

THE TRANSLATION OF LANGUAGES BY MACHINE*†

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INTRODUCTION

RECENT advances in linguistics, in information theory, and in digital data-handling techniques promise to make possible the translation of languages by machine. This paper proposes a system¹ for translating languages by machine—with the hope that when such a system is worked out in detail, some of the language barriers can be overcome. It is hoped, too, that the translations will have an accuracy and readability that will make them welcome to readers of scientific and technical literature.

Much of the work that has been done up to this time in the field of mechanical translation has been concerned with the possibilities of word-for-word translation^{2,3} because it can be easily mechanized. A word-for-word translation consists merely of substituting for each word of one language a word or words from the other language. The order of the words is preserved. Of course, the machine would deal only with the written form of the languages, the input being from a keyboard and the output from a printer. Word-for-word translations have been shown to be surprisingly good and they may be quite worth while, but they are far from perfect.

Since there is not a one-to-one correspondence between the vocabularies of different languages, a word-for-word translation must list alternative translations for most of the words and the choice among them is left to the ultimate reader, who must make his way through a multiple-choice guessing game. The inclusion of multiple choices confuses and slows the reader, even though he can frequently glean the correct meaning after study. Another great problem is that the word order, frequently quite different in the two languages, further obscures the meaning for the reader. Lastly, there are the more subtle difficulties of idioms and the particular quaint and different ways that various languages have of expressing the same simple things. While it has been suggested in the past that rough word-for-word translations could be put into final shape by a human editor, the ideal situation is that the machine should do the whole job. The system proposed here is believed to be capable of producing translations that are considerably better than word-for-word translations.

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† This version has been much reduced from the original—ED.

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The solution of the problems of multiple meaning, word order, idiom and the general obscurity of the meaning when translation is carried out on a word-for-word basis is to be found in translating on a sentence-for-sentence basis. This procedure can be simulated experimentally by separating a text into sentences and submitting each for translation to a separate person who would not have the benefit of seeing any of the other sentences. In most instances an adequate translation of each sentence would result. Very little would be lost by discarding all of the context outside of one sentence length.

There are striking parallels between language and error-correcting codes. Language is a redundant code, and we are here proposing to deal with code blocks longer than one word, namely, with blocks of a sentence length. Our problem is to specify the constraints that operate in the languages to at least a sentence length; this will be difficult because languages are so complex in their structure. However, we shall attempt to specify these constraints, or at least to lay the foundation for such a specification.

THE NATURE OF THE PROCESS

A code translation system can be looked upon as being much the same as a communication system. The main difference is that the decoder and the encoder are interchanged; a communication system usually has the encoder

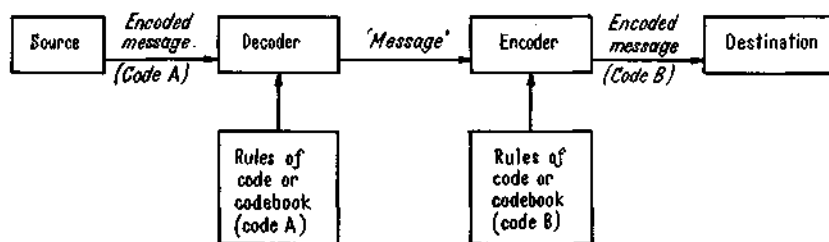


Figure 1.

first (see Figure 1). If the two codes are very similar, or in some sense equivalent, it may be unnecessary first to decode and then encode. It may be necessary only to decode partially. If the two codes are very different, it may be simpler to decode to a minimally redundant form of the original message before encoding in the new code. We would like to consider the process of language translation as a two-step process: first, a decoding, or at least a partial decoding; then a recoding into another of the hundreds of known languages. The difficulties associated with word-for-word translations arise from the use of only a partial decoding; that is, a decoding based on the word instead of the sentence or some larger block.

We can assume that most material in science and engineering is translatable or expressible in all languages of interest. An expression and its translation differ from one another in that they conform to the different constraints imposed by two languages. They are the same in that they have the same meaning. This meaning can be represented by some less redundant expression that is implicit in both language representations and which can be obtained by stripping off from one of them the trappings associated with that

particular language. This representation might be called a transition language. Attempts at a specification of the structure of the 'message' may get us into some of the difficulties associated with 'meaning', but a description of the same thing as a transition language comes naturally from a description of the constraints of the two languages, since the transition language is just a representation of the freedom of choice left after the constraints of the languages have been taken into account.

Many of the constraints of written language are quite constant—grammar and syntax are rather stable—but there are other constraints that are peculiar to each user of the language, each field of discourse, each cultural background. A restriction can perhaps be made in mechanical translation to one field of discourse so that it will be easier to specify the constraints. Since language is a very complicated coding system (and in fact not a closed system, but an open one in that new words, constructions and innovations are constantly being introduced by various users) the complete determination of the constraints is practically impossible. The best that one can do is to determine an approximate description of the constraints that operate; thus our translations will remain approximate.

What we mean by the concept of transition language in a language translation process can be illustrated by the word-for-word translation case. BOOTH⁴ pointed out that one could not go directly from the words of one language to the words of another language with a digital computer of reasonable size, but that it would be more economical to go through the intermediate step of finding the addresses of the output words. These addresses are in a less redundant form than the original words, and for the purposes of this discussion they will be considered as the transition language. What we mean by transition language in a mechanical translation process is the explicit directions for encoding which are derived by the decoder from the incoming text.

The practical feasibility of mechanical translation hinges upon the memory requirements for specifying the rules of the code, or the structure of the languages. Word-for-word translation is feasible because present-day digital data-handling techniques can provide memories large enough to store a dictionary. In other words, we can use a codebook technique for decoding and encoding on a word-for-word basis. If we want to translate on a sentence-for-sentence basis, we must find some method of specifying the structures of the languages which is compact enough to fit into practical memories. Obviously we cannot extend the dictionary concept by listing all of the sentences in the language with their translations. There are certainly in excess of 10^{50} sentences less than 20 words in length in a language like English.

Our problem then is to discover the constraints of the languages so that we can design practical decoders and encoders. We must bear in mind, however, that there is no unique solution. There are many ways in which the constraints, or rules of the code, may be formulated; there are many possible ways in which the transition language may be constructed. Our choice not only depends upon which two languages are involved in translation, and upon the direction of translation, but also upon the specific requirements of the particular translation scheme.

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We have pointed out that we want to translate on a sentence-for-sentence basis; that the feasibility of being able to do this depends upon whether or not we can state the structures of the languages in a form that is sufficiently compact for storing in a machine memory; and that the form of the statements of the structures must conform to certain other requirements, chief among them being that they be appropriate for use in decoders and encoders.

STRUCTURE OF LANGUAGE FROM THE POINT OF VIEW OF THE ENCODER

We want first to consider the form of the rules from the point of view of the encoder because they are simpler to explain and correspond more closely to other points of view commonly encountered. The encoder combines the message with the rules of the language in order to form the encoded message.

We want to limit the encoder to the words of the language. Of the various ways of doing this, perhaps the only one that seems feasible is to list the words of the language in a dictionary and to store this dictionary in the machine. Whether or not an attempt is made to reduce the number of entries in the dictionary by the use of a stem-affix routine, as is proposed by several authors, or by a method of splitting up compound words⁵, depends upon whether it will be more economical to supply the required routine or to supply the additional storage space needed to list in full all the words in their various inflected forms.

We want to encode in blocks of a sentence length. Since the words are to be listed in a dictionary, it seems appropriate to inquire whether a dictionary type of list could be used to assist in the encoding into sentences. It is certainly clear that it would be impossible to list all of the sentences of the language in a dictionary. The length of the list required to accommodate all structures of a code depends upon the redundancy of the structures but, more important, upon the size of the signalling alphabet and the length of the sequences. The use of words as a signalling alphabet and the use of sequences of sentence length is completely out of question because of the practical impossibility of listing and storing enough sentences.

In order to reduce the signalling alphabet, the concept of 'part of speech' is introduced. Larger structures are stated in terms of sequences of parts of speech instead of sequences of words. By the introduction of the concept of part of speech, we have factored the message into two parts. First, there is a sentence composed of a sequence of parts of speech, and the encoder has the opportunity of choice from among the various allowed sequences. Second, there is a further opportunity for choice from among the words that have the privilege of occurrence⁶ for each part of speech. In language, these two possibilities for choice correspond to structural meaning and lexical meaning. As an illustration of structural meaning, take the sentence: 'The man had painted the house'. A German sentence with approximately the same meaning as the one above, translated on a word-for-word basis, would be: 'The man had the house painted'. Here the words are the same, but the structural meaning is different.

As an example of the economy introduced by the concept of part of speech, consider the Markhoff source (see *Figure 2*) which will generate over 10^{21} English sentences using a vocabulary of about 35 words. By the use of

the concept of part of speech, whole lists of words are considered as equivalent so that with the 10 parts of speech there is only a small number of sentence types. It is estimated that there are millions of possible sentence types of which this diagram represents only a few. The structural meaning is indicated by the sentence type or choice of path through the diagram, the lexical meanings are indicated by the further choice of the individual words from each list.

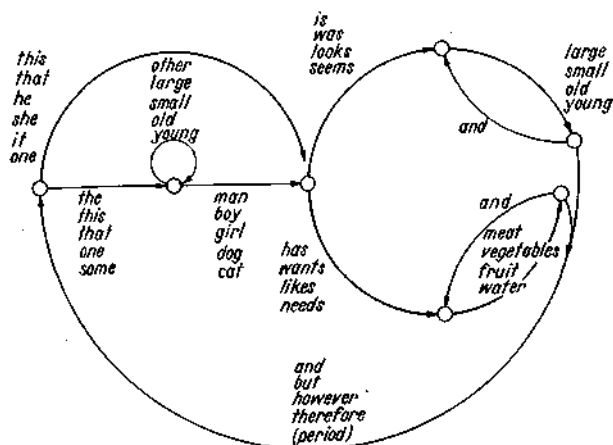


Figure 2.

The introduction of part of speech and the factoring of the message into a lexical and a structural part has reduced the total number of the possible representations of sentences. The number of different structures, however, is still too large to list in a dictionary. The further step that we propose is to take advantage of regularities in the sentence types. For example, the first three states in the diagram (Figure 2) and their connecting lines may be found included intact in many different sentence types and often more than once in a given sentence type. Just as we have grouped several words together to make a part of speech, we may group several paths together to form a phrase. If this programme is carried out in its full elaboration we are left with a number of intermediate levels of structure between the word and the sentence, such as various types of phrases and clauses. The levels are to be chosen in such a way that the total number of listed structures is reduced to a number that can be handled in a machine memory. Preliminary work seems to show that this can be achieved if the parts of speech number in the hundreds.

Then our rules of language, from the point of view of the encoder, are somewhat as follows. Select a sentence from among the sequences of clause types. For each clause type, select a clause from among the allowed sequences of phrase types. For each phrase, select a sequence of parts of speech. For each part of speech, select a word. In the translation process, the information required for the selections at each stage must be obtained from the decoder and may be called the 'message' represented in the transition language.

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STRUCTURE OF LANGUAGE FROM THE POINT OF VIEW OF THE DECODER

So far, the structure of language has been looked at from the point of view of the encoder which encodes in a given output language the 'message' provided for it by the decoder. The rules for decoding language into some representation of the 'message' are not just the reverse of the rules for encoding. If they were, mechanical translation would be much easier to accomplish than it appears to be. The difference between the point of view of the decoder and the encoder is just the difference between analysis and synthesis. The difference is illustrated in error-correcting codes that are easy to encode according to rules, but for which no rules are known for decoding in the presence of noise, although the message can be recovered by the use of a code book. In language, the difficulties in decoding are not the result of noise; they are the result of certain characteristics of the encoding scheme.

Decoding would be very simple if the part of speech of a word could be found out by looking at that word only. This is true to some small extent in languages that have inflectional endings and grammatical affixes. Much attention has been paid to these affixes for purposes of mechanical translation; but the fact remains that even in the most highly inflected languages, the parts of speech are imperfectly indicated by affixes on the words. The problem is even worse than that: a given word form may belong to more than one part of speech, and there is no way at all to tell which part of speech it is representing in a certain sentence by looking at the word itself. The context, or the rest of the sentence, must be examined. The lists of words that the encoder uses for each part of speech overlap, so that a given word may appear on several lists. In *Figure 2* it can be seen that several of the words appear in more than one list. The proper translation of these words into a language other than English requires a knowledge of the list from which the word was chosen. The decoder had this problem of deducing from which list the word was chosen. The statement that a word may belong to several parts of speech is just another way of saying that it may have several meanings. The concept of part of speech may be extended beyond the usual list to include not only the usual grammatical distinctions but, in addition, the distinctions that usually would be called 'multiple meanings'.

Probably all languages exhibit the phenomena of multiple meaning, one word making shift for more than one part of speech. It is interesting to speculate as to whether there is any utility to this phenomena, or whether it is just excess baggage, a human failing, another way in which our language does not come up to the ideal. One word/one meaning would presumably make our language more precise and would eliminate the basis for many pointless arguments and much genuine misunderstanding. It has been proposed that language be changed to approach the ideal of one word/one meaning so that mechanical translation would be easier⁷. Some of the advantages accruing from the phenomena of multiple meaning might be as follows: there is an economy of the vocabulary because part of the burden of carrying meaning is transferred to the word sequence. The

number of different structures available in a code goes as V^n , where V is the vocabulary size and n is the length of the sequences. In order to take advantage of the larger number of structures available, the words must acquire multiple meanings. There is the introduction of the possibility of the metaphoric extension of the meaning of words so that old words can be used for new concepts. There is the possibility of using a near synonym if a word with the exact meaning is not at hand, and of modifying the meaning of the near synonym to that intended by putting it in an appropriate context.

Since the lists of words for the different parts of speech used by the encoder overlap, there is the possibility that the same sequence of words may result from different intended structural meanings. In fact, this sometimes happens when the encoder is not careful, and we have a case of ambiguity. Sometimes the choice of an ambiguous sequence is intentional, and we have a pun. Puns, in general, cannot be translated, and we have to assume that unintentional ambiguity is at a minimum in the carefully written material that we want to translate.

The task of the decoder in a translation process is to furnish the information required by the encoder so that it can make the appropriate selections on each level of structure. This information is implicit in the incoming sequence of words and must be made explicit. The decoder is given only the words of the incoming text and their arrangement into sentences. It must reconstruct the assignment of the words to the parts of speech intended by the encoder and must make the structural meaning explicit so that it can be translated. The decoder must resolve the problems of multiple meaning of words or structures in case these meanings are expressed in several ways in the other language.

The decoder has available two things: the words and the context surrounding each of the words. The appropriate starting point for describing the structure of language from the point of view of the decoder is to classify the words of the language and the contexts of the language. The classification proceeds on the assumption that there is no ambiguity, that the assignment of words to parts of speech can be done by the decoder either by examining the form of the words themselves or by examining the context.

The classification of the words must be a unique one. Each word must be assigned to one and only one class. These we shall call word classes. In order to set up word classes, we classify together all word forms that are mutually substitutable in all sentences and behave similarly in translation. In practice, one of the difficulties of making such a classification is the problem of how detailed the classification should be. Certain criteria of usage must be ignored or in the end each word class will have only one word in it. As examples of the sort of classification that is intended, 'a' and 'the' would be assigned to different classes because 'a' cannot be used with plural nouns. 'To' and 'from' would be assigned to different word classes because 'to' is a marker of the infinitive. 'Man' and 'boy' would be assigned to different word classes because you can man a boat. 'Exact' and 'correct' would not be separated merely because one can exact a promise but correct an impression. Preliminary experimentation has indicated that the number of word classes needed for translating the structural meaning is of the order of many hundreds.

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The classification of contexts is very closely connected with the setting-up of word classes. A sentence can be considered as a sequence of positions; each position is filled by a word and surrounded by a context. Since we have classified words into word classes, each position in the sentence has associated with it a word class which can be determined uniquely by looking the word up in a special dictionary. The number of sentence-length sequences of word classes is much fewer than the number of sentences. All sentences that have the same sequence of word classes are considered equivalent. The context of a given position in a sentence can be represented by the sequence of word classes preceding the position and the sequence of word classes following the position, but all within one sentence length. It is these contexts that we propose to classify. We classify together all contexts that allow the substitution of words from the same set of word classes. We thus have set up both word classes and context classes.

The relationship between the word classes and the context classes can be illustrated by a very large matrix. The columns of the matrix represent all of the word positions in any finite sample of the language; the rows of the matrix represent different word forms in the vocabulary of the language. Each square in the matrix is marked with an *X* if the word corresponding to that row will fit into the context surrounding the position corresponding to that column. All words that have identical rows of *X*'s belong to the same word class. All contexts that have identical columns of *X*'s belong to the same context class.

The word classes and the context classes can be set up in such a way that the sentence sequence of context classes contains just the information that we require for specifying the original parts of speech, and thus the structural meanings, as well as the information that we require for resolving many of the multiple meanings of the words and of the larger structures.

The structure of language from the point of view of the decoder is as follows. Words are listed in a dictionary from which we can obtain for each its assignment to a word class. Sequences of word classes are also listed in the dictionary, together with their designations in terms of phrase types. Sequences of these phrase types are also listed in the dictionary, and so on, until we have sentence types. The procedure for the decoder is to look up in the dictionary the longest sequences that can be found listed, proceeding from word class sequences to phrase sequences, to clause sequences and so on. At each look-up step, the dictionary gives explicit expressions that lead in the end to a discovery of the context classes of each position. From this we obtain, for each word, its original assignment to a part of speech, and the structural meaning. Thus we have the 'message' or explicit directions for use in the encoder.

CONCLUSION

The mechanical translation of languages on a sentence-for-sentence basis is conceived of as a two-step process. First, the incoming text is decoded by means of a decoder working with the constraints of the input language expressed in dictionary form and based on word classes and context classes. The result of the decoding operation is a representation of the 'message', which is just the directions that the encoder needs to re-encode into the output language by using the constraints of the output language expressed

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in dictionary form and based on parts of speech. An assessment of the worth or the fidelity of the resulting translations must await completion of the detailed work required to set up the dictionaries and to work out the system in all detail. It is certain that the resulting translations will be better than any word-for-word translations.

The author is deeply appreciative of the opportunity that he has had for discussing these matters with his colleagues at the Research Laboratory of Electronics, Massachusetts Institute of Technology. He is particularly indebted to R. F. Fano, P. Elias, F. Lukqff and N. Chomsky for their valuable suggestions and comments.

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- ⁷ Chap. 10, Ref. 2

DISCUSSION

B. MANDELROT: A fundamental problem of linguistics has been brought to light by an attempt to design devices which can simulate language behaviour. This is linked to Turing machines (and to I. J. Good's comment on the paper by Spencer-Brown). The set of denumerable sequences of symbols, which can be generated by a computer of finite complexity, is denumerable. They are therefore negligibly few among all sequences. Are there any serious grounds for believing that the actually emissible sequences are denumerable, or should one accept the possibility of the set of rules of a language being infinite (though increasing 'very slowly' with the text runs) ?

D. M. MACKAY: When we learn as children to translate from one language to another we may begin by trying to substitute words directly for one another with the help of a dictionary. As we progress, we gradually pass over to a quite different kind of procedure. We try to discover what the original author *wants to convey* in the new language. In short, we pass over from thinking solely in terms of the *symbols* to thinking in terms of the *dispositions intended to be evoked* by the symbols. This is what distinguishes insightful translation from what some would prefer to call mere transcription.

A corresponding distinction exists between two different approaches which are covered by the name of mechanical translation. The first, at present almost universal, produces a translation by a correlation of syntactic structure in the two languages. No understanding is needed, in principle, of the dispositions intended to be evoked by the material to be translated. For this reason I would suggest that even Professor Yngve's ingenious 'transition language' would perhaps be better termed a 'transition code', since its function is not to select dispositions but rather symbols.

The second approach would be to make, as an intermediate step, a representation of the *dispositions* intended to be evoked by the material to be translated. A translation could then be achieved by producing, as the output, expressions in the other language which evoke the same dispositions. I know of no practical work being carried out on these lines and, as I have indicated in my paper in this Symposium, I suspect that

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it may have to wait on our understanding of information-processing in the human organism; but the product of such a translating device would, I think, be much closer to what we normally desire of a human translator. The difference would be shown most easily in the kinds of fault to which each would be liable. A translation on the first principle should quite faithfully reflect the syntactic structure of the original, but could easily fail seriously to convey the meaning. A translation on the second principle might allow only a loose inference to the syntactic structure of the original, but should on the whole faithfully reproduce its meaning.

The same line of thought suggests an answer to the question raised in discussion, as to what is meant by 'translatability'. An expression in one language may be said to be translatable into another if the disposition-complex it is intended to evoke in the hearer can be evoked by a suitable combination of terms in the other language. If, for example, the other language arises from a culture in which that disposition-complex is unrecognized, the expression is untranslatable unless and until someone discovers a linguistic way of evoking the required disposition in its users.

A. J. MAYNE: Judging by my own experience of *non*-mechanical translation of scientific papers, it seems to me that, in this field, a word-for-word translating machine is the most that is needed; usually, the complete translation should then be obtainable very easily by any scientist well acquainted with the subject-matter of the document being translated. For example, I have little knowledge of the German and Russian grammars and syntaxes, but I have found that I can get a very adequate idea of the meaning of a mathematical paper in either of these languages, if it is in a field I already know well.

COLIN CHERRY: I should like to make a comment similar to Dr. MacKay's, but expressed somewhat differently. If we classify semiotic matters into the classical divisions, syntactics, semantics and pragmatics, then 'mechanical translators', as they exist at present, carry out syntactic operations only; they should be called syntactic transformers. It is the human pre- and post-editors who apply the semantic rules; for only they can form the necessary extra-linguistic association. More strictly, the 'dispositions' selected in them are a private matter, for they depend upon the individual editor(s) experiences.

E. H. HUTTEN: It is often convenient and even useful to distinguish between syntactic and semantic rules in a natural language; but it would be wrong to forget that such a distinction is somewhat arbitrary. The rules so obtained (by a logical re-construction of ordinary usage) apply only for a given purpose and within a certain context. Moreover, the syntactic rules are not independent of the semantic rules: they are chosen so as to correspond to one another, for the language as a whole is to represent a certain interpretation of the events observed. Language reflects reality in a particular way given by the cultural, historical, social and other associations which underlie our usage of language.

V. YNGVE in reply: The sequences of words with which we are concerned here, like those sequences of digits tested for randomness by G. Spencer Brown, are of finite length. All actually existing sequences of words, and all actually emissible sequences of words, are of finite length, and their set is therefore denumerable. There are strong reasons for believing that the number of rules of sentence structure is finite. The effect of the rules of a language is to reduce the number of emissible sequences. It has been estimated that it may be possible to reduce the number of emissible sequences of length N to a fraction $f < (1/5)N$ of the total number of sequences of length N by the application of sentence structure rules alone. We may also be interested in sequences which are longer than sentence length. Very little has been done on the specification of the rules for these longer structures.

I completely agree with Dr. MacKay that a translating device which is able to operate with the 'dispositions' which were intended by the original author would provide a much better translation than the syntactic device envisioned here, but I

wonder if it is possible to discover the author's intentions. We can only assume that the author intends to evoke the dispositions to which the symbols that he uses are *conventionally* attached. In translating, we try to find symbols in the other language which are *conventionally* attached to similar dispositions. This is the reason why we had to assume that the material is translatable, that is, expressible in both languages. The ideal of an unambiguous universal language would seem to be unrealizable, but if we assume translatability we can pair expressions which are attached to the same dispositions in the two languages. The person who designs the machine makes use of his knowledge of dispositions and their conventional representations in the two languages. All that the machine does is to bring forth the symbols in one language which he has paired with the symbols in the other language.

There is no difference in principle, but only in degree, between a translation using dispositions and one using syntactic structures or, for that matter, a word-for-word translation. If the symbols involved are words, the dispositions involved can be found (but usually not uniquely) in a good dictionary; that is, on a word-for-word basis. On a sentence-for-sentence basis, additional dispositions can be found (the structural meaning) and a better knowledge of the individual word meanings can also be had. Our present task is to provide a dictionary of sentence types. Following this to its logical end, we would deal with longer and longer structures, obtain better and better approximations to the conventional dispositions which we assume the author intended, and require decoders and encoders with a memory capacity closer and closer to that of the human organism.

Code transformation and language translation differ only in degree. We use certain refined techniques of code transformation, worked out by people who can operate with the dispositions or meanings, and hope that the result will be good enough to be taken as a translation by those for whom it is intended.

In answer to Mr. Mayne: I am happy to find so many people who would have the patience to put up with what to many others is the general fogginess and frustrating inadequacy of word-for-word translations. It means that we shall have widespread acceptance for our sentence-for-sentence translation which, though perhaps also foggy and inadequate at times, will be much better. We are taking a course intermediate between what you would be satisfied with and what D. M. MacKay would like.

Yes, Dr. Cherry, we are very fortunate that the human readers, for whom our mechanical translations are intended, are intelligent and can apply semantic rules. In many cases these readers will be experts in the subject matter under discussion and can form many extra-linguistic associations. We are also very fortunate in being able to translate published and therefore carefully written, edited and, we hope, unambiguous material. Taking these facts into consideration, it is perhaps not surprising that for related languages even the product of a word-for-word substitution is moderately intelligible. It is, of course, our hope that the output of our 'syntactic transformers' will be accepted as translations that are adequate for many purposes, and that these translations can be produced, ready for the ultimate reader, with no pre- or post-editors or any persons intervening between the input text in the one language and the output text in the other.

Answering Dr. Hutten: In related languages, many syntactic structures are parallel in that they correspond to quite similar interpretations of the events observed. For example, German and English are quite similar in the use of singular and plural, subject and predicate, verb and object, noun and adjective *etc.* When the interpretations of events are different in the two languages, we have trouble in translation—mechanical or human. For example, the distinction between 'he goes' and 'he is going' in English, but not in German, and the use of definite and indefinite articles in English and German, but not in Russian. Fortunately, the structures of these related languages are actually nearly parallel, so that the assumption of translatability is almost valid. Their interpretations of events observed are very similar.