IMPLICATIONS OF MECHANICAL TRANSLATION RESEARCH *

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THERE are a number of exciting implications coming out of research into the question of translating languages by machine. In order to appreciate these implications, it is necessary to understand a little of the background of the research itself.

The world is divided into over four thousand language communities. Each of these communities speaks a language that is unintelligible to the others; thus all communication between them must take place at present through people who are to some extent bilingual. The problems that this fact causes are well known. The world pays a high price for the luxury of many separate languages.

A ray of hope appeared when, some fifteen years ago, a number of people[1, 2, 3, 4, 5] came to realize that the automatic digital computer could do many tasks besides compute. It was the dream of a handful of pioneers that someday computers could be programmed to translate languages and thus ease the burdens that the language barriers impose upon us. If this task could be accomplished, the free flow of information between language communities would be expedited; the economic, cultural, and social advantages would be far-reaching. Most of the early pioneers in the field appreciated the great difficulties that stood in the way of translating languages by machine, and many were discouraged by these enormous difficulties. But some others tried to see how far our current techniques and understanding of the problem could carry us.

MECHANICAL TRANSLATION RESEARCH

In the early days the simplest suggestion was to automate a dictionary. The machine would look up the input words in the incoming language, one by one, and substitute for them equivalents in the other language. It was hoped that by this means at least the rough meaning of the input text could be got across even though the output would be stylistically very poor. Those who pursued this possibility soon discovered that the results were extremely disappointing. A word-for-word translation by a simple substitution scheme such as this appears not to be at all useful.

People next tried to do something which would provide an improvement. Where the word-for-word translation gave several alternative meanings, attempts were made to find clues within a sentence which would indicate which meaning was intended. In cases where the input language word-order was different from that of the output language, simple rules were sought for automatically rearranging the word-order. The degree of improvement that such simple fixing up can produce is considerable, but the resulting translation is still a long way from being satisfactory.

The next step was the realization that it would be necessary for the machine to determine the grammatical or syntactic structure of each incoming sentence.[6] Many of the multiple meanings observable in a word-for-word translation could be resolved if the computer could determine the

* This work was supported in part by the National Science Foundation, and in part by the U. S. Army Signal Corps, the Air Force Office of Scientific Research, and the Office of Naval Research.

[1] Warren Weaver, "Translation," *Machine Translation of Languages*, edited by W. N. Locke and A. D. Booth (New York, 1955), pp. 15-23.

[2] R. H. Richens and A. D. Booth, "Some Methods of Mechanized Translation," *Machine Translation of Languages*, edited by W. N. Locke and A. D. Booth (New York, 19S5), pp. 25-46.

[3] V. A. Oswald, Jr., and S. L. Fletcher, Jr., "Proposals for the Mechanical Resolution of German Syntax Patterns," *Mod. Lang. Forum* **36,** no. 3-4 (1951): pp. 1-24.

[4] Erwin Reifler, "The Mechanical Determination of Meaning," *Machine Translation of Languages*, edited by W. N. Locke and A. D. Booth (New York, 1955), pp. 136-164.

[5] Y. Bar-Hillel, "Can Translation be Mechanized?" *American Scientist* 42 (1954) : pp. 248-260.

[6] Victor H. Yngve, "Sentence-for-Sentence Translation," *Mechanical Translation 2* (1955) : pp. 29-37,

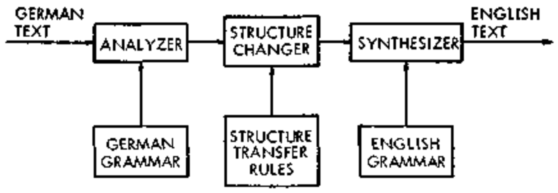

FIG. 1. Proposed method of translating by machine, showing a separation of the problem into routines at the top, and stored knowledge at the bottom, and, from left to right, an input-language section, an inter-language section, and an output-language section.

part of speech of each word in the input text and the way in which the words are grouped into phrases and clauses. This work on syntax has progressed quite satisfactorily for the last several years. Several things have come out of it. Our original realization that there is an extreme amount of complexity in the structure of language has been underlined. The kind of description of the syntax of sentences in a given language, done to the degree of completeness necessary as a basis for computer programs, is a task that will take linguists many more years to complete.

The way in which such language descriptions could be used in a program to effect a translation by the syntactic method [7] is shown in figure 1. Here the input text in German, for example, is fed into a sentence analyzer which uses the knowledge of the input language, stored in the box called German grammar, to analyze each input sentence, identifying each word for its part of speech and indicating the way in which the words are grouped into phrases and clauses. At the far right, we have a synthesizer for synthesizing the output text in English. The synthesizer does this by means of applying the rules of English grammar in the lower right-hand box. In order to take care of the circumstance that the structures of the two languages do not bear a one-to-one relationship to each other, we have in the center a structure changer, which changes its input (a statement of the structure of the incoming German sentence) into a statement, as output, of the structure of an English sentence that translates it. It is here that the various compromises inherent in translation are made. The knowledge needed by the structure changer in order to effect this structure change is contained in the lower middle box called structure transfer rules. It is assumed that these structure transfer rules will assist in getting the approximate meaning across, but again, questions of style will be more difficult. Output sentences may be somewhat awkward.

We have explored this scheme at the Massachusetts Institute of Technology (MIT) where various people have been working on English, German, French, Russian, Arabic, Finnish and Chinese. Some of the work on Arabic done by Arnold Satterthwait is especially interesting. Figure 2 shows an Arabic sentence and above it its transliterated form which is used as an input. Although the Arabic script runs from right to left, the transliterated input above it runs from left to right. The analyzer recognizes the first word as a verb *V,* and the second, as a subject S. The third and the fourth, a determiner and a noun, are recognized as an object *0,* connected to the verb by a dotted line to form a predicate *P.* This predicate, together with the subject, is taken as a clause *C.* This clause, together with the adverb *A,* is taken as a sentence S. On the basis of the Arabic words and this structure, the corresponding English structure and the corresponding English words are chosen. Here it should be noted that the translation is structure for structure: sentence for sentence, clause for clause, etc. The only difference is that the Arabic subject does not have a determiner as does the English. This sentence is one that was actually translated by the program written by Arnold Satterthwait. The program involves a greatly restricted vocabulary and operates

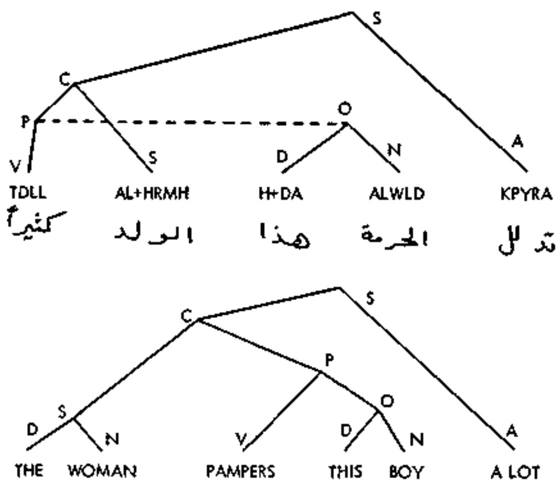

FIG. 2. Syntactic translation of Arabic to English, showing how the translation is structure-for-structure in spite of word-order differences.

[7] Victor H. Yngve, "A Framework for Syntactic Translation," *Mechanical Translation* 4 (1957): pp. 59-65,

يعرف الولد البلد

YVRF	ALWLD	ALBLD
knows	the boy	the town

The boy knows the town.

يعجب البلد الولد

YVJB	ALBLD	ALWLD
pleases (likes)	the town	the boy

The town pleases the boy.

The boy likes the town.

FIG. 3. An example of Arabic-to-English translation in which the second translation, but not the first, requires structure transfer rules to interchange subject and object.

with a greatly restricted group of sentences, but many difficult problems have been solved, particularly in the area of morphology.

Syntactic translation can involve complications however. Figure 3 shows an example that we know how to solve but haven't yet put into the program. In the top half is an Arabic sentence and its transliterated form, below that is a word-for-word translation, and finally a good translation: *The boy knows the town.* But in the bottom half there is a similar sentence that raises a problem. This sentence has the same structure and its translation can be obtained analogously if the verb is translated as *pleases.* But if the verb is translated as *likes,* which is perhaps the better rendition, then the Arabic *subject* must be translated into an English *object* and the Arabic *object* must be translated into an English *subject.* This is a rather simple example of the sort of problem that one meets in structural transfer.

THE UTILITY OF COMPLEXITY

It is a remarkable fact that languages are extremely complex. The reason for this great complexity had for a long time been obscure. It would seem that the forces of language development and evolution would tend to make languages simple so that they would be easy to learn and to use. But four years ago it became possible to understand perhaps the major reason for the complexity of languages.[8] This insight, offered as a contribution in the field of *linguistics,* came about only as a result of trying to devise *computer programs* to simulate human linguistics behavior and by applying methods of investigation borrowed from *physics.*

It seems that, as we speak, we incur commitments to finish our sentences in certain ways in order to make them grammatical. As an example of what these commitments are, take the following sentence: *When the president spoke, the people listened.* As we start this sentence with the word *when* we have two commitments, one to finish a dependent clause *when the president spoke,* and the other to follow this with an independent clause *the people listened.* Then, as we start to fulfill the first commitment with the word *the,* we have two new commitments making a total of three: the original one, that is to finish up with an independent clause, another to finish the subject of the dependent clause we started with the word *the,* and the third to follow this with a predicate like *spoke.* Apparently we cannot cope with more than about seven such commitments at any one time without forgetting what it was we were going to say. It can now be shown in detail that many of the myriad complexities of language serve to protect us from such calamities and that many others provide us with alternative methods of speaking which preserve the expressive power of the language. The maximum number of commitments at any one time in a sentence is called the depth of the sentence. The depth hypothesis explains many of the complexities of language in terms of their function in allowing a depth of about seven commitments, but no more.

It is now clear what the utility is, for a language like English, of a hierarchical part of speech system involving verb, noun, adjective, and two or three ranks of adverbs. The different parts of speech are not directly related to the meaning of the words, as is sometimes erroneously taught in our schools. Instead they provide an automatic method in the language of keeping track of grammatical commitments to make sure that there are

[8] Victor H. Yngve, "A Model and an Hypothesis for Language Structure," *Proc. Amer. Philos, Soc.* 104 (1960) : pp. 444-466.

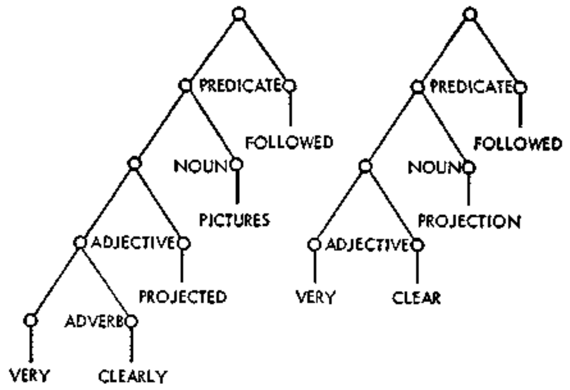

FIG. 4. Parts of speech provide a ladder for keeping count of grammatical commitments and limiting their number. The parts of speech change as words move up and down the ladder.

not too many of them. This is shown in figure 4 where two related sentences are diagrammed. It can be seen that the same meaning is carried by the adverb *clearly* in the one sentence and the adjective *clear* in the other sentence and that the same meaning is carried by the adjective *projected* in the one sentence and noun *projection* in the other. Thus, a part of speech is not related directly to the meaning, but instead to the rank of the word in the hierarchical structure of the sentence. This rank provides a counting mechanism from the top down to the left involving verb, noun, adjective, adverb, and adverb of a different class. This counting ladder allows only five or six grammatical commitments to be made. The language simply does not offer the facilities for increasing the depth of modification much further to the left.

It is now clear what the utility is, for a language like Turkish, of its highly agglutinative character involving long compound words made up of a stem and many suffixes. The phenomenon exists to a limited extent also in English. Figure 5 shows how agglutination operates to reduce the number of grammatical commitments. The three-word phrase *to build again* involves never more than one commitment, whereas the nearly synonymous word *rebuilding* would involve two commitments if it were composed of three separate words. Instead, the parts are agglutinated giving the single word *rebuilding* which involves no grammatical commitments. The price that the language pays for this saving in commitments, of course, is a larger vocabulary containing compound words. Thus, it is seen that complexity, which tends to load our permanent memory, is utilized to keep the language within the narrow confines of only seven commitments at any one time.

It is now clear why the position of the direct and indirect object in an English sentence is not fixed, except that the shorter object tends to come first. Figure 6 shows how this allows us to get easy commitments out of the way before embarking on potentially long and complex structures that could add dangerously to the number of grammatical commitments that we would have to remember in order to finish the sentence correctly. The choice of the order of the direct and indirect object in English is determined by feelings that are on the border line between grammatical and stylistic.

One of the results of this insight into the reason for the complexity of language is that we now can see our way clear to insure that the output translation is not only grammatically correct but also in some respects stylistically correct and elegant. This is something that we had never dreamed of being able to mechanize because we had always felt that the stylistic aspects of the text were questions of aesthetics and would not yield to mechanization. A clearer illustration of this point is shown in figure 7 where we see a typical leading sentence from a scientific article. This one appeared in the Physical Review. The sentence is in the passive to avoid a first-person singular pronoun. But the normal form of the passive would be subject-predicate as in *measurements were presented.* The curious thing is that phrase four actually modifies phrase two but is separated from it by the entire predicate, three. Thus easy commitments are got out of the way first. Phrase four, which potentially could involve a large number of commitments, is postponed to last place where it can start without an initial tax

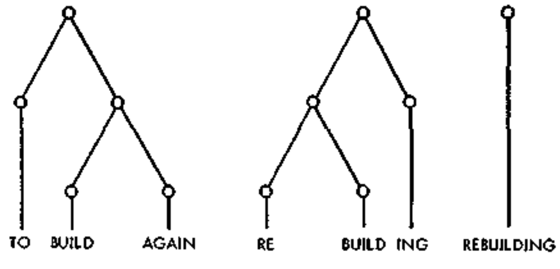

FIG. 5. The utility of compound words such as *rebuilding* is that they involve fewer grammatical commitments than if they were not compounded.

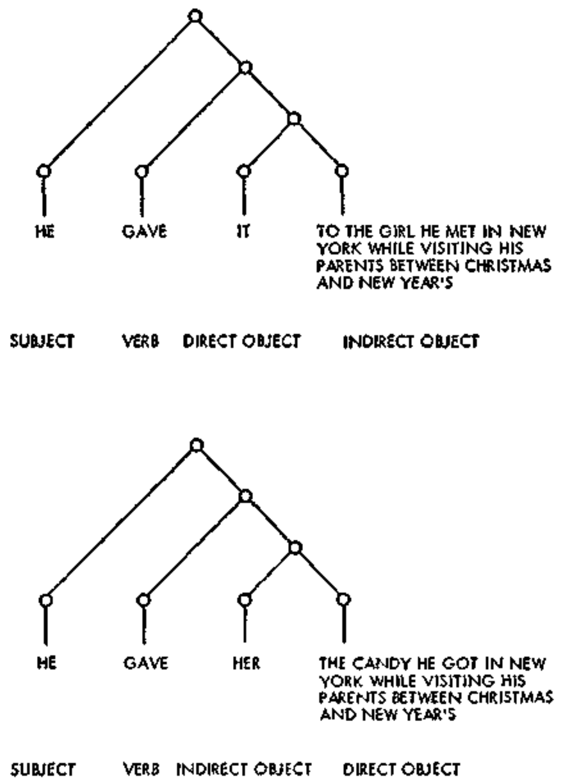

FIG. 6. Flexible word order in English makes it possible to build sentences in such a way that a "heavy" construction is delayed, minimizing depth and maintaining the expressive power of the language. Here the order of the direct and indirect object is changed so that in each sentence the element containing an unwieldy subordinate clause comes last.

of prior commitments. This is a typical complexity of English syntax that had previously been relegated to the area of the aesthetics of good writing. Now it can be seen that there is a good reason for this stylistic variant: It has solid utility for the language. And there is a system behind it that brings the possibility of mechanization. The result is that our position is almost exactly the reverse of what we had thought it was in the beginning. Then we were hoping to get the meaning across, but thought that correct grammatical structure and style would be too difficult. Now we think that we can get the grammatical structure and even the style across, but we are very worried about the meaning, which seems to be a much more difficult problem.

THE SEMANTIC BARRIER

Work in mechanical translation has come up against what we will call the semantic barrier. Even when we have programs which can give grammatical analyses of the incoming sentences, we still cannot make adequate translations because of the large amount of remaining ambiguity. We have come face to face with the realization that we will only have adequate mechanical translations when the machine can "understand" what it is translating and this will be a very difficult task indeed. Here I want to underline the word "understand" because this is just what I mean. When we use a language like English, it is a fact that we make full use of the *knowledge* that we *assume* the listener has in order to shorten and abbreviate our utterances. If I am walking down the street with my wife, I may see something unusual and a single word may convey to her what would require several paragraphs if I had been walking with a stranger. And if I am explaining something to my class at MIT, I can be much briefer than if I were trying to explain the same thing to high-school students. We now realize that a machine must also be given the ability to have this kind of understanding. Many of the former workers in mechanical translation are giving up in the face of the tremendous difficulties. It seems to them too remote a possibility that we shall ever be able to program machines to understand. But some of us are pressing forward undaunted, especially since the search is bound to lead us into a number of extremely interesting areas.

Elinor Charney at MIT has been studying how sentences carry meaning.[9] She is investigating that part of sentence-meaning which is a property of the sentence as a whole and not con-

1. In a recent paper

2. measurements

3. were presented

4. of the effect of alloying on the superconductive critical temperature of tin

FIG. 7. The grammatical complexity of separating the subject from its prepositional phrase modifier by the entire predicate is stylistically approved because it postpones a potentially deep expression, thus avoiding the piling up of grammatical commitments.

[9] Elinor K. Charney, "On the Semantical Interpretation of Linguistic Entities that Function Structurally," *National Physical Laboratory Symposium No. 13* (2 v., London, 1962) 2: pp. 543-560.

nected to the meanings of the denotative words like *boy* and *run*. As an example, in the sentence *If you are to get an electric train for Christmas, you must start being good now*, she is interested in the part of the meaning that can be schematized by *If x is to f, x must g*, which expresses the abstract meaning, *x's g'ing is a necessary condition of x's f'ing*. The abstract meaning is a property of the sentence as a whole and not a property of individual words. It is connected with the traditional but vaguely defined notion of the "complete thought" that a sentence expresses. There are cases of synonymity: *Only if x g's, will x f* (Only if you start being good now, will you get an electric train for Christmas) is synonymous with the above: although it has an entirely different structural schema, it expresses the same abstract meaning. Even slight changes in a schema may alter the sentence meaning drastically. Thus if we add the word *even* to the beginning of the first example, we get *Even if you are to get an electric train for Christmas, you must start being good now*. The abstract meaning has been completely changed: It is *x's f'ing is not a sufficient condition of x's not needing to g* instead of *x's g'ing is a necessary condition of x's f'ing*. The words like *even, if, only*, and *all*, that figure centrally in the expression of the abstract meaning are examples of *structural-constants*. Her research to date, using techniques from logic, gives good reason to believe that each structural-constant has a unique semantic function to perform and always performs the same operation in whichever structural context it occurs. The language system is seen as obeying a surprisingly small number of general laws since the structural-constants are interrelated in very simple and general ways.

Jared Darlington is working on the problem of translating ordinary language into the terminology of symbolic logic. In this connection, he has written two translation programs which accept input arguments formulated in a restricted English. One of these programs translates the arguments into the symbolism of propositional logic, and the other translates them into the symbolism of quantificational logic. Once an argument has been fully symbolized, it is tested for validity by means of the Davis-Putnam proof-procedure algorithm[10] with minor modifications. As an example of how far Darlington's work has come, the argument:

If I buy a new car this spring or have my old car fixed, then I'll get up to Canada this summer and stop off in Duluth. I'll visit my parents if I stop off in Duluth. If I visit my parents they'll insist upon my spending the summer with them. If they insist upon my spending the summer with them I'll be there till autumn. But if I stay there till autumn, then I won't get to Canada after all! So I won' have my old car fixed.[11]

was translated by hand into a format resembling the original in all essential respects, but in which some changes in wording were made in order to render the argument acceptable to the propositional logic translation program. For example, the first premiss was amended to read, "If I *either* buy a new car this spring or have my old car fixed, then I'll *both* get up to Canada this summer and stop off in Duluth." Also, the two sentential clauses in the second premiss were transposed in order to bring the sentence as a whole into the "if . . . then . . ." form; for the same reason, a *then* was inserted between the two sentential clauses in the third and fourth premisses. Finally, it was necessary to eliminate all nonessential differences in wording, such as that between the two phrases, "get up to Canada this summer" and "get to Canada after all." The argument thus pre-edited was translated by the program into the following propositional logic formulation, which in turn was proven valid by the evaluation program.

```
((((((A)OR(B))IMPLIES((C)AND(D)))
AND((D)IMPLIES(F))) AND( (F)IMPLIES
(H))) AND(((H)IMPLIES(J)) AND((J)
IMPLIES (NOT(C)))))IMPLIES(NOT(B))).
```

The argument:

All circles are figures. Therefore all who draw circles draw figures.[12]

was acceptable as it stands, requiring no pre-editing. The program translated the argument into the following quantificational logic formulation, and the evaluation program proved it valid.

```
(EA) (AB) (EC) (AD)(((P1A)IMPLIES(P2A) )
IMPLIES(((P1D)AND(P500BD))IMPLIES
((P2C)AND(P500BC)))).
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Darlington is at present working on a more

[10] Martin Davis and Hilary Putnam, "A Computing Procedure for Quantification Theory," *Jour. Assoc. for Computing Machinery* 7 (1960): pp. 201-215.

[11] I. M. Copi, *Introduction to Logic* (New York, 195S), p. 275.

[12] I. M. Copi, *Symbolic Logic* (New York, 1954), p. 140.

general program which will accept input arguments stated in a less restricted form of English, and which will automatically decide into what type of logic the argument would be initially translated. Another of the areas where promising leads are being followed, towards finding out how to make computers understand English, is in the area of programming languages. These are artificial languages designed for use by people who want to write programs for a computer. In a very real sense the computer understands these Ianguages. It shows its understanding by proceeding to carry out the instructions given by the programmer. This is not very remarkable in the case of the simplest of programming languages, but the tendency today is for programming languages to get more and more complex and to incorporate more and more of the features found in languages like English.

A NEW FIELD

A new field of research has grown up which revolves about languages, computers, and symbolic processes. This sometimes is called computational linguistics, mechanical linguistics, information processing, symbol manipulation, and so on. None of the names are really adequate. The implications of this research for the future are far-reaching. Imagine what it would mean if we had computer programs that could actually understand English. Besides the obvious practical implications, the implications for our understanding of language are most exciting. This research promises to give us new insights into the way in which languages convey information, the way in which people understand English, the nature of thought processes, the nature of our theories, ideas, and prejudices, and eventually a deeper understanding of ourselves. Perhaps one of the last frontiers of man's understanding of his environment is his understanding of man and his mental processes.

This new field touches, with various degrees of overlap and interaction, the already well-established diverse fields of linguistics, psychology, logic, philosophy, information theory, circuit theory, and computer design. The interaction with linguistics has already produced several small revolutions in methodology, point of view, insight into language, and standards of rigor and exactness. It appears that before we are done, linguistics will be completely revolutionized. The interaction with psychology has already produced a pile of papers and books. It is my opinion that the impact on logic will exceed the impact of the Boole-Frege movement and that eventually a large part of philosophy will have to be rewritten.

And the computer is central in this new field because it is in essence a complex symbol manipulating device. There is only one other complex symbol manipulating device in existence, the brain of man and animals.

As we progress in our ability to utilize computers for more and more sophisticated intellectual activities, we must pay attention to the sociological values. We must be careful that this new tool will be used for the benefit of mankind and not to his detriment. The idea of machines that think and understand creates a certain uneasiness in the minds of many people, but there need be no uneasiness if we are careful. Man must certainly keep in control, and many people must have an opportunity for understanding and evaluating the programs that we use, especially if they are making important decisions for us. The problem of understanding a complex computer program is quite similar to the problem of understanding any other complex system such as the organization of a corporation or a government or the complexity of the laws of a society. The best ray of hope in our efforts to understand complex programs is in the area of problem-oriented programming languages, by means of which the programmer can communicate with the computer using a limited number of high-level abstractions which he can readily comprehend. It may very well be that the techniques developed for understanding and writing complex computer programs can also be used for increasing our understanding of other complex man-made systems.