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MACHINE TRANSLATION

Machine translation, or automatic translation as it is sometimes called, is used here in the sense of translation from one natural language to another by computer. After some general considerations about translation, the challenges it offers, and the computer as a tool, the evolution of machine translation from the first conception to the present will be traced in three phases, ending with a discussion of a number of operating systems and a brief survey of current research.

Translation

Machine translation (MT) can be justified only if it is better, faster, or cheaper than human translation (HT); so comparisons between the two are in order, not only because economics will determine which wins out but more importantly because a better understanding of each can come from study and research into the other. HT may not be the best model for MT but it is the only one we have, so linguists and computer experts started from there. Up to now most of the work has been directed toward the translation of scientific and technical texts where the stylistic complications are less, speed is at a premium, and above all, there is more money.

Considering HT, let us ask two questions whose answers may seem surprising. First, what are the qualities that make a good translator of scientific and technical material? Experts generally agree that they are, in order of importance; (1) knowledge of the technical field of the text; (2) native command of the language to be translated into; and (3) knowledge of the language to be translated from. Intuitively, one would expect the order to be exactly the reverse.

Second, how does a translator work? The commonly accepted model, that he takes the words and grammar of Language A and replaces them with words and grammar of Language B, is simply wrong. No translator works that way. What he really does is to read or listen to the text in Language A to get the idea—and it is here that a knowledge of the technical field is essential—then he expresses the same meaning in Language B. Meaning is the substance of communication. Words and grammar are arbitrary conventions which have evolved over the years and differ from one language to another.

MEANING

Meaning (semantics) involves the sum total of all human experience, including its interpretation. For an individual it is the experiential environment shared with people of the same culture—what has been called "the encyclopedia in your head." Each word in our language carries an aura of associations which we have to sense in order to interpret it: word + associations = meaning. There are never two completely synonymous words in the same language—all their associations would have to be identical. Likewise, no word is an exact translation of any word in another language. That is why a translator can work only with ideas, i.e., meanings. He is able to equate words plus associations with meanings in two languages. His translation process is: word in Language A + associations = meaning = word in Language B + associations.

We tend to think of reading or hearing as linear phenomena, the one in space, the other in time, but the process of understanding is far from linear. The first few words we see or hear tell us in general what meaning to expect. We are constantly racing ahead in our minds, predicting what the author is going to say, checking to see that our prediction was right, trying one or more other interpretations if we were wrong. It is a curious fact that we are able to use this error correction device simultaneously on several levels. In a conversation we predict successive sounds, words, phrases, and sentences; filling in gaps caused by noise, strange accent, or careless speech until they make sense. Likewise in written text we correct misprints without even seeing them and fix up missing words or transposed lines as best we can, always on the basis of what "makes sense." Making sense; that is, having a meaning that fits the total context, is the ultimate criterion.

Simmons shows the implications for the computers of the 1960s:

> Evidence from psycholinguistic studies indicates that humans can select a particular sentence interpretation only on the basis of probabilistic cues that result from linguistic and environmental contexts. No computer system yet planned is capable of dealing with this level of subtlety *(1)*.

In other words, we humans hear what we expect to hear; we see what we expect to see. But we are always alert for any cue that indicates that our expectation was wrong. In that case, we take a second look at the text or play the spoken words back in our auditory memory and try a new interpretation that will make better sense.

But perhaps a computer does not have to understand the meaning of the text it is called upon to translate. After all, the "consumer" of the translation is a human with a brain. Maybe the computer can just translate words—a sort of automatic bilingual dictionary, giving several meanings if necessary, from which the human can choose. That is the way MT started, but the automatic dictionary is a poor crutch. It reminds one of the way foreign languages are frequently taught to humans—you give the student the translations of a few words and some grammar rules and he tries to work out the meaning of simple sentences. Then he tries to compose some. He is working from words to meaning and it is a frustrating process, slow and full of mistakes. This is not at all the way he learned his own language. According to Macnamara,

> . . . infants learn their mother tongue by first determining, independent of language, the meaning which a speaker intends to convey to them and then working out the relationship between the meaning and the expression they heard. In other words, the infant uses meaning as a clue to language, rather than language as a clue to meaning *(2)*.

Unfortunately, what Simmons wrote in 1966 is still true. Computers cannot predict meaning. This puts MT at a disadvantage with respect to each of the three requirements for a good human translator. With respect to the first, knowledge of the field, up to now no one has been able to build into a computer knowledge of a technical field such as a human specialist would have. As to command of human languages, native and foreign, involving as it does not only vocabulary and grammar but a whole encyclopedia of past experience of the individual and the race, this, too, is in the speculative future for computers.

Before going on, the matter of getting an input to a computer should be mentioned. From a written text it is a relatively easy matter of keyboarding or of optical recognition, but what of speech? To use the human analogy again, a baby hears and imitates the sounds its mother makes. It learns to map speech sounds into words and sentences with the aid of meaning. Macnamara says ". . . the main thrust in language learning comes from the child's need to understand and to express himself *(2)*.

Once again the computer has to work with less information than the human has. In normal speech there are no individual sounds or groups of sounds corresponding to letters or syllables or written words in any absolute sense. There are no pauses corresponding to the spaces between written letters or words.

Moreover, humans are able to interpret physically different combinations of sounds pronounced by different people with different voice quality and different accents as one and the same word. We do it, once again, by relying on the broad experiential context as well as the other words in the sentence. From this we predict the probable meaning, and decide what the individual words are.

Someone has likened the normal flow of speech to an omelette which you have to unscramble to find the individual words. Human beings do it effortlessly and unconsciously, but to get an input from speech to a computer requires a translation process analogous to that from one written language to another.

Though the terminology of some proponents of MT seems to imply that they are processing the spoken language, the fact is that no one has been able to get an input from speech to a computer. As Otten says,

> The optimism expressed in the mid and late fifties that speech recognition is primarily a matter of developing faster and more powerful computers has been replaced by the realization that we know too little about speech even to specify the computer one would like to have, much less to speak of programming it *(3)*.

Under the circumstance, research has concentrated on translating the written language, and that has provided a sufficient number of challenges; for instance, the resolution of ambiguity.

AMBIGUITY

When the meaning of a word or group of words is unclear, or when they have multiple meanings, they are said to be ambiguous. Rhodes *(4)* demonstrates the inevitability of ambiguity as follows: The human brain can engender 10^{100} concepts, far more than the 10^{80} elementary particles in the universe. An outside estimate for the number of words an individual might know is 10^6 or 10^7. So we cannot hope to coin a word for every new concept but are doomed to a situation where almost every word must bear several connotations.

Ambiguity, like its antonym, redundancy, is not only unavoidable, it plays a constructive role in communication. It allows one to remain vague when being precise would be wrong or harmful. Nevertheless, it may stand in the way of knowing exactly what the author meant. Redundancy helps resolve ambiguity. It makes assurance doubly sure. It is essential to get a message through in the presence of noise. In HT and in MT every available cue to the meaning must be used. The goal is to make the translation contain exactly the same amount of ambiguity and redundancy as the original. Otherwise *traduttore—traditore,* as the Italians say, translator—traitor.

Ambiguity can exist on the word, the syntactical, or the meaning level. Word ambiguity occurs mainly in isolated words. In Webster's Second Edition *(5),* "head" has fifty-one different meanings, thirty-six as a noun, eleven as a verb, and four as an adjective. Most word ambiguity disappears as soon as the word is in context.

Syntactical ambiguity occurs when two or more interpretations of the sentence structure are possible. An example is "Time flies." The ambiguity may not be immediately evident, but add a second sentence, "You cannot." Now the meaning of the first is changed but both are still ambiguous, as is shown by adding a third sentence, "Their flight is too swift." In any communication situation, syntactical ambiguity, like word ambiguity, is usually resolved by context. The speaker or writer usually makes sure that his meaning is clear. He should know his audience and be specific enough in his references to inform but not to insult them.

Semantic ambiguity is illustrated by the following:

I called you Friday.
I will call you Friday.

From the tense of the verb in the first sentence we know the day of the call was the previous Friday; from the tense in the second, the following Friday; but in order to know the date of either "Friday" we would have to know when the sentence was spoken or written. This is a first semantic ambiguity. There is a second. Perhaps the speaker is Robinson Crusoe. Now a whole new range of possible interpretations for both sentences comes to mind. Once again context, the total context, can resolve ambiguity.

Semantic ambiguity is compounded in translation. The area of meaning of a word in one language does not correspond exactly to the area of meaning of any one word in the other. Some Eskimo dialects have a number of words for "snow" depending on its quality. In English should we translate them all simply as "snow" or should we "annotate" each occurrence by adding an adjective like "grainy, flaky, mixed with water?" Obviously a lot has to be known about Eskimo as well as English usage to handle "snow."

If there are ambiguities, the translator tries to judge whether they are a function of differences in the two languages and cultures, in which case he tries to find the best way to resolve them in his translation, or whether they are purposeful on the part of the author, in which case he tries to find the right wording to retain them.

COMPUTERS AND PROGRAMMING

The "machines" of machine translation are a combination of hardware, which includes input and output devices plus one or more central processing units and memories, and software, which includes all the instructions to the computer. As to the hardware, its development has carried it far beyond the ken of the average educated individual. Computers were originally designed to compute, i.e., to work with numbers. In order to handle text processing, new I/O devices, new logic, and larger, faster memories were necessary.* These have been introduced in such variety that hardware is no longer a problem; almost everything needed for MT can be had "off the shelf." Fortunately the users of this advanced technology need not understand the detail of its design or operation.

Programming is a different matter. We have not yet reached the point where there are standard programs which will run translations and linguistic research problems but we have come a long way since the beginning of MT. In Winter 1957-1958, Yngve *(6)* at M.I.T. designed a programming language, which he called COMIT, for the use of linguists working on MT. This language was described by Sammet in 1972 as "The first realistic string handling and pattern matching language; most of its features appear (although with different syntax) in any other language attempting to do string manipulation." The influence of COMIT can be seen in most of the languages used for automated language processing, particularly SNOBOL, EOL, L^6, and PL/1. Advances in programming have to some extent kept pace with advances in hardware, but Sammet can still conclude, "We have not solved the problem of how to bridge the gap between what the person wants to say about solving his problem and the physical circuits in the machine" *(7)*.

These few comments on computers and programming will serve primarily to indicate the importance of the subject. For further information, see the appropriate entries. We shall now go back to the beginning of MT and trace the three phases of its evolution from 1946 to the present.

Phase I: 1946-1952

The earliest known suggestion that a machine could be made to translate languages was a patent application filed in Moscow in 1933 by Smirnov-Troyanski.

*It is understood that language is processed in a computer in coded patterns of electric impulses, not in its original form.

He claimed a method of simultaneous translation into several languages but unfortunately his scheme was visionary. Digital computers such as he would have needed to carry it out were not available for another 10 years during World War II. In 1946 Warren Weaver, secretary of the Rockefeller Foundation, and A. Donald Booth, director of the Birkbeck College Computation Laboratory in London, tentatively discussed the possible application of computers to the translation of languages. Weaver brought up the idea, developed 3 years later in a memorandum, "Translation" *(5),* that different languages are just different codes, the meaning of which could be discovered by breaking them with a computer as had been done during the war. Booth stressed the more immediately feasible goal of storing a bilingual dictionary in the computer memory and translating scientific articles word for word.

In the next few years Booth with others, notably Kathleen H. V. Britten at the Institute for Advanced Study in Princeton and Richard H. Richens of the Commonwealth Bureau of Plant Breeding and Genetics, Cambridge, England, did some experimenting. Booth and Richens worked out a simple word for word translation program in 1947. The deficiencies of this approach will be clear to anyone who has tried to puzzle out the meaning of a text in a language he does not know by looking up the words in a dictionary. Still, it was a start.

In 1948 Richens suggested an improvement. An ordinary dictionary, he reasoned, contains only the basic forms of words, the nominative singular of nouns, the infinitive of verbs; yet the case and number of noun forms and the person and number of verb forms are essential to real comprehension. But all the possible forms of every word far exceeded the memory capacity of the computers of the time. Therefore, he proposed that two bilingual dictionaries be put in the computer, a stem dictionary and an endings dictionary. The computer would take each successive word in the Language A text and look it up. If there was no match with any stem, it would "strip off" a letter at a time from the end until there was. Then it would store the corresponding B stem. Next it would look up the "stripped off" letters in the endings dictionary and finally combine the appropriate B endings with the B stem to give the correct translation.

On July 15, 1949 Weaver sent his "Translation" to some 200 of his acquaintances. To most it was the first suggestion they had ever heard that a computer might be used to translate languages. Because of its initial and enduring importance as a prediction and a program, it will be summarized here at some length:

The multiplicity of languages impedes cultural exchange and international understanding, he said, but electronic computers may be able to contribute to the solution of the worldwide translation problem. The fact that computers can break codes leads one to suppose that there are certain invariant properties which are, "to some statistically useful degree, common to all languages."

Weaver then quotes from a 1947 letter of his own to Norbert Wiener, the mathematician:

> Recognizing fully, even though necessarily vaguely, the semantic difficulties because of multiple meanings, etc., I have wondered if it were unthinkable to design a

> computer which would translate. Even if it would translate only scientific material (where the semantic difficulties are very notably less), and even if it did produce an inelegant (but intelligible) result, it would seem to me worth while.
>
> Also knowing nothing official about, but having guessed and inferred considerably about, powerful new mechanized methods in cryptography—methods which I believe succeed even when one does not know what language has been coded—one naturally wonders if the problem of translation could conceivably be treated as a problem in cryptography. When I look at an article in Russian, I say: "This is really written in English, but, it has been coded in some strange symbols. I will now proceed to decode."

Wiener in reply epitomized the semantic problem:

> I frankly am afraid the boundaries of words in different languages are too vague and the emotional and international connotations are too extensive to make any quasimechanical translation scheme very hopeful.

Booth and Richens, says Weaver, were not concerned at the time with multiple meaning, word order, idiom, etc., but only with the problem of mechanizing a stem dictionary. A mechanized dictionary cannot hope to be useful for literary translation

> in which style is important and in which problems of idiom, multiple meanings, etc. are frequent. . . . Large volumes of technical material might be usefully, even if not at all elegantly handled this way. . . . In mathematics . . . one can very nearly say that each word . . . has one and only one meaning.

The problems of multiple meaning of general terms such as "fast" meaning "rapid" or "motionless," he suggests, can perhaps be decided by consulting a certain number of adjacent words, i.e., the context.

We must go so deeply into the structure of languages as to come down to the level where they exhibit common traits:

> For widely varying languages, the basic logical structures have important common features. . . . Think, by analogy, of individuals living in a series of tall closed towers, all erected over a common foundation. When they try to communicate with one another, they shout back and forth, each from his own closed tower. It is difficult to make the sound penetrate even the nearest towers, and communication proceeds very poorly indeed. But, when an individual goes down his tower, he finds himself in a great open basement, common to all the towers. Here he establishes easy and useful communication with the persons who have also descended from their towers.
>
> Thus may it be true that the way to translate from Chinese to Arabic, or from Russian to Portuguese, is not to attempt the direct route, shouting from tower to tower. Perhaps the way is to descend, from each language, down to the common base of human communication—the real but as yet undiscovered, universal language—and then re-emerge by whatever particular route is convenient.

Statistical semantic studies should be undertaken as a basis for the cryptographic approach, Weaver felt:

> "Perfect" translation is almost surely unattainable. Processes, which at stated confidence levels will produce a translation which contains only X percent of "error" are almost surely attainable.

This memorandum triggered widespread response varying from one man who scoffed, "Rubbish," to the enthusiasm of Vannevar Bush, president of the Carnegie Institution of Washington, "I think the job could be done in a way that would be extraordinarily fascinating." Theoretical research was started by Yehoshua Bar-Hillel at the Research Laboratory of Electronics of the Massachusetts Institute of Technology. Erwin Reifler, a German-born associate professor of Chinese at the University of Washington started work on the translation of German and Chinese into English; William E. Bull, professor of Spanish at the University of California at Los Angeles began studying Spanish to English possibilities; Victor A. Oswald, Jr., professor of German, and Stuart L. Fletcher, Jr., a teaching assistant, also at UCLA, worked on German to English. But Russian to English MT, which was to become the major concern in the United States because of the importance of its scientific and technical literature and because few Americans could read it, did not get under way for a few more years.

The prolific Reifler in 1950 started a mimeographed series of memoranda "Studies in Mechanical Translation, MT," which he sent to all those he knew to be interested in MT. He was the first to suggest human intervention in the computerized translation process: a "pre-editor" would remove ambiguities by tagging words in the input text to indicate which of the many dictionary meanings was appropriate and a "post-editor" would polish up the style before final typing. Later he and others would suggest that authors should "write for MT" using a simplified and unambiguous vocabulary and syntax easily translatable by computers. Both the "pre-editor" and "writing for MT" were soon dropped as impractical. Editing the output of MT before publication was and is accepted today as desirable, just as it is for HT.

Bar-Hillel at M.I.T. became in 1951 the first full-time worker in the field. He soon wrote a paper describing the current state of MT research *(9).* The first published paper also appeared in 1951. This was by Oswald and Fletcher *(10).* Convinced that German word order must be rearranged for an adequate translation to English, the authors proposed tentative ways of doing it.

The initial phase of MT started by Booth and Weaver may be said to have ended with a conference at M.I.T. in the spring of 1952, financed by the Rockefeller Foundation and organized by Bar-Hillel, who invited all those known to be active in MT. The plan was to "contribute materially to progress in the field by bringing language and computer experts together in the same room, thus giving them a chance to learn each other's language as well as the power and limitations of each other's techniques." A start was made in learning to communicate, but the strongest impression was the disappointment of each group at the inability of the other to solve problems that looked simple. The computers of the day had not the capacity to cope with whole dictionaries, grammars, and large blocks of text, nor were there suitable programming languages for processing text. Nor was the linguists' theoretical and practical understanding of translation adequate to write the programs. Nevertheless, the direction that research should take was clear. Word frequency and translation studies for individual languages and for separate scientific fields would lay the groundwork for automatic dictionaries once sufficiently large memories became available, but since this seemed to be years away and since there was a clear trade-off between memory size and logical operations, more analysis of syntax was to be started immediately as a basis for more extensive logical operations.

The conference also saw the beginning of a continuing debate between the proponents of individual translation programs for pairs of languages and those in favor of an unambiguous, logical, intermediate language (sometimes also called a pivot, information, logical, or interlanguage) into which a text of the "source" language would first be translated and from which it could then be retranslated into any "target" language. Later it was to be pointed out that such an intermediate language would also be useful, if not essential, for information retrieval.

Phase II: 1952-1966

The M.I.T. conference had its intended effect of stimulating further activity in MT. In September 1952 the first discussion of MT was held at the Seventh International Congress of Linguists in London with forty present. The rate of publication picked up. Through 1952 there had been only one published paper, that by Oswald and Fletcher; in 1953 there were nine; in 1954, eight more; and for the next 10 or 15 years a gradually increasing number each year.

In March 1954 there appeared the first issue of a journal, *MT (Mechanical Translation),* edited and published by William N. Locke and Victor H. Yngve at M.I.T. with National Science Foundation support. In the same year the Ph.D. thesis of Anthony Oettinger *(11)* was accepted at Harvard University, the first of uncounted numbers of masters and doctors theses at many universities over the succeeding years. Oettinger described experiments in which a computer operating as an automatic Russian dictionary produced rough translations of technical texts which could be used effectively by specialists in the subject matter.

In 1954 also, MT "went public." Leon Dostert and Paul Garvin of Georgetown University worked with Peter Sheridan of IBM to prepare a public demonstration. A number of Russian sentences with a vocabulary of 250 words and their English equivalents were stored in an IBM 701 computer. Six rules of syntax were programmed to convert the Russian to English grammar. The result made headlines. The demonstration was a *tour de force* like a later one at the New York World's Fair in 1964. Neither could be generalized into operational MT. As Shreider wrote

> The first experiments in mechanical translation were started early in the fifties using very short texts; moreover, the translating algorithms were specially tailored just to these short texts, and it was for these reasons that demonstration effect was attained. . .. This illusion was due not only to the seemingly convincing demon-

> strations of machine translation capabilities referred to above, for the fiction of these demonstrations (supported by inordinately glib-tongued journalists) was not difficult to unmask. Nor had these demonstrations any significant impact in the scientific community. Much more serious is another illusion which was supported by many investigators. This is the illusion that the problem at hand was of an engineering nature, that machine translation had already been resolved in principle, and that to be implemented in practice, only considerable organizational efforts were required *(12).*

The first book, *Machine Translation of Languages* by Locke and Booth *(13),* appeared in 1955. In the same year experiments on the BESM computer at the Institute of Precision Mechanics and Computation of the USSR Academy of Sciences indicated that "machine translation had a good probability of success." Two years later a Russian translation of *Machine Translation of Languages* was published in Moscow and the Russian effort, which was eventually to outdistance that in the United States, was under way.

In October 1956 the second MT conference was held at M.I.T., this time with NSF support. Some thirty papers from the United States, Canada, and the United Kingdom were presented, and Panov sent a paper from the USSR Academy of Sciences where the early Russian work was concentrated. He published *Avtomaticheskij Perevod (Automatic Translation)* in 1956 and at about the same time *Voprosy Iazykoznaniia (Problems of Linguistics)* started a regular section on MT. Work spread rapidly in the United States, England, and the USSR, and research was started in France, Italy, and Scandinavia. From then on conferences, reports, published papers, and books multiplied. Only a few can be mentioned.

In 1958 the first All Union Conference on MT in Moscow brought forth seventy-one papers *(14);* the Institute for Precision Mechanics and Computational Technology of the Academy of Sciences, Moscow, started publication of a *Trudi, Machinii Perevod (Machine Translation);* and Booth, Brandwood, and Cleave *(15)* published *Mechanical Resolution of Linguistic Problems.* In France, Emile Delavenay published *La Machine à Traduire* in 1959 *(16),* and in the same year a Conference on Mathematical Linguistics in Leningrad dealt largely with MT.

In the United States an excellent, though occasionally caustic survey of the first years of MT "The Present Status of Automatic Translation of Languages," was published by Bar-Hillel in 1960 *(17).* Table 1 is a summary of his statistics. There was also some work in France, Germany, Poland, Hungary, Czechoslovakia, Switzerland, India, and a few more countries.

Also in 1960 came the first move toward the creation of a professional society for MT in the United States. An Ad Hoc Committee on Professional Problems in Machine Translation and Related Areas was set up, and this in turn recommended the formation of an Association for Machine Translation and Computational Linguistics (AMTCL). The association was founded in 1962 and in 1964 started publication of a newsletter, the *Finite String* (a reference to the strings of characters that make up languages). President David G. Hays in the first issue wrote, "The title of our association is a claim that this field of knowledge [computational linguis-

TABLE 1

STATUS OF MT, 1960

MT groups	Individuals	Annual expenditures ($)
14, US	~150	~1,500,000
3, England	~26	?
10, USSR	~300	~1,500,000
1, Milan	?	?
1, Jerusalem	4	4,000
29	~480	~3,004,000

tics], necessary for MT, is broader in application; in effect, we claim the disciplinary integrity of knowledge underlying all linguistic applications of digital computers." He thus gave a foretaste of the evolution MT was to undergo in the next few years, broadening, fusing with automatic language processing, and to a large extent losing its identity in the field of computational linguistics.

As the money being expended on MT grew into annual millions, the sponsoring agencies in the United States decided that regular meetings of the research groups would result in better communication and faster progress. A National Symposium on Machine Translation in 1960 was followed by a number of conferences sponsored by Wayne State University, each devoted to a theme: dictionary design and grammar in 1960, grammar codes for Russian-English dictionary entries in 1961, syntactic analysis in 1962, and semantic analysis in 1965.

The First International Conference on Machine Translation of Languages and Applied Language Analysis was held in 1961 at the National Physical Laboratory at Teddington, England. Other international conferences have continued to be held at frequent intervals in various countries; for example, the Second International Conference on Automatic Language Processing held in 1967 at Grenoble and the 1969 International Congress on Computational Linguistics in Stockholm.

As MT research continued and became more widespread, two trends could be seen; the first was on the theoretical level, a realization that an understanding of human expression requires an understanding of thought; semantics (meaning) could no longer be left to philosophers; too many ambiguities could be resolved only on this level. The second trend, linked with the first, was organizational, the growth of research by teams including people from outside linguistics and computer science, anthropologists, philosophers, psychologists, physiologists, communications specialists, mathematicians, and systems engineers, each bringing the insights of his own background.

The 1960s in the United States and in the USSR were stimulating times for all science, and MT was accepted as a fledgling science. English was the language of the largest number of scientific publications; Russian was second. Reading each other's publications was of the highest priority. In the United States and in the

United Kingdom few could read Russian and many translations were published, whereas in the USSR a knowledge of English was widespread and important books and journals were as likely to be reprinted in the original as to be translated.

In spite of a scarcity of competent translators for scientific and technical fields, NSF was able by 1965 to support the production of cover to cover translations of thirty-nine Russian journals. The Joint Publications Research Services (JPRS) had been set up in 1957 to service government agencies with translations,* and though the quality of translation and reproduction was poor and the service slow, a real need was met in many fields, including one called Foreign Developments in Machine Translation and Information Processing.

At the same time there was a rapid growth of commercial translating services and of commercially published translations of Russian books and journals. There were inevitable complaints at paying $40 for a translated book whose Russian original cost $2, or $150 to $350 for a subscription to a translated journal, but quality translation has always been expensive. It takes time, too. It was not unusual for a translated book to come out 2 or 3 years after the original, because the publishing process cannot start until the translation is done and edited. For journals a time lag of a few months was considered excellent. A year was not uncommon. The impetus given MT by these prices and these delays was considerable, though the growing availability of important books and articles in translated form eventually became a counterargument and one cause of a disillusionment with MT which set in in the middle 1960s in the United States.

Twenty million dollars had been poured into MT projects in the United States and abroad, but the goal of good, cheap, fast translations kept receding. At first any "intelligible" translation from a computer was an achievement, but for most people "intelligibility" is not enough. "Naturalness" has always been the goal of HT—a translation so good that people will not know it has been translated—but it is a goal rarely achieved and for MT it is usually conceded to be a remote possibility. In the middle 1960s, then, MT could produce intelligible but awkward translations of selected scientific and technical passages. To be acceptable for most purposes they had to be edited for clarity and style as HT is, and they often took longer and cost more than HT because for MT more editing was required.

Some time in 1963 or 1964 the sponsoring agencies led by NSF decided that the $20 million they had invested in MT had bought little in the way of practical results and that the end was not in sight. Leland Haworth, director of NSF, requested the National Academy of Sciences to set up a committee to advise NSF, the Department of Defense, and the Central Intelligence Agency on research and development in the general field of mechanical translation of foreign languages. The committee, under the chairmanship of John R. Pierce, a communications engineer from the Bell

*As of 1973, JPRS had in stock more than 50,000 translations of reports published since 1963 in Communist or Socialist countries, about half in scientific or technical fields. These are available to the public through the Clearinghouse for Federal Scientific and Technical Information and the U.S. Government Printing Office.

Telephone Laboratories, was called the Automatic Language Processing Advisory Committee (ALPAC) and it started work early in 1964. Members were John B. Carrol, an educational statistician; Charles F. Hockett, a linguist who resigned late in 1964 and was replaced by Eric P. Hamp, another linguist; David G. Hays, a linguist-philosopher; Anthony G. Oettinger, an applied mathematician; and Alan Perlis, a computer expert. The executive secretary was A. Hood Roberts, a linguist. ALPAC's charge was to study the strongly held but conflicting opinions about the promise of machine translation and recommend what were the most fruitful steps that should be taken. The committee interviewed seventeen witnesses, commissioned a number of studies, and in 1966 issued a report *(18)* which was to be as important in its own way for MT as Weaver's "Translation" had been. The committee concluded that MT was slower, less accurate, and twice as expensive as HT. Neither of the committee's two recommendations directly pertained to MT. They were: (1) continued and expanded support for computational linguistics, and (2) support for improvements in HT, including machine aids to translators such as automatic dictionaries. The general feeling throughout the world was one of incredulity. How could a committee of obviously capable people arrive at the conclusion that "there is little justification for massive support of MT?" The answer to this question has never been really clear.

First there were the exaggerated claims of success put out in advertising by computer companies. These were a two-edged sword. If they were believed, the need for support from government agencies was over. If they were not believed, then perhaps there was no future for MT and further support was a waste of money. Then, too, there was the swing toward more fundamental research in MT. Simmons notes, "However, most of these projects, notably those at M.I.T. and Harvard, had by that time redirected their efforts into more basic studies of the structure of languages and they considered MT only a distantly conceivable goal." *(19)*

The committee apparently decided that MT was a lost cause and that it should recommend support of the more general area of computational linguistics along with practical improvements in HT in order to keep government money flowing into linguistics research—this in spite of the gathering wave of antiscience feeling in government, which was to reduce radically the support of basic research by the Department of Defense, shift the emphasis of the NSF from basic to applied science, and eventually to see the abolition of top scientific advisory posts. Herbert A. Simon says, plaintively,

> To lay claims to the resources of his society, a scientist must produce what the society wants. And what it wants is a little knowledge and a lot of relevance. . . . We who have a thirst for knowledge can be thankful that basic knowledge usually does prove relevant to social needs. That's why we're tolerated and sometimes nurtured *(20)*.

The ALPAC Report was widely condemned as narrow, biased, and shortsighted. The most thoroughgoing commentary according to Harry Josselson was that by Zbiginew L. Pankowicz of Griffiss Air Force Base, Rome, New York, the only man in a United States sponsoring agency who stood firm in the face of the panic flight from MT that followed the report. Pankowicz criticized the committee for

> (1) inferior analytical work resulting in factual inaccuracies; (2) a hostile and vindictive attitude toward machine translation; (3) the use of obsolete and invalid facts and figures as a basis for condemnation of machine translation; (4) distortion of quality, speed and cost estimates in favor of human translation; (5) concealment of data reflecting credit on machine translation *(suppressio veri suggestio falsi),* and (6) willful omission of dissenting statements on machine translation, presented to the Committee by some experts in this field *(21).*

The reaction in the USSR was equally negative. Kulagina, Mel'chuk, and Rozentsveig wrote:

> We wish to declare decisively that this view has no real support: it is founded upon a failure to understand the problem in principle and confusion of its theoretical, scientific and practical aspects. The fact that machine translation has been ineffectual in practice to the present should, in our opinion, lead to an increase rather than a decrease in efforts in this area, especially in exploratory and experimental work. It is clear that no practical result can precede fundamental development of the problem, although the possibility is not excluded that useful practical results may be the product of early stages of research *(22).*

Josselson quotes a selection from *Nauchno-Tekhnicheskaja Informatsija (Scientific and Technical Information),*

> Those ideas which have originated and are originating in connection with MT are a contribution not only to the development of an MT system (a problem which is probably not acute in the United States) but also advance the resolution of one of the most important problems of the 20th Century—the problem of symbiosis of man and machines *(21).*

Phase III: 1966 to Present

After the enthusiasm of the first phase of MT work and the disappointments of the second, the third shows a spectrum of interests ranging from the practical to the theoretical with an experimental component in between. In the United States after the ALPAC Report a few organizations continued to provide gradually declining support for work on MT: Bunker-Ramo, IBM, and the Rand Corporation, for example. Government support disappeared except for the Air Force which continued to provide money for both operational and research MT.

Symbolic of the changed attitude toward MT in the United States is the reaction of the Association for Machine Translation and Computational Linguistics. In 1965 it had taken over sponsorship of the journal *MT (Mechanical Translation)* and had added *and Computational Linguistics* to the name. In 1968 AMTCL removed the MT from its name and became the Association for Computational Linguistics. Two years later it discontinued the journal.

Abroad the ALPAC Report caused a number of countries to re-evaluate their MT research but for the most part they continued it. Josselson *(21)* was able to list in 1970 the following research groups which had started work since 1960: The Centre d'Etudes pour la Traduction Automatique founded in 1962 at Grenoble; the Projet de Traduction Automatique of the University of Montreal; the Groupe de Linguistique Automatique, Brussels; Karlova University, Prague; The Computing Centre of the Hungarian Academy of Sciences; the Deutsche Academie der Wissenschaften, West Berlin; four groups in Japan; the Universidad Nacional Autónoma de México; the University of Nancy; the University of Debrecen, Hungary; the University of Saskatchewan; The Research Institute for Mathematical Machines, Prague; the University of Warsaw; the Institut Za Eksperimentalnu Fonetiku, Yugoslavia; and the Académie de la République Populaire Roumaine. In those 10 years reports of official research in MT had been issued by some seventy groups in fifteen countries: United States, USSR, Great Britain, France, Germany, Japan, Italy, Belgium, Canada, Mexico, Czechoslovakia, Yugoslavia, Rumania, Hungary, and Poland. These figures do not include research in computational linguistics or hardware. In 1970 a new journal *T. A. Informations (23)* was founded in France by the Association pour le Développement de la Traduction Automatique et de la Linguistique Appliquée (ATALA).

OPERATING SYSTEMS

It is not generally known that there are a number of MT systems in operation: three in the United States, one in Italy, and one in Russia at last count. These will be discussed in the order in which they started operation.

"Georgetown" System

The "Georgetown" system takes its name from the fact that it was developed by the late Leon Dostert at Georgetown University with NSF and CIA support. It was installed in 1963-1964 at two locations, one at the AEC Oak Ridge National Laboratory at Oak Ridge, Tennessee and the other at the EURATOM Scientific Information Processing Center at Ispra, Italy. In both places the system is said to be still essentially the same as it was when it was installed except for some dictionary additions and a switch to upper and lower case. It is designed to translate Russian scientific and technical material into English. The following description of its operation is from Kay *(24):*

> the Georgetown system . . . incorporated neither the notion of a grammatical rule nor the notion of a syntactic structure. . . . If a word to be translated could, in the abstract, be either an adjective or a noun, the process examined the word's context to determine in which capacity it functioned in the given sentence. The grammatical classifications that were thus appended to the words in a text could be used later to determine which of a list of possible English alternatives would serve to translate the word and to help decide on the eventual order of the words in the second language.

At Oak Ridge translations are made on demand for government scientists and engineers. The EURATOM installation provides translations for its own people and for a growing number of outsiders through the European Translations Center in Delft, Holland, the Centre National de Documentation Scientifique et Technique in Brussels, and the Maschinenfabrik Augsburg-Nurnberg in Germany. EURATOM had produced some 67,500 pages of translations in 7½ years and Oak Ridge some 51,000 in 6 years, prior to a study by Bozena H. Dostert *(25)* of the University of Texas Linguistics Research Center, wife of Leon Dostert. She attempted to find out what the customers of the Georgetown system thought of the product. The reasons given by those interrogated for using MT are that it is "quicker and cheaper" than HT, though it is difficult to know on what this judgment is based since, except in an emergency, MT translations are batched at both installations and run when the computers are free, and cost figures are unavailable, with the users themselves paying nothing. The output is "raw" (i.e., unedited) and users have to refer back to the original Russian text for formulas, diagrams, and illustrations. Nevertheless, 92.4% of the respondents judged the quality to be "acceptable" or "good." They said it took twice as long to read an MT text as the original English whereas HT took only 32% longer. Familiarity with subject matter was considered the primary factor in understanding MT texts, 93% of which were said to be "informative," 81.5% "complete," and 71.1% "readable." As to misinformation, 82.4% "never had that experience." "MT 'style' can readily be gotten used to," they said, and 96.1% "have recommended or would recommend MT to their colleagues." In short, Mrs. Dostert concludes, the Georgetown 1964 system is an "acceptable substitute" for HT.

Moscow Patent Office

Since 1964 the Central Research Institute for Patent Information in Moscow has developed and operated a specialized and quite sophisticated MT system for translating the weekly Official Gazette of the U.S. Patent Bureau into Russian *(26)*. The operation was originally programmed on a URAL-4 computer but may have been reprogrammed since. It is described by Josselson:

> An algorithm based on segment analysis provides for the delineation of operational units of text (syntagmas) such as noun groups and verbal combinations. The translation is carried out with the aid of a compiled dictionary of specified patterns of syntactic constructions *(27)*.

The program of the Moscow Patent Office has approximately 20,000 instructions. Its sixteen subroutines can be divided into four groups for different phases of the operation:

1. Text preparation: arrange words, search for words in the dictionary, analyze unknown words (i.e., not found in the dictionary), process idioms, select homographs, segment text into phrases.

2. Syntactic analysis of segments: locate pronominal antecedents, work out case information (morphological), analyze predicative units of text, analyze noun word combinations.
3. Synthesis of Russian text: synthesize Russian text, print out translation.
4. Auxiliary programs: master program, write information on magnetic tape, transfer information from tape to drum storage, print out intermediate program results.

FTD

From 1964 to 1970 the Foreign Technology Division (FTD) of the Air Force operated what was called the Mark II Translator. The "photoscopic store" memory, Russian-English dictionary, and minimal grammar were developed by IBM. Kay describes the operation of the system:

> During the life of the system, a vast Russian-English dictionary of stems, prefixes. and suffixes was amassed and new disks were made periodically to incorporate the new information. The logical capabilities of the machine, however, were rudimentary. Each stem and affix on the disk was accompanied by a pair of codes indicating classes of stems and affixes that could occur before and after it. Thus, when a Russian word was sought in the dictionary, various alternative classes might be found, and the one chosen would be determined by the choice made for the item immediately preceding it *(28).*

The machine output was edited and printed complete with illustrations, which accounted for 70% of the high costs and most of the time consumed.

It was Mark II output which the ALPAC Committee compared with JPRS translations and found it no faster, no better, and higher in cost.

SYSTRAN

In 1970 FTD replaced Mark II with the more efficient SYSTRAN, which had been developed by Peter Toma of LATSEC, Inc., La Jolla, California. Since 1967 the Rome Air Development Center has supported various improvements in SYSTRAN. Editing and recomposition provide an output more attractive and more convenient than that of the Georgetown systems but at perhaps three times the cost.

The SYSTRAN system was evaluated in 1972 by Leavitt, De Haven and Giese (29). Their aim was primarily cost analysis and control, but the postediting and recomposition functions were studied in detail since they contribute 37 and 38%, respectively, to the total cost. Currently available technology for aiding the editor and for machine composition, said the authors, would reduce these figures and speed up the process.

In addition to Russian-English translation, SYSTRAN offers English-Russian, German-English, Chinese-English, and French-English. Examples of the output of a pilot French-English system *(30)* will give some idea of the quality of the machine output prior to editing:

French aeronautical text	SYSTRAN output
Il faudra en premier lieu, par des essais, déterminer le gouvernail le plus éfficace. On jouera sur le profil, sur le turbulateur, éventuellement on essayera une dérive évidée (comme W. Hauenstein). Le gouvernail le plus éfficace possible sera évidemment utilisé en atmosphere agitée, lorsqu'il est dangereux de s'attarder trop longtemps près de la pente. Au contraire, en air calme on emploiera un gouvernail moins éfficace pour mieux louvoyer.	It will be necessary first, by tests, to determine the elevator the most effective. One will play on the profile, on the Turbo-Jet, eventually one will try an hollowed leeway (as W. Hauenstein). The elevator the most effective possible will be evidently used in perturbed atmosphere, when it is dangerous to linger too long near the slope. On the contrary, in calm air one will will use an elevator less effective for better to manoeuver.

Logos

A third operating MT system in the United States is the Logos III System, also developed with the support of the Rome Air Development Center and commercially available. It operates on an IBM 370/145 with virtual storage and runs under the CMS (Cambridge Monitor System). It is said to be "language independent"; that is, the software will handle any language in the data base. English-Vietnamese and English-Russian are said to be operational, with other data bases in preparation.

One application of an earlier Logos system was technical English to Vietnamese MT for military training manuals. Input was by optical scanner. Translation was sentence-by-sentence; mistakes were corrected by an editor and were entered into the computer via an editing language developed by Logos. COM microfilm was produced off-line for proofreading and correcting. Formating instructions were entered in the system and transmitted to photocomposing equipment for the final composition of the translated text. Technically, this was a giant step toward the future.

According to the Logos Corporation, the MT text needed to be edited 25% of the time and changes broke down as follows: syntactical, 9.5%; lexical 10.7%; stylistic 1.5%; errors in data base, 2.5%; words not found, 0.8%. The cost was 8 to 10¢ a word, about what most human translators charge. Their report closed with a comment that goes to the heart of the translation problem:

> . . . there are good reasons for questioning whether, with even the best of systems, the mission can be successfully accomplished. These reasons have to do with the vast differences in the technological levels of the English language and people and the Vietnamese language and people; it will take more than a computer to bridge the difference *(31)*.

Two names stand out in the development of operating MT systems in the United States. The first is that of Leon Dostert, originally a skeptic, then a convert to MT, who directed the Georgetown University effort and inspired many of his students to become leaders in the field. The other name is that of Zbigniew L. Pankowicz at the Rome Air Development Center of the U.S. Air Force. Special tribute should be paid to this administrator of courage and vision. It is he who made possible the development of Mark II, SYSTRAN, and Logos, and it is he who has persevered in the support of the group at the University of Texas, the leader today in experimental MT research in the United States.

RESEARCH

Two opinions on research strategy will serve to introduce the work of several projects and individuals. First, Alexander Ljudskanov:

> By giving due consideration to the particular characteristics of the translation process and its study, as well as to the differentiation of the aims of mathematical linguistics from the theory of MT and of the fields of competence and performance from each other, research in this field would be channeled in a direction both more realistic for our time and more closely in accord with the facts.

He goes on to say with reference to books and articles on MT,

> they have confused the problem by comparing machine translation with the long-practiced human translation, by equating the problems of translating scientific materials with those involved in translating literary materials, and by using the same evaluation criteria for the results *(32).*

A second opinion is that of Paul Garvin who distinguishes three approaches:

> The "brute-force" approach is based on the assumption that, given a sufficiently large memory, machine translation can be accomplished without a complex algorithm—either with a very large dictionary containing not only words but also phrases, or with a large dictionary and an equally large table of grammar rules. . . . Both versions of the "brute-force" approach have yielded translations on a fairly large scale, but of questionable quality.

As opposed to this,

> The "perfectionist" approach . . . is based on the assumption that without a complete theoretical knowledge of the source and target languages (based on a theoretical knowledge of language in general), as well as a perfect understanding of the process of translation both preferably in the form of mathematical models, the task cannot even be begun *(33).*

The "heuristic" or engineering approach which Garvin espouses falls between the two extremes. It is "translation oriented" and "probabilistic." The algorithm is

> a linguistic pattern recognition algorithm which, instead of matching portions of sentences against rules stored in a table, directs searches at the different portions of the sentence in order to identify its grammatical and lexical pattern. Thus, the essential characteristic of the algorithm is the sequencing of the searches,

> and in each search subroutine, only as much grammatical and lexical information is used as is appropriate to the particular search *(34)*.

Four substantial research projects will now be described, then the work of a number of smaller ones and individuals.

LRC

The first project will be considered in some detail. It is at the Linguistics Research Center (LRC) of the University of Texas at Austin and is directed by Winfred P. Lehmann with Rolf A. Stachowitz as research director. Fully automatic high quality German-English and English-German translation with no, or at least minimal, human editorial assistance is the goal, though the programs are language independent and can be applied to other pairs of languages. The translation process consists of "recognition" (analysis) of the elements of the "source" language text and "production" (synthesis) of the "target" language text. Meaning is to be transferred from one language to another through the substitution of linguistic and semantic units. Meaning can also be simplified or paraphrased as in automated indexing or abstracting by using the same languages for input and output.

The key to the LRC approach is expressed as follows:

> We may posit the existence of a universal base [of language structures] . . . the surface structures of any language can be related to such a universal base. Since the universal base in turn can be used for deriving the surface structures of any language, the universal base can serve as the intermediate language between any source language and any target language *(35)*.

We are reminded here of Weaver's analogy of towers with a common substructure.

Large German and English dictionary data bases have been prepared in which codes for syntactic and semantic selection criteria are assigned to each entry. In addition, recognition grammars have been written at various levels of abstraction: a "natural languages" grammar which, by a context-free parsing program, can derive from each natural language sentence one or more "standard strings" that bring together those words that logically belong together; a standard string grammar, also context-free, which identifies acceptable strings; and a "normal form" syntactic-semantic grammar which gives deep structures. The reverse of the recognition process, called "production" by LRC, starts with normal form deep structures identical with those of the recognition phase and derives one or more standard strings in the output language; the standard string grammar selects acceptable output strings and supplies corresponding natural language strings; finally the natural language grammar selects the appropriate constructions to make up a sentence and plugs in the lexical items with the correct endings (see Figure 1).

German verb-noun combinations illustrate the necessity of taking semantic relations into consideration in the transformation of surface structure to underlying structures. Thus a phrase like *Abstand nehmen (von)* corresponds to the English "to refrain, desist (from), give up."

Er nahm von diesem Plan Abstand. He gave up this plan.

To bring together discontinuous elements, such as *nahm Abstand,* the surface strings must be rearranged by deriving tentative standard strings from surface strings as:

Er nahm Abstand von diesem Plan.

An idea of the number and complexity of the rules which the LRC uses to resolve syntactical ambiguity may be had from the fact that seven steps are required to determine whether "page" in "the page slept" refers to a person or a piece of paper. The amount of new research is very substantial; for example, the classification of verbs and their complements into twenty-nine patterns used in *The Advanced Learner's Dictionary of Current English* by Hornby, Gatenby, and Wakefield was found after several years of experimentation to be incomplete, so a new classification was developed. The same had to be done for adjectives and for adverbs (35).

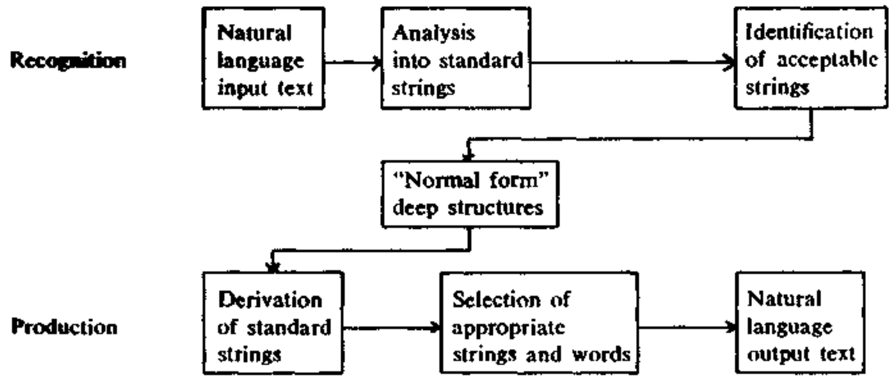

FIGURE 1. *Block Diagram of LRC System.*

A most important survey of the state of the MT art was published in a report by LRC in December 1971 *(36).* This report stresses the fact that Bar-Hillel, one of the first proponents of MT, who in the 1960s changed his mind and took the position that fully automatic high quality translation was an illusory goal because of the "semantic barrier," has once again become somewhat more optimistic. He writes,

> It is therefore, for instance, not inconceivable that a translation program with an unsatisfactory output for a certain user under given conditions might turn out to be more satisfactory if the conditions are changed, for instance, if the user is allowed to ask back certain questions and the computer is programmed to answer these questions upon request . . . [the human user] is the first and final judge, and it is he who will have to tell whether he is ready to trade quality for speed, and to what degree *(37).*

This is a challenge which the authors of the report are happy to accept. Rapid advances in computer hardware and software have removed the technological barriers to MT (except in the case of Chinese, Japanese, and similar languages), leaving only linguistic obstacles arising from incomplete analysis of linguistic performance at all levels. They conclude,

> Current linguistic theory is inadequate for machine translation . . . semantic representations derived from syntactic structures in the source language must be associated with syntactic structures in target language . . . comprehensive grammars do not yet exist for any languages . . . research in discourse analysis should be increased. . . . Machine translation can be designed with varying degrees of adequacy . . . *(38).*

LRC, like many other MT research projects, makes use of transformational grammar to go from surface structure (natural language syntax) to "deep structure" (logical syntax). A "tree diagram" is widely used to represent transformations. Kay gives an example,

> the sentence [S1], "Claims that John had passed the examination surprised the professor." The subject of this sentence is "Claims that John had passed the examination," which contains the second sentence [S2], "John had passed the examination," which has its own subject, "John." The relationships of these various parts to one another can be conveniently represented in a tree diagram. (See Figure 2.)

It will be noted that linguists' tree diagrams represent roots rather than branches because they start with surface phenomena and work down to the underlying logical relations. In actual translation operations on random sentences, a number of different surface structures (e.g., "John inherited the estate" or "the estate was in-

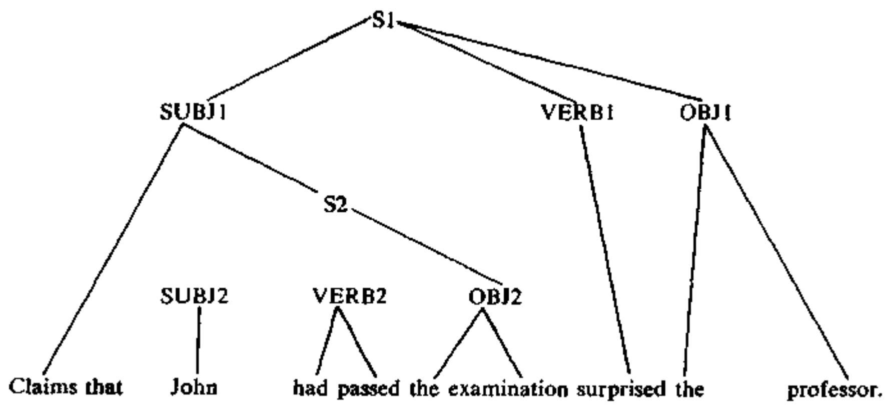

FIGURE 1. *(Reprinted from Ref.* 24, *p. 220, by permission of the American Academy of Arts and Sciences.)*

herited by John") may be represented by a single deep structure. This causes no difficulty at the analysis stage, but during synthesis the computer has to decide which of the possible surface structures shall be used. It depends partly on stylistic considerations. The situation may be even more complicated. Any syntactic ambiguity means more than one possible deep structure for the surface structure. Then both analysis and synthesis become a multiple choice guessing game. As said earlier, humans are adept at this game, eliminating such ambiguities with the help of context. To understand this process well enough to program a computer to do it is the challenge that faces LRC and everyone who wants to perfect MT.

Berkeley

A second ongoing MT research program in the United States is the Chinese-English project at the University of California, Berkeley, also supported by the Rome Air Development Center. It is described as "a practical combination of the theoretical and the pragmatic approaches to machine translation" *(39).* Further, "although the system is designed to be capable of translating standard modern written Chinese in general, it is at present intentionally biased in its data bases toward the translation of scientific texts in the fields of nuclear physics and biochemistry" *(40).*

It will be immediately recognized that the characters of Chinese and Japanese present special input difficulties. In the first place each character, of which there are several thousand in everyday use, has to be coded for input. Optical recognition would be the answer, but until it is perfected, skilled human interposition will be necessary. Second and no less important, individual characters represent syllables; there is no indication whatever of word boundaries. To identify the words, a series of characters has to be compared with the dictionary until a matching series is found. The longest possible match is used. In a more sophisticated routine a two way lookup operation matches first from left to right then right to left. If both find the same word, fine; if different words are found, they have to be carried along into later stages of the processing in the hope that syntactic or semantic information can resolve the ambiguity. Chinese verbs have no tense endings, nouns no sign for the plural. Context may provide the necessary information, if not it may be impossible to compose a correct English sentence.

The present status of the Berkeley project is described as follows:

> The cumulative efforts of the past several years have resulted in the materialization of a large dictionary, a complex grammar [or hierarchy of grammars], a sizeable corpus of machine-readable Chinese text and a sophisticated programming system. . . . Chinese sentences constitute the source language input. This is submitted to the parser and analyzed into structural trees. Interlingual processes then apply to these structures to map them into the appropriate equivalent English structure. These structures are then used for synthesis into the target English output by applying the necessary surface structure rules *(41).*

Postediting is necessary at present, but the eventual goal is "Chinese translations that could be used by casual readers directly and happily" *(42).*

G.E.T.A.

The Groupe d'Etudes pour la Traduction Automatique (G.E.T.A.) in Grenoble was founded in 1962 under the name Centre d'Etudes pour la Traduction Automatique and is directed by Bernard Vauquois. G.E.T.A. It is developing computerized methods for translating written texts from Russian into French with a small-scale effort also in German and Japanese. Poetry and other purely literary texts are excluded. A report on work up to 1970 *(43)* states the philosophy: Word for word translations are worthless even if the word order is rearranged; attempts to perfect the output by analyzing the syntax of sentences of Language L and synthesizing corresponding sentences in Language L´ have still not given high quality translation; the problem of automatic translation is the transformation of written text into meaning and the reverse transformation.

Like Nikolai D. Andreev in Leningrad and Sidney M. Lamb at Yale University, G.E.T.A. has proceeded on the assumption that a semantic interlanguage, a "pivot language," would have to be developed to formalize meaning "so that any text of any language could be formulated in it and then an equivalent text in any other language created from it" *(44).* By 1970 a series of models for the automatic translation process had been developed and parts of them had been programmed. The analysis of Russian into Pivot Language I and the generation of French had been debugged, expanded, and checked on more than 400,000 words of Russian text. "Intermediate results" could be shown as follows:

Analysis of Language L:
- (a) segmentation of words into stems and endings (morphological analysis)
- (b) 1) segmentation of sentences into phrases
  2) resolution of syntactical ambiguities
- (c) semantic analysis in Pivot Language II

Synthesis of Language L´:
- (d) Construction of new sentence patterns (syntactical synthesis)
- (e) Construction of words from stems and endings (morphological synthesis)

Pivot Language II has a more precise expression of basic concepts such as "time" or "determinacy" in invariant form and syntax such that deep structures can be generated from surface structures and vice versa. In reality the pivot languages are families of languages having a syntax closely allied to French but with vocabularies from the different "source" languages. The analysis stage of translation decomposes the sentences into elementary statements and shows the semantic relations between these statements. The final phase is called transfer rather than generation because little more than the substitution of lexical items is involved.

G.E.T.A. has chosen to treat only one sentence at a time, which limits the difficulties but means that words whose antecedent is outside the sentence, pronouns for example, cannot be handled. It should be added, however, that a few workers elsewhere have tackled "proforms" with some success.

After 1970 G.E.T.A. went through the trauma that every MT research project eventually goes through when an obsolete but reliable computer is replaced by a new, larger, faster but less reliable one. They took advantage of the disruption to create a new software system for handling the strings and tree structures in different linguistic models. They are making a careful study of the kinds of ambiguity in their large body of Russian text in order to devise ways of resolving them. Again and always, ambiguity is the key.

TAUM

The Project for Automatic Translation of the University of Montreal (TAUM), directed by Richard I. Kittredge, has as its goal the analysis of all grammatical features of all words in the text, plus a certain number of semantic ones: for nouns, whether they are animate, concrete, or abstract; for verbs, the kinds of subject and objects they can take and their possible constructions. These help resolve ambiguity at the word and syntactical levels. Kittredge writes,

> The purpose of the syntactic parsing . . . is to provide in a single tree structure the most important elementary sentences of which the input sentence was (transformationally) composed. . . . The ultimate aim is to represent each sentence (text) in predicate argument form where an argument is either a noun phrase or a sentence. In addition to the lexical items which are then hierarchically arranged, there are category symbols attached to constituents and their sub-parts, and features to represent syntactic and semantic sub-classes *(45).*

Jules Dansereau explains the two step operation,

> "Transfer" includes the decomposition of the English structure, the dictionary and the recomposition of French structure . . . "generation" receives the trees as reconstructed by "transfer"; its job is to decompose them in order to arrive at a syntactically well formed French string, giving all the necessary information to the morphological rules *(46).*

There is great diversity in the work of the smaller projects and individual researchers. Brian Harris at the University of Ottawa; Margaret Masterman and her group at the Cambridge Language Research Center, Cambridge, England; and Richard L. Bisbey and Martin Kay at the Rand Corporation Linguistics Research Project, Santa Monica, California, subordinate the machine to the human in Machine Aided Translation (MAT). Yngve's "partial translation" *(47)* (only stems of words translated) reappears in the "pidgin translation" of Harris *(48)* (stems and endings translated) and in Masterman's *(49)* "pidgin" word for word MT system. Loh Shiu-Chang *(50)* proposes for Chinese to English to resurrect Reifler's "pre-editor." Bisbey and Kay *(51)* would use not only a "pre-editor," who needs to know only the source language and "disambiguates" the input by identifying the correct syntactic analysis whenever more than one is furnished by the computer, but also a "posteditor," who needs to know only the target language and polishes up the style.

Masterman is also known for her work on "translating semantic meaning" by means of a hierarchically arranged bilingual thesaurus *(52, 53).* Her work prefigures much of the later work on structural semantics by Silvio Ceccato *(54)* in Italy, Tunco

Tamati and Tosihiko Kurihara (55) in Japan, and especially the imaginative work of I. A. Mel'chuk and A. K. Zholkovsky (56) in the USSR. Gardin comments on the latter:

> What these two linguists have achieved, indeed, is not only an original method of automatic translation, in which syntax and semantics are cleverly blended; the metalanguage which plays such an important part in this method can also be regarded as an information language, to the extent that it purports to carry basic meaning contents variously expressed in natural language forms *(57).*

Semantics theories continue to be many and varied as set forth by Bobrow, Fraser, and Quillan:

> We will not recount here the multifarious disagreements involved in all this, much less take sides. However, we would like to propose one sort of "dimension," along which it seems many of toe semantic theories may be located. Essentially, this dimension is the degree of complexity of the material that is assumed to constitute semantic information. For a performance model, this information is what would have to be stored in the memory of the device that produced and/or comprehended language. A position lying near the "complexity" end of this dimension would assume semantic information consists of complex configurations, forming overall a network of nodes, interrelated to one another by different kinds of links. A position closer to the middle of this continuum might assume that semantic information is structured into trees, but still trees using several different kinds of labeled linkages. Further along on this continuum one might find a theory that assumed a tree structure for semantic information but now one that used a single kind of linkage between nodes of the tree. Finally, a position near the "simplicity" end of our continuum might assume that semantic information consists simply of unordered aggregates of semantic features. Semantic theories of today seem to be spread all along this continuum *(58).*

Some of the most promising recent contributions are in the field of artificial intelligence, one of whose goals may be defined as the invention of a Turing machine which can carry on such an "intelligent" conversation that a person on the other end of the telephone will not know that he is talking to a machine rather than a human.

A recent book, which includes a useful summary of the work of a number of others, is that of Wilks, who writes,

> My approach, on the other hand, takes meaningful language as the basic material for analysis and explanation. It does not assign any theoretical status to a class of "grammatical sequences" over and above their being what some particular grammar produces, or admits, as well formed. *One aim of the present work, therefore, is to construct a theory that enables us to detect semantic forms directly, and not via a strong and conventional syntax analysis (59).*

He goes on,

> It is no more a priori foolish to classify semantic forms than to classify logical or syntactic ones. In fact they are related enterprises. In syntactic classification

> one examines the behavior of a word within a coarse framework of structures, and assigns it to large substitution classes. In semantic classification the framework mesh is finer and the substitution classes correspondingly smaller. I think it could be shown that there are syntactic analogues to basic semantic message forms . . . *(60).*

Wilks quotes John McCarthy,

> . . . Mathematical linguists are making a serious mistake in their concentration on syntax and, even more specially, on the grammar of natural languages. It is even more important to develop a mathematical understanding and a formalization of the kinds of information conveyed in natural language *(67).*

A large number of researchers in the Soviet Union are at work on linguistic semantic models, at the Institute of Linguistics, the Institute of the Russian Language, the Institute for Applied Mathematics, and the All Union Institute of Scientific and Technical Information (VINITI) of the Academy of Sciences, at the Moscow State Pedagogical Institute of Foreign Languages, not to mention groups in Leningrad, in other provincial cities, and in the other Soviet Socialist Republics. The trend seems to be toward what Rozentsveig *(62)* calls an "explanatory-combinatorial dictionary," which combines explicit descriptions of the ways, both semantic and syntactic, in which each word can combine with others; i.e., a dictionary that adds the functions of a thesaurus and a grammar, as the best dictionaries always have to a limited extent. Wilks affirms that the traditional distinction between syntax and semantics (and he might have added lexicography) is unnecessary in practice. His "templates" combine all three. He explains,

> I am not suggesting, though, that the manipulations to be described here are merely "dictionary based," if that is to be taken to mean having no theoretical presuppositions. There are in fact three important linguistic presuppositions on which the following analysis is based: namely, the use of templates for analysis, and stereotypes for generation ... in addition the principle . . . that by building up the densest, or most connected, representation that it can for a piece of language, the system of analysis will be getting the word senses and much of the grammar right *(63).*

None of the above-mentioned researchers limit their interests to MT. Most are simultaneously making contributions to the broader field (called automated language processing by information scientists and computational linguistics by linguists) which includes information retrieval, fact retrieval, question answering systems, automatic indexing, and abstracting (extracting). Sparck Jones and Kay *(64)* rightly regret that mutual understanding and interaction of information science and linguistics have up to now been slight. Each needs the insights of the other. Semantics, meaning, lies at the heart of the difficulties in all these areas. On that point nearly everyone agrees, but there the agreement ends. There are nearly as many theories about how to use meaning in automated language processing as there are individuals thinking about it. This is a healthy situation. The challenge is worthwhile because it goes deep into the nature of the human intellectual process. If we learn enough to do MT, we shall have contributed something even more important to the understanding of how the mind works.

Conclusion

In its 25 year history, machine translation became an internationally recognized field of research, then lost its identity in the larger field of computational linguistics to which it gave birth—except for operational MT which continues to be substantial in quantity but poor in quality.

The remaining barriers to improved quality lie in our incomplete understanding of the linguistic and psychological mechanisms of translation. Research is going forward with substantial assistance from specialists in other disciplines. Not only may any paper in linguistics or information processing be pertinent, but also papers in such disparate fields as logic, mathematical modeling, topology, the psychology and neurophysiology of perception and cognition, computer programming, and artificial intelligence.

Computers themselves have progressed to the point where they are efficient tools for MT with their direct input output hardware; large, fast, random access memories; and, equally important, procedural- and problem-oriented languages which facilitate efficient representation and manipulation of text. Computers can now be programmed to analyze written, but not yet spoken, text on the morphological and syntactical levels, and perhaps eventually to assign probabilities in order to predict meaning and resolve ambiguities as humans do.

Perhaps MT is now entering a third and final phase. Following a first phase of enthusiasm coupled with ignorance of the extent of the difficulties came a second of discouragement and loss of financial support. Now we see a new optimism that the deeper intellectual problems may be soluble.

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