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MACHINE TRANSLATION: HISTORY AND GENERAL PRINCIPLES

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The translation of natural languages by machine, first dreamt of in the seventeenth century, has become a reality in the late twentieth. Computer programs are producing translations - not perfect translations, for that is an ideal to which no human translator can aspire; nor translations of literary texts, for the subtleties and nuances of poetry are beyond computational analysis; but translations of technical manuals, scientific documents, commercial prospectuses, administrative memoranda, medical reports. Machine translation is not primarily an area of abstract intellectual inquiry but the application of computer and language sciences to the development of systems answering practical needs. After an outline of basic features and general methods, the history of machine translation is traced from the pioneers and early systems of the 1950s and 1960s, the impact of the ALPAC report in the mid-1960s, the revival in the 1970s, commercial and operational systems of the 1980s, and research during the 1980s.

1. Basic features and terminology

The term **machine translation** (MT) refers to computerized systems responsible for the production of translations with or without human assistance. It excludes computer-based translation tools which support translators by providing access to on-line dictionaries, remote terminology databanks, transmission and reception of texts, etc. The boundaries between machine-aided human translation (MAHT) and human-aided machine translation (HAMT) are often uncertain and the term computer-aided translation (CAT) can cover both, but the central core of MT itself is the automation of the full translation process.

Although the ideal goal of MT systems may be to produce high-quality translation, in practice the output is revised ('**post-edited**'). It should be noted that in this respect MT does not differ from the output of most human translators which is normally revised by a second translator before dissemination. However, the types of errors produced by MT systems do differ from those of human translators (incorrect prepositions, articles, pronouns, verb tenses, etc.). Post-editing is the norm, but in certain circumstances MT output may be unedited or only lightly revised, e.g. if it is intended only for specialists familiar with the text subject. Output might also serve as a rough draft for a human translator, i.e. as a 'pre-translation'.

The translation quality of MT systems may be improved either, most obviously, by developing more sophisticated methods or by imposing certain restrictions on the input. The system may be designed, for example, to deal with texts limited to the '**sublanguage**' (vocabulary and grammar) of a particular subject field (e.g. biochemistry) and/or document type (e.g. patents). Alternatively, input texts may be written in a '**controlled language**', which restricts the range of vocabulary, avoids homonymy and polysemy and complex sentence structures. A third option is to require input texts to be marked ('**pre-edited**') with indicators of prefixes, suffixes, word divisions, phrase and clause boundaries, or of different grammatical categories (e.g. the noun *co'nvict* and its homonymous verb *convi'ct*). Finally, the system itself may refer problems of ambiguity and selection to human operators (usually translators) for resolution during the processes of translation itself, i.e. in an 'interactive' mode.

Systems are designed either for two particular languages ('**bilingual**' systems) or for more than a single pair of languages ('**multilingual**' systems). Bilingual systems may be designed to operate either in only one direction ('uni-directional'), e.g. from Japanese into English, or in both directions ('bi-directional'). Multilingual systems are usually intended to be bi-directional; most bilingual systems are uni-directional. In some cases MT systems appear in versions for a number of languages, where each version is a bilingual system but which together do not constitute a true multilingual system (even if there are close similarities in the versions). By contrast, true multilingual systems are designed to provide translations from any one language into any one or more other languages within the same configuration.

In overall system design, there have been three basic types. The first (and historically oldest) type is generally referred to as the '**direct translation**' approach: the MT system is designed in all details specifically for one 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 the **source language (SL)** text to the **target language (TL)** text; the basic assumption is that the vocabulary and syntax of SL texts need not be analysed any more than strictly necessary for the resolution of ambiguities, the correct identification of TL expressions and the specification of TL word order; in other words, SL analysis is oriented specifically to one particular TL. Typically, systems consist of a large bilingual dictionary and a single monolithic program for analysing and generating texts; such 'direct translation' systems are necessarily bilingual and uni-directional.

The second basic design strategy is the '**interlingual**' approach, which assumes that it is possible to convert SL texts into semantico-syntactic representations common to more than one language. From such interlingual representations texts are generated into other languages. Translation is thus in two stages: from SL to the interlingua (IL) and from the IL to the TL. Procedures for SL analysis are intended to be SL-specific and not oriented to any particular TL; likewise programs for TL synthesis are TL-specific and not designed for input from particular SLs. A common argument for the interlingua approach is economy of effort in a multilingual environment. Translation from and into n languages requires n(n-1) bilingual 'direct translation' systems; but with translation via an interlingua just 2n 'interlingual' programs are needed. With more than 3 languages the interlingua approach is claimed to be more 'economic'. On the other hand, the complexity of the interlingua itself is greatly increased. Interlinguas may be based on a 'logical' artificial language, on a 'natural' auxiliary language such as Esperanto, a set of semantic primitives common to all languages, or a 'universal' vocabulary.

The third basic strategy is the less ambitious '**transfer**' approach. Rather than operating in two stages through a single interlingual representation, there are three stages involving underlying (abstract) representations for both SL and TL texts. The first stage converts SL texts into abstract SL-oriented representations; the second stage converts these into equivalent TL-oriented representations; and the third generates the final TL texts. Whereas the interlingua approach necessarily requires complete resolution of all ambiguities in the SL text so that translation into any other language is possible, in the transfer approach only those ambiguities inherent in the language in question are tackled; problems of lexical differences between languages are dealt with in the second stage (transfer proper). Transfer systems consist typically of three types of dictionaries (SL dictionary/ies containing detailed morphological, grammatical and semantic information, similar TL dictionary/ies, and a bilingual 'transfer' dictionary relating base SL forms and base TL forms) and various grammars (for SL analysis, TL synthesis and for transformation of SL structures into TL forms).

Within the stages of analysis and synthesis (or generation), most MT systems exhibit clearly separated components involving different levels of linguistic description: morphology, syntax, semantics. Hence, **analysis** may be divided into morphological analysis (identification of word endings, word compounds), syntactic analysis (identification of phrase structures, dependency, subordination, etc.), semantic analysis (resolution of lexical and structural ambiguities); **synthesis** may likewise pass through semantic synthesis (selection of appropriate compatible lexical and structural forms), syntactic synthesis (generation of required phrase and sentence structures), and morphological synthesis (generation of correct word forms). In transfer systems, the **transfer** component may also have separate programs dealing with lexical transfer (selection of vocabulary equivalents) and with structural transfer (transformation into TL-appropriate structures). In some earlier forms of transfer systems analysis did not involve a semantic stage, transfer was restricted to the conversion of syntactic structures, i.e. 'syntactic transfer'.

In many older systems, particularly those of the 'direct translation' type the components of analysis, transfer and synthesis were not always clearly separated. Some of them also mixed data (dictionary and grammar) and processing rules and routines. Later systems have exhibited various degrees of **modularity**, so that system components, data and programs can be adapted and changed without damage to overall system efficiency. A further stage in some recent systems is the **reversibility** of analysis and synthesis components, i.e. the data and transformations used in the analysis of a particular language are applied in reverse when generating texts in that language.

MT research and MT systems display an eclecticism of methods and linguistic frameworks which sometimes disturbs linguistic purists. MT is also criticized for failure to incorporate the latest advances of theoretical research. However, MT must confront the full range of language phenomena, complexities of terminology and structure, misspellings, 'ungrammatical' sentences, neologisms, detailed differences between languages - aspects which are not the concern of abstract linguistic theory. The construction of a MT system is a long-term project, it must use methods which are known to work reliably; it is essentially an 'engineering' task, applying techniques which are well known and well tested.

2. General problems and methods

The major problems of all MT systems concern the resolution of lexical and structural ambiguities, both within languages (monolingual ambiguity) and between languages (bilingual ambiguity).

Any monolingual ambiguity is a potential difficulty in translation since there will be more than one possible equivalent. Homographs and polysemes (English *cry*, French *voler*) must be resolved before translation (French *pleurer* or *crier*, English *fly* or *steal*); ambiguities of grammatical category (English *light* as noun, adjective or verb, face as noun or verb) must likewise be resolved for choice between *lumière, clair* or *allumer*, etc. Examples of monolingual structural ambiguities occur when a word or phrase can potentially modify more than one element of a sentence. In *old men and women*, the adjective *old* may refer only to *men* or to both *men* and *women*. Prepositional phrases can modify almost any preceding verb or noun phrase, e.g. (a) *The car was driven by the teacher with great skill*, (b) *The car was driven by the teacher with defective tyres* and (c) *The car was driven by the teacher with red hair*. Lexical and structural ambiguities may and often do combine: *He saw her shaking hands*, where *shaking* can be either an adjective ('hands which were shaking') or a verb component ('that she was shaking hands').

Bilingual lexical ambiguities occur primarily when the TL makes distinctions absent in the

SL: English *river* can be *rivière* or *fleuve* (*Fluss* or *Strom*); English *eat* can be German *essen* or *fressen*; English *wall* can be French *mur* or *paroi*, German *Wand*, *Mauer* or *Wall*. Even the apparently simple adjective *blue* can be problematic: in Russian a choice between *sinii* (dark blue) and *goluboi* (light blue) must be made. A more extreme, but not uncommon, example is illustrated by the translation of *wear* from English to Japanese. Although there is a generic verb *kiru* it is normal to use the verb appropriate to the type of item worn: *haoru* (coat or jacket), *haku* (shoes or trousers), *kaburu* (hat), *hameru* (ring or gloves), *shimeru* (belt, tie or scarf), *tsukeru* (brooch or clip), *kakeru* (glasses or necklace), *hayasu* (moustache).

Bilingual structural differences cover both general facts, e.g. that in English adjectives generally precede nouns but that they usually follow them in French, and differences conditioned by specific lexical differences. A familiar example occurs when translating the English verb *like* (*She likes to play tennis*) as a German adverb *gern* (*Sie spielt gern Tennis*). Other examples are: simple verbs (*trust*) rendered by circumlocutions (*avoir confiance à*); single clauses (*He pushed open the door*) restructured as a subordinate clause (*Il a ouvert la porte en la poussant*). Not uncommonly structural differences combine with lexical differences, e.g. the translation of *know* into French or German, where choice of *connaître* (*kennen*) or *savoir* (*wissen*) affects both structure (*Je connais l'homme, Ich kenne den Mann: Je sais ce qu'il s'appelle, Ich weiss wie er heisst*) and the translation of other lexical items (*what* as *ce que* and *wie*).

The tools available are familiar: the provision of dictionaries with lexical, grammatical and translational information; the use of morphological and syntactic analysis to resolve monolingual ambiguities and to derive structural representations; the use of contextual information, of semantic features, of case markers, and of non-linguistic ('real world') information to resolve semantic ambiguities. The context for resolution may be during analysis of the SL text, during generation of the TL text, or at a transfer stage.

Dictionaries contain information necessary for SL analysis (morphological variants, syntactic functions, semantic features, etc.) and for TL synthesis (translation equivalents, constraints on TL syntax and word formation, etc.). There may be a single bilingual dictionary as in many older 'direct' systems or, more commonly, there may be separate dictionaries for analysis (monolingual SL dictionary), transfer (bilingual SL-TL dictionary) and synthesis (monolingual TL dictionary). Dictionaries may contain entries in either full forms or only base (or root) uninflected forms.

Morphological analysis is concerned with the identification of base forms from infected forms of nouns, verbs and adjectives (irregular forms being entered as units in dictionaries), with the recognition of derivational forms (e.g. English *-ly* as an adverb derived from an adjective, German *-heit* as a noun from an adjective), and with the segmentation of compound forms in languages like German (*Dampfschiff, Dampfhammer*). All MT systems have problems with 'unknown' words, primarily neologisms (common in scientific and technical literature) but also unanticipated new combinations. If derivational elements and components can be correctly identified then some attempt can be made to translate, particularly with the 'international' equivalences of many elements (e.g. French *demi-* and English *semi-*, French *-ique* and English *-ic*). However, segmentation can be problematic, e.g. *extradition* analysed as both *extradit+ion* and *ex+tradition*, *cooperate* as both *co+operate* and *cooper+ate*. These would be resolved by dictionary consultation, but sometimes alternative segmentations are equally valid (German *Wachtraum* could be *guard room* (*Wacht+Raum*) or *day dream* (*Wach+Traum*), until one is eliminated at a later stage.

In MT as in other areas of computational linguistics there have been three basic approaches to syntactic structure analysis. The first aims to identify legitimate sequences of grammatical categories, e.g. in English article + adjective + noun. This approach led to the development of parsers based on '**predictive analysis**', i.e. a sequence of categories predicted that the following category would be one of a relatively limited set. The second approach aims to recognize groups of categories, e.g. as noun phrases, verb phrases, clauses, and ultimately sentences. These parsers are based on **phrase structure** or constituency grammar. The third approach aims to identify dependencies among categories, e.g. reflecting the fact that prepositions determine the case forms of German and Russian nouns, that the form of a French adjective is determined by the noun it modifies. The basis for these parsers is **dependency grammar**. Each approach has its strengths and weaknesses, and modern MT systems often adopt an eclectic mixture of parsing techniques, now often within the framework of a unification grammar formalism.

SL structures are transformed into equivalent TL structures by conversion rules, in the case of phrase structure or dependency trees by 'tree transducers', which may apply either unconditionally (English adjective+noun to French noun+adjective) or conditionally, triggered by specific lexical items (English *like* to German *gern*). Structural synthesis of TL sentences is similar: some syntax and morphology rules apply unconditionally (e.g. formation of English passives, case endings of German nouns after particular prepositions), others are conditional (irregular verb forms).

Morphological and syntactic analysis can resolve problems of category ambiguity (whether a particular occurrence of *light* is a noun, a verb or an adjective) but not homography (whether *light* as adjective is being used to mean 'not heavy' or 'not dark'), syntactic ambiguity (e.g. the *shaking hands* example), or any bilingual lexical differences. In MT two linguistic means are commonly employed. The first is the use of semantic features attached to dictionary items. Such features may resolve SL homographs: the occurrence of a subject noun with a 'bird' feature may suffice to identify the 'fly' sense of French *voler*. Semantic features in TL dictionaries may be applied during synthesis to resolve transfer ambiguities, e.g. in selecting *fressen* as a translation of eat when the subject is 'animal', but *essen* when it is 'human'. Problems of structural ambiguity can also be resolved with semantic features: in order to avoid mistranslation of *pregnant women and children* into French *femmes and enfants enceintes* (an actual example from Systran, below), features attached to *pregnant* might restrict modification to 'female' nouns and exclude modification of 'young' nouns.

The second approach is the identification of thematic (semantic or 'deep' case) roles such as the agents, recipients, instruments and locations of actions. Different sentence structures may involve the same case relations: *The doctor built his son a house during the war*; *The house was built in the war by the doctor for his son*; etc. Languages differ in the expression of cases (English and French prepositions and word order, German and Russian noun case endings, Japanese particles, etc.) and few surface markers are unambiguous (English *with* may express manner, attribute, or instrument), but there is sufficient universality of underlying meanings and structures to encourage their widespread use in MT systems.

Semantic features and case roles may be regarded as universals in interlingua and transfer systems. Further steps towards interlingual representations have included the decomposition of lexical items into semantic primitives (a basic set of components sufficient to distinguish meanings) and the analysis of structures into logical forms, e.g. in terms of predicates and arguments. A major difficulty with such analyses is the loss of surface information which may be essential to generate appropriate TL sentences in context: a logical analysis disregards theme and rheme structure and ignores differences of active and passive formation. The main problem for interlingua systems, however, is the treatment of bilingual lexical differences and specifically to what extent the interlingua should reflect all semantic differences and nuances of all the languages involved. For example, should the interlingua make the Japanese *wear* distinctions even for translating between French and English? In transfer systems the differences are handled by the transfer component; if languages happen to share the same distinctions then straight equivalents can be found, if they do not (*know* and *savoir/connaître*) then collocational (semantic or syntactic) information must be applied during transfer or during generation. Likewise for structural differences: whereas an interlingua system derives 'universal' representations (involving logical and case roles), transfer systems provide rules for relating specific bilingual differences.

A number of problems resist traditional linguistic treatment (syntactic and semantic analysis). The identification of the antecedent of a pronoun may well depend on (non-linguistic) knowledge of events or situations: *The soldiers killed the women. They were buried next day*. We know that the pronoun *they* does not refer to *soldiers* and must refer to *women* because we know that 'killing' implies 'death' and that 'death' is followed (normally) by 'burial'. This identification is crucial when translating into French where the pronoun must be *elles* and not *ils*.

Non-linguistic knowledge can be applied to many transfer problems, e.g. whether a *wall* is interior and exterior (*Wand* and *Mauer*), whether a *river* flows into the sea or not (*fleuve* and *rivière*), whether the object modified is normally dark blue or light blue (*sinii* and *goluboi*), etc. Such examples and many others are reasons for including knowledge bases of the artificial intelligence type in MT systems, either as adjuncts to traditional semantic analyses or as the basic mechanisms of lexical analysis and transfer.

The complexity (if not intractability) of lexical and structural ambiguity in the bilingual and multilingual context of MT has two main consequences. First is the persistence of apparently 'low-level' - errors (which no human translator would make), particularly incorrect selection of pronouns, prepositions, articles (e.g. choice of *the* or *a(n)* where none occurs in the SL, e.g. Russian or Japanese), verbal tenses, etc. Second is the attempt to circumvent problems by restriction to sublanguages, by seeking TL 'cover terms' (the single, most generally acceptable TL equivalent for a SL homograph), and by including phrases as dictionary items not only where obviously needed for idioms (*wage war*) and compounds with specific TL equivalents which cannot be derived from components (*make away with* and *faire disparaître*, *look up* and *aufsuchen*), but also for technical terms which have to be translated consistently in standard forms (*plug connector* as *raccord de fiche*).

MT systems can fail for many practical reasons: unknown words (neologisms or new compounds), misspellings (*supercede*, *persue*), British orthography instead of expected American (*traveller* for *traveler*), typographical errors (*from* instead of *form*), wrong usages (*principle* as an adjective), ungrammaticalness (*none of them were present*). The incorporation of robust fail-safe procedures is essential in operational systems. In many cases, this means producing translations from partial analyses. Even if full disambiguation cannot be achieved, a crude translation may be obtained with basic phrase structure identification. It is now common for systems to retain information from all levels of analysis; thus transfer (or interlingual) representations will combine morphological, syntactic, semantic and thematic information.

Historically, MT systems have progressively introduced 'deeper' levels of analysis and transfer. Early word-for-word systems were restricted to bilingual dictionaries and simple morphology. Later 'direct' systems introduced syntactic analysis and synthesis. Phrase structure and dependency analyses provided the basis for simple transfer systems with little semantic analysis ('syntactic transfer'). The addition of semantic features and case relations has lead to the now common type of 'semantico-syntactic' transfer system. The more extensive introduction of interlingual or quasi-universal items and structures characterizes 'advanced' transfer designs and, of course, interlingua systems. Finally, full conceptual-semantic analysis is a feature of interlingua systems based on or incorporating AI techniques.

3. Precursors and pioneers, 1933-1956

The use of mechanical dictionaries to overcome the barriers of language was first suggested in the 17th century. However, it was not until the 20th century that the first concrete proposals were made, in patents issued independently in 1933 by George Artsouni, a French-Armenian, and by a Russian, Petr Smirnov-Troyanskii. Artsouni designed a storage device on paper tape which could be used to find the equivalent of any word in another language; a prototype was apparently demonstrated in 1937. The proposals by Troyanskii were in retrospect more significant. He envisioned three stages of mechanical translation: first, an editor knowing only the source language (SL) was to undertake the 'logical' analysis of words into their base forms and syntactic functions; secondly, the machine was to transform sequences of base forms and functions into equivalent sequences in the target language; finally, another editor knowing only the target language (TL) was to convert this output into the normal forms of his own language. Troyanskii envisioned both bilingual and multilingual translation. Although his patent referred only to the machine which would undertake the second stage, Troyanskii believed that "the process of logical analysis could itself be mechanized".

Troyanskii was ahead of his time and was unknown outside Russia when, within a few years of their invention, the possibility of using computers for translation was first discussed by Warren Weaver of the Rockefeller Foundation and Andrew D.Booth, a British crystallographer. On his return to Birkbeck College (London) Booth explored the mechanization of a bilingual dictionary and began collaboration with Richard H.Richens (Cambridge), who had independently been using punched cards to produce crude word-for-word translations of scientific abstracts. However, it was a memorandum from Weaver in July 1949 which brought the idea of MT to general notice (Weaver 1949). He outlined the prospects and suggested various methods: the use of war-time cryptography techniques, statistical methods, Shannon's information theory, and the exploration of the underlying logic and universal features of language, "the common base of human communication".

Within a few years research had begun at Washington University (Seattle), at the University of California at Los Angeles and at the Massachusetts Institute of Technology. It was at MIT in 1951 that the first full-time researcher in MT was appointed, Yehoshua Bar-Hillel. A year later he convened the first MT conference, where the outlines of future research were already becoming clear. There were proposals for dealing with syntax by Oswald and by Bar-Hillel (his categorial grammar), suggestions that texts should be written in MT-oriented restricted languages, and arguments for the construction of sublanguage systems. It was obvious that fully automatic translation would not be achieved without long-term basic research, and (in the interim) human assistance was essential, either to prepare texts or to revise the output (known already as pre- and post-editing.) A number of participants considered that the first requirement was to demonstrate the feasibility of MT. Accordingly, at Georgetown University Leon Dostert collaborated with IBM on a project which resulted in the first public demonstration of a MT system in January 1954. A carefully selected sample of 49 Russian sentences was translated into English, using a very restricted vocabulary of 250 words and just 6 grammar rules. Although it had little scientific value, it was sufficiently impressive to stimulate the large-scale funding of MT research in the United

States and to inspire the initiation of MT projects elsewhere in the world, notably in the Soviet Union.

4. The decade of high expectation and disillusion, 1956-1966

Research tended to polarize between empirical trial-and-error approaches, often adopting statistical methods with immediate working systems as the goal, and theoretical approaches involving fundamental linguistic research and aiming for long-term solutions. The contrastive methods were usually described at the time as 'brute-force' and 'perfectionist' respectively. Any evaluation of the period must remember that computer facilities were frequently inadequate; much effort was devoted to improving basic hardware (paper tapes, magnetic media, access speeds, etc.) and to devising programming tools suitable for language processing. Some groups were inevitably forced to concentrate on theoretical issues, particularly in Europe and the Soviet Union. For political and military reasons, most US research was for Russian-English translation, and most Soviet research on English-Russian systems.

The research under Erwin Reifler at the University of Washington (Seattle) epitomized the word-for-word approach; it involved the construction of large bilingual dictionaries where lexicographic information was used not only for selecting lexical equivalents but also for solving grammatical problems without the use of syntactic analysis. Entries gave English translations with rules for local reordering of output. The huge lexicon made extensive use was made of English 'cover terms' for Russian polysemes, the inclusion of phrases and clauses and the classification of vocabulary into sublanguages. After initial work on German and English, the group was engaged on the foundations of a Russian-English system for the 'photoscopic store', a large memory device rather similar to the laser disk. From 1958 practical development was directed by Gilbert King at the IBM Corporation (Yorktown Heights, New York). A system was installed for the US Air Force which produced translations for many years, until replaced in 1970 by Systran (see below). By any standards the output was crude and sometimes barely intelligible, but unlike some MT researchers at the time, King never made excessive claims for his system. With all its deficiencies, it was satisfying basic information needs of scientists.

The empirical attitude was exemplified at the RAND Corporation (1950-1960), which distrusted current linguistic theory and emphasized statistical analyses. From a large corpus (Russian physics texts) were prepared bilingual glossaries with grammatical information and simple grammar rules; a computer program was written for a rough translation; the result was studied by post-editors who indicated errors; the revised text was analysed; the glossaries and the rules were revised; the corpus was translated again; and so the process continued in cycles of translation and post-editing. The main method of analysis was statistical distribution, but it was at RAND that David Hays developed the first parser based on dependency grammar.

The research under Leon Dostert at Georgetown University had a more eclectic approach, undertaking empirical analyses of texts only when traditional grammatical information was inadequate. The Georgetown group was the largest in the United States and there were considerable differences of viewpoint among its members. Four groups were set up, each encouraged to submit their methods for testing in open competition on a Russian chemistry text. Ariadne Lukjanow's 'code-matching' method produced excellent results but apparently with ad hoc corpus-specific rules; the 'syntactic analysis' method by Paul Garvin (who had prepared the linguistic basis for the 1954 demonstration system) was not ready in time for the test; and the 'sentence-by-sentence' method by Anthony Brown was an example of the empirical cyclical method. The 'general analysis' method by a group under Michael Zarechnak was the method adopted and named Georgetown Automatic Translation (GAT). This had three levels of analysis: morphological (including identification of idioms), syntagmatic (agreement of nouns and adjectives, government of verbs, modification of adjectives, etc.), and syntactic (subjects and predicates, clause relationships, etc.) GAT was initially implemented on the SERNA system, largely the work of Peter Toma (later designer of Systran), and then with the programming method developed by Brown for his own separate French-English system. In this form it was successfully demonstrated in 1961 and 1962, and as a result Russian-English systems were installed at Euratom in Ispra (Italy) in 1963 and at the Oak Ridge National Laboratory of the US Atomic Energy Commission in 1964.

Further development of his parsing method was continued by Paul Garvin at the Ramo-Wooldridge Corporation from 1960 to 1967. Garvin sought a middle way between the empiricists and the perfectionists. His fulcrum method was essentially a dependency parser, a linguistic pattern recognition algorithm which identified the fulcrum of a structure and the relationships of dependent elements to the fulcrum. At a later stage, Garvin introduced heuristic methods, employing statistical information when appropriate. The method was also applied at Wayne State University (1958-1972) in the development of a Russian-English system. As at Harvard, the limitation to syntax produced multiple analyses, and even after 14 years of development the parser was unable to deal with sentences having more than one predicate.

Anthony Oettinger at Harvard University believed in a gradualist approach. From 1954 to 1960 the group concentrated on the compilation of a massive Russian-English dictionary, to serve as an aid for translators (a forerunner of the now common computer-based dictionary aids), to produce crude word-for-word translations for scientists familiar with the subject, and as the basis for more advanced experimental work. From 1959 research focused on the 'predictive syntactic analyzer' - originally developed at the National Bureau of Standards under Ida Rhodes - a system for the identification of permissible sequences of grammatical categories (nouns, verbs, adjectives, etc.) and the probabilistic prediction of following categories. The results were often unsatisfactory, caused primarily by the enforced selection at every stage of the 'most probable' prediction. The system was revised to examine all possible predictions. (This was the Multiple-path Predictive Analyzer, from which was later developed Woods' familiar Augmented Transition Network parser.) However, the results were equally unsatisfactory: multiple parsings were produced of even apparently quite unambiguous sentences; some kind of semantic analysis to 'filter' out undesirable parses was clearly needed. By 1965 the group had effectively ceased MT research.

Research at MIT, started by Bar-Hillel in 1951, was directed by Victor Yngve from 1953 until its end in 1965. Whereas other groups saw syntax as an adjunct to lexicographic transfer, as a means of resolving ambiguities and rearranging TL output, Yngve placed syntax at the centre: translation was a three-stage process, a SL grammar analysed input sentences as phrase structure representations, a 'structure transfer routine' converted them into equivalent TL phrase structures, and the TL grammar rules produced output text. There is some evidence of the influence of transformational grammar (Chomsky was associated with the project for two years), but in many respects the practicalities of MT led MIT researchers away from Chomskyan theory. Much was achieved both in basic syntactic research and on developing the first string-handling programming language (COMIT). But eventually the limitations of the 'syntactic transfer' approach became obvious. By the mid-1960's Yngve acknowledged that MT research had come up against the 'semantic barrier... and that we will only have adequate mechanical translations when the machine can "understand" what it is translating' (Yngve 1964).

The Linguistic Research Center (LRC) at the University of Texas was founded by Winfried Lehmann in 1958 and, like MIT, concentrated on basic syntactic research of English and German.

Efforts were made to devise reversible grammars to achieve bi-directional translation within an essentially 'syntactic transfer' approach. The foundations were laid for the later successful development of the METAL system (below.)

At the University of California, Berkeley, the project under the direction of Syndney Lamb stressed the importance of developing maximally efficient dictionary routines and a linguistic theory appropriate for MT. Lamb developed his stratificational grammar with networks, nodes and relations paralleling the architecture of computers. Translation was seen as a series of decoding and encoding processes, from the graphemic stratum of SL text through its morphemic and lexemic strata to a sememic stratum, from which TL text could be generated by passing through a similar series of strata. Translation was characterized as word-by-word, each word examined within the broadest possible environment and not limited by sentence boundaries or immediate contexts.

There were no American groups taking the interlingua approach. This was the focus of projects elsewhere. At the Cambridge Language Research Unit, Margaret Masterman and her colleagues adopted two basic lines of research: the development of a prototype interlingua producing crude 'pidgin' (essentially word-for-word) translations, and the development of tools for improving and refining MT output, primarily by means of the rich semantic networks of a thesaurus (conceived as lattices of interlocking meanings.) At Milan, Silvio Ceccato concentrated on the development of an interlingua based on conceptual analysis of words (species, genus, activity type, physical properties, etc.) and their possible correlations with other words in texts.

In the Soviet Union research was as vigorous as in the United States and showed a similar mix of empirical and basic theoretical approaches. At the Institute of Precision Mechanics research began in 1955 shortly after a visit by Panov to see a demonstration of the IBM-Georgetown system. Experiments on English-Russian translation were on similar lines to the approach at Georgetown, but with less practical success. More basic research was undertaken at the Steklov Mathematical Institute under Lyupanov, Kulagina and others, mainly towards French-Russian translation. As at MIT attention was paid to the development of programming tools for linguistic processes. The research by Mel'chuk and others at the Institute of Linguistics in Moscow was more theoretical in nature, including work on interlinguas and leading to the stratificational 'meaning-text' model as a basis for MT (see below). However, the main centre for interlingua investigations was Leningrad University, where a team under Andreev conceived of an interlingua not as an abstract intermediary representation (which was Mel'chuk's approach) but as an artificial language complete in itself with its own morphology and syntax, and having only those features statistically most common to a large number of languages.

By the mid-1960s MT research groups had been established in many countries throughout the world, including most European countries (Hungary, Czechoslovakia, Bulgaria, Belgium, Germany, France, etc.), China, Mexico, and Japan. Many of these were shortlived and with no subsequent influence. But some groups created at the time became important later, in particular the project which begun in 1960 at Grenoble University.

5. The ALPAC report and its consequences

In the 1950s optimism was high; developments in computing and in formal linguistics, particularly in the area of syntax, seemed to promise great improvement in quality. There were many predictions of imminent breakthroughs and of fully automatic systems operating within a few years. However, disillusion grew as the complexity of the linguistic problems became more and more apparent. In a review of MT progress, Bar-Hillel (1960) criticized the prevailing assumption that the goal of MT research should be the creation of fully automatic high quality translation (FAHQT) systems producing results indistinguishable from those of human translators. He argued that it was not merely unrealistic, given the current state of linguistic knowledge and computer systems, but impossible in principle. For example, the word *pen* can have at least two meanings (a container for animals or children, and a writing implement). In the sentence *The box was in the pen* we know that only the first meaning is plausible; the second meaning is excluded by our knowledge of the normal sizes of (writing) pens and boxes. Bar-Hillel contended that no computer program could conceivably deal with such 'real world' knowledge without recourse to a vast encyclopaedic store. His argument carried much weight at the time. Many researchers were already encountering similar 'semantic barriers' for which they saw no straightforward solutions. Bar-Hillel recommended that MT should adopt less ambitious goals, it should build systems which made cost-effective use of man-machine interaction.

In 1964 the government sponsors of MT in the United States formed the Automatic Language Processing Advisory Committee (ALPAC) to examine the prospects. In its famous 1966 report it concluded 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 for further investment in MT research; instead it recommended the development of machine aids for translators, such as automatic dictionaries, and continued support of basic research in computational linguistics. The ALPAC report was widely condemned as narrow, biased and shortsighted. It is true that it failed to recognize, for example, that revision of manually produced translations is essential for high quality, and it was unfair to criticize MT for needing to post-edit output. It may also have misjudged the economics of computer-based translation, but large-scale support of current approaches could not continue. The influence of the ALPAC report was profound. It brought a virtual end to MT research in the United States for over a decade and MT was for many years perceived as a complete failure.

6. The quiet decade, 1967-1976.

In the United States the main activity had concentrated on English translations of Russian scientific and technical materials. In Canada and Europe the needs were quite different. The Canadian government's bicultural policy created a demand for English-French (and to a less extent French-English) translation beyond the capacity of the market. The problems of translation were equally acute in Europe, in particular within the European Communities with growing demands for translations of scientific, technical, administrative and legal documentation from and into all the Community languages. The focus of MT activity switched from the United States to Canada (Montreal) and to Europe.

At Montreal, research began in 1970 on a syntactic transfer system for English-French translation. The TAUM project (Traduction Automatique de l'Universite de Montreal) had two major achievements: firstly, the Q-system formalism, a computational metalanguage for manipulating linguistic strings and trees and the foundation of the Prolog programming language now widely used in natural language processing; and secondly, the METEO system for translating weather forecasts. Designed specifically for the restricted vocabulary and limited syntax of meteorological reports, METEO has been successfully operating since 1976. An attempt by

TAUM to repeat the success with another sublanguage, that of aviation manuals, failed to overcome the problems of complex noun compounds and phrases (e.g. *hydraulic ground test stand pressure and return line filters*), problems which would defeat human translators without relevant subject knowledge. TAUM came to an end in 1981.

The principal experimental efforts of the decade focused on interlingua approaches, with more attention to syntactic aspects than previous projects at Cambridge, Milan and Leningrad. Between 1960 and 1971 the group established by Bernard Vauquois at Grenoble University developed an interlingua system for translating Russian mathematics and physics texts into French. The 'pivot language' of CETA (Centre d'Etudes pour la Traduction Automatique) was a formalism for representing the logical properties of syntactic relationships. It was not a pure interlingua as it did not provide interlingual expressions for lexical items; these were translated by a bilingual transfer mechanism. Syntactic analysis produced first a phrase-structure (context-free) representation, then added dependency relations, and finally a 'pivot language' representation in terms of predicates and arguments. After substitution of TL lexemes (French), the 'pivot language' tree was converted first into a dependency representation and then into a phrase structure for generating French sentences. A similar model was adopted by the LRC at Texas during the 1970s in its METAL system: sentences were analysed into 'normal forms', semantic propositional dependency structures with no interlingual lexical elements. The research by Mel'chuk in the Soviet Union towards an interlingua system was more ambitious. His influential 'meaning-text' model combines a stratificational dependency approach (six strata: phonetic, phonemic, morphemic, surface syntactic, deep syntactic, semantic) with a strong emphasis on lexicographic aspects of an interlingua. Fifty universal 'lexical functions' were identified at the deep syntactic stratum covering paradigmatic relations (synonyms, antonyms, conversives (*fear: frighten*), verbs and corresponding agentive nouns (*write: writer, prevent: obstacle*), etc.) and a great variety of syntagmatic relations (inceptive verbs associated with given nouns, *conference: open, war: break out*; idiomatic causatives, *compile: dictionary, lay: foundations*, etc.) Although Mel'chuk emigrated in 1976 his ideas continue to inspire Soviet MT research to the present.

By the mid-1970s, however, the future of the interlingua approach seemed to be in doubt. Both LRC and CETA had problems which were attributed to the rigidity of the levels of analysis (failure at any stage meant failure to produce any output), the inefficiency of parsers (too many partial analyses which had to be 'filtered' out), and in particular the loss of information about the surface forms of SL input which could have been used to guide the selection of TL forms and the construction of acceptable TL sentence structures. As a consequence, it became widely accepted that the less ambitious transfer approach offered better prospects.

7. Operational and commercial systems in the 1980s

During the 1980s MT advanced rapidly on many fronts. Many new operational systems appeared, the commercial market for MT systems of all kinds expanded, and MT research diversified in many directions.

The revival was laid in the decade after ALPAC. Systems were coming into operational use and attracting public attention. The Georgetown systems had operating since the mid-1960s. As well as METEO, two other sublanguage systems appeared: in 1970 the Institut Textile de France introduced TITUS, a multilingual system for translating abstracts written in a controlled language, and in 1972 came CULT (Chinese University of Hong Kong) for translating mathematics texts from Chinese into English, a 'direct translation' system requiring extensive pre- and post-editing.

More significant, however, were the installations of Systran in 1970 by the US Air Force for Russian-English translation, and in 1976 by the European Communities for English-French translation.

Systran has been the most successful operational system so far. Developed by Petr Toma, who had previously worked for the Georgetown project, initially as a 'direct translation' system, its oldest version is the Russian-English system at the USAF Foreign Technology Division (Dayton, Ohio) which translates over 100,000 pages a year at an accuracy claimed to be over 95%. At the Commission of the European Communities (CEC) the English-French version was followed shortly by systems for French-English, English-Italian and subsequently for English into German, Dutch, Spanish and Portuguese, for French into German and Dutch, and there are plans for German into English and into French. The original design has been greatly modified, with increased modularity and greater compatibility of the analysis and synthesis components of different versions, permitting cost reductions when developing new language pairs. But it is still a large mainframe system operating in batch mode and post-edited output. Outside the CEC, Systran has been installed at a number of intergovernmental institutions, e.g. NATO and the International Atomic Energy Authority, and at a number of major companies, e.g. General Motors of Canada, Dornier, and Aerospatiale. The application at the Xerox Corporation is particularly noteworthy: post-editing has been virtually eliminated by controlling the input language of technical manuals for translation from English into five languages (French, German, Italian, Spanish, and Portuguese). It is one of the most impressive economically viable applications of MT in the world.

Another long-established commercial system running on mainframe computers is that of the Logos Corporation. This company's first effort in MT was an English-Vietnamese system for translating aircraft manuals during the 1970s. Experience gained in this ultimately short-term project was applied in the development of a German-English system which appeared on the market in 1982. Subsequently, Logos has expanded to other language pairs, notably English-French systems for Canadian translation services. Initially, Logos systems were based on a direct translation approach, but later systems are closer to a transfer design and incorporate sophisticated means for recording and applying semantic features.

Mainframe systems like Systran and Logos are in principle systems designed for general application, although in practice their dictionaries are adapted for particular subject domains, e.g. nuclear energy or aircraft engineering. Systems specifically designed for a particular environment have also been developed during the 1970s and 1980s. The Pan American Health Organization in Washington has built two mainframe systems, one for Spanish into English (SPANAM, basically a direct system) and the other for English into Spanish (ENGSPAN, a transfer system). Both were developed by just two researchers - showing what can be achieved with limited resources using well-tested and reliable techniques. Output is good, and excellent use is made of well-conceived post-editing facilities. Large tailor-made systems are the speciality of the Smart Corporation (New York). Customers have included Citicorp, Ford, and largest of all, the Canadian Department of Employment and Immigration. The principal feature of Smart systems is (as at Xerox) strict control of SL vocabulary and syntax. Texts are written in restricted English (interactively at terminals); manuals are clear and unambiguous, and translation is regarded as almost a 'by-product'.

The most significant feature of the 1980s has been the appearance of numerous microcomputer-based systems, generally crude in linguistic terms but providing satisfactory and economically viable results. They have secured for MT a higher public profile than any mainframe system could have done. Most systems have been rightly marketed not as full MT systems but as computer aids for translators. Earliest were the American Weidner and ALPS systems, which became commercially available in 1981 and 1983 respectively. The ALPS system offers three levels of assistance: multilingual word-processing, automatic dictionary and terminology consultation, and interactive translation. In the latter case, translators work with rough computer-produced versions. Weidner (later World Communications Center) has been more successful commercially, offering translation packages for a large number of language pairs, its Japanese-English systems being particularly popular. At the end of the 1980s other microcomputer-based systems have appeared: PC-Translator from Linguistic Products (Houston) in a large number of language pairs, GTS from Globalink (Fairfax, Va.) with systems for translating English into Spanish, French and German, and from mainland China, TRANSTAR for English-Chinese translation. Undoubtedly many more will appear in the next decade.

During the 1980s, however, the greatest commercial activity has been in Japan, where most of the computer companies have developed software for computer-aided translation, mainly for the Japanese-English and English-Japanese market, although they have not ignored the needs for translation to and from Korean, Chinese and other languages. Many of these systems are, like ALPS and Weidner, low-level direct or transfer systems with analysis limited to morphological and syntactic information and with little or no attempt to resolve lexical ambiguities. Often restricted to specific subject fields (computer science and information technology are popular choices), they rely on substantial human assistance at both the preparatory (pre-editing) and the revision (post-editing) stages. Examples are systems from Oki (PENSEE), Mitsubishi (MELTRAN), Sanyo, Toshiba (AS-TRANSAC), Hitachi (HICATS) and Fujitsu (ATLAS). Japanese input demands considerable pre-editing, but it is acceptable to operators of Japanese word processors who have to interpret Japanese script, with two vernacular alphabets (hiragana and katakana), Chinese characters, no capitals and no indicators of word boundaries. As consequence, however, good knowledge of Japanese is essential for usable results from Japanese-English systems.

The most sophisticated commercially available system so far is the METAL German-English system. It originates from research at the University of Texas University. After its interlingua experiments this group adopted an essentially transfer approach, with research supported since 1978 by the Siemens company in Munich (Germany). The METAL system, written in Lisp and intended for translation of documents in the fields of data processing and telecommunications, incorporates advanced linguistics and programming techniques and produces good quality output (although still needing post-editing) in a sophisticated text-processing environment. The German-English version appeared in 1988 and is to be followed by systems involving Dutch, French and Spanish as well as English and German.

8. MT research in the 1980s

Research since the mid-1970s has had three main strands: first, the development of advanced transfer systems building upon experience with earlier interlingua systems; secondly, the development of new kinds of interlingua systems; and thirdly, the investigation of AI techniques and approaches.

After the failure of its interlingua system, the Grenoble group (GETA, Groupe d'Etudes pour la Traduction Automatique) began development of its influential Ariane system. Regarded as one of the most advanced linguistics-based transfer systems, Ariane has influenced projects throughout the world. Of particular note are its flexibility and modularity, its powerful tree-transducers, and its conception of static and dynamic grammars. Different levels and types of representation (dependency, phrase structure, logical) can be incorporated on single labelled tree structures and thus provide considerable flexibility in multilevel transfer representations. GETA has been particularly prominent in the encouragement of international collaboration and in the training of MT researchers. For most of the 1980s the group was involved in the French national project Callliope, developing systems for aeronautics and computer science.

Similar in conception to the GETA-Ariane design has been the Mu system at the University of Kyoto under Makoto Nagao. Prominent features of Mu are the use of case grammar analysis and dependency tree representations, and the development of a programming environment for grammar writing (GRADE). The Kyoto research has been very influential in many subsequent Japanese MT research projects and in many of the Japanese commercial systems already mentioned. Since 1986, the research prototype is being converted into an operational system for use by the Japanese Information Center for Science and Technology.

Experimental research at Saarbrücken began in 1972. The SUSY system is a highly-modular multilingual transfer system displaying an impressive heterogeneity of linguistic techniques: phrase structure rules, transformational rules, case grammar and valency frames, dependency grammar, and variety of operation types: rule-driven, lexicon-driven, table-driven, the use of statistical data, preference rules, etc. Its main achievement lies in the in-depth treatment of inflected languages such as Russian and German, but many other languages were investigated, particularly English. Other projects include a French-German system (ASCOF) using semantic networks; and the development of a German generator (SEMSYN) to convert output from the Fujitsu ATLAS system in order to translate titles of Japanese scientific articles into German.

One of the best known projects of the 1980s has been the Eurotra project of the European Communities, probably the largest and most ambitious in the world. Its aim is the construction of an advanced multilingual transfer system for translation among all the Community languages. Conceptually the design owes much to the work at Saarbrucken and Grenoble. The need for explicit formalisms has been paramount, firstly because of the decentralization of research (in all member states) and secondly because multilinguality demands a level of abstraction not previously attempted in any MT project. Eurotra has embraced many advances of linguistic and computational theory, while the lexicon and empirical testing have been relatively neglected.

MT research in Japan, initially greatly influenced by the Mu project at Kyoto University, shows a wide variety of approaches. While transfer systems predominate there are also a number of interlingua systems (e.g. the PIVOT system from NEC, recently marketed) and knowledge-based systems (e.g. the LUTE project at NTT, the Lamb system of Canon). Most significant for the future is the multilingual multinational project with participants from China, Indonesia, Malaysia and Thailand and the involvement of major Japanese research institutes, including the governmental Electrotechnical Laboratory (ETL) in Tokyo. An ambitious interlingua approach has been adopted with knowledge-based contextual analysis for disambiguation. In both linguistic and organizational terms it is as ambitious as Eurotra.

The revival of interest in interlingua systems is worldwide. In Bolivia, the ATAMIRI system (primarily for English and Spanish) is based on a South American language Aymara. In the Netherlands, the innovative research group established by a software company in Utrecht has developed a version of Esperanto as the interlingua in its DLT (Distributed Language Translation) system. Designed for monolingual users wishing to convey messages in other languages, the system requires interactive collaboration in the analysis and disambiguation of input texts in order that output can be produced fully automatically. Another interlingua project in the Netherlands is innovative in another respect. This is the Rosetta project at Philips (Eindhoven), which is exploring the use of Montague semantics and reversible grammars. Interlingual representations are semantic trees derived on the compositionality principle from the corresponding equivalent syntactic structures in the languages involved (English, Dutch and Spanish).

Although outside North America and Western Europe, the Japanese have been most active recently, they have not been alone. MT research is vigorous in Korea (in collaboration with both Japanese and American groups as well as with governmental support), in Taiwan (e.g. the ArchTran system), in mainland China at a number of institutions and in Southeast Asia (particularly in collaboration with the GETA group.) There has been an increase in activity in the Soviet Union. The ALPAC report had a negative impact during the 1970s, and a number of advanced MT projects lost support. In 1976 most research was concentrated at the All-Union Centre for Translation in Moscow. Systems for English-Russian (AMPAR) and German-Russian translation (NERPA) were developed based on the direct approach, and although work on a more advanced transfer system for French-Russian has continued, most activity in the Soviet Union is focused on the production of relatively low-level operational systems, often involving the use of statistical analyses.

Recent developments in syntactic theory, in particular unification grammar, lexical-functional grammar and government-binding theory, have inspired many small-scale MT experiments in the United States and Europe. Another influence has been logical programming, particularly with the Prolog language. Some Japanese groups have adopted Prolog, but its most substantial application
has been in the experimental LMT English-German system at IBM.

For many observers the most likely source of techniques for improving MT quality is research on natural language processing within the context of artificial intelligence (AI). Investigations of AI methods in MT research began in the mid-1970s with Yorick Wilks' work on 'preference semantics' and 'semantic templates'. Further inspiration came from the research of Roger Schank at Yale University, and particularly from the development of expert systems and knowledge-based approaches to text 'understanding'. The basic justification for AI approaches is the argument that since translation is concerned primarily with conveying content any MT system must be capable of 'understanding' the meaning of texts by reference to extra-linguistic knowledge.

A number of projects have applied AI approaches, particularly the use of knowledge banks - some in Japan (e.g. the LUTE project and the ETL research for the Japanese multilingual project), others in Europe (e.g. at Saarbrücken and Stuttgart), and many in North America. One of the most important is at Carnegie-Mellon University in Pittsburgh which has examined in depth the construction of knowledge-based MT systems, with particular attention to interlingua structures, to interactive dialogue, and to problems of text generation. As at DLT and many other centres, there is also interest in the integration of translation and text composition programs: senders of messages would interactively compose texts in their own language which the system would reformulate, rather than translate, in another language. Obvious applications would be conventional business correspondence, hotel reservations, etc.

In the view of many MT researchers, however, the extent to which AI-type understanding can be applied in full-text translation is uncertain. Although much knowledge and text understanding is language-independent, above all in scientific and technical domains, a great deal of MT analysis and synthesis is determined by language-specific features: the semantics of the general (non-technical) lexicon, theme-rheme structures, nominalization, tenses and aspects of verbs, etc. As the interlingua projects of the 1970s demonstrated, the generation of TL texts cannot neglect information about the 'surface' forms of SL texts. Consequently, whatever the basic approach, most future MT systems will continue to present a mixture of methodologies.

Until recently, MT has dealt exclusively with written text. Yet, most desirable of all is probably automatic speech translation, and research has started. British Telecom began in 1984 to investigate a pattern-matching approach, translating a small set of standard business phrases from English into French and vice versa. A more ambitious project in Japan (ATR Automatic Translation Telephony Research) aims to deal with unrestricted input, using a knowledge-based and AI understanding approach. The success of speech recognition research, which has encouraged these projects, has rested on sophisticated statistical analyses rather than linguistic analysis. The success has also revived statistical approaches to MT itself, last seen in the 1950s. The main centre for research on these lines is the IBM Research Center at Yorktown Heights.

The multiplicity of system types which have emerged during the 1980s has revealed possibilities which were undreamt of when MT was first proposed in the 1940s. Many have been made possible by advances in computer technology, and there are already a number of current developments which suggest future lines of investigation (e.g. the application of parallel and connectionist processing); however, the fundamental problems of computer-based translation are concerned not with technology but with language, meaning, and understanding, and the social and cultural differences of human communication.

9. Further reading

The general history of MT is covered by Hutchins (1986), updated by Hutchins (1988). Basic sources for the early period are Locke & Booth (1955), Booth (1967) and Bruderer (1982). For the period after ALPAC (1966) there are good descriptions of the major MT systems in Slocum (1988), Nirenburg (1987) and King (1987), while Vasconcellos (1988) and the Aslib conferences (1979-) provide the wider perspectives of commercial developments and translators' experiences. The general introduction by Lehrberger & Bourbeau (1988) is particularly valuable for its discussion of the evaluation of MT systems, and Nagao (1989) provides a Japanese view of developments and the future.

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