PRACTICAL EXPERIENCE OF MACHINE TRANSLATION
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THE EVOLUTION OF MACHINE TRANSLATION SYSTEMS

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The development of MT system design is described in four periods: the early experimental period (1946-54), the period of large-scale research on 'direct translation' systems (1956-66), the period after the ALPAC report in which the 'interlingual' and 'transfer' approaches were developed (1966-75), and the current period in which interactive systems and 'artificial intelligence' approaches have appeared together with proposals for the multilingual system EUROTRA (since 1975).

The evolution of machine translation has been influenced by many factors during a quarter century of research and development. In the early years the limitations of computer hardware and the inadequacies of programming languages were crucial elements, and they cannot be said to be trivial even now. Political and economic forces have influenced decisions about the languages to be translated from, the source languages as they are commonly called, and the languages to be translated into, the target languages. In the 1950's and 1960's concern in the United States about Soviet advances in science and technology encouraged massive funding of experimental Russian-English systems. Today the bicultural policy of Canada justifies support of English-French translation systems and the multilingual policy of the European Communities has led to sponsorship of research into a multilingual system. Other obviously important factors have been the intelligibility and readability of translations and the amount of 'post-editing' (or revising) considered necessary.

This paper will concentrate, however, on the 'internal' evolution of machine translation, describing the various strategies or 'philosophies' which have been adopted at different times in the design of systems. It will be concerned only with systems producing fully translated texts; not, therefore, with systems providing aids for translators such as automatic dictionaries and terminology data banks. Only brief descriptions of major systems can be included - for fuller and more comprehensive treatments see Bruderer [l] and Hutchins [2], where also more detailed bibliographies will be found; and for a fuller picture of the linguistic aspects of machine translation see Hutchins [3]. This account will also be restricted to systems in North America and Europe - for descriptions of research in the Soviet Union, which has evolved in much the same way, see Harper [4], Locke [5], Bar-Hillel [6], Roberts and Zarechnak [7], and other references in Hutchins [2].

1. THE FIRST PERIOD, 1946-1954: THE EARLIEST EXPERIMENTS

Although there had been proposals for translation machines in the 1930's (see Zarechnak [8] for details), the real birth of machine translation came after the war with the general availability of the digital computer. From 1946 there were some simple experiments by Booth and Richens in Britain, mainly on automatic dictionaries, but it was the memorandum sent by Warren Weaver in 1949 [9] to some 200 of his acquaintances which launched machine translation as a scientific enterprise. Weaver had been impressed by the successful use of computers in breaking enemy codes during the war and suggested that translation could also be tackled as a decoding problem. He admitted that there were difficult semantic problems but mentioned the old idea of a 'universal language' as a possible intermediary between languages. Before long there were projects underway at many American universities. The early systems were invariably attempts to produce translations by taking the words of a text one at a time, looking them up in a bilingual dictionary, finding the equivalents in the target language and printing out the result in the same sequence as in the source text. If a word happened to have two or more possible translations, they were all printed. The method was obviously unsatisfactory and it was not long before attempts were made to rearrange the sequences of words, which meant that some kind of syntactic analysis was needed.

2. THE SECOND PERIOD, 1954-1966: OPTIMISM AND DISILLUSION

In 1954 the research team at Georgetown University set up a public demonstration intended to show the technical feasibility of machine translation. With a vocabulary of just 250 Russian words, only six rules of grammar and a carefully selected sample of easy Russian sentences, the system demonstrated had no scientific value but, nevertheless, it encouraged the belief that translation by computer had been solved in principle and that the problems remaining were basically of an engineering nature [5, 8]. In the next ten years, research in the United States was supported on a massive scale - at 17 institutions to the tune of almost 20 million dollars, it has been estimated [7] - but the promised 'break-throughs' did not materialise, optimistic forecasts of commercial systems 'within five years' came to nothing, awareness of serious linguistic problems increased, and above all the translations produced were usually of very poor quality. In 1964 the National Science Foundation set up the Automatic Language Processing Advisory Committee (ALPAC) at the instigation of sponsors of machine translation. It reported in 1966 [10] that machine translation was slower, less accurate and twice as expensive as human translation and recommended no further investment. Research in the United States suffered immediate reductions and machine translation became no longer a 'respectable' scientific pursuit.

Although the report was widely condemned as biased and shortsighted - see Locke [5] and Josselson [11] - its negative conclusions are not surprising when we look at the systems in operation or under development at the time. For example, the Mark II system installed in 1964 to produce Russian-English translations for the U.S. Air Force was only a slightly improved version of one of the earliest word-by-word systems (Kay [12]). The translations required extensive 'post-editing' and were not rated highly.

The general strategy employed in systems during this period until the mid-1960's was the 'direct translation' approach (fig. 1): systems were designed in all details specifically for one pair of languages, nearly always, at this time, for Russian as the source language (SL) and English as the target language (TL). The basic assumption was that the vocabulary and syntax of SL texts should be analysed no more than necessary for the resolution of ambiguities, the identification of appropriate translations and the specification of the word order of TL texts. Syntactic analysis was designed to do little more than recognition of word classes (nouns, verbs, adjectives, etc.) in order to deal with homographs (e.g. control as verb or noun). Semantic analysis was rare, being restricted to the use of features such as 'male', 'concrete', 'liquid' etc. in cases where context could resolve ambiguities (e.g. foot cannot be 'animate' in the contexts foot of the hill and foot of the stairs.)

A typical example is the Georgetown University system, which in fact proved to be one of the most successful using the 'direct' approach [12, 13]. In 1964 Russian-English systems were delivered to the U.S. Atomic Energy Commission and to Euratom in Italy; both were in regular operation until very recently. The Georgetown research team adopted what Garvin was later [14] to call the 'brute force' method of tackling problems: a program would be 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 program of intractable complexity, with no clear separation of those parts which analysed SL texts and those parts which produced TL texts. Syntactic analysis was rudimentary; there was no notion of grammatical rule or syntactic structure, even less of a 'theory' of language or translation. In addition, any information about the grammar of English or Russian which the program used was incorporated in the very structure of the program itself. Consequently modification of the system became progressively more and more difficult [12]. In fact, both the Georgetown systems remained unchanged after their installation in 1964.

During this period linguistics had very little impact in practice on the design of machine translation systems. The tradition of Bloomfield which dominated American linguistics in the 1940's and 1950's concentrated on descriptive techniques and on problems of phonology and morphology; it had little interest in syntax or in semantics. Nevertheless, there were some researchers who developed methods of syntactic analysis based on explicit theoretical foundations. For example, Paul Garvin [14] developed his 'fulcrum' method which produced phrase structures indicating dependency relations between constituents, e.g. adjective to noun, noun to finite verb, noun to preposition (see fig. 2). The method was adopted in the Wayne State University project, which revealed its shortcomings; after ten years' work (1959-1972) a very complex program was still unable to parse Russian sentences with more than one finite verb [15] . However, by this time Chomsky had already shown [16] why such syntactic models, in particular the equivalent and more familiar phrase structure version (fig. 3), were in principle inadequate for the representation and description of the syntax of natural languages. Chomsky proposed the transformational-generative model which linked 'surface' phrase structures to 'deep' phrase structures by transformational rules.

In a survey of machine translation in 1960 Bar-Hillel [6] did not doubt that methods of syntactic analysis could be greatly improved with the help of linguistic theory, but he expressed his conviction that semantic problems could never be completely resolved and that, therefore, high-quality translation by computer was impossible in principle.

3. THE THIRD PERIOD, 1966-1975: DIVERSIFICATION OF STRATEGIES

After the ALPAC report in 1966, research in machine translation continued for some time on a much reduced scale. Its goals had become more realistic; no longer were translations expected to be stylistically perfect, the aim was readability and fidelity to the original. On the other hand, there emerged a number of linguistically more advanced systems based on 'indirect' approaches to system design and there was a welcome increase in the variety of source and target languages.

Research continued throughout on 'direct translation' systems. Two of them became fully operational systems during this period. The best known is SYSTRAN, designed initially as a Russian-English system and used in this form by the U.S. Air Force since 1970. Later it was adapted for English-French translation and this version was delivered in 1976 to the Commission of the European Communities. At various stages of development are further versions for French-English and English-Italian translation [17, 18]. SYSTRAN may be regarded as essentially a greatly improved descendant of the Georgetown 'direct translation' system. Linguistically there is little advance, but computationally the improvements are considerable. The main ones lie in the 'modularity' of its programming, allowing for the modification of any part of the processes to be undertaken without the risk of impairing overall efficiency, and in the strict separation of linguistic data and computational processes. It is therefore able to avoid many of the irresolvable complexities of the monolithic Georgetown system.

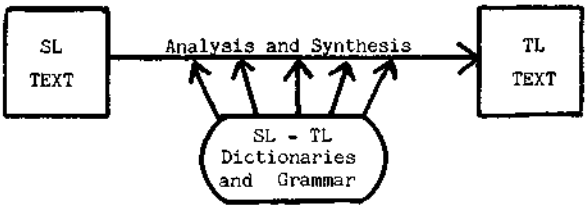


Figure 1. Direct MT system

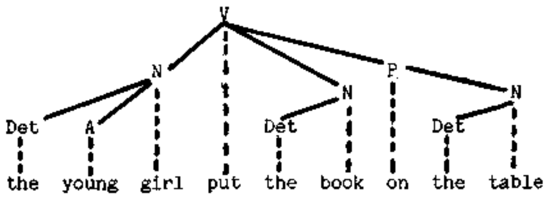


Figure 2. Dependency structure analysis

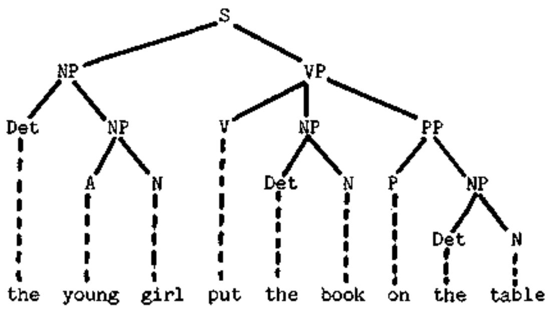


Figure 3. Phrase structure analysis

In SYSTRAN there are five basic stages in the translation process [18, 19, 20]: Input, Main dictionary lookup, Analysis, Transfer and Synthesis (fig. 4). The Input program loads the text and the dictionaries, and checks each word against a High Frequency dictionary. Next the remaining words are sorted alphabetically and searched for in the Main Stem dictionary. Both dictionaries supply grammatical information, some semantic data and potential equivalents in the target language. The Analysis program makes seven 'passes' through each sentence: i) to resolve homographs, by examining the grammatical categories of adjacent words; ii) to look for compound nouns (e.g. blast furnace) in a Limited Semantics dictionary; iii) to identify phrase groups by looking for punctuation marks, conjunctions, relative pronouns, etc.; iv) to recognise primary syntactic relations such as congruence, government and apposition; v) to identify coordinate structures within phrases, e.g. conjoined adjectives or nouns modifying a noun; vi) to identify subjects and predicates; and vii) to recognise prepositional structures. The Transfer program has

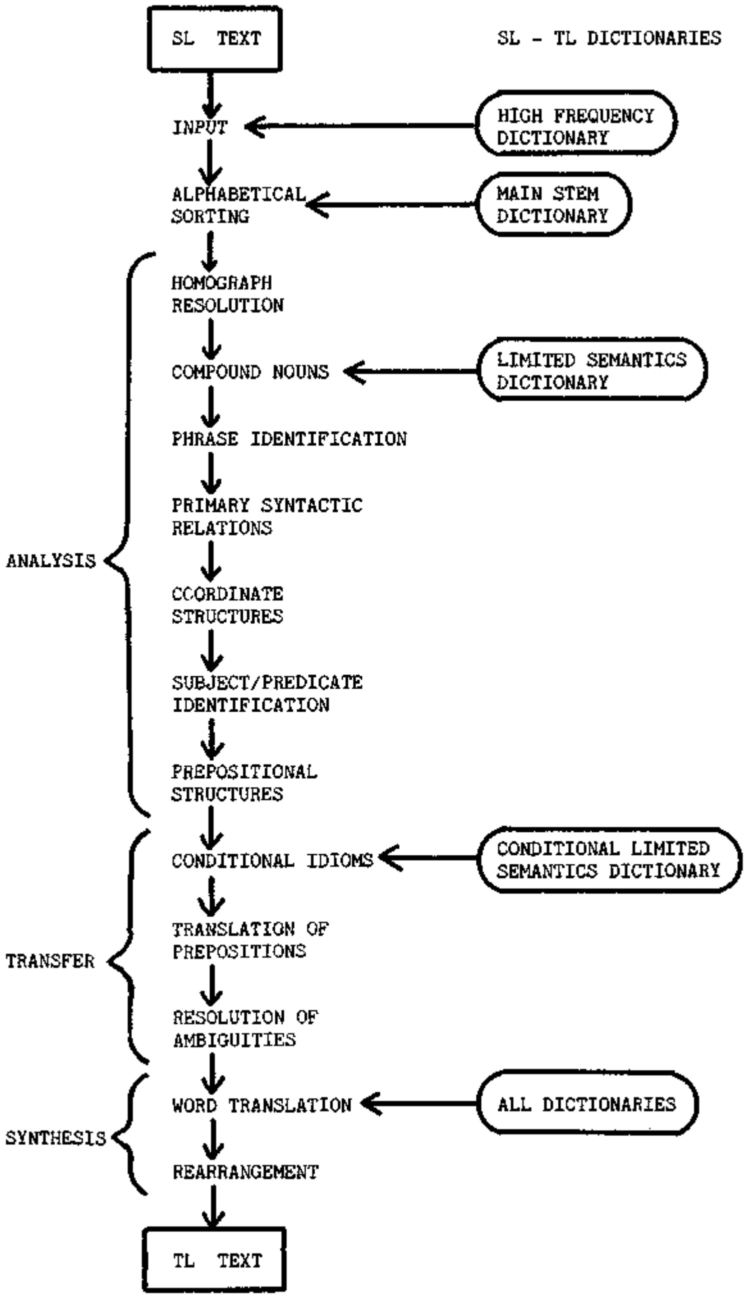


Figure 4. SYSTRAN stages of translation

three parts: i) to look for words with idiomatic translations under certain conditions, e.g. agree if in the passive is translated as French convenir, otherwise as être d'accord; ii) to translate prepositions, using the semantic information assigned to words which govern them and which are governed by them; and iii) to resolve the remaining ambiguities, generally by tests specified in the dictionaries for particular words or expressions. The last stage Synthesis produces sentences in the target language from the equivalents indicated in the dictionaries, modifying verb forms and adjective endings as necessary, and finally rearranging the word order, e.g. changing an English adjective-noun sequence to a French noun-adjective sequence.

Like its Georgetown ancestor, SYSTRAN is still basically a 'direct translation' system: programs of analysis and synthesis are designed for specific pairs of languages. However, in the course of time it has acquired features of a 'transfer' system, as we shall see below, in that the stages of Analysis, Transfer and Synthesis are clearly separated. In principle, the Analysis program of English in an English-French system can be adapted without extensive modification to serve as the Analysis program in an English-Italian system [20]. Likewise, the Synthesis programs are to some extent independent of particular source languages. Nevertheless, despite its 'modular' structure SYSTRAN remains a very complex system. The lack of explicit theoretical foundations and consistent methodology as far as linguistic processes are concerned gives many of its rules an ad hoc character. This is particularly apparent in the assignment of 'semantic features' to words and expressions in the dictionaries, as Pigott [21] has demonstrated.

The other 'direct translation' system which became operational in this period was LOGOS, a system designed to translate American aircraft manuals into Vietnamese and said to be now in the process of adaptation for translating from English into French, Spanish and German [l]. Like SYSTRAN, its programs maintain a complete separation of the Analysis and Synthesis stages and so, although the procedures themselves are designed for a specific pair of languages, the programs are in principle adaptable for other pairs. In common with nearly all modern systems there is no confusion of programming processes and linguistic data and rules. But like SYSTRAN the linguistic foundations of the system are weak and inexplicit.

By contrast, the systems which have adopted the 'indirect' approach have been greatly influenced by theories of linguistics. The possibility of translating via an intermediary 'universal' language had been suggested by Weaver in his memorandum [9], but it was not until the 1960's that linguistics could offer any models to apply. The 'interlingual' approach to machine translation attracted two research teams in the early 1960's, at the University of Texas and at Grenoble University. In 'interlingual' systems translation is a two-stage process: from the source language into the interlingua and from the interlingua into the target language (fig. 5).

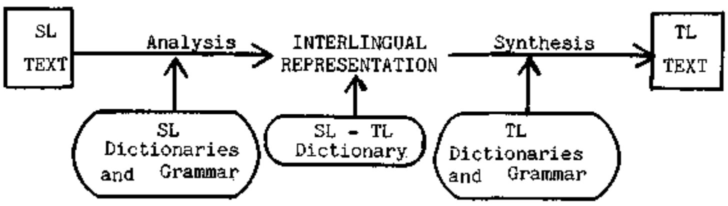
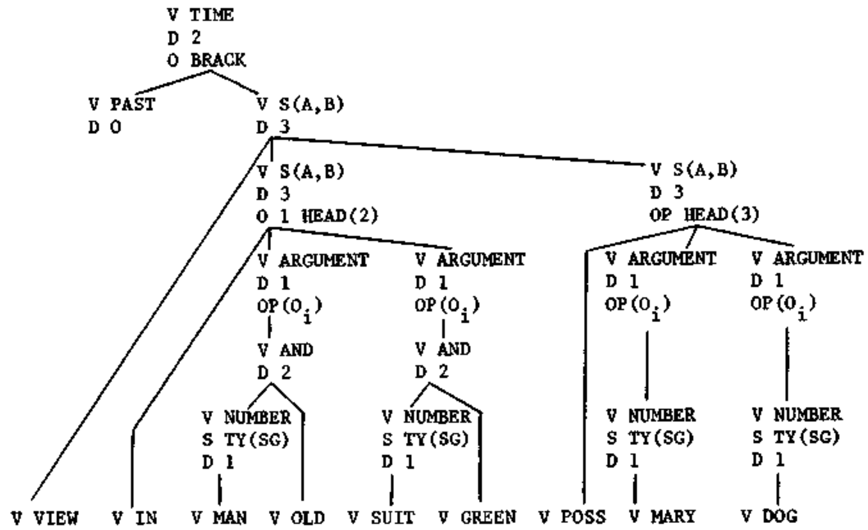


Figure 5. Interlingual MT system.

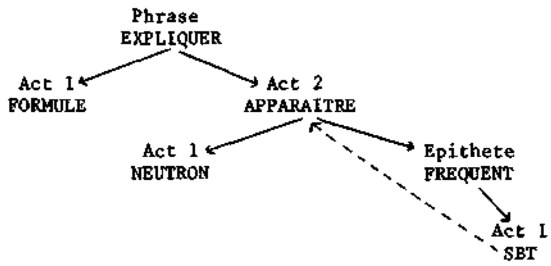
Programs of analysis and synthesis are completely independent, using separate dictionaries and grammars for the source and target languages. The systems are therefor designed so that further programs for additional languages can be incorporated without affecting the analysis and synthesis of languages already in the system.

For the structure of an interlingua there was one obvious model at the time provided by Chomsky's theory of transformational grammar in its 1965 version [22]. It was argued that while languages differ greatly in 'surface' structures they share common 'deep structure' representations and that in any one language 'surface' forms which are equivalent in meaning (e.g. paraphrases) are derived from the same 'deep' structure. Consequently, 'deep structures' may be regarded as forms of 'universal' semantic representations. The Texas team adopted this model in a German-English system (METALS) intended to include other languages later [23]. Although they soon found that the Chomskyan conception of transformational rules would not work in a computer program of syntactic analysis - as did many others in computational linguistics (cf. Grishman [24]) - they retained the basic transformational approach. The Analysis program in METALS was in three stages. On the basis of grammatical information from the source language dictionary, the program first produced several tentative 'strings' (sequences) of word-classes (nouns, verbs, etc.). The next stage examined each potential 'string' in turn and constructed for it possible phrase structure analyses; unacceptable strings were eliminated. In the third stage, semantic information from the dictionary was used to test the semantic coherence of the phrase structures (e.g. by testing for compatible semantic features of verbs and subjects). Then the acceptable phrase structures were converted into a 'deep structure' representation in which relationships between lexical items were given in terms of 'predicates' and 'arguments' (fig. 6 gives an example of a METALS representation).



An old man in a green suit looked at Mary's dog
Figure 6. METALS interlingual representation

In the Grenoble system (CETA), designed for Russian-French translation [25], the method of analysis was very similar in basic strategy. As in METALS, the first stage produced familiar 'surface' phrase structures, often more than one for a single sentence. But for 'deep structures' the Grenoble, team adopted the dependency model for representing relationships between lexical items (fig. 7). As in METALS, the representation is given in the propositional logical form of 'predicates' (verbs or adjectives) and their 'arguments' or 'actants' (nouns, noun phrases or other propositions). The linguistic model for CETA derives ultimately from Tesnière, but the team was much influenced by the Russian MT researcher Mel'chuk (for details see Hutchins [3]).



The formula explains the frequent appearance of the neutron.

Fig. 7 CETA interlingual representation

The generation of target language sentences from 'deep structure' representations was also designed on similar lines in the two systems. In the first stage of Synthesis lexical items of the source language were replaced by equivalents of the target language. Then, the resulting target language 'deep structure' was converted by a series of transformations using semantic, syntactic and morphological data provided by the target language dictionaries into 'surface' sentence forms.

From this description it should be clear that neither system created a genuine interlingua; in both cases, the interlingua was restricted to syntactic structures; no attempt was made to decompose lexical items into semantic primitives, which would be necessary for interlingual semantic representations. The conversion of source language vocabulary into the target language was in both cases made through a bilingual dictionary of base forms of words or idioms. Consequently, some semantic equivalents could not be handled if there were different 'deep structures', e.g. He ignored and He took no notice of her, in METALS. In this respect, analysis did not go far enough. In other respects, however, it was found that analysis often went too far since it destroyed information about the 'surface' forms of source language texts which could have helped the generation of translated texts, e.g. information about which noun ('argument') was the subject, whether the verb was passive, and which clauses were subordinated. Even more serious perhaps was the rigidity of the processes: failure at one stage of analysis to identify components or to eliminate an incorrect parsing affected the performance of all subsequent stages. Too often, too many phrase structures were produced for each sentence: one common source of difficulty in English is the syntactic ambiguity of prepositional phrases, which can modify almost any preceding noun or verb. For example, on the table modifies put in The girl put the book on the table, but modifies book in The girl saw the book on the table; syntactic analysis alone cannot make the correct assignment, only semantic information (about the verbs put and see) can determine which phrase structure is acceptable (cf. figs. 2 and 3). The frequency of such syntactic indeterminacies results in the production of far too many phrase structures which are later found to be semantically incoherent. The CETA team concluded that what was needed was a more sensitive parser, one which could deal straightforwardly with simple sentences but which had access to a full battery of sophisticated analytical techniques to tackle more complex sentences.

In retrospect, the 'interlingual' approach was perhaps too ambitious at that time: the more cautious 'transfer' approach was probably more realistic as well as being, as we shall see, flexible and adaptable in meeting the needs for different levels or 'depths' of syntactic and semantic analysis. In the 'transfer' approach both the source and target languages have their own particular 'deep structure' representations. Translation is thus a three-stage process (fig. 8): Analysis of texts into source language representations, Transfer into target language representations, and Synthesis of texts in the target language. The goal of analysis is to produce representations which resolve the syntactic and lexical ambiguities of the language in question, without necessarily providing unique representations for synonymous constructions and expressions. No analysis is made of elements which might have more than one correspondent in target languages (e.g. English <u>know</u> and French <u>connaître</u> and <u>savoir</u> or German <u>wissen</u> and <u>können</u>). It is the task of Transfer components to convert unambiguous source language representations into the appropriate representations for a particular target language. This can involve restructuring to allow for different conditions attached to particular lexical elements, e.g. English <u>remember</u> is not a reflexive verb but its French equivalent <u>souvenir</u> is, and for differences in syntactic rules, e.g. English allows participle clauses as subjects (<u>Making mistakes is easy</u>) but French and German only infinitive clauses. The depth of syntactic analysis in 'transfer' systems is therefore in general much 'shallower' than more ambitious 'interlingual' systems which would attempt to formulate universal representations. Semantic analysis is also less ambitious, restricted primarily to resolution of homographs and tests of the semantic coherence of potential syntactic analyses.

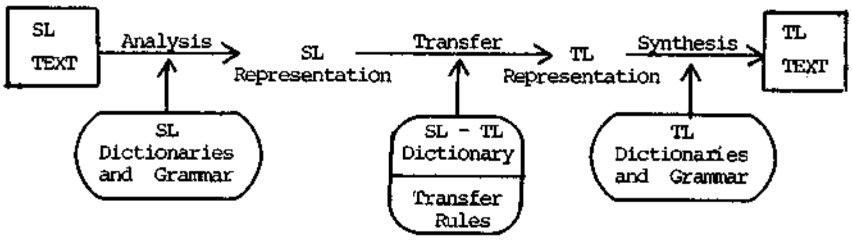


Figure 8. Transfer MT system

The best known example of a 'transfer' system is the TAUM project at the University of Montreal, an English-French system supported by the Canadian government since the mid-1960's and now close to operational installation for the Canadian Air Force as TAUM-Aviation [26, 27]. The basic stages of TAUM are given in fig. 9. The first Analysis stage is Morphological analysis. This identifies English suffixes (TRIED → TRI + ED, INTERVIEWING → INTERVIEW + ING) and prefixes (UNDERSTOOD → UNDER + STOOD) and constructs possible base forms (TRI → TRY). These are then searched for in Dictionary lookup, which assigns grammatical information (TRY → ZV(TRY), INTERVIEW → N(INTERVIEW) or ZV(INTERVIEW)). The next stage, Syntactic analysis, recognises first noun phrases and complex verb forms and then constructs phrase structures in 'canonical forms'; for example, verbs are put before subject and object nouns (i.e. as predicates are put before arguments in CETA) and passives are made active. Unlike the 'interlingual' systems, however, information about the original surface form is retained. An example of a TAUM analysis [26] is shown in fig. 10. The top line gives the final 'deep' representation, the

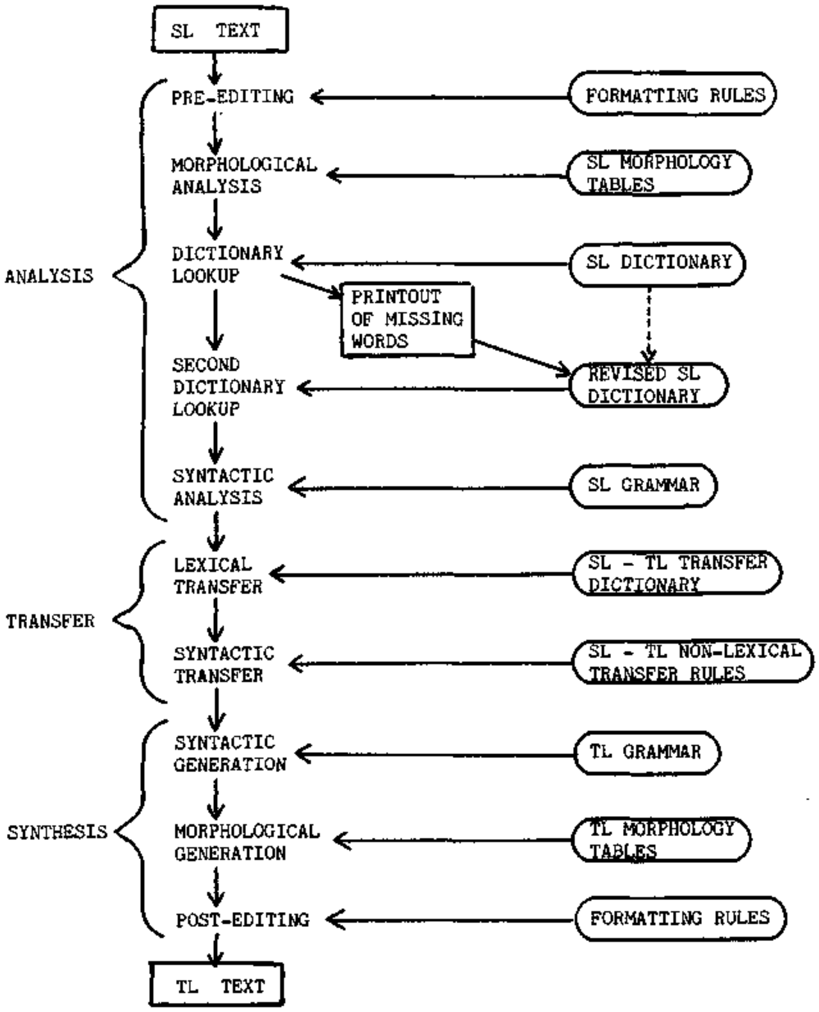


Figure 9. TAUM stages of translation

lines below giving intermediary stages of analysis from the original sentence on the bottom line. This shows inversion of article and noun in noun phrase formation: DET(ART(DEF)) + N(COMMITTEE) $\rightarrow$ NP(N(COMMITTEE), DET(ART(DEF))), the testing of interview as noun (N) or verb (ZV), the inversion of the verb and its suffix -ing in order to identify the durative tense BE + -ING, and the placing of the verb information before the noun phrase (top line). The transfer stage operates in two parts as we have already indicated: first the conversion of lexical elements from English forms to French and restructuring the analysis representation as necessary, and then the transformation of the non-lexical structure into forms acceptable in French synthesis. The Synthesis program, also in two basic stages,

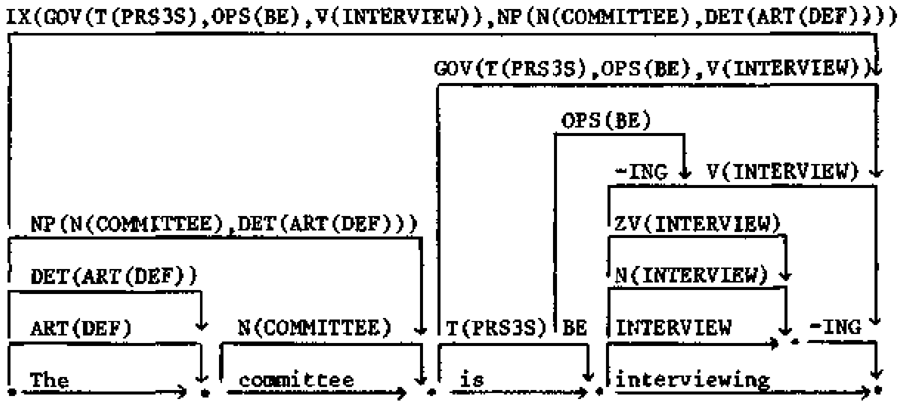


Figure 10. Syntactic analysis in TAUM

generates first an appropriate syntactic structure (given the constraints on lexical formations indicated by the French dictionary) and then produces the correct 'surface' morphological forms of verbs, adjectives and articles.

Another example of a 'transfer' system is the Russian-German project at the University of Saarbrücken which began in 1967. The SUSY stages of analysis, transfer and synthesis [28, 29] have basic similarities to those of TAUM, with 'deep' representations also going no further initially than resolving ambiguities within the source language itself. However, problems with pronouns, complex verb groups and elision of nouns and verbs in Russian 'surface' forms demonstrated the necessity for 'deeper' analyses. Since about 1976, the transfer representations in SUSY have been more abstract, approximating more closely an 'interlingual' type of representation. Changes have also taken place in the TAUM representations in recent years. Experience on the Aviation project since 1977 has led to the introduction of partial semantic analysis in order to deal with the extremely complex noun phrases encountered in English technical manuals; thus, for example, the analysis of <u>left engine fuel pump suction line</u> would show (fig. 11) functional (FUNCTION), locative (LOC), possessive (HAS) and object (OBJ) relations derived from semantic features supplied by the English dictionary [27].

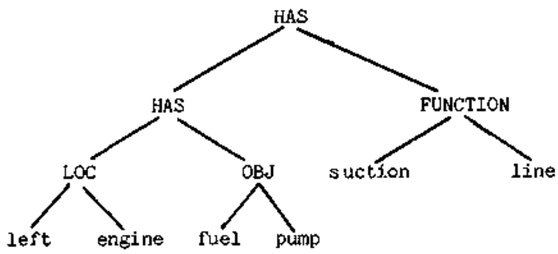


Figure 11. Semantic analysis in TAUM

4. THE CURRENT PERIOD, SINCE 1975: RENEWAL OF OPTIMISM

These changes in TAUM and SUSY during the last five years or so have coincided with developments elsewhere which blur the previous clear typology of systems into 'direct', 'interlingual' and 'transfer'. At Grenoble there has been a fundamental rethinking of MT system design prompted by changes in computer facilities in 1971. The CETA system revealed disadvantages of reducing texts to semantic representations which eliminated useful 'surface' information. The new system GETA [30] is basically a 'transfer' system with stages of analysis, transfer and synthesis much as in TAUM and SUSY, but it retains the general form and 'depth' of the dependency-model representations of the previous Grenoble system. Although the ideal of interlingual representations is no longer the goal, it is intended that the 'deep structure' analyses should be of sufficient abstractness to permit transfer processes to be as straightforward as possible. These developments in GETA, TAUM and SUSY indicate there is now considerable agreement on the basic strategy, i.e. a 'transfer' system with some semantic analysis and some interlingual features in order to simplify transfer components. At the same time, even the 'direct translation' system SYSTRAN has acquired features of a 'transfer' approach in the separation of analysis, transfer and synthesis stages (cf. outlines of the TAUM and SYSTRAN systems in figs. 4 and 9) and in the consequently easier adaptability of SYSTRAN to new language pairs [20].

However, this apparent convergence of approaches in recent years is confined to the design of fully automatic systems dealing with uncontrolled text input and not involving any human intervention during the translation process itself. (The need for at least some human revision of translated texts from operational systems like SYSTRAN is a subsidiary process lying strictly outside the MT systems as such.) In the last five years or so there have appeared a number of 'limited language' systems and 'interactive' systems.

One example of a system with limited syntax and semantics is METEO, developed by members of the Montreal team and using experience of TAUM, which has been translating English weather forecasts into French since 1976 [31]. Another is TITUS, which translates abstracts in the field of textile technology from and into English, French, German and Spanish. Abstracts are written in a standard regulated format, called the 'canonical documentation language', and translated via a simple code interlingua [32]. Such 'limited' systems are, of course, the practical application of what is common knowledge in the field, namely that systems can be more successful if the semantic range and syntactic complexity of texts to be translated can be specified. It is probably unrealistic to expect any MT system to deal with texts in all subjects; there are good practical reasons for providing topical glossaries, as in SYSTRAN, which can be selected as needed. There are possibilities that the selection of glossaries might be automated - there are pointers in the research at Saarbrücken on statistical techniques as aids in homograph resolution [28] and in research on 'sublanguages' by Kittredge [33] and others - but it could be argued that this is more easily and cheaply done by someone knowledgeable in the field concerned.

The attractiveness of 'interactive' machine translation lies precisely in making the best use of both human translators and computers in fruitful collaboration. There are good arguments, practical and economic, for using the computer only for what it can do well, accessing large dictionaries, making morphological analyses and producing simple rough parsings, and for using human skills in the more complex processes of semantic analysis, resolving ambiguities and selecting the appropriate expression when there is a choice of possible translations. Interactive systems offer the realistic possibilities of high-quality translation - a prospect which is still distant in fully automatic systems. The best known interactive system is CULT, which has been producing English translations of Chinese mathematical texts since 1975. Also well known is the system at Brigham Young University (now known as ALPS) for translating English texts simultaneously into French, German, Spanish, Portuguese and eventually many other languages. And most recently of all, there is the appearance of the Weidner system. The first experimental system was MIND in the early 1970's [34]; this was based on the 'transfer' approach, with the computer interrogating a human consultant during the analysis stage about problems with homographs or about ambiguities of syntax, e.g. the problem of prepositional phrases mentioned earlier. CULT is basically a 'direct translation' system [35], involving human participation during analysis for the resolution of homographs and syntactic ambiguities and during synthesis for the insertion of English articles and the determination of verb tenses and moods. The Brigham Young system is 'interlingual' in approach [36], with close human interaction during the analyses of English text into 'deep structure' representations (in 'junction grammar', a model with some affinities to Chomskyan grammars), but with as little as possible during synthesis processes.

The Brigham Young system is regarded by its designers as a transitional system using human skills to overcome the problems of systems like GETA and TAUM until research in artificial intelligence has provided automatic methods. Researchers in machine translation have taken an increasing interest in the possibilities of artificial intelligence, particularly during the last five years or so. In 1960 Bar-Hillel [6] believed he had demonstrated the impossibility of high-quality machine translation when he argued that many semantic problems could be resolved only if computers have access to large encyclopaedias of general knowledge. (His particular example was the homograph <u>pen</u> in the simple sentence <u>The box is in the pen</u>. We know it refers to a container here and not to a writing instrument, but only because we know the size and form of the objects.) However, it is precisely problems of text understanding involving knowledge structures which have been the subject of much research in artificial intelligence (see Boden [37] for references). As yet, little attention has been paid directly to problems of translation, despite arguments that machine translation provides an objective testbed for AI theories (Wilks [38]).

One of the first to experiment with an AI approach to machine translation was Yorick Wilks [38] who used a method of semantic analysis directly on English texts and thus attempted to bypass problems of syntactic analysis. He also introduced the notion of 'preference semantics': dictionary entries did not stipulate obligatory features but only indicated preferred ones (e.g. <u>drink</u> did not insist that subject nouns always be 'animate', it would allow abnormal and metaphoric usages such as <u>cars drink petrol</u>). Wilks made use of 'commonsense inferences' to link pronouns and their antecedent nouns. For example, in <u>The soldiers fired at the women and we saw several of them fall</u> the linking of the pronoun <u>them</u> to <u>women</u> rather than to <u>soldiers</u> is made by a 'commonsense rule' stating that animate objects are likely to fall if they are hit. A more advanced mechanism for making inferences is embodied in the notion of 'scripts'. At Yale University, Carbonell has recently [39] devised a rudimentary 'interlingual' machine translation system based on the story-understanding model of Roger Schank and associates. A simple English text, the report of an accident, is analysed into a language-independent conceptual representation by referring to 'scripts' about what happens in car accidents, ambulances and hospitals, etc. in order to 'understand' the events described. The resulting representation is the basis for generating texts in Russian and Spanish using methods rather similar to those in the Transfer and Synthesis programs of TAUM, SUSY and GETA. Finally, mention should be made of the research at Heidelberg on the SALAT system of machine translation [40], a 'transfer' system of the GETA type, which is experimenting with 'deduction' processes to resolve problems with pronouns, to decide between alternative analyses and to determine the correct translation of lexical elements.

There are naturally many reservations about the feasibility of using methods of artificial intelligence in machine translation systems; the complexities of knowledge-based procedures in a full-scale system can only be guessed at. It is apparent that any modern system must have sufficient flexibility to experiment with different methods of analysis, including AI methods, to make realistic comparisons of their effectiveness and to incorporate new approaches without detrimental effects on any existing successful procedures.

This kind of flexibility in both computational and linguistic processes is to be an integral feature of the multilingual EUROTRA system. The project for an advanced machine translation system to deal with all languages of the European Communities has been established and funded by the Commission after widespread consultations. The project has been set up as a cooperative effort, involving at present the expertise of researchers in six European countries. In general design, EUROTRA represents the culmination of recent thinking in the field [17, 41]. It will be basically a 'transfer' system incorporating the latest advances in semantics and artificial intelligence, with the transfer components kept as simple as possible. As in all modern systems it will maintain strict separation of algorithmic processes and linguistic data, it will be highly 'modular' in structure enabling linguists and programmers to develop individual parts independently and to experiment with new methods, it will be hospitable to data created on other systems (e.g. the dictionaries and topical glossaries of SYSTRAN [17]) and it is intended to be easily adaptable to other computer facilities and networks, in particular to future computer systems. EUROTRA is being designed from the beginning as a multilingual system which will be able to produce translations simultaneously in many languages. It is an ambitious project involving considerable complexities in organisation, collaboration and coordination [41], but it is not unrealistic and it inaugurates a genuine step forward in the evolution of machine translation.

5. TAILPIECE: SUMMARY OF EVOLUTIONARY STAGES

This description of the evolution of MT systems has been essentially chronological. Many writers refer to 'generations' of machine translation, usually in order to promote their own system as an example of the latest generation. For some the first generation is represented by the simple word-by-word systems, the second generation added syntactic analysis and the third incorporated semantics of some kind [5, 20]. For others the first generation is represented by the 'direct translation' systems, the second by the 'indirect' systems and the third by systems based on artificial intelligence approaches [2, 42]. As a result SYSTRAN, for example, is sometimes classified as a 'third generation' system because it incorporates some semantic analysis, and sometimes as a 'first generation' system because it adopts the 'direct translation' approach. In addition, there is no place for the 'interactive' systems unless we regard them as 'transitional' stages between generations, as does Melby [38] with the Brigham Young system, or as 'hybrid' forms - i.e. CULT would belong to the first generation as a 'direct' system and Brigham Young to the second as an 'interlingual' system.

It appears, however, that research on machine translation falls into fairly distinct periods. (Information on when projects and systems started and finished, as well as other basic data, will be found in the table attached to this paper.) The first period extended from the end of the Second World War until the Georgetown public demonstration of machine translation in 1954. It was a period of mainly small-scale experiments using word-by-word methods. The second period, which lasted until the ALPAC report in 1966, was characterised by vast U.S. governmental and military support of Russian-English systems based on the 'direct translation' approach. In the third period, when support was reduced and machine translation suffered widespread public neglect, research concentrated on 'interlingual' and 'transfer' approaches while, at the same time, 'direct' systems were further developed and became operational in a number of locations. The fourth period began about 1975 with the interest of the Commission of the European Communities in the possibilities of machine translation, marked by the trials of SYSTRAN and the sponsorship of the international EUROTRA project. At about the same time, 'interactive' systems came to public notice and the potential application of AI research began to be discussed. Furthermore, since 1976 there have been a number of conferences [43, 44, 45] indicating a quickening of general interest in the future of machine translation. This fourth period may well prove to be the most exciting and promising of them all.

REFERENCES

[l] Bruderer, H.E. Handbuch der maschinellen und maschinenunterstützten Sprachübersetzung. München, Vlg. Dokumentation, 1978.
[2] Hutchins, W.J. 'Machine translation and machine-aided translation' Journal of Documentation 34 (1978), 119-159
[3] Hutchins, W.J. 'Linguistic models in machine translation' UEA Papers in Linguistics 9 (1979), 29-52
[4] Harper, K.E. 'Machine translation' Current Trends in Linguistics, vol.1: Soviet and East European Linguistics (The Hague, Mouton, 1963), 133-142
[5] Locke, W.N. 'Machine translation' Encyclopedia of Library and Information Science, vol. 16 (New York, Dekker, 1975), 414-444
[6] Bar-Hillel, Y. 'The present status of automatic translation of languages' Advances in Computers 1 (1960), 91-163
[7] Roberts, A.H. and Zarechnak, M. 'Mechanical translation' Current Trends in Linguistics, vol. 12: Linguistics and adjacent arts and sciences, pt.4 (The Hague, Mouton, 1974), 2825-2868
[8] Zarechnak, M. 'The history of machine translation', in: Henisz-Dostert, B. et al. Machine translation (The Hague, Mouton, 1979), 3-87
[9] Weaver, W. 'Translation', in: Locke, W.N. and Booth, A.D. (eds.) Machine Translation of languages (New York, Wiley, 1955), 15-23
[10] Languages and machines: computers in translation and linguistics. A report by the Automatic Language Processing Advisory Committee, Division of Behavioral Sciences, National Academy of Sciences, National Research Council. Washington, D.C., 1966
[11] Josselson, H.H. 'Automatic translation of languages since 1960: a linguist's view' Advances in Computers 11 (1971), 1-58
[12] Kay, M. 'Automatic translation of natural languages' Daedalus 102 (1973), 217-229
[13] Macdonald, R.R. Georgetown University machine translation research project. General report 1952-1963. Washington, D.C., 1963
[14] Garvin, P.L. On machine translation: selected papers. The Hague, Mouton, 1972
[15] Josselson, H.H. et al. Fourteenth (Final)-annual report on research in computer-aided translation Russian-English, Wayne State University, April 1972.
[16] Chomsky, N. Syntactic structures. The Hague, Mouton, 1957
[17] Rolling, L.N. 'The second birth of machine translation' Paper given at 7th Cranfield International Conference on Mechanised Information Storage and Retrieval Systems, July 1979 [18]
[l8] Van Slype, G. and Pigott, I. 'Description du système de traduction automatique SYSTRAN de la Commission des Communautés Européennes' Documentaliste 16 (1979), 150-159
[19] Toma, P. 'SYSTRAN as a multilingual machine translation system', in: ref [44] 569-581
[20] Toma, P. 'SYSTRAN: ein maschinelles Übersetzungssystem der 3. Generation' Sprache und Datenverarbeitung 1 (1977), 38-46
[21] Pigott, I.M. 'Theoretical options and practical limitations of using semantics to solve problems of natural language analysis and machine translation', in: MacCafferty, M. and Gray, K. (eds.) The analysis of meaning: Informatics 5 (London, Aslib, 1979), 239-268
[22] Chomsky, N. Aspects of the theory of syntax. Cambridge, Mass., M.I.T.Pr., 1965
[23] Lehmann, W.P. and Stachowitz, R. Development of German-English machine translation system. Final (annual) report(s). Austin, Univ. Texas, Linguistics Research Center, 1972(-1975)
[24] Grishman, R. 'A survey of syntactic analysis procedures for natural language' American Journal of Computational Linguistics, microfiche 47 (1976)
[25] Vauquois, B. La traduction automatique à Grenoble. Paris, Dunod, 1975
[26] TAUM 73. Project de Traduction Automatique de l'Université de Montréal. Rapport, Jan. 1973 (microfiche)

[27] Isabelle, P. et al. 'TAUM-Aviation: description d'un système de traduction automatisée des manuels d'entretien en aéronautique'. Paper given at COLING 1978
[28] Maas, H.D. 'The Saarbrücken automatic translation system (SUSY)', in: ref. [44], 585-92
[29] Ergebnisse der Satzanalyse und transformationelle Synthese im Saarbrücker Übersetzungssystem SUSY. Saarbrücken, Univ. d. Saarlandes, 1977
[30] Boitet, C. 'Where does GETA stand at the beginning of 1977?', in ref. [44], vol. 2, 88-120
[31] Chandioux, J. 'METEO: un système opérationnel pour la traduction automatique des bulletins metéorologiques destinés au grand public', META 21 (1976), 127-133
[32] Zingel, H.J. 'Experiences with TITUS II' International Classification 5 (1978), 33-37
[33] Kittredge, R. 'Textual cohesion within sublanguages: implications for automatic analysis and synthesis'. Paper given at COLING 1978.
[34] Kay, M. 'The MIND system', in: Rustin, R. (ed.) Natural language processing (New York, Algorithmics Pr., 1973), 155-188
[35] Loh, S.C. et al. 'Machine translation of Chinese mathematical articles' ALLC Bulletin 6 (1978), 111-121
[36] Melby, A.K. 'Design and implementation of a computer-assisted translation system' British Computer Society Natural Language Translation Specialist Group, Newsletter 9 (1980), 7-19
[37] Boden, M. Artificial intelligence and natural man. Hassocks, Harvester Pr., 1977
[38] Wilks, Y. 'An intelligent analyzer and understander of English' Communications of the ACM 18 (1975), 264-274
[39] Carbonell, J. et al. Knowledge-based machine translation. Research report, Yale University, 1978
[40] Hauenschild, C. et al. 'SALAT: machine translation via semantic representation', in: Bauerle, R. et al (eds.) Semantics from different points of view (Berlin, Springer, 1979), 324-352
[4l] King, M. 'EUROTRA: a European system for machine translation' (mimeo , 1979)
[42] Vauquois, B. 'Automatic translation: a survey of different approaches' in: Statistical methods in linguistics (Stockholm, 1976), 127-135
[43] FBIS Seminar on Machine Translation. American Journal of Computational Linguistics, microfiche 46 (1976)
[44] Overcoming the language barrier. Third European Congress on Information Systems and Networks, Luxembourg, May 1977. München, Vlg. Dokumentation, 1977-78. 2 vols.
[45] Translating and the computer. Proceedings of a seminar, London, November 1978; ed. B.M. Snell. Amsterdam, North-Holland Publ. Co., 1979

TABLE OF MACHINE TRANSLATION PROJECTS AND SYSTEMS[1]

NAME	LOCATION	PROJECT LEADER(S)	LANGUAGES	STRATEGY[2]	RESEARCH DATES	EXPERIMENTAL SYSTEM	OPERATIONAL SYSTEM	USER(S)
	Washington U.	Reifler	G-E;R-E	direct	1949-62			
	Mass. Inst. Tech.	Bar-Hillel Yngve	R-E	direct	1951-65			
GAT(-SLC)	Georgetown U.	Dostert	R-E	direct	1952-63	1960	1964	AEC (1964-), EURATOM (1964-76)
	Harvard U.	Oettinger	R-E	direct	1953-67?			
	National Bureau of Standards	Rhodes	R-E	direct	1958-64			
	Rand Corp.	Hays, Harper	R-E	direct	1958-67?			
	IBM Yorktown Heights		R-E	direct	1958?-66		1964 (=Mark II)	USAF (1964-70)
	Wayne State U.	Josselson	R-E	direct	1959-72			
METALS	Texas U.	Lehmann	G-E	interlingual	1961-?	1967		
CETA	Grenoble U.	Vauquois	R-F	interlingual	1961-71	1967		
SYSTRAN	Latsec Corp. (1968-)	Toma	R-E	direct	1964-	1967	1970	USAF (1970-), NASA (1974-), EURATOM (1976-)[3]
			E-F	direct		1975		CEC (1976-)
			F-E	direct		1978		CEC (1978-)
LOGOS	Logos Corp. (1970-)	Scott	E-Viet	direct	1965-?	1970	1971	USAF (1971-73)
			E-F	direct	1975?-			
TAUM	Montreal U.	Kittredge	E-F	transfer	1966-	1971		
TAUM-Aviation	Montreal U.		E-F	transfer		1976		Canadian AF
TAUM-METEO	Montreal U.	Chandioux	E-F	limited			1976	Bureau des Traducteurs (1976-)
POLA	California U.	Wang	Ch-E	transfer	1967-75			
SUSY	Saarbrücken U.		R-G;(E-F, E-G,Esp)	transfer	1967-	1974		
CULT	Hong Kong Ch.U.	Loh	Ch-E	interactive (direct)	1969-		1975	Acta Mathematica Sinaica (1975-)
GETA	Grenoble U.	Boitet, Vauquois	R-F	transfer	1971-	1976		
	Brigham Young U.	Lytle	E-mult	interactive (interlingual)	1971-	1975	1980	
TITUS II	Inst. Textile de France	Ducrot	E,F,G,S	limited (interlingual)	1972-		1974	various Europeantextile doc. centres (1974-)
Weidner	Weidner Communications Inc.		E,F,G,P,S, Arabic	interactive (direct)	1978-		1979	
SALAT	Heidelberg U.		E,F,G,R	transfer	1978?-			
EUROTRA	(European Comm.)		mult	transfer	1979-			CEC

Abbreviations: E (English), F (French), G (German), R (Russian), S (Spanish), P (Portuguese), Ch (Chinese), Viet (Vietnamese), Esp (Esperanto) mult (multilingual)

Notes: 1. Projects and systems in the USSR and East Europe have been omitted. 2. See text for details. 3. A number of other users have been reported more recently.