lexical entries in the translation system.

In addition to the standard advantages that a database management system offers (multi-user access, automatic consistency and integrity checks, definition of various data views for different users), the skilful use of the relational model in the design of the LOLA database allows for independence of data base design from the current lexical entry format, and storage of additional lexical information that is available in machine readable dictionaries and may be used in later versions of our MT prototypes. Transfer-independent information can be reused for other language-pairs as well as for other NLP applications. The reversibility of the data for the two directions of one language pair, as well as the general reusability for multilingual translation, will be further investigated.

8 Interactive Disambiguation

Natural languages are rich in ambiguities of different sorts, some inherent to a given source language, others only manifested in the context of translation into another language. As demonstrated in previous sections, special attention is paid in this project to automatic disambiguation, using syntactic, semantic, and statistical methods. Yet there are cases where all these methods fail - partly because some sentences are ambiguous even for human readers, and partly because some knowledge needed for automatic disambiguation may be missing in the system. In these cases we resort to interactive disambiguation.

Our approach, which can be described as Interactive Disambiguation by Rephrasing, is based on several assumptions: (a) Ambiguities are frequently a consequence of a delicate balance in the structure of the sentence, a balance which can be disrupted even by minor changes; (b) it is easy for a human reader to decide whether or not a paraphrase of a sentence preserves the original meaning; (c) it is not necessary for a system to fully understand the source of an ambiguity in order to identify it and decide whether or not it may be preserved on translation.

Interaction is done in natural terms - presenting the user with paraphrases corresponding to the different tentative interpretations of the ambiguous source sentence. Thus, for example, the sentence

“Old filters and valves should be replaced.”

yields two paraphrases:

(a) “Old filters and old valves should be replaced.”

(b) “Valves and old filters should be replaced.”

And the sentence

“The management requests control information.”

is paraphrased as:

(a) “The management requests the information.”

(b) “The requests control the information.”

The identification of ambiguities is done by examining the data structure produced by the Slot Grammar based parser. The user selects the correct interpretation, and his/her decision is evaluated and then reflected in that data structure, to be forwarded to the next phase of translation. It is also possible to replace the original sentence by the unambiguous paraphrase, if the user so wishes.

To make interactive disambiguation a useful tool, user interaction should be minimal and as friendly as possible.

9 The original idea was presented in [Ben-Ari/Berry/Rimon 88]. In parallel to the practical development of the disambiguation component for the IBM project, Danit Segev (Ben-Ari) is further pursuing more theoretical questions as part of her work an a PhD dissertation in the Technion, Haifa.
ble. The following are the principles of our approach;
(a) source language terms are used whenever possible;
(b) technical linguistic terms are avoided; (c) the user
is prompted only for untranslatable ambiguities (the p-
reservability of an ambiguity on translation depends on
the target language(s) under consideration), (d) the us-
er is not prompted for problems that can be solved by
automatic means (e.g. semantic and statistical) in other
phases of the translation process; and (e) repetitions are
avoided as much as possible.

The place of user interaction in the translation process
depends on the operational environment. In some cir-
cumstances it can be seen as "the last resort" for disam-
biguation, coming into the picture when all other meth-
ods do not provide a clear-cut resolution. But one may
also consider interactive disambiguation as a pre-process
- a writing aid (rather than a post-editing tool). In such
an environment, where the text author is available (and
may even be an occasional mono-lingual user) it is very
important to carry out all interaction in source language
terms. In situations where the source text is to be trans-
lated into more than one target language, this approach
represents obvious savings.

9 Sample Translations
The following are a few examples, illustrating the opera-
tion of our prototypes. The examples demonstrate some
of the problems and solutions discussed above.

Example 1: German into English
G: Der Chef setzte die Debatte für 3 Stunden aus.
E: The boss adjourned the discussion for 3 hours.

Example 2: German into English
G: Der Mann setzte mit seiner Arbeit aus.
E: The man interrupted his work.

Example 3: German into English
G: Muß ich warten, bis die Versicherung die Kosten an-
erkennt, ehe ich meinen Wagen reparieren lasse?
E: Must I wait till the insurance company accepts the
costs before I have my car repaired?

Example 4: German into English
G: Der Benutzer packt die Systemeinheit, den Bildschir-
m und die Tastatur aus. Er schließt die Tastatur über
ein Tastaturkabel an die Systemeinheit an und stellt ihre
Höhe mit Hilfe der Stützen ein.
E: The user unpacks the system unit, the screen and
the keyboard. He attaches the keyboard by a keyboard
cable to the system unit and adjusts its height with the
help of the feet.

Example 5: English into Spanish
E: Record the model number, system-unit serial number,
and key serial number.
S: Anote el número de modelo, el número de serie de la
unidad central y el número de serie de las llaves.

Example 6: English into Spanish
E: Slide the drive toward the front of the system unit
until it touches the cover plate.
S: Deslice la unidad hacia la parte frontal de la unidad
central hasta que toque la placa frontal de la cubierta.

Example 7: English into Spanish
E: Slide the assembly fully into the system unit until the
metal fins on the assembly bracket are pressing against
the rear of the system unit.
S: Introduzca el conjunto completamente en la unidad
central hasta que las aletas metálicas de la pieza de suje-
ción del conjunto estén presionando contra la parte pos-
terior de la unidad central.

Example 8: English into Spanish
E: If the above items are correct and the testing pro-
grams on the Reference Diskette found no problem, have
the system unit and option serviced.
S: Si los elementos arriba descritos son correctos y los
programas de prueba en el diskette de consulta no de-
tectoron ningún problema solicite servicio técnico para
la unidad central y la opción.

Example 9: English into German
E: If the above items are correct and the testing pro-
grams on the Reference Diskette found no problem, have
the system unit and option serviced.
G: Wenn die obengenannten Punkte korrekt sind und die
Testprogramme auf der Referenzdiskette keine Störung
fanden, lassen Sie die Systemeinheit und die Systemer-
weiterung warten.

Example 10: English into German
E: Slide the assembly fully into the system unit until the
metal fins on the assembly bracket are pressing against
the rear of the system unit.
G: Schieben Sie die Baugruppe vollständig in die Syste-
meinheit, bis die Metallplättchen auf dem Konstruktions-
rahmen gegen die Rückseite der Systemeinheit drücken.

Example 11: English into German
E: Wenn der Bildschirm erscheint, folgen Sie den Anweisungen auf dem Bildschirm und wählen Sie den Computer testen.

G: Wenn der Bildschirm, der in Schritt 2 auf Seite 7 gezeigt wird, erscheint, folgen Sie den Anweisungen auf dem Bildschirm und wählen Sie den Computer testen.

References

[BenAri/Berry/Rimon, 1988] Translational Ambiguity Rephrased. Danit Ben-Ari, Dan Berry and Mori Rimon. Proceedings of the 2nd Conference on Theoretical and Methodological Issues in Machine Translation, Carnegie-Mellon University, 1988.

[Berth/Lappin, 1991] Arendse Berth and Shalom Lappin. A Meaning Postulate Based Inference System for Natural Language. To appear in Proceedings of the 2nd Bar-Ilan Symposium on Foundations of AI, Ramat-Gan, Israel 1991.

[Bläser/Schwall/Storrer, 1991] Brigitte Bläser, Ulrike Schwall and Angelika Storrer. LOLA - A Workbench for LMT-Lexicographers. IBM 1KBS Technical Report in preparation, Heidelberg, 1991.

[Breidt, 1990] Elisabeth Breidt. Die Behandlung von mehrdeutigen Verben in der maschinellen Übersetzung. Master’s Thesis, Tübingen University, 1990; IBM IKBS Technical Report 158, Heidelberg, 1991.

[Byrd, 1983] Roy J. Byrd. Word Formation in Natural Language Processing Systems. Proceedings of the 8th IJCAI Conference, 1983.

[Carbonell/Brown, 1988] Jaime Carbonell and Ralf Brown. Anaphora Resolution: A Multi-Strategy Approach. Proceedings of the 12th COLING Conference, 1988.

[Carter, 1987] David Carter. Interpreting Anaphors in Natural Language Texts. Ellis Horwood publishing, 1987.

[Casajuanua et al., 1987] Ramon Casajuanua, Consuelo Rodriguez, Luis Sopena, Celia Villar. Towards an Interfaced Environment for Spanish Document Verification and Composition. Proceedings of the 3rd Conference of the EACL, 1987.

[Dagan/Itai, 1990] Ido Dagan and Alon Itai. Processing Large Corpora for Reference Resolution. Proceedings of the 13th COLING Conference, 1990.

[Dagan/Itai/Schwall, 1991] Ido Dagan, Alon Itai and Ulrike Schwall. Two Languages Are More Informative than One. Proceedings of the 29th Meeting of the ACL, 1991.

[Dahlgren, 1988] Kathleen Dahlgren. Naive Semantics for Natural Language Understanding. Boston, 1988.

[Fujsakski et al., 1989] T. Fujisaki, F. Jelinek, J. Cocke, E. Black, T. Nishimoto. A Probabilistic Parsing Method for Sentence Disambiguation. Proceedings of the 1st International Workshop on Parsing Technologies, Pittsburgh, 1991.

[Herz/Rimon, 1991] Jacky Herz and Mori Rimon. Local Syntactic Constraints, Proceedings of the 2nd International Workshop on Parsing Technologies (ACL-SIGPARSE), Cancun, 1991.

[Jensen/Heidorn, 1982] Karen Jensen and George Heidorn. The Fitted Parse: 100% Parsing Capability in a Syntactic Grammar of English. Research Report RC 9729, IBM Research Division, Yorktown Heights, 1982.

[Klavans/Wacholder, 1989] Judith Klavans and Nina Wacholder. Documentation of Features and Attributes in UDICT. Research Report RC 14251, IBM Research Division, Yorktown Heights, 1989.

[Lappin/McCord, 1990] Shalom Lappin and Michael C. McCord. Anaphora Resolution in Slot Grammar. Computational Linguistics, vol. 16, pp. 197-212, 1990.

[Leass/Schwall, 1991] Herbert Leass and Ulrike Schwall. An Anaphora Resolution Procedure for Machine Translation. IBM IKBS Technical Report, Heidelberg, 1991.

[Marshall, 1983] Ian Marshall. Choice of Grammatical Word-Class Without Global Syntactic Analysis. Computers in the Humanities, vol. 17, pp. 139-150, 1983.

[McCord, 1980] Michael C. McCord. Slot Grammars. Computational Linguistics, vol. 6, pp. 31-43, 1980.

[McCord, 1985] Michael C. McCord. LMT: A Prolog-Based Machine Translation System. Proceedings of the 1st Conference on Theoretical and Methodological Issues in Machine Translation, Colgate University, 1985.

[McCord, 1989a] Michael C. McCord. Design of LMT: A Prolog-Based Machine Translation system. Computational Linguistics vol. 15, pp. 33-52, 1989.

[McCord, 1989b] Michael C. McCord. LMT. MT Summit II, pp. 94-99, Munich, 1989.

[McCord, 1990] Michael C. McCord. Slot Grammar: A System for Simpler Construction of Practical Natural Language Grammars. In R. Studer (ed.), Natural Language and Logic, Lecture Notes in Computer Science 459, Springer Verlag, Berlin, 1990.

[Neff/Boguraev, 1989] Mary S. Neff and Branimir K. Boguraev. Dictionaries, Dictionary Grammars and Dictionary Entry Parsing. Proceedings of the 27th Meeting of the ACL, 1989. A more complete version appeared as: From Machine-Readable Dictionaries to Lexical Data Bases. Research Report RC 16080, IBM Research Division, Yorktown Heights, 1991.

[Neff/Byrd/Rizk, 1988] Mary S. Neff, Roy J. Byrd, and Omneya A. Rizk. Creating and Querying Hierarchical Lexical Data Bases. Proceedings of the 2nd ACL Conference on Applied NLP, 1988.

[Neff/McCord, 1990] Mary S. Neff and Michael C. McCord. Acquiring Lexical Data From Machine-readable Dictionary Resources for Machine Transla-
tion. Proceedings of the 3rd Conference on Theoretical and Methodological Issues in Machine Translation, University of Texas, 1990.

[Rodriguez et al., 1990] Consuelo Rodríguez, Luis Sopena, C. Valladares, Celia Villar. A Lexical Database of Spanish for Natural Language Applications. Proceedings of the ALLC Conference, 1990.

[Zapata/Arrarte, 1991] Isabel Zapata, Gerardo Arrarte. Spanish Generation Morphology for an English - Spanish MT System. Technical Report in preparation, Madrid, 1991.

[Zelinsky-Wibbelt, 1988] Cornelia Zelinsky-Wibbelt. Semantische Merkmale für die automatische Disambiguierung: Ihre Generierung und ihre Verwendung, Eurotra-D Working Paper No. 4 IAI, Saarbrücken, 1988.