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MACHINE TRANSLATION AND MACHINE-AIDED TRANSLATION

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The recent report for the Commission of the European Communities on current multilingual activities in the field of scientific and technical information[1] and the 1977 conference on the same theme[2] both included substantial sections on operational and experimental machine translation systems, and in its *Plan of action*[3] the Commission announced its intention to introduce an operational machine translation system into its departments and to support research projects on machine translation. This revival of interest in machine translation may well have surprised many who have tended in recent years to dismiss it as one of the 'great failures' of scientific research. What has changed? What grounds are there now for optimism about machine translation? Or is it still a 'utopian dream'? The aim of this review is to give a general picture of present activities which may help readers to reach their own conclusions. After a sketch of the historical background and general aims (section I), it describes operational and experimental machine translation systems of recent years (section II), it continues with descriptions of interactive (man-machine) systems and machine-assisted translation (section III), and it concludes with a general survey of present problems and future possibilities (section IV).

I. HISTORY AND BACKGROUND

1. Although the first proposals for the mechanization of translation were made over forty years ago (independently by a Russian, Smirnov-Troyanskii, and by a Frenchman, Artsrouni) it was only with the general availability of the electronic computer after the war that the idea was taken up seriously[4]. Tentative experiments had been conducted in Britain since 1946, but it was a memorandum sent by Warren Weaver to some 200 of his acquaintances in 1949[5] that launched machine translation as a scientific enterprise. Research groups were formed all over the United States. Simple demonstrations of the technical feasibility of machine translation (henceforth: MT), notably the 1954 demonstration by IBM and the research team at Georgetown University,[6] encouraged US government agencies to invest vast sums in MT research. By 1965 it was estimated that MT research had been supported at seventeen institutions to the tune of almost 20 million dollars[7]. Early 'breakthroughs' promising commercially available MT systems 'within five years' (the most popular forecast)[8] came to nothing; awareness of the linguistic complexities of the task grew steadily; failure to develop optical character readers (so crucial to economically attractive MT) was a further disappointment; and the translations produced were crude and often almost unreadable. In 1964 at the instigation of the sponsoring agencies the National Science Foundation set up a committee to look at the general field. In 1966 this committee, the Automatic Language Processing Advisory Committee (ALPAC), reported[9] that MT was slower, less accurate and twice as expensive as human translation and that ‘there is no immediate or predictable prospect of useful machine translation.’ It saw no need in the United States for further investment in MT

research; there was no shortage of translators and no overwhelming demand for translations. Instead, it recommended the development of machine aids for translators, such as automatic dictionaries, and continued support in the general field of computational linguistics.

The report was widely condemned as narrow, biased and shortsighted. It was criticized strongly by Pankowitz (one of the most influential sponsors of MT) for its 'factual inaccuracies... hostile and vindictive attitude... use of obsolete and invalid figures... distortion of quality, speed and cost estimates... concealment of data reflecting credit on MT. wilful omission of dissenting statements' (quoted by Josselson)[10]. MT researchers protested that improvements were imminent and that, in short, ALPAC's dismissal of Mt was premature.[11,12] But, whether the criticisms were valid or not, the damage had been done: MT research in the United States suffered immediate reductions and a loss of status which it has never recovered. The effect of ALPAC was also felt in other countries where quite different conditions prevailed: MT research everywhere was cut back.

Since 1967 MT research has continued at much reduced levels, virtually ignored by linguists, computer scientists, librarians, information scientists, and almost forgotten by the general public. Its achievements go unrecognized. The last decade has witnessed an increasing sophistication in Mt experimental systems, in both linguistic and computational aspects, an emphasis on interactive man-machine systems, and the development of machine aids for the human translator. At the same time, operational MT systems have become available providing reasonably acceptable translations within restricted subject fields.

2. In the United States MT activity concentrated on the translation of Russian scientific and technical material for a relatively small number of potential users. In Canada and the European Communities today the situation is quite different. 'The Canadian government's policy of biculturalism... results in a demand for translation which far surpasses the capacity of the market, especially as far as technical translation is concerned'.[13] The problems of the European Communities are probably even greater, since 'from the moment the Community enters into its legislative role, that is to say when it takes decisions or makes recommendations, the rule requiring translations into all the languages [of the member states] is strictly applied'.[14] In addition translations for the numerous working documents of the Commission must be provided together with the technical and economic documentation. The Commission has one of the largest translation services in the world; machine translation and the use of computer aids become, in this context, viable propositions.

3. Since fully automatic high quality translation was abandoned as a feasible goal (argued most persuasively by Bar-Hillel),[15-17] MT researchers have adopted more modest objectives. On the one hand, where full automation of translation processes is attempted, the aim is to produce translations which are good enough for the particular purposes of readers,[17] translations which may not be stylistically adequate or even acceptable (if they had been done by human translators) but which succeed in conveying the intended message of the original. On the other hand, where good quality is the objective, there has been a concentration on the development of interactive systems and the construction of

linguistic data banks providing translators with assistance in specialized terminology.

4. The intention of this review is to survey what seems to be the most important developments in recent years, to assess the present situation and to guess at future directions. It does not aim to be either complete or comprehensive. (For a full survey of the field see Bruderer's forthcoming handbook.)[18] It concentrates on the main developments since about 1970, i.e. after the 'watershed' of ALPAC. For those interested in the details of earlier research there are a number of comprehensive surveys,[7-10,15,19-22] good bibliographies,[23-25] and standard collections of papers.[4,26-31] This review also says nothing about MT activity in the Soviet Union (for a simple reason: inadequate knowledge of Russian), but on the evidence of surveys by Harper,[32] Papp[33] and some of the above[7,15,20] and from recent collections,[34-36] research on MT has developed there on very much the same lines as in the United States and Europe.

5. There are three main reasons why information scientists and librarians should be interested in MT. First, there is the prospect or hope that viable operational MT systems might help to relieve the problems of handling an increasing volume of publications in science, technology, economics and social sciences (a diminishing proportion of which is written in English) both by librarians, indexers and information officers and by the scientists, technologists, economists and administrators who have to read them. Secondly, the growth of international co-operation in the sphere of documentation and information retrieval (e.g. EURONET) promotes the development of multilingual indexing tools (multilingual thesauri), the exchange of documentary information between services (translations of titles, abstracts and indexing data) and the development of techniques for access to multilingual data bases. Thirdly, since many processes in indexing, abstracting and retrieval involve translation of some kind (from and into natural languages and documentary languages) it is to be hoped that MT research will suggest techniques and methods applicable to the automation of these processes.

The relevance of MT work in these areas is not elaborated in this review beyond a few remarks in the closing section where MT methods are looked at in the general context of automated language processing. To go further would entail detailed discussion of current trends in automatic indexing and classification and in automated information retrieval systems.

II. Machine translation

1. There have been basically two overall strategies which researchers have adopted in the design of MT systems. In the first, the system is designed in all its details specifically for a particular pair of languages, e.g. Russian as the language of the original texts (the source language) and English as the language of the translated texts (the target language). Translation is direct from source language (SL) text to target language (TL) text; the vocabulary and syntax of the source language is analysed as little as necessary for acceptable target language output. For example, if a Russian word can be translated in only one way in English it does not matter that the English word may have other meanings or that the Russian might have two or more possible translations in another language. Likewise, if the original Russian word order can be retained in English and

give acceptable translated sentences, there is no need for syntactic analysis. In other words, analysis of the source language is determined strictly by the requirements of the target language. By contrast, in the second strategy, analysis of SL texts is pursued independently of the TL in question. Translation is indirect via some kind of 'intermediary language' or via a transfer component operating upon 'deep syntactic' or semantic representations of SL texts and producing equivalent representations from which TL texts can be generated. For example, a Russian passive sentence might be analysed as a deep syntactic form which allows for translation in English as either an active or a passive according to circumstances (e.g. the demands of idiomaticity, constraints on English verb forms, etc.) Likewise the various Russian expressions for 'large', 'great', 'extreme', etc. which differ in their distribution according to the nouns and verbs with which they occur, might all be represented as (say) Magn and translated in English by whichever is the most appropriate idiomatic form for the corresponding English noun or verb.

The 'direct translation' approach was adopted by virtually all the MT systems developed before 1966/7. Indirect translation has been favoured by most MT systems since 1967. For this reason, many writers refer to 'direct' MT systems as 'first generation' systems and to 'indirect' MT systems as 'second generation' systems.

2. Whatever strategy is adopted translation involves the analysis of SL texts and the synthesis of TL texts. Before proceeding to the description of MT systems an outline is given of common procedures for handling lexical, grammatical and semantic data and of various problems to be overcome.

2.1 Dictionaries, obviously essential components, contain information needed for SL analysis (morphological variants, syntactic functions, semantic features, etc.) and for TL synthesis (translation equivalents, constraints on TL forms, etc.). There may be one single bilingual dictionary (as in many 'direct translation' systems), or separate ones for analysis (monolingual SL dictionary), transfer (bilingual SL-TL dictionary) and synthesis (monolingual TL dictionary). The dictionary for analysis may be divided into one containing only morphological information, one for only semantic information, one for high-frequency words, one for irregular forms (e.g. of verbs), one for idioms, etc. and there may be separate dictionaries for particular subjects ('microglossaries'). Separation has the advantage of easier compilation and exchangability but the disadvantage of slower machine times than with single dictionaries.

2.2 Morphological analysis. Dictionaries may contain entries in either full forms or only 'base' uninflected forms. In the former case dictionary look-up can be direct, in the latter some morphological analysis must first be done to separate endings (e.g.*-ed,-s,-ing)* from stems or 'base' forms. At the same time syntactic functions of endings may be identified. Idioms and compounds (i.e. multiple word constructions) are usually searched for as wholes on the 'longest match' principle and treated subsequently as single units (e.g. *in the process of* as a preposition).

2.3 Syntactic analysis is based on the grammatical categories or 'word-classes' (noun, verb, adjective, etc.) assigned to words of SL sentences during dictionary look-up and/or morphological analysis. At its simplest a parser (syntactic analyser) may just identify acceptable word-class sequences (e.g. Det +N+V+Det +N+P+Det +N, underlying *The operator controlled the machine at a console)*—often sufficient to distinguish some homographs (words with different functions having the same form, e.g. *control* as noun or verb). A more elaborate parsing would identify functional groupings such as noun phrases, verb phrases, relative clauses, etc. and their combinations in sentence structures. Various grammatical models have been used in MT; two main types are the familiar phrase-structure model (Fig. 1) and the dependency model which relates constituents as 'governors' (necessary constituents of groups) and their dependants (Fig. 2)

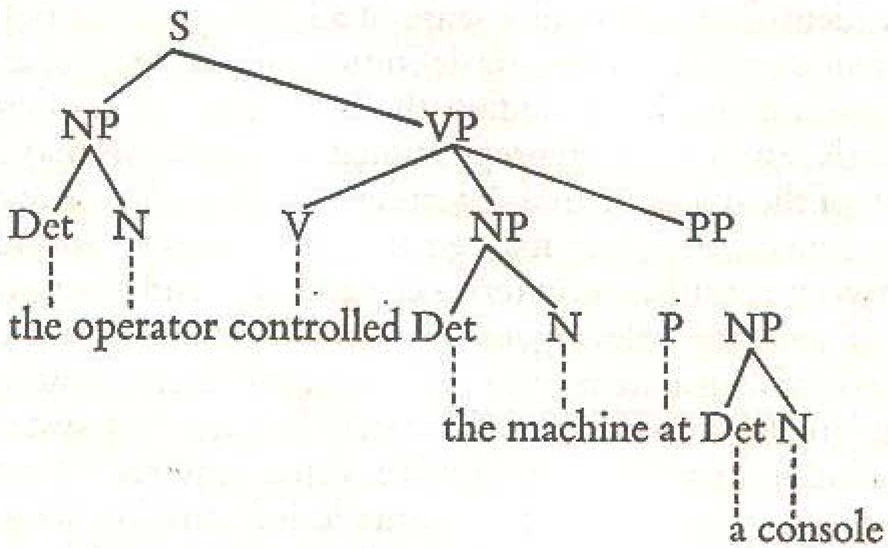

FIG. 1

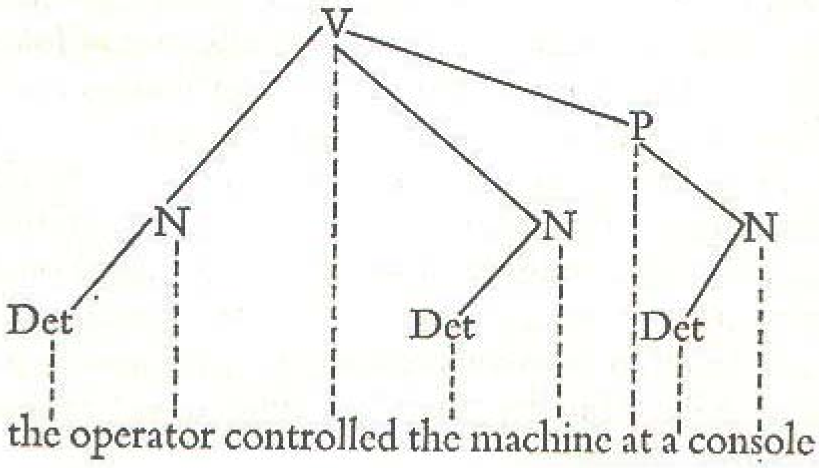

FIG. 2

For the description of natural language syntax, however, such 'context-free' grammars are inadequate. They fail, for example, to relate different structures having the same functional relationships (e.g. *The headmaster gave the parents a lecture yesterday* and *Yesterday the headmaster gave a lecture to the parents).* The transformational grammars of Chomsky and Harris overcome such deficiencies by deriving equivalent 'surface' structures from the same 'deep' phrase structure by transformational rules.

Various parsing strategies have been developed. A parser may produce all the possible syntactic analyses of a sentence or just one (hopefully the 'correct' or 'best' one), operating in a single 'pass' of the sentence or in sequential 'passes', either left-to-right or right-to-left. Analysis may be 'bottom-up', i.e. building from noun groups (Det + N → NP) to prepositional phrases (P + NP → PP) and verb phrases (V + NP → VP) to sentences (NP + VP → S), or it may be 'top-down', i.e. checking for the satisfaction of possible structures (S, NP, VP, PP) against the word-classes of the actual sentence. All parsers have difficulties with multiple analyses; e.g. since a prepositional phrase may be governed by either a verb or a preceding noun phrase a sequence such as $V + N_1 + P + NP_2 + P + NP_3$ must have parsings which relate NP_2 and V, NP_2 and N_1, NP_3 and V, NP_3 and NP_1, NP_3 and NP_2 in all possible combinations. Only semantic information allows us to decide, e.g., that in *They threw the boy in the river* the PP modifies *threw* and not *the boy.*

2.4. Semantic analysis in many MT systems is restricted to the resolution of ambiguities remaining after morphological and syntactic analysis. Semantic features such as 'animate', 'male', 'concrete', 'liquid', etc., included in dictionary entries, may identify the particular sense of a homograph or polyseme in a text, e.g. in *The crook escaped* the semantic definition of *escape* may specify an 'animate' subject (thus automatically excluding the inanimate sense of *crook,* 'shepherd's staff'). Similarly, ambiguities in prepositional constructions may be resolved, e.g. the exclusion of the 'instrumental' interpretation of *with* in *The youth hit the child with red hair.* Semantic analysis may go further, however, and identify semantic relations between constituents in terms of predicates and arguments (or 'actants') or in terms of semantic roles (agents, patients, locations, instruments, etc.). The further analysis of lexical items into their semantic components (primitives), e.g. *boy* as 'young' 'male' 'human' 'being', is rarely found in MT systems.

2.5. The resolution of residual ambiguities often requires reference to discourse relations and text structures or to pragmatic information such as 'knowledge' about the external reality. In a case such as *The police followed the man with binoculars* we need information from elsewhere in the text or from the actual situation in order to know who had the binoculars. Similarly, in the case of *Jean lui a donné un livre* we must refer back to some preceding sentence (probably) in order to decide whether *lui* should be translated as *him* or *her.* Not infrequently we invoke 'knowledge of the world', e.g. in *The women were murdered by the terrorists. They were buried three days later* we know that 'they' refers to 'women' (and thus is translated as *elles* and not *ils* in French) because we know that (normally) only dead people are buried and that murder implies death. There are obvious difficulties in incorporating such information into analysis procedures, and it was this factor above all that persuaded Bar-Hillel[15,16] that MT could never be completely satisfactory.

2.6 Synthesis is in many ways easier than analysis. It may be done cumulatively during SL analysis, or in a single 'translation' stage, or in a series of steps (semantic synthesis, syntactic synthesis, morphological synthesis). The production of TL texts includes the selection of appropriate TL forms where there may be alternative possibilities (e.g. French *savoir* and *connaître* as translations of *know),* the choice of appropriate TL syntactic structures (e.g. passive or active), and the generation of correct morphological forms (e.g. *English, go* + past → *went,* French *de* + *le* → *du).*

2.7 In the absence of all-purpose optical character readers, texts for translation must be converted into machine-readable form. In many MT systems this process is combined with some 'pre-editing', e.g. marking non-linguistic data (mathematical and chemical formulae) and sentence boundaries. After translation there is likewise a 'post-editing' stage for reformatting output (paragraphing, indenting) and restoring non-linguistic data. However, in operational systems 'post-editing' usually includes also some manual revision of the translation itself.

3. The following descriptions of MT systems include reports of any evaluations which have been made of the quality of translations produced, and in the Appendix some sample translations are illustrated. In assessing translation quality two criteria are widely used: intelligibility and fidelity. A translation should not be difficult to read and it should convey the intended message of the original correctly. The two do not necessarily coincide: a translation may be easy to read and understand and yet not be faithful to the original, or it may be correct and yet be almost unreadable. Fidelity must be the first aim, particularly in science, technology, medicine, etc.; at the very least, homographs must be resolved, prepositions and conjunctions correctly translated, and technical vocabulary correctly rendered.[37] No wrong analyses and no ambiguities in the TL text where there are none in the SL text can be tolerated. Intelligibility, on the other hand, is less important: some infelicities of style or word usage can be accepted if the meaning is not distorted—after all, scientists are apparently not excessively irritated by the English of some foreign colleagues. Revision (or 'post-editing') should, therefore, be confined to 'stylistic' changes and should not, ideally, involve corrections of translation errors.

4. First generation MT systems

4.1. The earliest MT systems adopted a crude 'word-for-word' approach to translation. Words of a SL text were looked up in a large bilingual dictionary, the TL equivalents were selected, some simple rearrangements of word order were made to suit TL practice, and the results were printed out. A typical example was the Mark II system for Russian-English translation[38] installed in 1964 at the Foreign Technology Division of the US Air Force and in regular use until 1970. It was an only slightly improved version of one of the very earliest systems, Erwin Reifler's at Seattle.[15] In essence it consisted of a bilingual dictionary (held on a fast memory device, the so-called 'photoscopic store') which gave for each stem and for each suffix a pair of codes indicating the classes of stems and affixes that could occur before and after it. Analysis was restricted to the simple matching of codes, and 'translation' was no more than the printing out of all English equivalents for Russian forms not eliminated by the code-matching process. Not surprisingly the crude results (example 1 in Appendix) were not rated highly; 'post-editing' by a human revisor was essential. Even then, Orr and Small[39] found that in tests for comprehensibility post-edited MT texts scored 'significantly lower statistically' than manual translations of the same texts and that unrevised MT texts were much worse still. In another study[40] a sample 200 pages revealed 7,573 errors needing revision, of which 35% were omitted words, 26% wrong words, 12% incorrect choices and 13% wrong word orders. When asked for their views by ALPAC, six editors of American scientific journals ranked the Mark II translations consistently lower than JPRS human translations. It was largely such unfavourable opinions that influenced ALPAC's recommendations.[9]

4.2. For many years the MT research group at Georgetown University under Leon Dostert was the largest in the United States.[38,41-43] In 1960 four subgroups were experimenting with different approaches to syntactic analysis. From the group under Zarechnak came the basic parser of the 'Georgetown' system and from A.F.R.Brown the basic programming method, the Simulated Linguistic Computer (SLC). In 1964 (while ALPAC was meeting) the group delivered an operational Russian-English system to the Atomic Energy Commission at Oak Ridge National Laboratory and to EURATOM in Ispra, Italy. At Oak Ridge the system is apparently still in use, and at EURATOM it was replaced only in 1976 by the SYSTRAN system (4.3 below). The Georgetown approach was 'empirical' (Bar-Hillel's term):[15] a program was written for a particular text corpus, tested on another corpus, amended and improved, tested on a larger corpus, amended again, and so forth. The result was a monolithic grammar of 'monstrous size and complexity' with no clear separation of analysis and synthesis.[38] Despite its complexity, syntactic analysis was very rudimentary, devoted to nothing more than resolving ambiguities in the assignment of word-classes through examination of preceding and following sequences of grammatical categories. The methods were *ad hoc*, there was no notion of grammatical rule or of syntactic structure. The grammatical classifications assigned to words in a text were later used to determine which of the possible English alternatives could translate the individual Russian words and to help decide the eventual word order of English sentences. 'Such information about the structure of Russian and English as the program used was built into the very fabric of the program so that each attempt to modify or enhance the capabilities of the system was more difficult, and more treacherous, than the last.'[38] And indeed, the Georgetown systems at both Oak Ridge and EURATOM have remained virtually unchanged since 1964. The only alterations were those needed for transfer from an IBM 7090 to an IBM 370; the linguistic aspects were untouched.[44] Nevertheless, operators of the two systems have regularly reported the satisfaction of users with the output even though they receive unedited versions[45-48] (example 2 in Appendix): 92% of 58 respondents to a questionnaire[49] rated them as 'good' or 'acceptable', 82% found that information was translated sufficiently comprehensively, 71% found the translations 'readable' (although they took 32% longer to read than human translations); as for fidelity: 87% of the sentences were judged to be correctly translated (even if difficult to understand) and 76% of the technical words were correct or intelligible. In sum, 96% of the users would recommend MT to colleagues. It would seem from these surprisingly favourable results that many users would rather have low quality MT than no translation at all.

4.3 Peter Toma, who was chiefly responsible for the Oak Ridge and Ispra installations of the Georgetown system, is the designer of the operational Russian-English system SYSTRAN[50-52] — a greatly improved version of the Georgetown approach. Under development since 1968 by LATSEC Inc., SYSTRAN replaced Mark II at FTD in 1970 (cf. II.4.1 above), it was used by NASA during the Apollo-Soyuz project, and it replaced the Georgetown system at Euratom in 1976. The SYSTRAN system has also been developed for English-French translation—it is this system which the Commission of the European Communities has taken for a trial period.

The Russian-English version of SYSTRAN has been documented in a series of reports.[53-56] Unlike its ancestor SYSTRAN is built on the principle of 'modularity': each stage of analysis and synthesis is clearly separated and the linguistic and computational facts are kept apart, allowing changes in procedures to be made more easily. There are four basic stages: Input, Dictionary look-up, Syntactic analysis, Translation. In the first stage Russian text is input on magnetic tapes via IBM MT/ST tape cartridges using SYSTRAN's own transliteration system. Each word is then given a text sequence number for unique identification during processing. Dictionary look-up makes use of two dictionaries. First, every word is checked against the High Frequency dictionary, which also contains the first word of idioms, and those found are written onto a file. All other words are then sorted alphabetically and run against the Master Stem Dictionary. Endings are checked for acceptability and, if valid, information on grammatical (and some semantic) properties and English equivalents is assigned to the Russian words. They are then sorted back into the original text sequence. Syntactic Analysis is done by a multiple-pass bottom-up parser (cf.II.2.3):

> The SYSTRAN parser includes four major 'passes'. The first resolves homographs. The second examines the sentence from right to left, setting switches to remember, as it progresses from word to word, exactly what types of potential syntactic relationships are possible within each clause, given the types of words already encountered. Using these switches, this pass establishes the basic structures within the sentence (verb plus object, preposition plus object, etc.) The third pass, scanning from left to right, extends these relationships, identifying enumerated objects, appositional structures, etc. The fourth pass, using the data accumulated by the preceding passes, including information about clause boundaries, types of main and subordinate clauses, and the range or extent of embedded clauses, is then able to execute scans… looking for the subject(s) and predicate(s) of each individual clause.[57]

The final stage, Translation, consists of many subroutines using information from the dictionaries and the syntactic analysis for the selection and rearrangement of the English output. One subroutine is devoted to the insertion of definite and indefnite articles (a tricky problem when translating form a language with no articles) combining syntactic information (e.g. whether the Russian noun is qualified by a following genitive noun, prepositional phrase or relative clause), semantic information (e.g. whether the Russian is an ordinal number) and information on English equivalents (e.g. English 'mass' nouns usually require definite articles).

Analysis of the Russian text goes only so far as appears sufficient to identify acceptable English equivalents and to produce readable English text. When the designers want to improve some unsatisfactory feature they look for the simplest manipulation of syntactic or semantic coding, irrespective of the procedures in other parts of the program. In other words, each solution is made on an ad hoc basis. For example, some Russian lexical entries signal changes in syntactic structure to fit English usage: ESLI includes a code to change a Russian infinitive construction ('if to examine…') to an English finite form ('if we examine…').[53] Other syntactic changes involve manipulation of the English output: 'noun + *of* + verbal noun + *of* + noun' becomes 'noun + *of* + gerundive + noun', e.g. *result of treatment of burns* (RESUL6TAT LECENI4 OJOGOV) becomes *result of treating the burns*.[55] In some cases 'semantic classification' is used. Translation of Russian prepositions is often regulated by the semantic class of adjacent verbs or nouns: DO is translated as *up to* if the preceding verb or noun is [+increase] and as *down* to if it is [+decrease], PO is translated as *along* if the following noun is [+linear], as *over* if [+nonlinear] and as *using* if [+mental tool].[56] Similarly, Russian 'noun + genitive noun' structures may be translated as English 'noun + noun' (where the first noun modifies the second and corresponds to the Russian genitive) only if the 'semantic class' of the Russian genitive is COMP(osition), MATH(ematics), MEAS(ure), MOTION, OPTICS, QUAL(ity), etc.[55] Clearly these 'semantic classes' have nothing to do with the semantics of Russian, they are *ad hoc* labels (some indicating 'components of meaning', others subject fields) designed solely to overcome difficulties with the English output, and there is no sign that any are used in other subroutines.

These examples illustrate the way SYSTRAN's procedures are designed for a specific SL-TL pair. They illustrate the essentially empirical approach: there is no question of an underlying linguistic theory, no attempt at a consistent methodology; problems are tackled as they arise and improvements are made if proposed solutions seem to work in most cases. It is claimed, however, that SYSTRAN can be easily adapted to simultaneous translation from one SL into a number of TLs.[57] The claim appears to be that the algorithms of Syntactic Analysis and Translation are sufficiently general for any SL and any TL. A great deal of the syntactic reordering specific to a SL-TL pair is handles by dictionary rules (as we have seen for the Russian-English pair) and semantic 'analysis' is based entirely on dictionary entries. The semantic classifications appropriate for one SL-TL pair are unlikely to be of much use for other pairs. Nevertheless it is true that further TLs could be added by expanding SL dictionary entries to include the data for each new TL, and that this would no affect the basic analytical processes. However, we can only guess at the consequences of such considerable increases in complexity upon dictionary look-up times and the translation processes in general.

Many years of development (nearly twenty years if we include Toma's experience at Georgetown) have gone into the Russian-English MT system. How good are the translations? Unfortunately there is has been no rigorous independent evaluation of recent output – the report by Leavitt *et al*.[58] was concerned mainly with cost analysis and control and the optimization of post-editing and recomposition functions (which contribute 37% and 38% respectively to total costs.) We have little more than Sinaiko's rather informal comparison of a 1964 Mark II translation and a 1971 SYSTRAN translation of the same Russian text (itself a good translation of an English article).[59] He found that Mark II left 1.2% of the words untranslated and SYSTRAN 2.3% and that Mark II provided alternative translations for 6.3% of the words and SYSTRAN for 5.3%. A comparison of raw output from SYSTRAN and the revised text showed that the post-editor had changed 35% of the text in some way. Sinaiko concluded that 'little progress has been made in recent years'. Later output from SYSTRAN would, however, seem to be somewhat better (example 3 in Appendix.)

The English-French version of SYSTRAN has had a shorter period of development. Few details of the system are available, but from brief descriptions[1,18] the basic design is no different from the Russian-English version. We do, however, have a recent evaluation made for the Commission of the European Communities.[60] Tests were made on abstracts, articles and Community documents comparing manual translation (unrevised), revised manual translation, unedited MT, revised MT and the original English. On scores of intelligibility (clarity and comprehensibility) unedited MT compared poorly (44-47%, or 66% after updating of MT dictionary) with human translations (87-96% unrevised, 99% revised), original texts (94-98%) and revised MT (92-97%). As for fidelity, while 86-95% of verb and noun groups were considered to have been correctly translated, only 61-80% of 'grammatical agreements (gender, number, elisions, contractions, person, voice, tense, mood) were correctly rendered'. It was concluded that the quality of unrevised MT (example 4 in Appendix) was 'still far from satisfactory', although marked improvements are hoped for in two or three years time!

4.4 Apart from SYSTRAN the most important 'direct' MT system of recent years is the English-Vietnamese translation system, LOGOS.[61] Like SYSTRAN its programs maintain a complete separation of analysis and synthesis although the procedures themselves are specifically designed for one particular SL-TL pair. There is no pre-editing, the program automatically detects word boundaries, segments into sentences and identifies parenthetical sequences. After dictionary look-up (base forms, with separate table of endings) syntactic analysis resolves word-class ambiguities by a right-to-left parser. There is no attempt to produce a complete phrase structure analysis, only to obtain enough information to perform necessary transformations into acceptable Vietnamese syntactic forms. In the transfer phase, English adjective-noun groups are inverted for Vietnamese noun-adjective groups, English passives are changed into actives (since Vietnamese has no passive voice), and complex nominal constructions (e.g. *Wires can be disconnetced upon removal of clip*) are simplified (*You can disconnect wires when you have removed clip*). LOGOS is avowedly syntax-oriented; the designer admit that post-editing cannot be eliminated since many mistranslations could only be removed by semantic analysis or in some cases by reference to pragmatic information (cf. II.2.5).

Further development has continued; LOGOS III now offers also translations from English into Russian and French,[1,21] but details are not readily available (cf. Bruderer).[18] However, LOGOS I was the subject of a thorough evaluation by Sinaiko and Klare.[62] They tested the ability of 172 Vietnamese student pilots with knowledge of English to read and understand a US Air Force manual in the original English, a high quality manual translation in Vietnamese, an unedited LOGOS translation and a revised LOGOS translation. As a control the readability of the English original was tested on 88 American student pilots. Scores for comprehension were best for the human translations, next for revised MT and worst for unedited MT; regarding clarity, revised MT scored better than human translation, with unedited MT worst. The most surprising result, however, was that the Vietnamese students' comprehension scores for the English original texts were slightly higher than for the best human translations; and that, furthermore, Vietnamese who had been in the United States for five or six months did almost as well in English comprehension tests as the Americans (the control group). Similar tests with a US Navy manual confirmed these results.[68] The investigators concluded that 'perhaps the best way to help Vietnamese use US manuals is to improve the readability of the English text itself', which 'could provide the considerable bonus of helping American users as well… and might be done at no more total cost (if as much as) than translation itself.'

4.5 Other current projects on 'direct' MT systems have been reported, e.g. the Xonics system (Russian-English), the Smart Communications system (English-French and English-Persian), and various experimental systems in Japan (Kyoto, Tokyo),[64] Germany (Cologne) and the United Kingdom (Cardiff)[65] – for brief details see Bruderer.[18] None appear to go further in syntactic or semantic analysis than SYSTRAN or LOGOS, or even in some cases[64] than the Georgetown system.

4.6 Characteristic features of 'direct' MT systems have been the adoption of basically empirical approaches to linguistic analysis, the general lack of sound theoretical foundations, the restriction of SL analysis to information needed for adequate synthesis in a specific TL, and the heavy reliance on post-editing to produce acceptable translations. Attempts to solve semantic and syntactic problems have usually involved expansion of dictionary data – leading inevitably to such complexities that improvements become almost impossible (as in the Georgetown system, II.4.2). Semantic analysis, indeed, has been virtually ignored, particularly in the period up to 1967. Difficulties were often simply avoided by printing out all alternatives and leaving selection to post-editors, as in Mark II (example I in Appendix) and in the National Physical Laboratory's Russian-English system[66-68] (example 5). But syntactic analysis was also often inadequate; too often parsers produced either no analyses at all or far too many. The deficiencies of 'context-free' grammars (II.2.3) were gradually realized, and more attention was paid to linguistic research. Later 'direct' MT systems show signs of having benefited to some extent from earlier experience, but most of the effort on improving syntactic procedures and on developing semantic analysis has taken place in research on 'second generation' systems.

5. *Second generation systems*

5.1. Already in Weaver's memorandum of 1949 we find the first suggestion of an interlingual strategy for MT.[5] His memorable metaphor was of 'individuals living in a series of tall closed towers, all erected over a common foundation'. Shouting between towers gives very poor communication; only by descending to the common basement is good communication achieved. Perhaps, Weaver suggested, 'the way to translate… is not to attempt the direct route, shouting from tower to tower… [but]… to descend, from each language, down to the common base of human communication… and then re-emerge by whatever particular route is convenient'.

5.2. The idea of a universal language has, of course, a long pedigree in philosophy (Locke, Leibniz, etc.) but its practical implementation has so far eluded even the most ingenious proposals.[69] None of the designers of second generation systems would claim to have constructed genuine interlingua. Instead we find two closely related approaches. In one, the 'interlingua' is a form of representation common to two particular languages, where translation is thus a two-stage process, from SL to interlingua and from interlingua to TL. In such systems the designers intend (or hope) that the same interlingua can be used for translation from and into other languages. In the other approach, the 'intermediary' between languages is a 'transfer component': for any particular language, SL analysis and TL synthesis are performed in the same way whatever the other language may be, only the transfer component is specifically designed for a particular SL-TL pair. Translation is thus a three-stage process: SL analysis, Transfer, TL synthesis. Both approaches employ at least three dictionaries: a monolingual SL dictionary giving morphological, syntactic and semantic information needed for analysis; a bilingual SL-TL dictionary restricted mainly to semantic information; and a monolingual TL dictionary for synthesis.

5.3. An advantage of the indirect approaches often put forward (e.g. Andreev)[70] is that in multilingual MT systems there are considerable savings if only one program of analysis and only one of synthesis need to be written for each language in the systems. By contrast, in 'direct' MT systems new programs have to be compiled for each new SL-TL pair. In practice, however, few 'indirect' systems have yet experimented with more than two or three languages on any scale; the potential savings have yet to be realized. The more important advantages of indirect approaches lie therefore in the linguistic and computational aspects. The 'brute force' trial-and-error approach of most direct MT systems[6] has been rejected in favour of thorough analyses of linguistic processes and careful design of appropriate and efficient computational procedures.

6. The 'interlingual' approach

6.1. The Centre d'Études pour la Traduction Automatique (CETA) at the University of Grenoble began research on MT in 1961. In the following ten years it developed the interlingual approach in a system for Russian-French translation of mathematics and physics texts which was tested from 1967 to 1971 on a corpus amounting to 400,000 words.[71-74] In addition some trials were made with the system on SL texts in German and Japanese.

The central feature of the CETA system was a 'pivot language', an artificial language free of the morphological and syntactic constraints of natural languages. Its syntax was designed as the common base of the syntactic structures of the languages in the system. Its lexicon, however, did not represent a common base; instead the pivot language conjoined the lexical units of whichever two languages were being processed (usually Russian and French). In other words the CETA pivot language was a true interlingua in syntax but it was a 'transfer' mechanism in lexicon. Further, it was not intended that all sentences with the same meaning would be analysed as (or generated from) one unique pivot language representation, although it was seen as a first step in the direction of such a 'universal language'.

Analysis and synthesis in CETA proceeded in clearly separated stages. After pre-editing (cf. II.2.7), Dictionary look-up identified word-stems and affixes. The next stage, Morphological analysis, eliminated unacceptable stem-affix groupings, e.g. the segmentation of *habilité* as HABILIT + É would be accepted (past participle of HABILITER) but not as HABIL + ITÉ, since the dictionary would record –ETÉ as the nominalization suffix for HABILE. Syntactic analysis was in two stages, first a phrase-structure analysis (using the Cocke parser) and then 'interpretation' in a dependency-tree representation. The first stage included a treatment of discontinuous elements (e.g. *look…up*, *take…away*) which entailed the creation of a new tree triggered by 'variables' assigned to particles (*up*, *away*); in the new tree the elements would be contiguous in an acceptable structure. In the second stage, the 'surface syntactic' structure was augmented by dependency relations, e.g. in a VP the V was marked as 'governor' and the NP as 'dependent' (cf. II.2.3). In this form, the tree entered the Transfer stage where it was converted into a pivot language representation. In the pivot language lexical units were classed as either predicatives or non-predicatives, where the arguments of predicatives (which included adjectives/adverbs as well as verbs) could be either non-predicatives (nouns, articles) or other predicatives (cf. II.2.4). Thus transformation into pivot language syntax involved the further analysis of dependency relations and the removal of word-classes (N, V, Adj, etc.), resulting in a tree such as:[71]

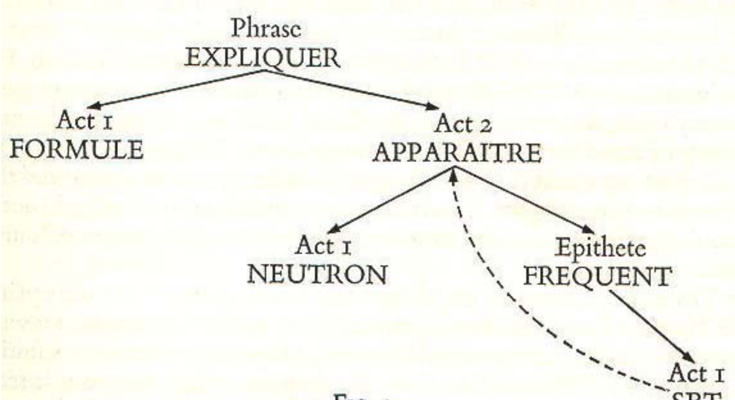

FIG. 3

(where SBT stands for the argument dependent on FRÉQUENT, i.e. APPARAITRE). At the same time the semantic compatibilities of SL lexical units were checked enabling unacceptable syntactic analyses to be 'filtered out' (cf. II.2.4).

Synthesis began with the substitution of SL lexical units in the pivot language representation by their equivalent TL units. In Syntactic synthesis, units were examined for their potential word-classes and for dependency relations with other word-classes. First a predicative was located and its arguments checked as possible NP dependents, and, if one argument was itself a predicative, the possibility of a clause structure was also investigated (e.g. *'...que... apparaitre...'* as well as *apparition*). Then the argument nodes (Act 1, Act 2, etc.) were replaced by acceptable categories (V, NP, Adj, etc.), elements were recorded to conform closer to TL syntax, and the synthesis of TL words was begun (e.g. Act2 (APPARAITRE) became either V(APPARAISSENT) or NP(APPARITION)). Morphological synthesis completed the process by consulting the TL dictionary and editing variants (e.g. LE→L' before A, E, I, O, U.)

An appraisal of the system in 1971 revealed that only 42% of sentences were being correctly translated and that readers found only 61% comprehensible. Although over half the incorrect sentences were caused by input errors, insufficient computer capacity and defects in programs which could be easily amended, it was found that the remainder lay beyond the system's capabilities. The main trouble was the rigidity of the levels of analysis; if morphological analysis failed because the dictionary had no entry for a word or did not record all homographic variants, then this affected all subsequent processes; if syntactic analysis failed to parse any part (however small) of a sentence, it was rejected. In addition, the parser was inefficient: it attempted too many partial analyses which came to nothing, and it produced too many analyses which had to be 'filtered out' later. What was needed was a parser which did nor use its full armoury of analysis for every simple phrase structure but reserved the more complex parts for only complicated sentence structures. Finally, it was concluded that better synthesis would be possible if information about the 'surface' forms of SL sentences was also transferred; in the existing system information on choice of subject noun, use of passive, subordination of clauses, etc. was largely lost during conversion to pivot language representations, but such information could help considerably the selection of appropriate TL expressions.

6.2. Another important example of the interlingual approach is the research done at the University of Texas at Austin by Lehmann and others.[75-81] Starting at roughly the same time as CETA, the group aimed to produce a German-English translation system (METALS) which could be adapted to other language pairs. Like many other American groups the Texas team was strongly influenced by the theory of transformational-generative grammar (Chomsky),[82] in particular by the current argument that while languages differ in 'surface structures' they all share the same 'deep structures' and that, since transformational rules do not affect the meanings of sentences, deep structures may be regarded as forms of 'universal' semantic representations.

The Texas 'deep structure' interlingua was based on much the same principles as CETA's pivot language: it was primarily a syntactic interlingua, no semantic decomposition of lexical items was attempted, and transfer was by the substitution of SL 'words' by TL 'words' to form TL deep structures. Nor was it seen as a true 'universal language': it could not handle such semantic equivalences as *He ignored her* and *He took no notice of her* since they would have different deep structures.[76]

There were also similarities with CETA in the processes of analysis and synthesis. Analysis was performed by three 'grammars' working in sequence. After morphological analysis and dictionary look-up, the 'surface sentence' was converted by a 'surface grammar' into one or more tentative 'standard strings', in which, for example, elements discontinuous on the surface were brought together. The 'standard grammar' tested these tentative standard strings for well-formedness and for each one accepted, it derived one or more phrase-structure representations. The 'normal form grammar' then interpreted (or 'filtered') each standard tree and produced semantically well-formed 'normal' forms, i.e. deep structure representations with lexical items in semantically compatible relationships expressed (as in CETA) in terms of 'predicates' and 'arguments'. Synthesis proceeded first by the substitution of TL lexical elements, then the conversion of 'normal forms' into 'standard strings' and finally into 'surface sentences'.

The Texas system suffered, like CETA, from an inadequate 'context-free' (bottom-up) parser, often producing too many analyses (e.g. for nominal constructions with prepositional phrases, II.2.3). With no intersentential and discourse semantics there were often multiple 'normal forms' for a single 'surface sentence' and since one normal form could be the source of many surface forms the problems of synthesis were also multiplied. As a MT system it was clearly unsatisfactory. However, almost from the beginning the Texas system was conceived as a general-purpose system designed also for other automated language processes. In later years (the project ended in 1975), most emphasis was placed on the system's ability to produce single 'normal form' semantic representations from a great variety of surface forms and its consequent potential for automatic indexing and abstracting.[76]

7. The 'transfer' approach

7.1. In the earliest formulation of a transfer system by Yngve in 1957,[83] transfer was conceived as an operation essentially between representations of 'surface syntactic' structures (i.e. derived by phrase-structure analysis or similar approaches and not relating semantically equivalent syntactic structures). This conceptualization underlies the 'transfer' system developed experimentally until 1975 at CETIS, the Euratom research centre in Ispra (Italy). In SLC II,[48,84] named after the Georgetown program used at Euratom (II.4.2), translation was performed in five stages: Pre-editing (see II.2.7); Dictionary look-up and morphological analysis, combined much as in SYSTRAN

(II.4.3); Transfer, the heart of the system, comprising syntactic analysis (primarily the resolution of ambiguities left after morphological analysis) into dependency-tree representations (as developed by the Italian Operational School, e.g. Ceccato[85-86] – see also II.8.3 below), and transformation into TL representations by a bilingual dictionary and tree-conversion rules; then Morphological synthesis, producing TL surface forms; and Post-editing. Only the analysis programs were developed in any detail since most recent activity concentrated on experiments with SLC II as an automatic indexing system.[87]

However, as we have seen, analysis which goes no further than 'surface structures' is generally inadequate for MT. Researchers adopting the transfer approach now assume that transfer must take place between 'deep structure' or (quasi)semantic representations. On the other hand the complete semantic analysis found in 'interlingual' systems is not thought necessary or even desirable, particularly when SL and TL have similarities in both syntax and vocabulary.

7.2. The TAUM project at Montreal (T.A.U.M.—Traduction Automatique de l'Université de Montréal) represents a typical example of the 'transfer' approach. It is also the second generation system nearest to full operational implementation. For these reasons it is described here in some detail. Supported by the Canadian government since 1962, the TAUM project's goal has been the design of a fully automatic English-French translation system.[88-92] At present the team is constructing an operational system for translating American aeronautics manuals for the Canadian Air Force—Project Aviation.[13,93]

In TAUM there are five basic stages: Morphological analysis of English, Syntactic analysis of English, Transfer, Syntactic generation of French, Morphological generation of French. Each stage consists of a grammar of 'Q-systems'. Q-systems (Q = Quebec) are the computer programming development of Colmerauer[94] for the manipulation of tree structures and strings of trees irrespective of the labels attached to the nodes of trees. A tree may be fully articulated as in a phrase-structure representation, e.g. PH(SN(IL), SV(V(MANGE),SN(LA,CHOUCROUTE))), or it may represent a list (items separated by commas), e.g.L(A,B,C,D), where each item may itself be a tree, or it may represent a categorization, e.g. PREP(TO), or a single node, TODAY (i.e. degenerate trees). A string of trees is defined as a sequence of trees separated by plus signs, e.g. SN(PAUL) + V(VIENDRA) + DEMAIN + CHEZ + PRON(MOI). A Q-system rule converts strings (of one or more trees) into new strings. A rule may apply to any part of a string, and may include variables for labels, lists or trees, e.g. PREP(A*) + SN(X*) → OBJIND(P(A*),SN(X*)) where A* is a variable for a label (TO, FROM, . . .) and X* is a variable for a list. Clearly, the Q-system formalism is very powerful, capable it would seem of modelling any formal grammar.

(1) Morphological analysis proceeds as follows: assignment of category labels to constants (prepositions, conjunctions, articles, pronouns), e.g. WITHIN → P(WITHIN), SEVERAL -t QUANT(SEVERAL), IN THE PROCESS OF → P(INTHEPROCESSOF); segmentation of prefixes, e.g. UNDERSTOOD → UNDER + STOOD; regularization of irregular forms, e.g. ANALYSES → SW(ANALYSIS) + S, STOOD -t SW(STAND) + ED(PST); restoration of prefixes, e.g. UNDER + SW(STAND) → SW(UNDERSTAND); segmentation of any word not previously identified as a constant or irregular (i.e. not already assigned a category: P, QUANT, SW) into its stem and

suffix, first by splitting of terminal -S, -ED, -ING, -LY, etc., e.g. TRIED → TRI + ED, PUTTING → PUTT + ING, SERIES → SERIE + S, then constructing the base form by, e.g. undoing the doubling of final consonants (PUTT → PUT) or replacing final I by Y (TRI → TRY). Dictionary look-up searches for both segmented forms (TRY + ED, SERIE + S, FLY + S) and full unsegmented forms (TRIED, SERIES, FLIES), rejects unlocated forms (SERIE, TRIED), and rewrites those found as sequences of category label (ADJ, N . . .), 'word' (entry form in English-French transfer dictionary) and feature list (ANI, CONC, ABST, etc. for nouns; or, for verbs, features of admissible arguments (subject nouns, objects, etc.) and obligatory prepositions, e.g. TO for *listen).*

(2) Syntactic analysis has two stages: recognition of noun phrases and complex verb forms, converting category label plus 'word' sequences into trees, e.g. ART(U*) → DET(ART(U*)), rearranging constituents as needed, e.g. DET(V*) + N(X*) → NP(N(X*), DET(V*)); and establishment of sentence structure in 'canonical form'. The latter incorporates both phrase structure rules and transformational rules: input strings of trees are formed into single complex trees and reordered (or reformed) as 'deep structure'-type representations. Verbs are put before their argument noun phrases, passive constructions are made active, extraposed *it* forms are transformed (e.g. It be ADJ that S → S be ADJ) and relative pronouns are replaced by REL and the head noun copied into its argument position in the clause. However, complete transformational analysis is not pursued as it is not felt to be necessary for English-French translation. Fig. 4 gives a sample analysis:

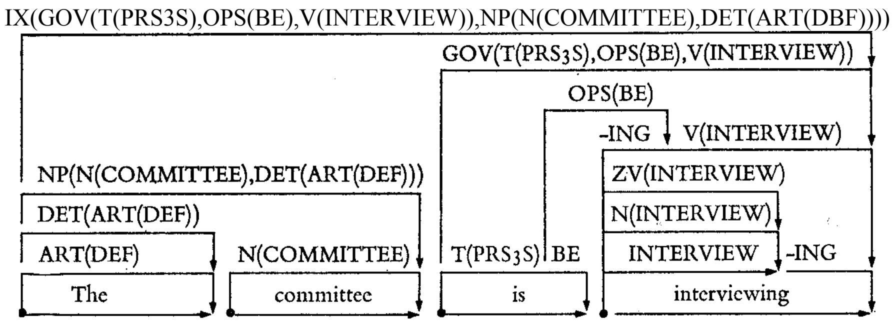

Fig. 4

(3) Transfer has two parts: translation of category labels and 'words' via a bilingual dictionary, which may involve the decomposition of trees into strings, e.g. NP(N(MAN),/,*H) → NP_1 +(+N+(+ HOMME +)+*H+); and modification of certain parts of trees to simplify generation, e.g. NP_1 → P(SUBJ) + SN, NP_2→P(OBJ) + SN.

(4) Syntactic generation: successive Q-systems break down the complex tree output from Transfer into strings of (degenerate) trees. For example the noun phrase: SN(N(GENS),DET(LES), GP(P(DE),SN(N(VILLAGE),DET(LE))))

becomes: DET(LES) + SN(N(GENS), GP (. . .))

DET(LES) + N (GENS) + GP(P(DE), SN(N(VILLAGE),DET(LE)))

DET(LES) + N (GENS) + P(DE) + SN(N(VILLAGE),DET(LE))

DET(LES) + N(GENS) + P(DE) + DET(LE) + N(VILLAGE)

(5) Morphological generation, finally, converts trees and strings into single 'surface' forms, e.g. DET(LES) → *les,* P(DE) + DET(LE) → *du.*

Characteristic features of MT transfer systems are well illustrated in TAUM: the clear separation of stages, the separation of linguistic data from processing algorithms (in this case, Q-systems), the use of separate dictionaries for analysis (stage 1), transfer (stage 3) and synthesis (stage 5). Analysis goes no further than 'deep structure' (and sometimes not that far); semantic analysis is confined to the use of semantic features during tree conversion in Transfer; and pragmatic or discourse analysis is absent, with one exception. This is the incorporation of an intersentential routine, the so-called REF-Bug, BO which moves left to right, across, into and out of sentences (or rather their ‘deep structure’ representations) replacing ‘each pronoun by the most recent noun of the same gender and number which it has met.’

When completed (it is hoped, at the end of 1978), Projet Aviation will be the first operational second generation MT system. Preliminary results are encouraging (example 6 in Appendix). In one particular it will differ from TAUM as described; morphological analysis will be performed not by Q-systems but by a parser, REZO, based on Woods’ augmented transition network parser (IV.5 below). Projet Aviation will not, however, be the first experience of the TAUM group in designing an operational system. In 1974 TAUM was commissioned by the Canadian Bureau des Traductions to produce a system for the translation of weather forecasts from English to French. TAUM-METEO,[95-97] fully operational since early 1976, translates daily 1,500-2,000 short reports for broadcasting to the general public (example 7 in Appendix). The restricted vocabulary and stereotyped syntax of meteorological reports enabled the designers to greatly simplify the basic TAUM system. The stage of morphological analysis before dictionary search was dropped because there were so few variant forms of English words in reports. Instead of three separate dictionaries, only one was needed to give the French equivalents of English expressions and French morphological data. The parser and the synthesis program were similarly much simplified. METEO fails to translate only 20% of reports, largely because input is unedited and contains errors of typing, spelling and punctuation, all outside the control of the system itself. Although limited in scope, TAUM-METEO is the first, and so far only, MT system producing regular translations for public consumption.

7.3 Other transfer systems on much the same lines as TAUM have been reported, e.g. the Xyzyx Information Corporation system (English-French) and the Kyushu University system (English-Japanese).[18] More important from the standpoint of MT system design, however, is the Chinese-English MT project at the University of California, Berkeley, the POLA system (Project on Linguistic Analysis).[98-100] Stages of analysis and synthesis were basically similar to those in TAUM, the differences arising from problems peculiar to the analysis of Chinese. The lack of sentence-delimiting and word-delimiting symbols required a preliminary segmentation of Chinese text into tentative sentences and ‘subsentences’ on the basis of punctuation marks and constants (prepositions, conjunctions, etc.), and meant that in dictionary look-up searches had to be made for the longest matching sequences of Chinese characters. With most Chinese words having multiple syntactic functions, more than usual recourse had to be made to semantic features for the resolution of syntactic ambiguities. A major problem of obvious general significance was the automatic recognition of Chinese characters. Much effort was devoted to this task, with some measure of success before the project ended in 1975. Concentration on the Chinese problems led to a neglect of the English aspects: the synthesis program existed in no more than a sketch. However, on the computational side

POLA had many advanced features: the grammar was broken down as a flexible sequence of 'subgrammars' allowing linguists to rewrite small areas without fear of impairing the system as a whole; and the whole program was written in a 'structural programming language' (GASP) which made it 'highly machine independent' and easily adaptable to any large-scale third generation computer.

7.4 A change in computer facilities in 1971 encouraged the research team at Grenoble to rethink the design of their MT system. Now called Groupe d'Études pour la Traduction Automatique (GETA), the team decided on a transfer approach. Experience with the 'interlingual' CETA system (II.6.1) had revealed disadvantages in reducing texts to semantic representations and destroying in the process a good deal of 'surface' information useful for TL synthesis. The aim of GETA[71,101-105] is to design a MT system capable of translating from and into any European language, which incorporates greater flexibility in both its programming and its linguistic aspects, which like POLA is machine independent, and which is amenable to co-operative activities with other MT research groups.

GETA has three major algorithmic components, one for the conversion of string representations into tree structures (ATEF), one for the transformation of trees into trees (CETA) and one for the conversion of trees into strings (SYGMOR). In addition there is an algorithm for consultation of the transfer dictionary (TRANSF). Each algorithm is suited to particular stages of the translation process. There are basically five stages, very similar to those in TAUM: Morphological analysis, using a battery of dictionaries to produce all possible category assignments and preliminary identification of some noun and verb groups, i.e. converting strings into partial tree structures by the ATEF algorithm; Syntactic analysis, producing dependency-tree type 'deep structure' representations (akin to those in CETA (11.6. 1) but not intended as 'pivot language' forms) via the tree-tree conversion algorithm CETA; Transfer, producing TL 'deep structure' representations by SL-TL dictionary substitutions (via TRANSF) and tree transformations (via CETA) working closely together; Syntactic synthesis, producing TL 'surface' trees suitable for transformation in the final stage, Morphological synthesis, into TL strings by the SYGMOR algorithm.

However impressive the linguistic design of GETA (and this aspect should not be ignored), its principle importance lies probably in its algorithmic features.[106-108 The] GETA team insists that the algorithms employed at any particular stage should be no more complex and no more powerful than necessary for handling the linguistic data in question. On this argument it rejects the use of such powerful algorithms as Q-systems (II.7.2) and augmented transition networks (IV.5) for string manipulation in morphological analysis and synthesis, and proposes instead the non-deterministic finite state ATEF and SYGMOR algorithms. For the transformation of tree structures the extremely flexible CETA algorithm has been developed. CETA provides the mechanism for the transformation of one abstract tree or subtree into another; the linguist decides what transformations are to be used in particular instances and what conditions are to be attached to their use. He constructs 'subgrammars' applied in any order and under any conditions he may specify. Thus he might construct a set of different subgrammars for the treatment of noun groups, one for simple cases, another for complex cases. Each subgrammar can function in one of two distinct modes: the unitary mode where rules are applied once only, or the exhaustive mode where rules may be applied to trees on which they have already operated—each rule may be recursive as long as the (sub) tree it produces has fewer nodes than its origin, this prevents infinite recursion. Thus the ‘grammar’ of a CETA system is a network of subgrammars, where the transition from one subgrammar to another is controlled by conditions specified by the linguist. The system gives the linguist a vast choice of models, great liberty of strategy in the application of subgrammars (permitting one linguistic model in one subgrammar and another elsewhere) and the assurance that, whatever the strategy or ‘grammar’, there will always be a result at the end of a finite application of rules. CETA subgrammars do not test for the *acceptability* of structures (i.e. they do not filter out ill-formed structures) but test for the applicability of rules of transformation;[101] even if no rule can apply there will always be a tree as output on which other subgrammars may operate.

In. addition to this, the GETA system as a whole appears to be very flexible. It designed, for example, to permit interactive man-machine processing in both analysis and synthesis[72] (see also III.2 below). Furthermore, there is no reason t suspect that it could not easily incorporate ‘real world knowledge’ and 'common sense inferences’ (on the lines of Wilks' research, II.8.2 below) in its semantic processing.[109]

7.5 Although still in the early experimental stages, GETA promises to provide a sound foundation for future MT research, particularly for the development of multilingual systems by co-operative efforts. International co-operation in MT research has been stimulated by the foundation in 1974 of the LEIBNIZ group. [104,110] Many members of this group have adopted GETA algorithms and have essentially the same conceptualization of MT system design. At a meeting in 1975 agreement was reported on the formal definition of ‘transfer’ languages. Work within the ‘Leibniz’ framework is proceeding at GETA (Russian and French), Nancy (English), Campinas, Brazil (Portuguese) and Saarbrücken (Russian, German, French and English). The latter team, which began work on a Russian-German transfer system in 1967, has developed a six-step analysis program producing GETA-type dependency tree representations.[111] One interesting development is a program for resolving word-class ambiguities which is very largely independent of the SL under analysis. As at GETA the ultimate aim is a multilingual system, but while programs exist for the analysis of Russian, French, English and German sentences, programs for transfer and synthesis exist at present only for German. Furthermore, intersentential relations and problems of pronominalization have not yet been tackled.

8. *Semantics-based MT*

8.1 While it is obviously a promising sign of progress in MT research that there can be broad agreement on basic design principles, to the extent that international cooperation can be envisaged, there remain areas of linguistic processing in which research can be said to have hardly begun. In particular the semantics and pragmatics of texts have been scarcely explored in depth.

All the MT systems so far described are essentially syntax-based. However much semantic information is included in intermediary representations, syntactic analysis is the central component: semantic analysis operates only after syntactic structures have been determined. There is another sense also in which these systems are syntax-based: their analytical procedures are restricted to sentences. There are admittedly mechanisms, e.g. in TAUM, to deal with cross-sentence pronominalization, but the semantic links between sentences—those features which make a sequence of sentences into a cohesive whole[112] –

have been neglected. Many researchers have recognized these deficiencies in their systems (e.g. the Texas group and GETA) but so far only tentative suggestions for treating intersentential relations have been made.[113]

8.2 The importance of Wilks' MT model[114-116] lies precisely in the exploration of an alternative semantics-based approach to analysis and also of semantic and pragmatic text structures. His framework is the research on language understanding by workers in Artificial Intelligence (e.g. Schank -- see Boden [117] for a good introduction). His basic approach is 'interlingual' and analysis and synthesis proceed through clearly defined stages; Wilks describes English-French translation.

The first pass is a fragmentation routine which partitions text at punctuation marks and specified keywords (prepositions, conjunctions, etc.) rendering for example *I advise him to go* as '(I advise him)(to go).' Each fragment is then tested against an inventory of templates, semantic frames expressing the 'gists' of (parts of) sentences in the form of triples of semantic features. The template MAN HAVE THING ('some human being possesses some object') would be matched on a sentence such as *John owns a car.* MAN, HAVE and THING are interlingual elements which would be found as the principal, or head, semantic categories in the semantic formulas representing *John, own* and *car* respectively in the English dictionary.

Semantic formulas are constructed from a set of 70 primitive semantic units, 'elements', and left and right brackets, e.g. *drink* has the formula: ((*ANI SUBJ) (((FLOW STUFF)OBJE) ((*ANI IN) (((THIS(*ANI(THRU PART))) TO) (BE CAUSE))))). This is to be read as 'an action, preferably done by animate things (*ANI SUBJ) to liquids ((FLOW STUFF)OBJE), of causing the liquid to be in the animate thing (*ANI IN) and via (TO indicating the direction case) a particular aperture of the animate thing; the mouth of course'. [102] (Semantic decomposition goes no further than necessary for the purpose; in this context there is no need to distinguish *mouth* from other apertures.) The notion of preference is an important feature of Wilks' semantic formulas: SUBJ displays the preferred agents of actions and OBJE the preferred objects or patients. They do not stipulate obligatory features of agents and patients—as is the practice in syntax-based grammars (cf. CETA, METALS, TAUM). They allow therefore 'abnormal' usages (e.g. cars drinking petrol) while still expecting the 'normal'. In this way Wilks' 'preference semantics' is able to cope with many kinds of metaphorical expressions.[118]

Matching heads of semantic formulas against possible templates can resolve ambiguities which in syntax-based systems is done by syntactic analysis. For example, in *Small men sometimes father big sons* the verbal sense of *father* is picked out because only a template with CAUSE at this position fits the other heads of the fragment; in syntactic analysis it would be picked out because only a phrase structure with Verb at this position is acceptable. Other homographs are disambiguated at this stage by the examination of selectional preferences (e.g. *drink* would prefer the liquid' interpretation of *Scotch* rather than the 'animate' interpretation when this occurs in OBJE position.) In the next stage, elements of fragments not so far included in templates are examined for their relationships to those already identified. Thus, adverbs are linked to 'actions', adjectives to 'agents' or 'patients', indirect objects to 'actions', and so forth. The program searches for the strongest dependencies, those which account for the whole structure in terms of the semantic preferences of all components. Then the semantic representations of fragments which have been produced (e.g. Fig.5*)* are tied together in a network.

```
John ↔ gave ↔ book
         ↑         ↑
       Mary      the
```

Fig. 5

Searches are made for the dependencies of fragments on their preceding or succeeding fragments, e.g. a temporal phrase *during the war* could be tied to the 'action' element of an earlier or later representation by a 'location' case marker. Such ties are made not only within sentences but also across sentence boundaries, since the basic unit for analysis is not the sentence but the phrase (fragment). Some ties involve more than looking for semantic densities, they make use of 'common sense inferences'. [116,119] For example, in *The soldiers fired at the women and we saw several of them fall* the linking *of them* to *women* rather than to *soldiers* is made by reference to a 'common sense rule' stating that if an animate object is hit it is likely to fall. Such rules, Wilks stresses, are not interpreted as truth claims about the physical world but as simply reflections of our common understanding (which may differ according to cultural background).

When the whole text has been interpreted as a cohesive semantic representation, each English word (or rather its semantic formula) is replaced by one or more French 'stereotypes' (one for each distinctive sense). Stereotypes specify the semantic conditions which must be met by formulas in the same or related fragments in order that the appropriate French lexical items can be generated. For each stereotype there corresponds a French 'surface' form. Synthesis is thus a recursive matching of stereotypes within and across fragments (Herskovits).[120]

8.3 The distinctive features of Wilks' MT model are the semantic 'parser' operating wholly on semantic features, the use of preference semantics and common sense inference rules, and the analysis of discourse relationships. We may envisage such components in future MT systems: semantic parsers as alternative analysers in GETA-type 'subgrammars', preference semantics replacing the more rigid 'selectional restriction' semantics of present systems, inference rules as components of disambiguation routines, and intersentential semantics as an integral part of SL text analysis. Most doubt will probably be expressed over the role of pragmatic information in analytical procedures. While most MT researchers have agreed that discourse analysis of some kind is necessary for the resolution of a number of ambiguities, e.g. the problems of pronominalization (II.2.5), there are undoubted difficulties about the incorporation of 'knowledge' components—of which Wilks' common sense inference rules are one example. A number of MT researchers in the past have indeed stressed the importance of such pragmatic information. Ceccato, for example, argued that for adequate MT the machine had to be supplied with a 'body of knowledge'.[85] His 'correlational analysis' approach to MT anticipated Wilks' AI approach to some extent both in this emphasis on the interaction of semantics and 'world knowledge' and in the notion of mapping expressions on to triples of linguistic features (in Ceccato's case, a 'correlation' of one correlator and two correlata specifying syntactic or semantic categories). Others, however, from Bar-Hillel[15] onwards, have argued that such a complicated component is just not feasible on the scale required for MT systems—it may work well in the restricted models of Artificial Intelligence, but the success is unlikely to be repeatable when dealing with large amounts of data covering a wide spectrum of topics. Nevertheless, it would seem likely that we shall see in the future experiments in MT with analysers incorporating a certain amount of pragmatic information, perhaps on the lines of Winograd's work, [121] i.e. parsers which combine heuristically syntax, semantics and 'knowledge' of the properties of the 'world' being talked about. (The GETA system with its network of 'subgrammars' would appear to offer a suitable framework for such research.) We can only speculate on the future directions of research in this area, and we cannot yet predict what impact it may have on the design and construction of future MT systems.

III. INTERACTIVE AND MACHINE-AIDED TRANSLATION

1. Fully automatic translation of good quality is regarded by many as an unattainable goal. Some have explored the possibilities of interactive MT, in which man and machine collaborate in the production of translations; others have exploited the computer's capacity to retrieve rapidly and accurately information from large data banks by developing mechanized aids for the human translator.

2. *Interactive MT systems*

The collaboration of man and machine in interactive systems may take a variety of forms. Human participation may be restricted to those parts of the translation process where automation has encountered greatest difficulties, i.e. primarily in the resolution of syntactic and semantic ambiguities in the analysis of SL texts. Or it may go further and involve preliminary, preparation of the text before input ('pre-editing'), e.g. simplification of expressions, marking structural relations, and so on, or involve the selection of TL forms when alternatives are offered. The full range of possibilities has yet to be explored as research on interactive systems has been surprisingly slow to develop.

2.1 The MIND system developed by Kay at the Rand Corporation [122-123] is a general-purpose language data processing system, comprising 'a set of fundamental linguistic processors which can be combined on command to carry out a great variety of tasks from grammar testing to question-answering and language translation'. These processors include morphological and syntactic analysers, a semantic file processor, a transformational component, a morphological synthesizer and an interactive disambiguator. As a MT system, MIND takes the form of a human-aided 'transfer' system. Morphological and syntactic analysis is performed automatically to yield 'deep structure' representations which are converted by transformational rules into TL 'surface forms' and finally realized by morphological synthesis. The role of the disambiguator is to mediate between the analysis components and a human consultant for the resolution of ambiguities. Given a sentence such as *They filled the tank with gas* the human assistant might be asked:

DOES THE WORD 'TANK' REFER TO
1. A MILITARY VEHICLE?
2. A VESSEL FOR FLUIDS?

DOES 'GAS' REFER TO
1. GASOLINE?
2. VAPOR?

or: DOES 'THEY' REFER TO
1. SOLDIERS?
2. TANKS?
3. SHELLS ? (or any other recently used noun)

As well as such problems of homography and pronominal reference, he might be asked to resolve syntactic ambiguities, e.g. in the case of *He saw the girl with the telescope:*

DOES THIS MEAN

1. 'SAW WITH THE TELESCOPE'?
2. 'GIRL WITH THE TELESCOPE'?

The disambiguator itself decides what the problems are and what questions would resolve them in the most efficient way, i.e. it designs and implements its own strategy of problem-solving. As MIND develops a more sophisticated 'semantic file' containing knowledge of 'reality' (cf. II.8.3) it is envisaged that fewer problems will have to be put to the human consultant and the interactive component will diminish in significance. However, MIND is seen primarily as a 'laboratory' system and not as a prototype for any eventual operational system (for MT or any other linguistic data processing).

2.2 The 'transfer' approach has also been adopted at Brigham Young University, Provo (Utah), for a MT system which, while at present human-aided, is hoped eventually to be fully automatic. The team has chosen to test Junction Grammar (a theory developed by Eldon Lytle)[124] for the 'interlingual' representation of sentences in a system where English analysis is performed interactively at a video screen and where transfer and synthesis into multiple languages (at present French, German, Spanish and Portuguese) is performed automatically.[125] Most work in this research project has been done on the interactive program for 'deep structure' analysis of English sentences and on the design of a language-independent transfer algorithm.

2.3 CULT seems to be the only operational interactive MT system.[126-128] It has been developed at the Chinese University of Hong Kong for Chinese-English translation of mathematics and physics texts, and since 1975 has been in regular use for the translation of issues of *Acta Mathematica Sinaica.* Accounts of the system, while stressing its 'heavy emphasis on pre-editing', do not make clear the full extent of human involvement in the translation processes. It is, however, clearly based on a 'direct translation' approach. Sentences are analysed and translated one at a time in a series of passes. The parser identifies little more than 'surface' sequences of grammatical categories to assist the resolution of homography and certain ambiguities of syntactic structure. After each pass a portion of the sentence is translated into English, the human 'editor' apparently intervening for the insertion of articles, the determination of voice and tense of verbs, and the resolution of semantic and syntactic ambiguities. If the parser fails, he translates the complete sentence.

2.4 Intervention on a comparable scale seems to be envisaged in the proposed SLUNT system,[129-130] in which problems of ambiguity, idiomaticity and syntactic complexity are to be avoided by simplification of the text either before or during translation. Likewise in the much more speculative research done by Chafe at the University ofCaliforna,[131] translation involved the human 'assistant' in an interactive reconstruction of the processes by which the original (SL) text had been realized (or 'verbalized') in order that parallel processes might be applied to produce a TL text with the same content.

2.5 Interactive MT would seem to be most attractive, however, where human involvement is reduced to a minimum and restricted exclusively to resolving problems of analysis; otherwise the person concerned might just as well translate the complete text alone. Clearly, in contexts where simultaneous translation of the same text into a number of languages is required (as in the Brigham Young University system) there is even greater justification for interactive systems; the effort devoted to improving the quality of the analysis can be spread over a larger output of translated texts. This would seem to be a promising line of future MT research, offering the prospect of higher quality translations than perhaps most current operational MT systems.

3. *Machine aids for translators*

3.1 Whereas the 'second generation' MT systems and interactive MT systems are still largely at the experimental stages, when we turn to machine-aided translation we are concerned for the most part with successful practical applications of computers in fully operational systems.

Machine aids for translators have been developed in response to the ever more pressing needs of translators, particularly in large governmental and industrial units, for rapid access to up-to-date glossaries and dictionaries of terminology in science, technology, economics and the social sciences in general. The difficulties of the technical translator are well known: the rapidly changing vocabulary of many sciences and disciplines, the emergence of new concepts, new techniques and new products, the often insufficient standardization of terminology, the multiplicity of information sources of variable quality and reliability, etc. It is not surprising to learn[132] that a translator may spend up to 60% of his time consulting dictionaries, glossaries and other terminological sources. Furthermore, in large translation services the same information may be looked for on different occasions by many other translators. The savings to be achieved by centralization are obvious, and a number of European and Canadian bodies involved in large-scale translation activities have now implemented computer-based 'terminology data banks'.

The information needed by the translator does not often coincide with that contained in the automatic dictionaries used in MT systems. He rarely needs to know about grammatical functions, syntactic and semantic categories, morphological variants, inflected forms, etc.—information essential for automatic analysis. Nor does he often need to consult dictionaries for items of general vocabulary. His primary concern is to find appropriate equivalents for special and technical terms. He needs reliable information about precise meanings, connotations and ranges of usage; if possible he wants to have authoritative definitions of technical terms and examples of them in actual use (particularly in the case of newly-coined terms).

There are other differences between MT dictionaries and terminology data banks concerning access to the information. Entries in data banks are generally made under the 'base forms' which users are familiar with from consulting conventional dictionaries (infinitive forms of verbs, nominative singular forms of nouns, etc.) and which they are thus able to use without difficulty when formulating searches and interrogating the data bases. The kind of morphological analysis found in MT systems is rarely needed; where access has been made possible from variant forms (e.g. when words are taken directly from texts) the simple truncation of endings is usually sufficient. More problematic is access to compound forms and phrases; most data banks enter them as single units while allowing searches on any component words (except, in some cases, words of general vocabulary).

Multilingual terminology data banks have been developed primarily for *(a)* the provision on demand of information about individual words and phrases (definitions, examples, translations); *(b)* the production of glossaries specifically related to the texts to be translated; and *(c)* the production of up-to-date specialized dictionaries and glossaries for more general use. Some systems have assumed additional functions: automatic editing of translated texts, storage of complete texts when these are subject to frequent updating (e.g. manuals, administrative instruments), and the production of glossaries for teachers of foreign languages.

3.2 The emphasis in the EURODICAUTOM and TERMIUM systems has been on providing translators with immediate direct access to terminological data. EURODICAUTOM [14,133] is the terminology data bank for translation services of the European Communities (developed from DICAUTOM, [134-135] one of the first data banks, used since 1963 at the Coal and Steel Community in Brussels). It covers all the languages of the Communities in a wide range of subjects. TERMIUM [136-137] was established at the University of Montreal in 1970 as a central repository of terminological data for Canadian translation services, and initially includes only English and French terms. In both systems particular stress is laid on the value to translators of authoritative definitions and examples of texts illustrating terms in actual usage—neither provided in genera] by conventional dictionaries. The contents of the EURODICAUTOM and TERMIUM data banks are compiled from information gathered by the translators themselves in the normal course of their work. When a new term is encountered (single word, compound or phrase), the translator provides a passage illustrating its usage, a passage in the other language containing an equivalent expression, a definition from a reliable source (e.g. a standard), subject field code(s), and bibliographical reference(s). No translated texts are accepted as illustrative material. Access to the data is possible through any component words of compounds or phrases (although not, in TERMIUM, through some general terms such as *process).* Both systems provide on-line direct access in conversational mode, EURODICAUTOM incorporating also some partial morphological analysis (automatic truncation of suffixes). In addition, both systems produce specialized multilingual glossaries for internal use only, i.e. in the case of EURODICAUTOM within the institutions of the European Communities.

3.3 The LEXIS system[138-142] developed by the West German Bundessprachenamt (previously the Übersetzerdienst der Bundeswehr), a pioneer in mechanized aids for translators since 1965, is designed for the production of up-to-date dictionaries, glossaries and special word lists of scientific and technical terms and for the production of text-related glossaries for the use of translators working on particular texts. Dictionaries and glossaries from the LEXIS data base are produced in a variety of formats: computer printout, reduced photocopies of printout, microfiche (COM), conventional printing via photocomposition. (In 1976 500 glossaries were produced.) Access to the data bank is also available direct through visual display units at four centres in Germany. But it is the text-related glossaries for which LEXIS is best known. These are lists which give translators the TL equivalents for all terms in specific SL texts which they have indicated they need help with. Difficult or unfamiliar terms are underlined by translators during their initial reading of texts, they are converted into ‘base’ forms, fed into the computer as search terms, located in the data bank, and printed out with their TL equivalents. The terms may be listed in the order in which they occur in the original text or in alphabetical order. The former is of most value to translators working alone on texts, the latter where a team of translators is working on a single large project. Glossaries do not, of course, relieve translators from making decisions about how particular passages are to be translated, but the experience of the Bundessprachenamt over many years has been that ‘text-related glossaries can be a decisive aid towards improving translation work both quantitatively and qualitatively’ and that their usefulness ‘increases in proportion to the frequency of technical terms in the text to be translated’.[143] Over the years the coverage of the data bank has improved considerably: in 1966 when the bank contained 110,000 entries 70% of the terms requested (for loo text-related glossaries) were absent, in 1976 when it contained 900,000 entries no more than 20% were missing.[142] (The bank now contains 1,200,000 entries.)[144] Missing entries are, of course, made good immediately by the translators but it is inevitable that texts in the fields of science and technology will always contain words and expressions not previously encountered. The bottleneck of the system is the manual input of search terms: translators have to decide what ‘base’ forms are to be looked for, to distinguish verb forms from homographic noun forms (e.g. CONTROL, TO), to eliminate hyphens, to decide what parts of compounds are to be checked, etc.[141] A fully automatic program, AUTOQEST,[145] has been developed which identifies single and compound terms in texts, looks for them in the data bank and prints out the results, but it can be used only if texts are already machine-readable, and this is very rare. There is a clear need for an optical character reader able to deal with all current typefaces.

3.4 The TEAM system (Terminologie-Erfassungs- und Auswertungs-Methode) has been developed at the Siemens company.[146-149] Its data base is a multilingual dictionary containing over 700,000 entries covering more than two million scientific and technical terms in the major European languages (English and German predominate, but there are substantial numbers of French, Italian, Spanish, Portuguese, Russian and Dutch terms as well). Apart from recording the equivalencies of terms in different languages, the entries include grammatical information for each term, indications of subject fields, definitions, examples of the use of terms in context, and indications of the sources and reliability of the information given. Entries are compiled mainly by the translators themselves from specialized literature and technical documentation. TEAM provides direct on-line access via VDU to the data base, it produces multilingual specialized dictionaries, glossaries for foreign language teaching courses, and text-related glossaries for individual translators. As at the Bundessprachenamt the possibilities of producing such glossaries automatically from machine-readable input are being explored.[149]

3.5 The interesting feature of NORMATERM,[150-152] the automatic dictionary system developed since 1973 by AFNOR (Association Française de Normalisation) for access to terms used in French and English standards, is that it is based on a thesaurus. Entries are made under descriptors from the ISO thesaurus, and each record's associative relations (broader terms, narrower terms, related terms) to other entries. Each entry includes bibliographic data on the source (i.e. the standard), the French and English terms corresponding to the descriptors), any of their synonyms (including obsolete and proscribed terms), abbreviations, generic and specific terms (in French only) and a definition in French. Access is available on-line direct via descriptors or terms. The system also produces regular English-French and French-English indexes to standardized terminology.

3.6 In the next few years we shall probably see many more terminology data banks coming into operation (e.g. the one under development at the University of Dresden)[153] and an increase in the international co-operation which has already begun between the largest centres, e.g. the exchange of multilingual terminology data between the Siemens and Philips companies[147] and between TERMIUM and EURODICAUTOM.[154] We shall also undoubtedly see further developments in the interactive facilities of systems, quite possibly on the lines of Lippmann's research at IBM. In Lippmann's experimental computer-aided translation system[155-156] the translator is provided with facilities to produce and edit translations at a computer terminal and to consult and update dictionaries as needed. Lippmann describes[155] an on-line session in which a translator types in his translation, amends typing errors, looks up words and phrases in a dictionary, inserts missing entries, calls upon another user of the system, for information, and asks for a printout of the finished translation. Elsewhere[157] Lippmann describes the on-line generation and editing of text-related glossaries (for use either on- or off-line) and the possibility of providing interpreters with on-line access to dictionaries during consecutive or simultaneous interpretation.

3.7 The -wider ramifications of terminology data banks have been stressed by Krollmann.[158] He envisages the creation of large-scale 'linguistic data banks' which would combine in one integrated system multilingual dictionaries for lexicographic work (for production of dictionaries and glossaries and for co-ordination and standardization of terminology), multilingual dictionaries for machine-aided translation (for production of text-related glossaries and for direct access to multilingual terminology data), monolingual dictionaries (as sources of definitions), thesauri for retrieval and documentation purposes, index files of translations (e.g. on the lines of Aslib's Index), and archives of completed translations (for regular updating). It is a proposal which highlights the common interests of translators, terminologists, dictionary compilers and publishers, compilers of multilingual and monolingual thesauri and indeed anyone needing data bases of multilingual terminology.

IV. PROBLEMS, METHODS, AND THE FUTURE

1. The present activities in. machine translation and machine-aided translation need to be seen in the wider context of research on the automation of linguistic processes and in the context of activities in documentation and information science. Problems are often common to many different processes involving language and translation, and methods developed in one area may well be applicable in others. In general terms we may ask what are the techniques and procedures on which there is broad agreement in MT research and in machine-aided translation and which could perhaps have application in the automation of documentation and information storage and retrieval processes; what are the outstanding problematic areas and where may we look for solutions in the future; and what is the prospect of good quality MT in coming years?

2. From the descriptions in the preceding section it is clear that the compilers of terminology data banks have much in common with compilers of multilingual thesauri. Both have to deal with the problems raised by compound terms, synonyms and quasi-synonyms, homonyms, generic terms, etc. (how they should be entered and what kinds of cross-references should be made). Both have to have procedures to deal with neologisms and to deal with terms or concepts present in one language but absent in another. Both

have a common concern with precision in usage ('vocabulary control' in thesauric terms), and therefore provide definitions (e.g. 'scope notes') and examples of actual usage. Where searches are automated, both have the problems of unrecorded words and phrases and of dealing with morphological variants of terms which are entered. The former is a general problem (shared by all automated systems, MT and automatic indexing included) for which there can obviously be no easy solution, if any. The latter, however, can be tackled by techniques which are now well established.

3. Morphological analysis, indeed, causes few difficulties. It is surprising in fact that there seem to be no standard programming 'packages' available[159] since the same techniques are found repeatedly in one system after another. There seems also to be a broad measure of agreement (among MT researchers at least) on the general strategy of morphological analysis and dictionary look-up; the approaches of TAUM (II.7.2) and of GETA (II.7.4) are now typical.

4. What all systems lack is an all-purpose optical character reader. Without it, the automated processing of text, for whatever purpose, cannot be as attractive economically as it might otherwise be. Existing optical character readers are restricted to a few (often only one or two) special type-faces, and they are used mainly by publishing houses for the preparation of material for photocomposition.[160] Only EURODICAUTOM and TEAM of the systems described seem to make regular use of OCR for computer input. In most systems therefore texts have to be converted manually into machine-readable form. This has the advantage that some 'pre-editing' can be done (II.2.7) for which otherwise automatic procedures would be needed, e.g. in order to distinguish between the use of the stop in abbreviations and its use as a sentence marker (which is by no means as simple as it might appear).

5. As far as syntactic analysis is concerned there is now less dispute over methods and techniques than in the past. The previous confusing variety of parsing strategies and grammatical models has been replaced by a relatively limited number of parsers with proven computational efficiency[161]—few now need more than a minute to parse the most complex sentences. A general characteristic of present-day parsers is the clear separation of the algorithmic processes from the 'grammatical' data applied in analyses. They can thus be easily adapted to non-syntactic processes (e.g. parsing based on semantic features, or morphological analysis).

There are currently two main types of parsers which are favoured: parsers based on unrestricted (general) rewriting rules and parsers based on augmented transition networks. In terms of formal (mathematical) models both types are equivalent in power to transformational grammars (II.2.3). The first type of parser has been illustrated in describing the Q-systems used in TAUM (II.7.2). Other variants are the 'powerful parser' developed by Kay and Kaplan [162] for the MIND system (III.2.1), the tree-transducer CETA in the Grenoble MT system (II.7.4), and Winograd's parser PROGRAMMAR.[121] Their advantage for MT purposes is that they always produce some analysis for a structure: they are not 'acceptors' but ''transformers' (cf. the comments above, II.7.4). The second type of parser can be illustrated by the efficient and flexible parser developed by Woods. [163-164] It consists of a series of finite state transition networks in which the arcs of one network may be labelled with the names of other networks. For example, in the 'grammar' displayed in Fig. 6, transition to state 2 requires the first word of a sentence (S) to be an 'auxil(iary verb)', while transition from 2 to 3 requires satisfactory completion of the NP network, i.e. testing for categories ‘pron’, ‘det’, etc. and reaching state 7 or state 8. The transformational capability of the parser is achieved by adding conditions to the arcs and by specifying ‘building instructions’ to be executed if the arc is followed. Thus, for example, transition of arc ‘aux’ to state 2 would specify the ‘building’ of the first elements of an interrogative (phrase) structure, which could be confirmed or rejected by the instructions associated with later arcs. Woods’ parser overcomes many of the difficulties that Petrick, the MITRE group and others encountered in attempting to devise parsers with reverse transformational rules.[161] Both types of parser provide extremely .flexible and powerful techniques of wide potential application. Variants of the first type have been used in MT (as we have seen) not only for syntactic analysis but also for morphological analysis (TAUM), semantic analysis (CETA), and stages of synthesis (TAUM and CETA). Similarly, Woods’ parser has been applied to morphological analysis (in Projet Aviation) and to semantic analysis (e.g. Simmons)[165] as well as in numerous systems to syntactic analysis. Today, therefore, we can say that parsing presents few computational problems; as ever, it is primarily the linguistic aspects which cause the major difficulties.

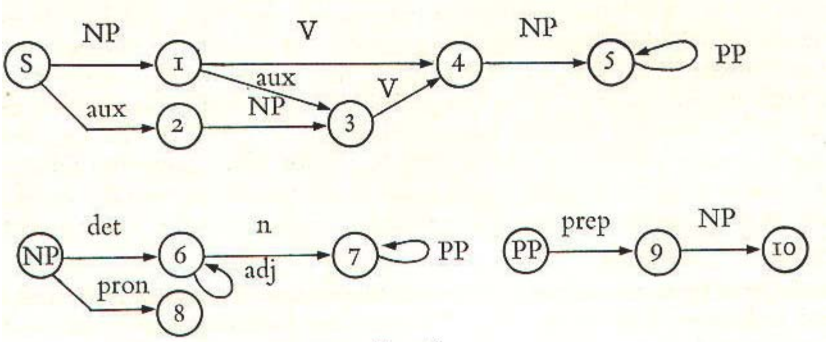

FIG. 6

6. The problems are greatest in the area of semantic analysis. Whereas in morphology and syntax there are well established and well tried techniques and general procedures, and the linguistic aspects have been thoroughly researched for many years not only by linguists but also by researchers in computational linguistics (not least, MT researchers), the position in semantics is far less clear. Systems differ considerably in the amount and type of semantic analysis which is regarded as necessary. In MT the primary emphasis is on routines of disambiguation, in order to distinguish the different senses of SL words and phrases (i.e. to resolve homography and ambiguous syntactic structures) and in order to select appropriate TL forms according to the (semantic) context. Problems of synonymy are less important; it is not always necessary for the purposes of translation to ensure that all expressions having the same meaning receive the same representation (for TL synthesis)—indeed, as the experience of CETA and the Texas group has shown (II.6. and II.6.2) there can be some disadvantages in pursuing semantic analysis this far. Consequently, most MT systems go little further (if at all) than the use of a few semantic features for deciding between alternative syntactic analyses (cf. SYSTRAN and TAUM). On the other hand, in ‘language understanding’ models in Artificial Intelligence research the analysis of texts may often need to involve the invocation of extra-linguistic ‘knowledge’ of the ‘real’ properties of objects, concepts and events and the making of

‘common sense’ inferences about their relationships to each other. We have seen (II.8.3) that there are arguments for including such procedures in MT also, although it is not clear how much use they would have in comparison with other (somewhat simpler and better understood) procedures for disambiguation, particularly when translating between languages having similarities in vocabulary and syntactic formations. By contrast, the automation of linguistic aspects of indexing and abstracting would seem to require at least the depth of semantic analysis found in the ‘interlingual’ MT systems (since problems of synonymy have crucial significance) and it is highly plausible that they would need the kind of analysis involving some ‘encyclopedic knowledge’ which is seen in the AI models. For this reason, information scientists may perhaps have more to learn from current AI research on semantics [166] than from current ‘transfer’ MT systems where semantic analysis to this depth is not felt to be always necessary.

7. The area of discourse analysis presents a similar confused picture. It is only relatively recently that linguists have studied intersentential relations and text structures (cf. Halliday,[112] van Dijk,[167] Petöfi & Rieser [166]). MT researchers have recognized the importance of text analysis, e.g. for resolving certain pronominalization problems, but very little progress has been made. More has been done by AI researchers, e.g. on intersentential semantics (cf. II.8.2) and on the use of ‘frames’ or ‘scripts’ to interpret standard discourse fragments (cf. Boden,[117] and Charniak & Wilks[169]). These developments could well have a great impact on the future of MT [170] and indeed on all automated systems involving text analysis.

8. However, much of this research on semantics and discourse is still in its early infancy. For many years to come, most system designers will prefer to stay within the limitations of what we know computers can do well and not to indulge in the more speculative areas of linguistic and Al research. Interactive systems are likely to continue to be attractive in MT as they are in information retrieval and fact retrieval; statistical methods will probably remain dominant in automatic indexing and abstracting (extracting);[171] and, for many purposes, systems with restricted syntax and/or semantics will continue to be favoured (cf. METEO, and in documentation: TITUS [172]).

9. But the ultimate question remains: what are the prospects of fully automatic translation of good quality? What has been the progress in MT in the ten years since ALPAC? There are pessimists such as Petrick[173] who see virtually no improvement in either design or performance compared to MT ten years ago. As we have seen, MT systems which have achieved operational capability have been based on ‘first generation’ designs going back to the earliest days of MT research. There is no doubt that the products of the Georgetown and LOGOS systems are not really satisfactory. The SYSTRAN Russian-English translations may be somewhat better (although there needs to be a thorough independent analysis of their quality, on the lines perhaps of Sinaiko’s evaluation of LOGOS, cf. II.4.4), but the English-French translations by SYSTRAN are not yet considered adequate for the modest requirements of the Commission of the European Communities (II.4.3). Unless ‘raw’ MT output is acceptable (as it has been apparently by scientists at Oak Ridge National Laboratory, II.4.2, and as it might be for some internal European Communities documents), the translations must be extensively revised by human editors. The costs of revision can be high: ‘raw’ Mark II output cost $2.74 per 1,000 words,[1] revised Mark II translations $30;[9] for SYSTRAN (Russian-English) the figures are $10 [1] (or $15[174]) and $40,[1] respectively. And the work of revision

can be extremely tedious. It is often 'easier for the revisor to translate a text anew than to edit the inadequate output of a mediocre translator. And since the best the computer can achieve is the level of the mediocre human translator, revising the computer product is even more difficult, time-consuming and uneconomical'.[143] It may take almost as long to post-edit a MT text as to translate from scratch.[59] The situation is only marginally improved if revision is done at a console via text-editing procedures, as is under development for SYSTRAN;[175] the retyping of the text is eliminated, but the revisor must still correct errors which no human translator would be expected to make.

The quality of the translations of existing operational MT systems is not, therefore, good enough on the whole. Terminology data banks are undoubtedly more attractive for large translation services at the present time: the quality is maintained, the efficiency of translators may be improved, and translators are not relegated to the 'drudgery' of revising MT output. But what of the future? Are the 'second generation' MT systems going to produce translations of higher quality? There is no doubt about the greater linguistic and computational sophistication of current experimental systems. Much has been learnt about the syntax and semantics required for automatic translation. The experience of the last decade provides a sound foundation for the future. There have been the disappointments of such refined systems as METALS, POLA and the earlier CETA, but the lessons have been successfully absorbed in the increased flexibility and adaptability of current research efforts. The prospect of markedly improved MT lies certainly some way in the future; of the 'second generation' systems the one nearest to operational status, TAUM, is likely to produce somewhat better translations than the 'first generation' systems but whether these will be of good enough quality to be acceptable with no human revision has yet to be seen. In general the future of MT is not without promise; there are now broad areas of agreement among many MT researchers on the overall design and strategy of MT systems, there are the beginnings of international co-operative efforts (in the 'Leibniz' framework, supported by the Commission of the European Communities),[3] and there are encouraging developments in research on the more intractable problems of semantic and text analysis. There is now a mood of quiet optimism in MT research; it is a mood which should not be lightly dismissed.

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APPENDIX

Sample extracts of machine translations (unedited)

1. Mark II (Russian-English) (from ref. 9, p. 22)

Biological experiments, conducted on different space aircraft/vehicles, astro-physical space research and flights of Soviet and American astronauts with/from sufficient convincingness showed that short-term, orbital flights lower than radiation belts of earth in the absence of heightened solar activity in radiation ratio are safe. Obtained by astronauts of dose of radiation at the expense of primary cosmic radiation and radiation of external radiation belt are so small that cannot render harmful influence on organism of person.

. . . Thus, consideration of certain from basic radiobiological problems shows that in given region still very many unsolved questions. This and intelligibly, since space radiobiology is very young division of young science—space biology. However is base to trust that jointly scientists of different specialities of various countries of world/peace radiobiological investigations in outer space will be successfully continued and expanded.

2. Georgetown system (Russian-English)

(a) Oak Ridge National Laboratory (from: ref. 41; for another example see ref. 7)

By by one from the first practical applications of logical capabilities of machines was their utilization for the translation of texts from one tongue on other. Linguistic differences represent the serious hindrance on a way for the development of cultural, social-political and scientific connections between nations. Automation of the process of a translation, the application of machines, with a help which possible to effect a translation without a knowledge of the corresponding foreign tongue, would be by an important step forward in the decision of this problem.

(b) Euratom (from: ref. 176; for other examples see ref. 43)

In contemporary conditions great value is given to automation and to the mechanization of processes of information activity; there is automatized and also the process of indexing of the documents. Quality and the labor-consumption of indexing scientific—the technical documents from informationly-prospecting languages (IPYA) descriptor type it is possible to count depending on semantic power IPYA, if one understands under semantic power IPYA: 1) quantity of dictionary composition IPYA, 2) the degree of expression of the basic relations between units IPYA and 3) the presence of grammatical means in IPYA. . . . In the right time known several methods of automatic indexing, in the number of which enters and also automatic KLASSIFITSIROVANIE. Most known from number realized on practice is the method KWIC. In the given work is studied one of the possible methods of indexing and the prospects of its automation.

3. SYSTRAN (Russian-English) (from ref. 56; for another example see ref. 174)

The question concerning the semantic interpretation of the models of a sentence is one of the most complex questions of the modeling theory of sentences. The multiple attempts at the semantic substantiation of the models of sentences, which took place of the purely structural classification of the models of the sentence of the descriptivists, as well as the serious criticism of these attempts and the calls to deny the semantic interpretation of the models of a sentence are known...

The given above arguments testify, however, not to impossibility or inexpediency of the simulation of semantics of a sentence, but only to the undeveloped quality of the questions, connected with methods and criteria for semantic simulation. It is possible with assurance to say at present that principal deficiency and principal reason for the failures of those experiments of the semantic simulation which undergo criticism in studies of recent years, is that in all appropriate cases the simulation was carried out at the level of surface structures, while syntactic semantics by its very nature must deal with deep syntax.

4. SYSTRAN (English-French) (from L. N. Rolling) /title and abstract/
[Simple device for rapid decoloration of electropherograms.
Existing methods for removal of excess Amido black dye from electropherograms of proteins (used for identification of the species of origin of meat or fish samples) are critically discussed, with special reference to time consumption and the possibility of decoloration of stained protein bands. A simple device developed for decoloration of electropherograms is described: the electropherogram is placed in a trough through which 7% acetic acid solution is circulated by means of a pump; the used acetic acid solution is decolorized by means of an activated C column before recirculation.]
Dispositif simple pour décoloration rapide des électrophérogrammes.
On examine en critique les méthodes existantes pour l'élimination du colorant excessif amido-noir des électrophérogrammes de protéines (employées pour l'identification des espèces d'origine des échantillons de viande ou de poissons), en se référant tout particulièrement à la consommation de temps et à la possibilité de la décoloration des bandes protéiques souillées. On decrit un dispositif simple développé pour la décoloration des électrophérogrammes: l'électrophérogramme est placé dans une cuvette par laquelle la solution d'acide acétique 7% est circulée au moyen d'une pompe; la solution employée d'acide acétique est décolorée au moyen d'une colonne C activée avant le recyclage.

5. National Physical Laboratory (Russian-English) (from ref. 67)
Metal melted into furnace(s) is possible to present in the form. of continuous
in
block , but then to cut out from it elementary cube of any dimension and
assembly and engrave size also
to define its resistance.
determine

6. TAUM – Projet Aviation (English-French) (from J. Dansereau)
[The utility system, supplies half the hydraulic power to operate the ailerons, rudder, and horizontal tail flight controls, and all the power to operate the landing gear, speed brakes, wheel brake system, nose wheel steering, stability augmentor system, gun gas deflectors, gun gas purging system operation and the two-position nose gear strut. The flight control system supplies the remaining half of the hydraulic power to operate the ailerons, rudder and horizontal tail flight controls . . .
In addition to periodic replacement, the flight control and utility system filters in the fuselage aft section should be replaced whenever the hydraulic systems are suspected of being contaminated.]
Le circuit de servitudes fournit la moitié de l'énergie hydraulique pour actionner les ailerons, le gouvernail de direction, et les plans de l'empennage horizontal, et toute l'énergie pour actionner le train d'atterissage, les aéro-freins, le circuit du servo-amortisseur, les déflecteurs de gaz du canon, le fonctionnement d'évacuation de gaz du canon et la contrefiche à deux positions du train avant. Le circuit de commande de vol fournit l'autre moitié de l'énergie hydraulique pour actionner les ailerons, le gouvernail de direction et les plans de l'empannage horizontal...

En plus du remplacement périodique, la commande de vol et le circuit de servitudes filtre dans la parte arrière du fuselage devrait être remplacé chaque fois que les circuits hydrauliques sont soupçonnés d'être contaminé.

7. TAUM-METEO (English-French) (from ref. 95; for other examples see refs. 96, 97)

[LOWER ST JOHN RIVER VALLEY	VALLÉE DU BAS ST JEAN
UPPER ST JOHN RIVER	HAUT ST JEAN
WIND WARNING ENDED BOTH REGIONS. SNOW AND BLOWING SNOW TONIGHT BECOMING INTERMITTENT NEAR DAWN FRIDAY. CLOUDY WITH PERIODS OF LIGHT SNOW FRIDAY. STRONG GUSTY NORTHEASTERLY WINDS TONIGHT BECOMING NORTHWESTERLY WINDS FRIDAY AFTERNOON.]	FIN DE L'AVIS DE VENT POUR LES DEUX RÉGIONS. CETTE NUIT NEIGE ET POUDRERIE DEVENANT PASSAGÈRES VENDREDI À L'AUBE. VENDREDI NUAGEUX AVEC FAIBLES CHUTES DE NEIGE PASSAGÈRES. CETTE NUIT VENTS FORTS DU NORD EST SOUFFIANT EN RAFALES DEVENANT VENTS FORTS DU NORD QUEST VENDREDI APRÈS-MIDI.

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