Machine translation: a concise history

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1. Introduction

This paper traces the history of efforts to develop computer programs (software) for the translation of natural languages, commonly and traditionally called 'machine translation' (MT), or, in non-English-speaking countries, 'automatic translation' (*traduction automatique*, *avtomaticheskij perevod*). A brief history can of course mention only the most significant research systems and projects and only the most important operating and commercial systems (and none in any detail[1]).

From the beginning, researchers concentrated almost exclusively on the translation of scientific and technical documents, where the difficulties of cultural differences and variable contexts are less acute than in the more 'culture-bound' translation of literature, legal texts, and many areas of sociology. In science and technology, the demand for translation has almost always exceeded the capacity of the translation profession, and these demands are growing rapidly. In addition, the coming of the Internet has created a demand for immediate online translations, which human translators cannot possibly meet.

Basically there are two types of demand. There is the traditional need for translations of 'publishable' quality, particularly the production of multilingual documentation for large corporations. Here the output of MT systems can save time and costs by providing draft translations which are then edited for publication – this mode of use being called human-aided machine translation (HAMT). However, what is often needed is not a 'perfectly' accurate rendition but something that can be produced quickly (sometimes immediately) conveying the essence of the original text, however grammatically imperfect, lexically awkward and stylistically crude. The latter is often called 'machine translation for assimilation' in contrast to the production of publishable-quality translations, called 'machine translation for dissemination'. More recently a third application has been identified where MT is used in social interchange (electronic mail, chatrooms, etc.) where again high-quality is not essential: 'machine translation for communication'.

The field embraces also the related development of computer-based translation tools for the use of human translators, initially electronic dictionaries and glossaries, and terminology management systems, later translation databases and translator workstations.

2. Precursors and pioneers, 1933-1956

Although we may trace the origins of machine translation (MT) back to seventeenth century ideas of universal (and philosophical) languages and of 'mechanical' dictionaries, it was not until the twentieth century that the first practical suggestions could be made – in 1933 with two patents issued in France and Russia to Georges Artsrouni and Petr Trojanskij respectively. Artsrouni's patent was for a general-purpose machine which could also function as a mechanical multilingual dictionary. Trojanskij's patent, also basically for a mechanical dictionary, went further with proposals for coding and interpreting grammatical functions using 'universal' (Esperanto-based) symbols in a multilingual translation device.[2]

Neither of these precursors was known to Andrew Booth (a British crystallographer) and Warren Weaver when they met in 1946 and 1947 and put forward the first tentative ideas for using the newly invented computers for translating natural languages[3]. In 1948 Booth worked with Richard H. Richens (Commonwealth Bureau of Plant Breeding and Genetics, Cambridge, UK) on morphological analysis for a mechanical dictionary. By this time, the idea of mechanical translation (as it was known almost invariably in the period up to the early 1960s) had occurred independently to a number of people, and in July 1949 Warren Weaver (a director at the Rockefeller Foundation) put forward specific proposals for tackling the obvious problems of ambiguity (or 'multiple meanings'), based on his knowledge of cryptography,

[1] For full accounts see Hutchins (1986, 1988, 1994, 1999). For a collection of seminal articles see Nirenburg et al. (2003)
[2] See Hutchins & Lovtsky (2000).
[3] For the early history of MT see Hutchins (1997) – with bibliographical references.

statistics, information theory[4], logic and language universals. This memorandum was the stimulus for MT research in the United States.

Then, in May 1951 Yehoshua Bar-Hillel was appointed to do research at the Massachusetts Institute of Technology (MIT). After visiting all those interested in the subject he wrote a state-of-the-art report, in which he outlined some of the basic approaches to MT questions; and in June 1952, he convened the first MT conference (at MIT), which was attended by nearly everyone already active in the field. It was already clear that full automation of good quality translation was a virtual impossibility, and that human intervention either before or after computer processes (known from the beginning as pre- and post-editing respectively) would be essential; some hoped this would be only an interim measure, but most expected that it would always be needed. At the conference, various ideas were put forward for pre-editing and post-editing, for micro-glossaries as means of reducing ambiguity problems (selecting appropriate target lexical items), and for some kind of syntactic structure analysis. Various suggestions for future activity were proposed; in particular, Léon Dostert from Georgetown University, who had come as a sceptic, argued that what was required was a public demonstration of the feasibility of MT in order to attract research funding.

Accordingly, he collaborated with IBM on a project which resulted in the first demonstration of a MT system on 7th January 1954. It was the joint effort of Peter Sheridan of IBM and Paul Garvin at Georgetown. 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.[5] The demonstration attracted a great deal of media attention in the United States. Although the system had little scientific value, its output was sufficiently impressive to stimulate the large-scale funding of MT research in the USA and to inspire the initiation of MT projects elsewhere in the world, notably in the USSR.

In the same year, the first journal was founded by William Locke and by Victor Yngve, who had succeeded Bar-Hillel at MIT in 1953 – the journal *Mechanical Translation* was to carry some of the most significant papers until its eventual demise in 1970 – and also in this year, the first doctoral thesis in MT, Anthony G. Oettinger's study for a Russian mechanical dictionary. The years 1954 and 1955 saw the foundation of a group in Cambridge, England, under Margaret Masterman, a group in Milan under Silvio Ceccato, the first Russian groups at the Institute of Precise Mechanics and Computer Technology, the Institute of Applied Mathematics, Leningrad University, etc. and the start of various Chinese and Japanese projects. And in 1955 the first MT book appeared, a collection edited by Locke and Booth (1955), including Weaver's 1949 memorandum, Booth and Richens' experiments, some papers given at the 1952 conference, and other contributions from Bar-Hillel, Dostert, Oettinger, Reifler, and Yngve.

3. High expectations and disillusion, 1956-1966

When MT research began, there was little help to be had from current linguistics. As a consequence, in the 1950s and 1960s, the research methods tended to polarize between, on the one hand, empirical trial-and-error approaches, which often adopted statistical methods for the 'discovery' of grammatical and lexical regularities which could be applied computationally, and, on the other hand, theoretical approaches which involved the projects in fundamental linguistic research, indeed the beginnings of research in what was later to be called 'computational linguistics'. The contrastive methods were usually described at the time as 'brute-force' and 'perfectionist' respectively; the aim of the former being the development of systems producing useful if crude quality translations in the near future, and that of the latter being the eventual development of systems producing output requiring little or no human editing.

This first decade[6] saw the beginnings of the three basic approaches to MT (until the appearance of corpus-based approaches in the late 1980s – see section 9 below). The first was the 'direct translation' model, where programming rules were developed for the translation specifically from one source language

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[4] Weaver, a statistician, collaborated with Claude Shannon on the first book about information theory (Shannon and Weaver 1949). Shannon was also involved in cryptanalysis during the war.

[5] For a detailed account of the experiment see Hutchins (2004).

[6] A general history of the period is given in chapters 4 to 8 of Hutchins (1986), with substantial bibliography; valuable sources are the collections by Locke and Booth (1955), Edmundson (1961), Booth (1967), Rozencvejg (1974), Bruderer (1982), Hutchins (2000), and Nirenburg et al. (2003).

(SL) into one particular target language (TL) with a minimal amount of analysis and syntactic reorganisation. Many researchers sought to reduce the problems of homonyms and ambiguity by simplifying bilingual dictionaries, i.e. by providing single TL equivalents for SL words which would hopefully 'cover' most senses, and would therefore not demand the analysis of contexts (usually immediately adjacent words), and would permit the word order of the SL original to be maintained as much as possible.

The second approach was the 'interlingua' model, based on abstract language-neutral representations (codes or symbols independent of both SL and TL), where translation would then be in two stages, from SL to interlingua and from interlingua to TL. The third approach was less ambitious: the 'transfer approach', where conversion was through a transfer stage from abstract (i.e. disambiguated) representations of SL texts to equivalent TL representations; in this case, translation comprised three stages: analysis, transfer, and generation (or synthesis).

In most cases, the 'empiricists' adopted the 'direct translation' approach, often using statistical analyses of actual texts to derive dictionary rules – often of an ad hoc nature, with little or no theoretical foundation. The 'perfectionists' were explicitly theory-driven, undertaking basic linguistic research, with particular attention given to methods of syntactic analysis. Some groups pursued the interlingua ideal, and believed that only fundamental research on human thought process (what would later be called artificial intelligence or cognitive science) would solve the problems of automatic translation. The more pragmatic among them concentrated on simpler syntax-based 'transfer' models, leaving problems of semantics to some later stage.

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 – in particular, COMIT developed at MIT by the team under Victor Yngve. Some groups were inevitably forced to concentrate on theoretical issues, particularly in Europe and the Soviet Union. For political and military reasons, nearly all US research was for Russian-English translation, and most Soviet research focussed on English-Russian systems, although the multilingual policy of the Soviet Union inspired research there on a much wider range of languages than elsewhere.

The research under Erwin Reifler at the University of Washington (Seattle) epitomized the dictionary-based 'direct' 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 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. From 1958 practical development was directed by Gilbert King at the IBM Corporation (Yorktown Heights, New York), and a system installed for the US Air Force produced 'translations' until the early 1970s. By any standards the output was crude and sometimes barely intelligible, but no excessive claims were made for the system, which with all its deficiencies was able to satisfy basic information needs of its users.

Many researchers at the time distrusted linguistic theory – the formal linguistics of Zellig Harris and Noam Chomsky had scarcely begun – and preferred to develop methods based on the analysis of language corpora. For example, researchers at the RAND Corporation undertook statistical analyses of a large corpus of Russian physics texts, to extract bilingual glossaries and grammatical information. On this basis, a computer program was written for a rough translation; the result was studied by post-editors; the glossaries and the rules were revised; the corpus was translated again; and so it continued in cycles of translation and post-editing. The main method of analysis was initially statistical distribution, although it was at RAND that David Hays later developed the first syntactic parser based on dependency grammar.

The research under Léon Dostert at Georgetown University had a more eclectic approach, undertaking empirical analyses of texts only when traditional grammatical information was inadequate. Initially there were several groups at Georgetown, for many years the largest in the USA. One group was led by Paul Garvin, who later left to found his own group at the Bunker-Ramo Corporation, and to develop his 'fulcrum' method, essentially a dependency parser; another led by Ariadne Lukjanow worked on a code-matching method; a third one-man 'group' (Antony Brown) experimented with a pure example of the cyclical method on a French-English system; and the fourth group under Michael Zarechnak developed the method eventually adopted. This, the Georgetown Automatic Translation (GAT) system, 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, and then with the programming method developed by Brown. In this form it was successfully installed by Euratom in Ispra (Italy) in 1963 and by the US Atomic Energy Commission in 1964, both continuing in regular use until the late 1970s.

Anthony Oettinger at Harvard University believed in a gradualist approach. From 1954 to 1960 his 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 to be 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. However, the results were often unsatisfactory, caused primarily by the enforced selection at every stage of the 'most probable' prediction. (Nevertheless, an improved version, the Multiple-path Predictive Analyzer, led later to William Woods' familiar Augmented Transition Network parser.)

The research at MIT was directed by Victor Yngve from 1953 until its end in 1965. Here syntax was placed at the centre: a SL grammar analyzed 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. But in the end, Yngve recognised that a "semantic barrier" had been reached, and that further progress would be very difficult. It may be noted that despite Chomsky's association with the group for a short time, transformational grammar had little influence – indeed there is virtually no evidence of Chomskyan approaches in any MT research at this time.

The Linguistic Research Center (LRC) at the University of Texas, founded by Winfried Lehmann in 1958, concentrated also on basic syntactic research. Efforts were made to devise reversible grammars to achieve bi-directional translation within an essentially 'syntactic transfer' approach, laying foundations for the later development of the METAL system.

At the University of California, Berkeley, the project under the direction of Sydney Lamb stressed the importance of developing maximally efficient dictionary routines and a linguistic theory appropriate for MT. This was Lamb's stratificational grammar, with networks, nodes and relations paralleling the architecture of computers. Translation was seen as a series of decoding and encoding processes, via a series of strata (graphemic, morphemic, lexemic, sememic).

There were no American groups taking the interlingua approach; US projects tended to adopt less speculative approaches despite Weaver's earlier advocacy. Interlinguas were 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 (utilizing mathematical lattice theory as a basis.) At Milan, Silvio Ceccato concentrated on the development of an interlingua based on 'cognitive' processes, specifically on the conceptual analysis of words (species, genus, activity type, physical properties, etc.) and their possible correlations with other words in texts – a forerunner of the 'neural networks' of later years.

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 the research under D.Y. Panov on English-Russian translation was on lines similar to that at Georgetown, but with less practical success – primarily from lack of adequate computer facilities. More basic research was undertaken at the Steklov Mathematical Institute by Aleksej A. Ljapunov, Olga S. Kulagina and Igor A. Mel'čuk (of the Institute of Linguistics) – the latter working on an interlingua approach that led to his 'meaning-text' model. This combined 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 (e.g. synonyms, antonyms, verbs and their corresponding agentive nouns, etc.) and a great variety of syntagmatic relations (e.g. inceptive verbs associated with given nouns, *conference: open, war: break out*; idiomatic causatives, *compile: dictionary, lay: foundations*, etc.)

Interlingua investigations were consonant with the multilingual needs of the Soviet Union and undertaken at a number of other centres (Archaimbault and Léon 1997). The principal one was at Leningrad State University, where a team under Nikolaj Andreev conceived an interlingua not as an abstract intermediary representation 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 short-lived; an exception was the project which begun in 1960 at Grenoble University (see section 5 below).

Throughout this period, research on MT became an 'umbrella' for much contemporary work in structural and formal linguistics (particularly in the Soviet Union), semiotics, logical semantics, mathematical linguistics, quantitative linguistics, and nearly all of what would now be called computational linguistics and language engineering (terms already in use since early 1960s). Initially, there were also close ties with cybernetics and information theory. In general, throughout the early period, work on MT (both theoretical and practical) was seen to be of wide relevance in many fields concerned with the application of computers to 'intellectual' tasks; this was true in particular for the research on 'interlingual' aspects of MT, regarded as significant for the development of 'information languages' to be used in document retrieval systems.

4. 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 improvements 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, and many agreed that research had reached an apparently insuperable 'semantic barrier'. In an influential survey, 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. He demonstrated his argument with the word *pen.* It 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 such problematic examples are common and 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, although later developments in artificial intelligence (and within MT on knowledge-based systems, section 7 below) have demonstrated that his pessimism was not completely justified.

For some time MT research continued vigorously – indeed many new groups were set up, particularly outside the United States and Europe – with research now focussed mainly on syntactic analysis and preliminary investigations of semantics. At the same time, the first working systems (from IBM and Georgetown) were being installed – prematurely in the view of many researchers – and the availability of poor-quality translations was being appreciated by users who wanted immediate results and did not need to have human-quality versions.

Nevertheless, the imminent prospect of good-quality MT was receding, and in 1964 the government sponsors of MT in the United States (mainly military and intelligence agencies) asked the National Science Foundation to set up the Automatic Language Processing Advisory Committee (ALPAC) to examine the situation. In its famous 1966 report[7] it concluded that MT was slower, less

[7] For a detailed analysis of the ALPAC report see Hutchins (2003)

accurate and twice as expensive as human translation and that “there is no immediate or predictable prospect of useful machine translation” (ALPAC 1966). 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 the continued support of basic research in computational linguistics. Paradoxically, ALPAC rejected MT because it required post-editing (despite the fact that human translations are also invariably revised before publication) and because it assumed the demand was for top-quality translations, even though the sponsoring bodies were primarily interested in information gathering and analysis, where lower quality would be acceptable. Although widely condemned at the time as biased and short-sighted, the influence of ALPAC was profound, bringing a virtual end to MT research in the USA for over a decade; and indirectly bringing to an end much MT research elsewhere – the funding bodies in the Soviet Union arguing that the chances of success were even smaller with their much poorer computer facilities. In addition, the ALPAC report ended the previous perception of MT as the leading area of research in the investigation of computers and natural language. Computational linguistics became an independent field of research.

5. The quiet decade, 1967-1976.

Research did not stop completely, however. Even in the United States groups continued for a few more years, at the University of Texas and at Wayne State University. But there was a change of direction. Where “first generation” research of the pre-ALPAC period (1956-1966) had been dominated by mainly ‘direct translation’ approaches, the “second generation” post-ALPAC was to be dominated by ‘indirect’ models, both interlingua and transfer based.[8]

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 translation profession. The problems of translation were equally acute within the European Community, with growing demands for translations of scientific, technical, administrative and legal documentation from and into all the Community languages. While in the United States MT was not revived for many years, in Canada and Europe (and later in Japan, and elsewhere) its need did not cease to be recognised, and development continued.

At Montreal, research began in 1970 on a syntactic transfer system for English-French translation. The TAUM project (Traduction Automatique de l’Université de Montréal) had two major achievements: firstly, the Q-system formalism for manipulating linguistic strings and trees (later developed as the Prolog programming language), and secondly, the Météo system for translating weather forecasts. Designed specifically for the restricted vocabulary and limited syntax of meteorological reports, Météo has been successfully operating since 1976 (since 1984 in a new version). The TAUM group attempted to repeat this success with another sublanguage, that of aviation manuals, but failed to overcome the problems of complex noun compounds and phrases, and the project ended in 1981.

The principal innovative experiments of the decade focused on essentially interlingua approaches. Between 1960 and 1971 the group established by Bernard Vauquois at Grenoble University developed a system for translating Russian mathematics and physics texts into French. Its ‘pivot language’ (influenced to some extent by the research of Kulagina and Mel’čuk in Russia) represented only the logical properties of syntactic relationships; it was not a pure interlingua as it did not provide interlingual representations for lexical items – these were translated by a bilingual transfer mechanism. Analysis and generation involved three levels: phrase-structure (context-free) representation, a dependency structure, and a ‘pivot language’ representation in terms of predicates and arguments. A similar model was adopted at the University of Texas during the 1970s in its METAL system for German and English: sentences were analyzed into ‘normal forms’, i.e. semantic propositional dependency structures with no interlingual lexical elements. At the same time in the Soviet Union, Mel’čuk continued his research on a ‘meaning-text’ model for application in MT (see above).

However, by the mid-1970s, the future of the interlingua approach seemed to be in doubt. The main problems identified were attributed by the Grenoble and Texas groups to the rigidity of the levels of

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[8] For more details of this period see chapters 10 to 13 of Hutchins (1986); and for technical descriptions of the main systems (TAUM Météo and Aviation, GETA-Ariane, METAL, Systran) see Whitelock and Kilby (1995)

analysis (failure at any one stage meant failure to produce any output at all), the inefficiency of parsers (too many partial analyses which had to be 'filtered' out), and in particular loss of information about surface forms of the SL input which might have been used to guide the selection of TL forms and the construction of acceptable TL sentence structures. As a consequence, it seemed to many at the time that the less ambitious 'transfer' approach offered better prospects.

6. Operational and commercial systems, 1976-1989

In the decade after ALPAC, more systems were coming into operational use and attracting public attention. The Georgetown systems had been operating since the mid-1960s. As well as Météo, 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) specifically designed for translating mathematics texts from Chinese into English.

More significant, however, were the first Systran installations. Developed by Peter Toma, its oldest version is the Russian-English system at the USAF Foreign Technology Division (Dayton, Ohio) installed in 1970. The Commission of the European Communities purchased an English-French version in 1976 and followed it by systems for translation of most other languages of the European Communities (now European Union). Over the years, the original ('direct translation') 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. Systran has been installed at numerous intergovernmental institutions, e.g. NATO and the International Atomic Energy Authority, and at many major companies, e.g. General Motors, Dornier, and Aérospatiale. The application at the Xerox Corporation was particularly noteworthy: post-editing has been virtually eliminated by controlling the vocabulary and structures of technical manuals for translation from English into French, German, Italian, Spanish, Portuguese, and Scandinavian languages.

From the early 1980s until recently, the main rival of Systran was the system from the Logos Corporation, developed initially by Bernard E. Scott as an English-Vietnamese system for translating aircraft manuals during the 1970s. Experience gained in this project was applied to the development of a German-English system which appeared on the market in 1982; during the 1980s other language pairs were developed.

At the end of the 1980s appeared the commercial METAL German-English system, which had originated from the research at the University of Texas University. After its interlingua experiments in the mid 1970s this group adopted an essentially transfer approach, with research funded since 1978 by the Siemens company in Munich (Germany). Other language pairs were later marketed for Dutch, French and Spanish as well as English and German.

Systems such as Systran, Logos and METAL were in principle designed for general application, although in practice their dictionaries have been adapted for particular subject domains. Special-purpose systems, designed for one particular environment, were also developed during the 1970s and 1980s. The Pan American Health Organization in Washington built two mainframe systems, one for Spanish into English (SPANAM) and the other for English into Spanish (ENGSPAN), both essentially by just two researchers, Muriel Vasconcellos and Marjorie León. Large tailor-made systems have been the speciality of the Smart Corporation (New York) since the early 1980s. Customers have included Citicorp, Ford, and largest of all, the Canadian Department of Employment and Immigration. The principal feature of the Smart systems is (as at Xerox) strict control of input (English) vocabulary and syntax so that minimal revision of output is needed.

During the 1980s, the greatest commercial activity was in Japan, where most of the computer companies (Fujitsu, Hitachi, NEC, Sharp, Toshiba) developed software for computer-aided translation, mainly for the Japanese-English and English-Japanese markets, although they did not ignore the needs for translation to and from Korean, Chinese and other languages. Many of these systems were 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 were popular choices), they relied on substantial human assistance at both the preparatory (pre-editing) and the revision (post-editing) stages.

Some of the Japanese systems were designed for microcomputers. But they were not the first in this market. The earliest were the American Weidner and ALPS systems in 1981 and 1983 respectively. The ALPS system offered three levels of assistance: multilingual word-processing, automatic dictionary and terminology consultation, and interactive translation. In the latter case, translators could work with MT-produced rough drafts. The system also included an early form of 'translation memory' (see section 8 below.) However, the ALPS products were not profitable, and from the mid 1980s onwards the company diverted into providing a translation service rather than selling computer aids for translators. The Weidner systems offered packages for a large number of language pairs, with its Japanese-English systems being particularly popular. In the late 1980s Weidner was acquired by Bravice but shortly afterwards the company was wound up. By this time, however, other systems for personal computers had come onto the market (PC-Translator from Linguistic Products, GTS from Globalink and the Language Assistant series from MicroTac).

7. The revival of research: 1976 to 1989

The revival of MT research during the later half of the 1970s and early 1980s was characterised by the almost universal adoption of the three-stage transfer-based approach, predominantly syntax-oriented and founded on the formalisation of lexical and grammatical rules influenced by linguistic theories of the time.[9]

After the disappointment of its interlingua system, the Grenoble group (GETA, Groupe d'Etudes pour la Traduction Automatique) began development of its influential Ariane system. Regarded as the paradigm of the "second generation" linguistics-based transfer systems, Ariane influenced projects throughout the world in the 1980s. Of particular note were its flexibility and modularity, its algorithms for manipulating tree representations, and its conception of static and dynamic grammars. Different levels and types of representation (dependency, phrase structure, logical) could be incorporated on single labelled tree structures and thus provide considerable flexibility in multilevel transfer representations. However, like many experimental MT systems, Ariane did not become an operational system (despite involvement in a French national MT project), and active research on the system ceased in the late 1980s.

Similar in conception to the GETA-Ariane design was the Mu system developed at the University of Kyoto under Makoto Nagao. Prominent features of Mu were 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 had great influence on many Japanese MT research projects and on many of the Japanese commercial systems. Since 1986, the research prototype has been converted to an operational system for use by the Japanese Information Center for Science and Technology for the translation of abstracts.

Experimental research at Saarbrücken (Germany) began in 1967, developing from the mid 1970s a multilingual transfer system SUSY (Saarbrücker Übersetzungssystem), displaying a heterogeneity of techniques: phrase structure rules, transformational rules, case grammar and valency frames, dependency grammar, the use of statistical data, etc. Its main focus was the in-depth treatment of inflected languages such as Russian and German, but other languages were also investigated, including English and French. The group also developed a 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 was the Eurotra project of the European Communities.[10] Its aim was the construction of an advanced multilingual transfer system for translation among all the Community languages – on the assumption that the 'direct translation' approach of the Communities' Systran system was inherently limited.. Like GETA-Ariane and SUSY the design combined lexical, logico-syntactic and semantic information in multilevel interfaces at a high degree of abstractness. No direct use of extra-linguistic knowledge bases or of inference mechanisms was made, and no facilities for human assistance or intervention during translation processes were to be incorporated. A major defect, readily conceded by those involved, was the failure to tackle problems of the lexicon, both

[9] Primary sources for descriptions of systems in the 1980s are the collections of King (1987), Nirenburg (1987) and Slocum (1988).

[10] Results of the project were published by the Commission of the European Communities in a series *Studies in Machine Translation and Natural Language Processing* (10 vols., 1991-1998.)

theoretically and practically. The project had involved many university research groups throughout the Community, but by the end of the 1980s no operational system was in prospect and the project ended, having however achieved its secondary aim of stimulating cross-national research in computational linguistics.

During the latter half of the 1980s[11] there was a general revival of interest in interlingua systems, motivated in part by contemporary research in artificial intelligence and cognitive linguistics. The DLT (Distributed Language Translation) system at the BSO software company in Utrecht (The Netherlands), under the direction of Toon Witkam, was intended as a multilingual interactive system operating over computer networks, where each terminal was to be a translating machine from and into one language only. Texts were to be transmitted between terminals in an intermediary language, a modified form of Esperanto. Analysis was restricted primarily to morphological and syntactic features (formalised in a dependency grammar). There was no semantic processing; disambiguation took place in the central interlingua component. The project[12] made a significant effort in the construction of large lexical databases, and in its final years proposed the building of a Bilingual Knowledge Bank from a corpus of (human) translated texts (Sadler 1989) – in this respect anticipating later example-based systems (see section 9 below).

A second interlingua project in the Netherlands, innovative in another respect, was the Rosetta project at Philips (Eindhoven) directed by Jan Landsbergen. The aim was to explore the use of Montague grammar in interlingual representations – semantic representations were derived from the syntactic structure of expressions, following the principle of compositionality; for each syntactic derivation tree there was to be a corresponding semantic derivation tree, and these semantic derivation trees were the interlingual representations. A second important feature was the exploration of the reversibility of grammars, i.e. the compilation of grammatical rules and transformations that would work in one direction for syntactic and semantic analysis of a language and in the other direction for the generation (production) of correct sentences in that language.[13] Reversibility became a feature of many subsequent MT projects.

It was in the latter half of the 1980s that Japan witnessed a substantial increase in its MT research activity. Most of the computer companies (Fujitsu, Toshiba, Hitachi, etc.) began to invest large sums into an areas which government and industry saw as fundamental to the coming "fifth generation" of the information society.[14] The research, initially greatly influenced by the Mu project at Kyoto University, showed a wide variety of approaches. While transfer systems predominated there were also interlingua systems, e.g. the PIVOT system at NEC and the Japanese funded multilingual multinational project, launched in the mid 1980s (and continuing to the present day) with participants from China, Indonesia, Malaysia and Thailand and the involvement of major Japanese research institutes.

During the 1980s many research projects were established outside North America, Western Europe, and Japan – in Korea (sometimes in collaborative projects with Japanese and American groups), in Taiwan (e.g. the ArchTran system), in mainland China at a number of institutions, and in Southeast Asia, particularly in Malaysia. And there was also an increase in activity in the Soviet Union. From 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, but there was also work under the direction of Yurij Apres'jan based on Mel'čuk's 'meaning-text' model – Mel'čuk himself had been obliged to leave the Soviet Union in 1977. This led to the advanced transfer systems FRAP (for French-Russian), and ETAP (for English-Russian). Apart from this group, however, most activity in the Soviet Union focused on the production of relatively low-level operational systems, often involving the use of statistical analyses – where the influence of the 'Speech Statistics' group under Raimund Piotrowski at Leningrad State University has been particularly significant for the development of many later commercial MT systems in Russia.

During the 1980s, many researchers believed that the most likely means for improving MT quality would come from natural language processing research within the context of artificial intelligence (AI).

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[11] For detailed coverage of the period see Hutchins (1988) and Hutchins (1994).

[12] Results were published by Foris (Dordrecht) in a series *Distributed Language Translation* (7 vols., 1986-1991)

[13] The most comprehensive account was published by the group under a pseudonym (Rosetta 1994)

[14] The Japanese investment in MT and artificial intelligence projects had a major impact (Feigenbaum and McCorduck 1984), and may well have stimulated the revival of government funding in the US (see section 9 below)

Investigations of AI methods in MT began in the mid-1970s with Yorick Wilks' work on 'preference semantics' and 'semantic templates' (i.e. means for identifying the most common or most favoured collocations of entities, concepts, activities in particular structural relationships, such as subject-verb, verb-direct object, etc.)[15] 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'.

A number of projects applied knowledge-based approaches – some in Japan (e.g. the LUTE project at NTT, and the ETL research for the Japanese multilingual project), others in Europe (e.g. at Saarbrücken and Stuttgart), and many in North America. The most important group was at Carnegie-Mellon University in Pittsburgh under Jaime Carbonell and Sergei Nirenburg, which experimented with a number of knowledge-based MT systems (Goodman and Nirenburg 1991). The basic system components were a small concept lexicon for the domain, an analysis and a generation lexicon for both languages, a syntactic parser with semantic constraints, a semantic mapper (for semantic interpretation), an interactive 'augmentor', a semantic generator producing TL syntactic structures with lexical selection, and a syntactic generator for producing target sentences. The concept lexicon and the semantic information in the analysis and generation lexicons (i.e. defining semantic constraints) were language-independent but specific to the domain. The core of the system was the interlingual representation of texts, in the form of networks of propositions, derived from the processes of semantic analysis and of interactive disambiguation performed by the 'augmentor' with reference to the domain knowledge of the 'concept lexicon'. By the end of the 1980s, the Carnegie-Mellon team had fully elaborated its KANT prototype system and was ready to begin the development of an operational knowledge-based system for the Caterpillar Corporation – also involving a company-developed controlled language, in order to improve overall quality.

Since the mid 1980s there has been a trend towards the adoption of 'unification' and 'constraint-based' formalisms (e.g. Lexical-Functional Grammar, Head-Driven Phrase Structure Grammar, Categorial Grammar, etc.) In place of complex multi-level representations and large sets of transformation and mapping rules there are mono-stratal representations and a restricted set of abstract rules, with conditions and constraints incorporated into specific lexical entries. It has led to a simplification of analysis, transformation and generation, and at the same time, the components of these grammars are in principle reversible. The syntactic orientation, which characterised transfer systems in the past, has been replaced by 'lexicalist' approaches, with a consequential increase in the range of information attached to lexical units in the lexicon: not just morphological and grammatical data and translation equivalents, but also information on syntactic and semantic constraints and non-linguistic and conceptual information.

The expansion of lexical data is seen most clearly in the lexicons of interlingua-based systems, which include large amounts of non-linguistic information. Many groups are investigating and collaborating on methods of extracting lexical information from readily available lexicographic sources, such as bilingual dictionaries intended for language learners, general monolingual dictionaries, specialised technical dictionaries, and the terminological databanks used by professional translators. A notable effort in this area was the Electronic Dictionary Research project in the late 1980s, supported by several Japanese computer manufacturing companies. This lexical activity continues to the present time. Large database and dictionary resources are available through the Linguistic Data Consortium (in the United States) and the European Language Resources Association (ELRA), an organization which has also inaugurated a major biennial series of conferences devoted to the topic – the Language Resources and Evaluation Conferences (LREC).

8. Translation tools and the translator's workstation

During the 1980s, translators were becoming familiar with the benefits of computers for their work – word processing, creation of individual glossaries, facilities for on-line access and transmission of documents. They were not, however, satisfied with the quality of output of MT systems as such. It was clear already that translators wanted to have computer aids where they are in control of processes, and not to be 'slaves' of automatic systems.[16] Many tools were developed, notably for concordancing, dictionary

[15] An account appears in Whitelock and Kilby (1995)
[16] An influential advocate of computer aids was Martin Kay (1980), a sceptic about current trends of MT research.

creation, terminology management, and document transmission. In the early 1990s, however, came the most significant development, the marketing of integrated tools in the 'translator's workstation' (or 'workbench').

Translation workstations combine multilingual word processing, OCR facilities, terminology management software, facilities for concordancing, and in particular 'translation memories'. The latter facility enables translators to store original texts and their translated versions side by side, i.e. so that corresponding sentences of the source and target are aligned. The translator can thus search for phrases or even full sentences in one language in the translation memory and have displayed corresponding phrases in the other language, either exact matches or approximations. In addition, translation workstations often provide full MT programs (for translating segments, paragraphs or whole texts), to be used or adapted by translators as appropriate. The original ideas underlying these various computer-based facilities for translators go back to the early 1980s (see Hutchins 1998).

There are now many vendors of workstations. The earliest were Trados (Translator's Workbench), STAR AG (Transit), IBM (the TranslationManager, no longer marketed), the Eurolang Optimizer (also no longer available). During the 1990s and early 2000s many more appeared: Atril (Déjà Vu), SDL (the SDLX system), Xerox (XMS), Terminotix (LogiTerm), MultiCorpora (MultiTrans), Champollion (WordFast), MetaTexis, and ProMemoria. The translation workstation has revolutionised the use of computers by translators; they have now a tool where they are in full control, using any (or none) of the facilities as they choose.

9. Research since 1989

The dominant framework of MT research until the end of the 1980s was based on essentially linguistic rules of various kinds: rules for syntactic analysis, rules for lexical transfer, rules for syntactic generation, rules for morphology, lexical rules, etc. The rule-based approach was most obvious in the transfer systems of Ariane, METAL, SUSY, Mu and Eurotra, but it was also at the basis of the various interlingua systems, both those which were essentially linguistics-oriented (DLT and Rosetta), and those which were knowledge-based (KANT). Since 1989, however, the dominance of the rule-based approach has been broken by the emergence of new methods and strategies which are now loosely called 'corpus-based' methods[17].

9.1. Corpus-based approaches

The most dramatic development has been the revival of the statistics-based approaches – seen as a return to the 'empiricism' of the first decade (section 3 above) and a challenge to the previously dominant rule-based 'rationalism' of the 1970s and 1980s[18]. With the success of stochastic techniques in speech recognition, a group at IBM (Yorktown Heights, New York) began to look again at their application to MT. The distinctive feature of their Candide system was that statistical methods were used as virtually the sole means of analysis and generation; no linguistic rules were applied. The IBM research was based on the corpus of French and English texts contained in the reports of Canadian parliamentary debates (the Canadian Hansard). The essence of the method was first to align phrases, word groups and individual words of the parallel texts, and then to calculate the probabilities that any one word in a sentence of one language corresponds to a word or words in the translated sentence with which it is aligned in the other language (a 'translation model'). The outputs were then checked and rearranged according to word-to-word transition frequencies in the target language, derived from the corpus of bilingual texts (a 'language model'). What surprised most researchers brought up in linguistics-based methods was that the results were so acceptable: almost half the phrases translated either matched exactly the translations in the corpus, or expressed the same sense in slightly different words, or offered other equally legitimate translations.

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[17] The main sources for research since 1990 are the MT Summit conferences (AMTA 1991, AAMT 1993, EAMT 1995, AMTA 1997, AAMT 1999, EAMT 2001, AMTA 2003, AAMT 2005), the AMTA conferences (AMTA 1994, 1996, 1998, 2000, 2002, 2004, 2006), the EAMT conferences (EAMT 2004, 2005, 2006), and the TMI conferences (TMI 1990, 1992, 1993, 1995, 1997, 1999, 2002, 2004). In this paper references are not included for all systems and projects. An online repository of MT literature is the *Machine Translation Archive* (http://www.mt-archive.info/).

[18] The two sides, 'empiricists' and 'rationalists', were first directly confronted at the TMI-92 conference at the University of Montreal in June 1992 (TMI 1992).

Since this time statistical machine translation (SMT) has become the major focus of many research groups, based primarily on the IBM model[19], but with many subsequent refinements. The original emphasis on word correlations between source and target languages has been replaced by correlations between 'phrases' (i.e. sequences of words, not necessarily 'traditional' noun phrases, verb phrases or prepositional phrases), by the inclusion of morphological and syntactic information, and by the use of dictionary and thesaurus resources. There has been a vast increase in the sizes of aligned bilingual databases and of monolingual corpora used in 'language models'; and the SMT approach is being applied to an ever widening range of language pairs.[20] The main centres for SMT research are the universities of Aachen and Southern California, and they have been recently joined by the Google Corporation.

The second major 'corpus-based' approach – benefiting likewise from improved rapid access to large databanks of text corpora – was what is known as the 'example-based' (or 'memory-based') approach.[21] Although first proposed in 1981 by Makoto Nagao[22], it was only towards the end of the 1980s that experiments began, initially in some Japanese groups and during the DLT project (section 7 above). The underlying hypothesis of example-based machine translation (EBMT) is that translation often involves the finding or recalling of analogous examples, i.e. how a particular expression or some similar phrase has been translated before. The approach is founded on processes of extracting and selecting equivalent phrases or word groups from a databank of parallel bilingual texts, which have been aligned either by statistical methods (similar perhaps to those used in SMT) or by more traditional rule-based methods. For calculating matches, some groups use semantic methods, e.g. a semantic network or a hierarchy (thesaurus) of domain terms, other groups use statistical information about lexical frequencies in the target language. A major problem is the re-combination of selected target language examples (generally short phrases) in order to produce fluent and grammatical output. Nevertheless, the main advantage of the approach (in comparison with rule-based approaches) is that since the texts have been extracted from databanks of actual translations produced by professional translators there is an assurance that the results will be idiomatic. Unlike SMT, there is little agreement on what might be a 'typical' EBMT model, and most research is devoted to example-based methods applicable in any MT system.

Although SMT is now the dominant framework for MT research, it is recognised that the two corpus-based approaches are converging in many respects in so far as SMT is making more use of phrase-based alignments and of linguistic data, and EBMT is making wider use of statistical techniques. As a consequence it is becoming more difficult to isolate distinctive features of the two models.[23]

Since these corpus-based approaches to MT research rely to a great extent on the availability of bilingual and multilingual text corpora (and indeed also monolingual corpora), there has been a major focus in the last decade or more on the collection and evaluation of text databases. And since statistical corpus-based approaches have also become dominant in the wider field of computational linguistics and natural language processing, linguistic resources are now central to both MT and NLP, with the collateral consequence that the MT is now returning to the 'mainstream' of computational linguistics – a position which it lost after ALPAC report (see section 4 above), and which is reflected in the coverage of the already-mentioned Linguistic Data Consortium, the European Language Resources Association, the biennial Coling conferences, and the biennial Language Resources and Evaluation Conferences (LREC).

9.2. Rule-based approaches

Although the main innovation since 1990 has been the growth of corpus-based approaches, rule-based research continued in both transfer and interlingua systems.[24] A number of researchers involved in Eurotra worked within the theoretical approach developed, e.g. the CAT2 system at Saarbrücken; and one

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[19] The first account of the IBM model was Brown et al. (1988). The 'classic' text is by Brown et al. (1993). An outline history of SMT research has been given by Ney (2005).

[20] Currently papers on SMT dominate most MT conferences; see the *Machine Translation Archive*

[21] For detailed descriptions of methods in example-based MT see Somers (1999) and the collection of articles by Carl and Way (2003).

[22] See Nagao 1984. A precursor of EBMT, not always acknowledged, was Sadler (1989) – see section 7.

[23] For one attempt see Hutchins (2005)

[24] For more details of rule-based MT research in the period see Hutchins (1994) and Hutchins (1999)

of the fruits of Eurotra research was the PaTrans transfer-based system developed in Denmark for Danish/English translation of patents.

Another example of the linguistics-based transfer approach has been the LMT project, which had begun under Michael McCord in the mid-1980s, at a number of IBM research centres in Germany, Spain, Israel and the USA. Implemented in Prolog, LMT ('Logic-programming Machine Translation') has the traditional four stages: lexical analysis; syntactic analysis of source texts, producing representations of both surface and deep (logical) relations; transfer, involving both isomorphic structural transfer and restructuring transformations; and morphological generation of target texts.

The interlingua approach continued at Carnegie-Mellon University (CMU). In 1992, it began a collaboration with the Caterpillar company on a large-scale knowledge-based and controlled-language system CATALYST for multilingual translation of technical manuals. Towards the end of the decade, the knowledge-based approach at CMU was combined with developments in statistical analysis of text corpora for the rapid prototyping and implementation of special-purpose systems (DIPLOMAT), e.g. for translation of Serbo-Croatian in military operations.

In the mid 1990s other interlingua-based systems were started, e.g., the ULTRA system at the New Mexico State University developed by Sergei Nirenburg, the UNITRAN system based on the linguistic theory of Principles and Parameters, developed at the University of Maryland by Bonnie J. Dorr (1993), and the Pangloss project, a collaborative project involving the universities of Southern California, New Mexico State and Carnegie-Mellon.

Pangloss itself was one of three MT projects supported by ARPA (Advanced Research Projects Agency), the others being the IBM statistics-based project mentioned above, and a system developed by Dragon Systems. The restitution of US government support for MT research signalled the end of the damaging impact of the ALPAC report (section 5 above).

Finally, at the end of the 1990s, the Institute of Advanced Studies of the United Nations University (Tokyo) began its multinational interlingua based MT project – based on a 'standardised' intermediary language, UNL (Universal Networking Language), for initially the six official languages of the United Nations and six other widely spoken languages (Arabic, Chinese, English, French, German, Hindi, Indonesian, Italian, Japanese, Portuguese, Russian, and Spanish) – involving groups in some 15 countries.

9.3. Speech translation

One of the most significant developments since the late 1980s has been the growing interest in spoken language translation[25], presenting the formidable challenges of combining speech recognition and synthesis, interpretation of conversations and dialogues, semantic analysis, and sensitivity to social contexts and situations. British Telecom did some experiments in the late 1980s on a spoken language phrasebook type system. However, the first long-standing group was established in 1986 at ATR Interpreting Telecommunications Research Laboratories (based at Nara, near Osaka, Japan). ATR has been developing a system for telephone registrations at international conferences and for telephone booking of hotel accommodation[26]. Slightly later came the JANUS project, under Alex Waibel at Carnegie-Mellon University, and subsequently collaborating with the University of Karlsruhe (Germany) and with ATR in a consortium C-STAR (Consortium for Speech Translation Advanced Research). The JANUS project has also focussed on travel planning, but the system is designed to be readily expandable to other domains.[27] Both the ATR and the C-STAR projects are still continuing. A third shorter-lived group was set up by SRI (Cambridge, UK) as part of its Core Language project (Alshawi 1992), and investigated Swedish-English translation via 'quasi-logical forms'. On a much larger scale has been the

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[25] Conferences have been devoted to this topic alone, e.g. *Spoken language translation: proceedings of a workshop* sponsored by the Association for Computational Linguistics and by the European Network in Language and Speech, 11 July 1997, Madrid, Spain. Most ACL conferences (e.g. Coling), AMTA conferences, and the 'MT Summit' conferences include papers on speech translation. In recent years (2004, 2005) there has also been a series of *International Workshops on Spoken Language Translation*. See also the special issue of *Machine Translation* (vol. 15, nos. 1-2, 2000) devoted to spoken language translation research. For further information on the systems mentioned in this section see articles in the *Machine Translation Archive* (http://www.mt-archive.info).

[26] The fullest description in English is by Kurematsu and Morimoto (1996)

[27] For details of the JANUS project see Levin et al. (2000)

fourth spoken language project, Verbmobil, directed by Wolfgang Wahlster and funded from 1993 until 2000 by the German government at a number of universities. The aim of Verbmobil was the development of a transportable aid for face to face English-language commercial negotiations by Germans and Japanese who do not know English fluently. As with Eurotra (section 7 above), although the basic goal was not achieved the development of efficient methodologies for dialogue and speech translation and the establishment of top-class research groups in Germany in the field were considered notable successes.[28]

More recently, spoken language projects have been set up for doctor-patient communication between English, French and Japanese (MedSLT) – based on the above-mentioned SRI research in Cambridge and Sweden – and for commercial exchange and tourism between English, French, German and Italian (NESPOLE!), also involving Catalan and Spanish (in its FAME ancillary project). Simpler is conception is the 'voice translator' developed for the US military (Phraselator), a kind of phrasebook with spoken output in a number of languages, Hindi, Thai, Indonesian, Pashto, Arabic, etc.

Loosely related to this interest in spoken language translation are a number of systems developed for the translation of television captions (or subtitles) – from English into Spanish and Portuguese, from English into Korean, English into French and Greek, etc. The particular constraints of the task include not just dealing with spoken language (transcribed and then reduced) but also the space limitations on screens and the fact that comprehension of written texts can be slower than that of speech.

9.4. Hybrid systems

The expansion of methodologies in the past decade and the introduction of new applications for automated translation processes have highlighted the limitations of adopting one single approach to the problems of translation. In the past, many MT projects were begun by researchers who saw MT as a testbed for a particular theory or particular method, with results that were either inconclusive or of limited application. It is now widely recognised that there can be no single method for achieving good-quality automatic translation, and that future models will be 'hybrids', combining the best of rule-based, statistics-based and example-based methods.

One approach is the idea of running parallel MT systems and combining the outputs: the so-called 'multi-engine' system – the group at Carnegie-Mellon University has investigated combinations of knowledge-based and example-based systems. More commonly, hybrids are currently envisaged as systems combining the statistical methods of SMT or EBMT with some linguistics-based methods (from rule-based approaches), particularly for morphological and syntactic analysis. An example is the research at Microsoft (Dolan et al. 2002). However, there are other ways to combine corpus-based and rule-based methods, as the research at the National Tsing-Hua University (Taiwan) (Chang & Su 1997) illustrates: lexical and syntactic rules can be statistically derived from corpus data and optimized by feedback from output.

9.5. Evaluation

MT evaluation has become a major and vigorous area of research activity. In the 1990s there were numerous workshops dedicated specifically to the problems of evaluating MT, e.g. Falkedal 1994, Vasconcellos 1994, and the workshops attached to many MT conferences. The methodologies developed by Japan Electronic Industry Development Association (JEIDA 1992) and those designed for the evaluation of ARPA (later DARPA) supported projects were particularly influential (ARPA 1994), and MT evaluation proved to have significant implications for evaluation in other areas of computational linguistics and other applications of natural language processing.[29] Initially, most measures of MT quality were performed by human assessments of such factors as comprehensibility, intelligibility, fluency, accuracy and appropriateness.[30] But such methods of evaluation are expensive in time and effort and so efforts have been made, particularly since 2000, to develop automatic (or semi-automatic) methods.

One important consequence of the development of the statistics-based MT models (SMT, section 9.1 above) has in fact been the application of statistical analysis to the automatic evaluation of MT

[28] A collection of papers from the project has been edited by Wahlster (2000)
[29] As seen in the already mentioned Language Resources and Evaluation Conferences, organized by ELRA.
[30] For such evaluation methods the research group at ISSCO has been particularly important – see, e.g. King et al. (2003)

systems. The first metric was BLEU from the IBM group, followed later by the NIST (National Institute for Standards and Techniques)[31]. Both measures are based on the availability of human produced translations (called 'reference texts'). The output from an MT system is compared with one of more 'reference texts'; MT texts which are identical or very close to the 'reference' in terms of word sequences score highly, MT texts which differ greatly either in individual word occurrences or in word sequences score poorly. The metrics tend to rank rule-based systems lower than SMT systems even though the former are often more acceptable to human readers. Consequently, there is no denying their value for monitoring whether a particular system (SMT or EBMT) has or has not improved over time, but there is much doubt about the general value of these metrics for comparative MT evaluations, and search for more suitable and sensitive metrics has intensified.

10. Operational and commercial systems since 1990

The use of MT systems accelerated in the 1990s. The increase has been most marked in commercial agencies, government services and multinational companies, where translations are produced on a large scale, primarily of technical documentation. This was the major market for the mainframe systems: Systran, Logos, METAL, and ATLAS. All have installations where translations are being produced in huge volumes; already in 1995 it was estimated that over 300 million words a year were being translated by such companies.

One of the fastest growing areas of use has been in the industry of software localisation.[32] Here the demand is for supporting documentation to be available in many languages at the time of the launch of new software. Translation has to be done quickly (as soon as software is to be marketed), but the documentation contains much repetition of information from one version to another. The obvious solution has been MT and, more recently, translation memories in translation workstations. A recent related development has been the localization of web pages on company sites – again, the demand is for immediate results and there is much repetition of information. Translation for website localization is growing perhaps even more rapidly than that for software products, and there are now a number of computer tools to support website developers, e.g. IBM's WebSphere.

During the 1990s, the development of systems for specific subject domains and users has also expanded rapidly – often with controlled languages and based on specific sublanguages. Controlled languages involve restrictions on vocabulary (selection of authorized terms or use of unique senses) and grammar (style norms appropriate for particular document types or subject areas), in order to reduce problems of disambiguation during translation.[33] Systems were produced by Volmac Lingware Services for a textile company, an insurance company, and for translating aircraft maintenance manuals; Cap Gemini Innovation developed a system to translate military telex messages; and in Japan, CSK developed its own system in the area of finance and economics, and NHK a system for translating Japanese news broadcasts into English. The LANT company (later Xplanation b.v.) has developed controlled language MT systems based on the old METAL system. The ESTeam company (based in Greece) concentrated initially on the 'controlled language' of manufacturers' lists of equipment components, but then expanded to more text-like documents, developing customer systems for many companies (and recently including the European Union). Most successful of all controlled language systems continues to be the previously mentioned 'Smart Translator' from the Smart Corporation.

Since the beginning of the 1990s, many systems for personal computers have appeared.[34] The increasing computational power and storage capacities of personal computers makes these commercial systems the equal of most mainframe systems of the 1980s and earlier – and in many cases, more powerful. However, there has not been an equivalent improvement in translation quality. Nearly all are based on older transfer-based (or even 'direct translation') models; few have substantial and well-founded

[31] For BLEU see Papineni et al. (2002); for NIST see Doddington (2002). Both have been applied by (D)ARPA in its evaluations of MT projects supported by US research funds.

[32] For current information about localization see the website of the Localization Industry Standards Association (http://www.lisa.org).

[33] Controlled languages developed as a research area in its own right during the 1990s (CLAW 1996; also EAMT 2003). Most proceedings of MT conferences include papers on this topic.

[34] For information about current commercial systems see the *Compendium of translation software* on the EAMT website (http://www.eamt.org/compendium.html)

dictionaries; and most attempt to function as general-purpose systems, although most vendors do offer specialist dictionaries for a variety of scientific and technological subjects. In nearly all cases, the systems are sold in three basic versions: systems for large corporations ('enterprise' systems), usually running on client-server configurations, systems intended for independent translators ('professional' systems), and systems for non-translators ('home use').

Two of the earliest systems to be sold widely on personal computers were PC-Translator (from Linguistic Products, Texas) and Power Translator (from Globalink). Globalink merged first with MicroTac (producer of the Language Assistant series), and was later acquired by Lernout & Hauspie. The original mainframe systems of Systran are now marketed not only in versions for use by enterprises, but also on personal computers for professional translators and for home use. The two mainframe systems from the Pan American Health Organization (SPANAM and ENGSPAN) are likewise now also available as PC software for independent translators. The METAL system was adapted by GMS (now Sail Labs) as the T1 system sold by Langenscheidt (mainly as a 'home' system), and as the Comprendium system sold by Sail Labs itself primarily for enterprises and professional users. IBM's LMT system was also downsized as the Personal Translator PT (sold initially by IBM and von Rheinbaben & Busch, and now by Linguatec GmbH). The Transcend system (Transparent Language) derived from the old Weidner system (via Intergraph) and is now sold by the SDL company (developers of a translator's workstation) together with Easy Translator (a 'home' system) and Enterprise Translation Server (both also originally from Transparent language Inc.)

From the former Soviet Union have come Stylus (later renamed ProMT) and PARS, marketing systems for Russian and English translation, and various other languages (French, German, Ukrainian, etc.) In Western Europe the ProMT systems were for a time marketed as the Reverso series by the Softissimo company. Other PC-based systems from Europe include: PeTra for translating between Italian and English; the Winger system for Danish-English, French-English and English-Spanish (now no longer available); and TranSmart, the commercial version of the Kielikone system (originally developed for Nokia), for Finnish-English translation.

Numerous systems for Japanese and English have continued to appear from Japanese companies; in fact, there has been an almost bewildering history of systems appearing one year, selling successfully for a brief period and then disappearing. Among the longest lasting have been products from Fujitsu (ATLAS), Hitachi (HICATS), Toshiba (initially known as ASTRANSAC), NEC (Crossroad, previously Pivot), Cross Language (formerly Nova: the Transer series), and Sharp (Power E/J, now Honyaku Kore-Ippon). But there are also good-quality US products, the LogoVista system from the Language Engineering Corporation (later absorbed by LogoMedia), the Tsunami and Typhoon systems from Neocor Technologies (also bought by Lernout & Hauspie, and now no longer available), as well as systems from WebSphere and Systran. Systems for English to and from Korean came only late in the 1990s (e.g. Systran, LogoMedia, TranSphere, etc.)

There are now a number of systems for Arabic (notably the Sakhr, Cimos and AppTek systems), and a growing number of systems for Chinese (e.g. Transtar, LogoMedia, Systran, TranSphere) – with the spotlight from US government agencies there is now much encouragement for the developers of other systems for these two languages based on more recent research.

Systems for language pairs other than English as either source or target have been less prominent. However, most of the American and European companies mentioned above do offer systems for such pairs as French-German, Italian-Spanish, Portuguese-Spanish, and there are a number of system offering Japanese-Chinese, Japanese-Korean, etc.

Despite all this commercial activity there are many other languages which have been poorly served. There is still a lack of commercial systems for most languages of Africa, India, and South East Asia – and those that do exist are not easily accessible.

The most recent development has been the incorporation in a number of PC systems of means for speech input of sentences (or texts) for translation, and for spoken output of the results. (These are not, of course, true speech translation systems which, as indicated in 9.3 above, have yet to reach operational implementation.) Undoubtedly based on the improvement reliability and ease of use of speech recognition systems, these products began appearing during the last years of the 1990s. One of the most recent examples is ViaVoice Translator from IBM, combining its LMT automatic translation system and its successful ViaVoice dictation system.

The examples above of company acquisitions, the demise of old systems and the regular appearance of new systems and new versions of old systems illustrate that commercial change is as much part of MT history as research developments, and that failure is now as much a feature of MT as of any other business. The first instance was the Weidner/Bravice collapse (section 6 above). Many small companies have come and gone during the last two decades. But there have also been examples of apparently thriving companies which have not been able to maintain their position in the market. The Logos Corporation rivalled Systran Inc. with its 'enterprise' systems in the 1980s, but was sold in the late 1990s to another company (globalwords AG), and has now gone completely. The Comprendium system offered good quality systems for large corporations during the 1990s (based in part on the METAL system), but it too has gone. A well-publicised (even notorious) example is the story of Lernout & Hauspie. This firm made its reputation in speech recognition products. In early 1998 it decided to expand into the MT area and purchased a number of companies (Globalink, Neocor, AppTek, Sail Labs, AILogic), with the aim of integrating systems for a wide range of languages as one product (iTranslator). At the same time it acquired interests in translation services (Mendez SA) and received financial support from government sources in Belgium. But the company overstretched itself, got into financial difficulties (including some alleged irregularities) and went into liquidation in late 2001. Some of the companies it had acquired managed to re-establish themselves (e.g. AppTek and, briefly, Sail Labs) but in other cases the market has lost competent and previously well-received systems (e.g. those of Globalink and Neocor).

This fragility in the MT market may explain why it has not been until after 2000 that commercial systems based on SMT methods have appeared. In contrast to the well-established rule-based methods, statistical approaches have perhaps been seen as too risky or perhaps to be premature, as SMT research has been active for little more than a decade. Nevertheless, there are now SMT systems on the market (from Language Weaver), significantly for language pairs which attract government support (Arabic-English, Chinese-English, Hindi-English, Somali-English) and which have represented particularly difficult challenges for rule-based approaches. Recently, Language Weaver has been joined by Google, whose vast text resources are particularly appropriate for SMT approaches – again, the language pairs currently on test are Arabic-English, Chinese-English, Japanese-English, etc.[35]

11. MT on the Internet

Since the mid 1990s, the Internet has exerted a powerful influence on MT development. First, there has been the appearance MT software products specifically for translating Web pages and electronic mail messages offline (i.e. on receipt or before sending). Japanese companies led the way, but they were followed quickly elsewhere. Second, beginning in the mid 1990s, many MT vendors have been providing Internet-based online translation services for on-demand translation. The pioneer was the service offered in France by Systran on the Minitel network during the 1980s, but the idea was not taken up more widely until CompuServe introduced a trial service based on the Transcend system in 1995. Shortly afterwards, the now best known service Babelfish appeared on the AltaVista site offering versions of Systran to translate French, German and Spanish into and from English (and later many other language pairs). It was followed by numerous other online services (most of them free of charge), e.g. Softissimo with online versions of its Reverso systems, LogoMedia with online versions of LogoVista and PARS. Some services offer post-editing by human translators (revisers), at extra cost, but in most cases the results are presented untouched in any way. Many of them can be accessed through 'MT portals', i.e. independent services offering a range of translation systems from one or more system vendors.

The translation quality of online MT services is often poor, inevitably given the colloquial nature of many source texts, but these services are undoubtedly filling a significant (and apparently widely acceptable) demand for immediate rough translations into users' own languages for information purposes – the function offered by earlier mainframe systems in the 1960s, often ignored then and in later years. Despite their widespread use and the obvious impact they have on the public 'image' of MT – often negative – online MT services have been largely neglected by most MT researchers (Gaspari 2004).

A particular challenge for MT is the use of online systems for translation into languages which users do not know well. Much of the language used on the Internet is colloquial, incoherent,

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[35] The 'ultimate' aim of Google appears to be the development of multiple MT systems to support worldwide access to all the texts on its databases.

'ungrammatical', full of acronyms and abbreviations, allusions, puns, jokes, etc. – this is particularly true for electronic mail and the language of chatrooms and mobile telephones. These types of language use differ greatly from the language of scientific and technical texts for which MT systems have been developed. However, recently a UK company Translution has released a system for online translation of emails (as well as web pages) between English, French, German, Italian and Spanish. The demand must be substantial, and no doubt more systems will come in the near future.

The Internet has also encouraged somewhat less scrupulous companies to offer online versions of electronic dictionaries (or phrase books) as 'translation systems'. Anyone using such products for translating full sentences (and text) is bound to get unsatisfactory results – although if users do not know anything of the target languages they will be unaware of the extent of the incomprehensibility of the results. Such systems are undoubtedly damaging for the perception of MT as a whole; as damaging as the failure of some vendors and some service providers to stress that their fully automatic systems (whether online or not) produce only rough versions that should always be used with caution.

12. Conclusion

It is now clear that different types of MT systems are required to meet widely differing translation needs. Those identified so far include the traditional MT systems for large organisations, usually within a restricted domain; the translation tools and workstations (with MT modules as options) designed for professional translators; the cheap PC systems for occasional translations; the use of systems to obtain rough gists for the purposes of surveillance or information gathering; the use of MT for translating electronic mail and Web pages; systems for monolinguals to translate standard messages into unknown languages; systems for speech translation in restricted domains. Some of these needs are being met or are the subject of active research, but there are many other possibilities, in particular combining MT with other applications of language technology (information retrieval, information extraction, summarization, etc.) As MT systems of many varieties become more widely known and used, the range of possible translation needs and of possible types of MT systems will become more apparent and will stimulate research and development in directions not yet envisioned.

13. References

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