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CAN TRANSLATION BE MECHANIZED?

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A GOOD translation of a novel requires many qualities from the translator. He must be a native speaker or have at least native-like command of the language into which he translates, the *target language;* he must have a good knowledge of the language from which he translates, the *source language*, and preferably have lived among the people who habitually speak the source language; he must have some knowledge of the author's biography and cultural background, and of the social situation prevailing at the time and place of the novel's action; he must have imagination and some original creative ability; and finally he must also have everything that is included under experience. Even if the translator possesses all these qualities to the highest degree, he is still apt to be accused of being a traitor to the author's original intentions—every translator being by necessity a traitor: *traduttore, traditore*, as the Italian proverb goes.

In view of all these essential requirements, the very idea of trying to explore the possibilities of mechanizing part or all of the translation process may seem a frivolous waste of time, a psychopathic epiphenomenon of a materialistic culture to which nothing is holy—least of all human dignity. This is the almost universal reaction of all literary-minded people when they are confronted with the suggestion of mechanizing translation. Understandable as this reaction is, it is, of course, not sufficient to deter further exploration of this admittedly somewhat queer idea. Only too often what have proved to be sound innovations have been ridiculed in their beginnings, the ridicule turning out to be nothing but a rationalization of mental laziness and temperamental opposition to new-fangled ideas.

It is not merely intellectual curiosity that induces us to inquire into the possibilities of mechanized translation, though this is a sufficient reason. The translation load is constantly increasing all over the world. Many, many millions of words are translated daily by United Nations agencies alone, and much important material remains untranslated, and therefore not sufficiently utilized, for lack of trained translators and the high cost of human translation. Leaving aside what at the present moment can be only Utopian speculations about the adoption of some natural or artificial language as an international auxiliary medium of communications, quick, accurate, and low-cost translation is, and will continue to become, a major desideratum for diplomacy and its martial extensions, for finance and science, for literature and journalism alike.

The obstacles put in the way of spreading information by the fact that much valuable scientific material, for example, remains insufficiently utilized in translation, are well known and form only one aspect of the immobilization of accumulated knowledge which has reached dangerous proportions and alarms many scientists. Let us not stop here to deal with the other aspects of the same phenomenon. A solution of the constantly increasing translation load for science, disregarding such radical solutions as the imposition of a universal language, can obviously be achieved in only one or any combination of the following three ways: (1) Better training of future scientists in foreign languages; (2) Increase in the number of professional translators; (3) Partial or complete mechanization of the translation process. A decision on the optimal combination of these possible actions cannot be taken until the third procedure has been adequately explored.

But is it not obvious that a translation of a novel, say from Russian into English, performed by a machine so constituted that its complexity is still inferior to that of a human being—and it will probably take millennia to produce machines of such complexity—will be worthless, for the reasons stated above? Let us grant this immediately. To my knowledge, none of the investigators, who have devoted some time to speculations about machine translation, have been thinking in terms of a completely automatic translation of an artistic creation. But if we restrict ourselves to scientific publications and are ready to compromise on the completeness of the translation—not too much, of course, lest we trivialize our problem—it is surely no longer obvious that our attempts must be doomed to failure. I would claim, on the contrary, that it is obvious that something can be achieved along this line. Scientific writers have been trained to write in such a way that the understanding of their texts is dependent only to a negligible degree on a knowledge of their biography and their cultural background, and the imaginative or recreative powers of their readers. This being so, it would seem that even a good translation of a scientific paper will not require the full capacities of human brain power. Some of the partial operations within a complete translation process seem to be rather routine, and we know by now that routine work of a certain type can often be performed by machines as well as it can by human beings, and sometimes better and more quickly.

The real problem is, therefore: How much of the translation process is similar to establishing telephone connections or solving differential equations—operations whose performance was regarded, until recently, to require human intelligence but are now performed with great efficiency by what are popularly known as "mechanical brains?" In other words, how much of this process is reducible to a small set of elementary operations like matching and counting, perhaps to be iterated millions of times?

Part of any translation process consists in correlating certain words of the source language to certain words or phrases of the target language.

This operation seems to be a likely field for mechanization. It is, therefore, not surprising that the first device thought of by almost anybody who has dealt with this problem was a *mechanical dictionary* combined with, and following in time, a *mechanical recognizer.* The latter device is expected to be able, probably through some kind of electronic scanning, to identify, automatically, sequences of print symbols, usually words, and to transmit a coded transform of the identified unit to the dictionary in which it will be matched against its entries. If agreement is established, the target language correlate, or correlates, of the transform would then automatically be printed out. Though no satisfactory mechanical recognizer exists today, there seems to be a very good chance that such a device will be perfected in the near future [10]. We shall work on the assumption of its availability, being fully aware that otherwise a human operator will have to be charged with the task of transforming any given printed material into a form utilizable by the machine.

Notice that a "word," for a mechanical recognizer, would be a certain sequence of letter shapes framed by spaces or certain punctuation marks. *Go* and *goes* would be different words, but *run* (the verb) and *run* (the noun) would be the same word.

Our problem can now be formulated with this question: For a given sentence of the source language, what part of the complete translation is provided by the target language expressions correlated with the words of this sentence? Probably one's first reaction would be that such a "mechanical" *word-by-word,* or *literal, translation* stands hardly any chance of being satisfactory. Though this statement is doubtless correct in general, it has been repeatedly shown that, for some pairs of languages, with a paper belonging to a restricted scientific field, and with suitably prepared dictionaries, the output of such a correlating machine would be intelligible to an expert in a specific subject, armed perhaps with a few instructions, but without any knowledge of the source language proper. It seems, for instance, that the literal English correlates of most Russian mathematical papers would enjoy a sufficiently high intelligibility [1]. This sounds reassuring enough, but unfortunately, there are still many strings attached even to this modest result. These strings are of a quantitative rather than of a qualitative nature. Intelligibility *on principle* might have some theoretical importance, but it will remain practically valueless if the cost-time factor involved is disproportionately large.

Let us now consider German as a source language. Its most complete dictionaries contain about 400,000 entries. These, however, are not our "words," since verbs are represented in them only by their infinitives, nouns by their singular nominative, and so on. On the other hand, homographs form multiple entries, whereas they form one "word." Since on the average there are four to five "derivatives" corresponding to each such German entry, these numbers are pure estimates, substantiated by no more than common sense, in view of the strange lack of actual counts. The German language as a whole would contain up to 2,000,000 words! To each such word, if the largest dictionaries were taken as a basis, would correspond from one to perhaps a hundred different English correlates with an average of, say, 10 correlates which are not necessarily single words. The complete mechanical dictionary would then have to contain some 30,000,000 words of an average length of possibly 5 letters. If a simple alphabetical coding is used, the storage capacity of this mechanical dictionary would then have hundreds of millions, if not billions, of bits—and let the reader who is unacquainted with these technical terms not stop to worry about their exact significance. Here then is a tremendous technical problem, if we take into consideration that the time allocated to the matching of a word in the input with a word in the dictionary has to be measured in seconds, perhaps even in tenths of seconds, to be acceptably effective, not to speak of the high cost of such a storage for present devices. Moreover, an output of this complexity would probably pose, in general, too high a load on the final reader.

When I mentioned above the practical feasibility of literal translation, one of the qualifications I added was that of a "suitably prepared dictionary." A dictionary of the type I have just described, though good enough as a theoretical illustration, would certainly not be considered "suitable." What can be done, then? There are various ways of reducing the enormous numbers just mentioned, and they can be taken either separately or in some judicious combination.

One method involves adding an additional piece of mechanical equipment of a somewhat more involved nature, namely, a *morphological analyzer*. This device will be charged with the task of reducing the derivatives to stem and affix; for German and Russian, to stem and suffix. The 2,000,000 German words, for instance, are derivatives of some 500,000 stems. There are more stems than entries, since weak verbs will have, in general, two stems, for instance, *lob* and *gelobt* for the entry *loben.* (unless some *prefix*-analysis is also performed); strong verbs sometimes many more, for instance, *geb, gib, gab, gäb, gegeben* for the entry *geben,* etc., combined with about a hundred suffixes. In Russian there are no more than 80,000 entries in the largest dictionaries; the number of stems might therefore not be much greater than 100,000. Whether the suffix-analysis is performed by a kind of chopping off of one tail-letter after another and constant comparison with the stem dictionary or by some wholesale comparison with a suffix list, need not be discussed here. This is an important technical problem that will require extensive experimentation before a definite answer can be given.

A second method which, in distinction to the first, does not require any additional equipment, consists in taking full advantage of the restricted field of interest of many scientific books and of most articles. Out of the 400,000 German word entries, a great majority are practically never used in any scientific publication, and 5000 entries suffice to cover between 80 per cent and 95 per cent of the words used in any German publication on, for example, brain surgery [2]. Some 3000 entries would take care of almost all words occurring in Russian mathematical papers [3]. Consequently the preparation of *idioglossaries* is a rewarding task for machine translation, at least so long as no revolutionary improvements in storage capacities and access time are made. Of course, if the second method is used alone, not in combination with the first one, the number of words will be much larger than the number of entries, but still less than the theoretical number, since many derivations are never, or rarely, used in scientific writing. If one is ready to miss the translation of a word occasionally, then all verb forms except those of the third person can be forgotten and, similarly, many noun derivatives and the like. Reliance on an idioglossary not only reduces highly the list of words that has to be scanned, it also often reduces the number of correlates. The use of the German *Rinde* in brain surgery context has as its only English correlate *cortex* and never one of the other correlates appearing in a general dictionary, such as *bark, rind,* or *crust* [4].

A third method would utilize more efficient codings than those based upon alphabetical letter-by-letter coding. However, a discussion of this topic would lead into technicalities without being sufficiently rewarding. We shall, therefore, be satisfied with not having overlooked this possibility [5].

The fourth method, and the last to be discussed here, would reduce further the load on the final reader, or *post-editor*—if there is someone whose task is to transform the machine's output into idiomatic language —by eliminating some or all syntactic ambiguities and perhaps also by rearranging the source language text according to some standard target language order. To illustrate: Assume that the German sentence,

Paul gibt seiner Schwester einen Apfel

(for the purposes of illustration, a non-scientific simple example was chosen), is to be translated into English. On a simple word-by-word basis, the machine output might look like this:

Paul	*gives*	*of-his*	*(its, her)*	*sister*	*a*	*apple*
	yields	*to-his*	*(its, her)*	*nurse*	*an*	
	renders				*one*	
	emits					
	evolves					
	expresses					

Notice first that there is no way of deciding whether *sister* or *nurse* is the correct correlate of *Schwester.* This semantic ambiguity is inherent in the German original, and the mechanical translation should by no means be less ambiguous than the original itself. The *context,* whether the linguistic environment or the extralinguistic situation in which this sentence was uttered, will presumably suffice to eliminate this ambiguity. There has, however, crept into the set of English correlates an ambiguity of a syntactic character, which was nonexistent in the German original. Whereas the only correct translation (up to semantic ambiguities) is clearly:

Paul gives an apple to his sister,

the set of correlates allows also, though admittedly with less likelihood the rendition:

Paul gives an apple of his sister

(with less likelihood, since a *gives*-sentence without an indirect object is not very frequent, and certainly not in literary style). Though this gratuitous ambiguity will hardly do much harm in the given example and would probably be eliminated through the immediate context, there are sure to be cases where the additional ambiguity will be more serious and not so simply excluded. A mechanical procedure that would uniquely determine that in this sentence *seiner* is dative and provides for similar decisions in the more serious cases might therefore be of considerable value, for certain language pairs probably of decisive importance.

With respect to German, for instance, there are various features that would make a word-by-word translation often look rather inadequate. One of these features is the separation of prefixes. Even for such a simple sentence as: *Paul gibt Trunkenheit vor,* it is unlikely that anybody, unacquainted with German, would be able to derive from the set of literal correlates the correct translation: *Paul simulates drunkenness.*

Paul	*gives*	*drunkenness*	*before*
	yields		*in front of*
	renders		*for*
	emits		*from*
	evolves		*of*
	expresses		*forward*
			on
			formerly

It is possible, of course, and even probable that the context would enable one, with some effort, to induce the word *simulates,* but it is clearly desirable to have this done automatically. By the way, if the reader should have the feeling that the correlate list is too elaborate, I can assure him that this feeling is shared by many who have been working on this problem. Dictionaries will have to be radically revised for machine translation.

Now there are various ways of remedying this situation. The theoretically simplest remedy would be to rearrange the original sentence into the pseudo-German:

Paul vorgibt Trunkenheit

with *gives advantage, pretends, alleges,* and *simulates* as the correlates of *vorgibt.* But both the elimination of syntactic ambiguities and the rearrangment go, of course, far beyond the facilities of the mechanical dictionary with which we started. Is it still possible to have such operations performed by an automaton? The answer, I think, is a very definite *Yes,* though the detailed justification of this answer cannot be given here. I claim that a good part, if not all, of a syntactic analysis, can be performed mechanically, though only on the basis of a new type of syntactic description which I have termed elsewhere *Operational Syntax* [6]. This kind of syntactic description is only in its beginnings, but there are good reasons to believe that its preparation, in the case of those languages for which a satisfactory ordinary syntactic description already exists, should prove to be not too difficult.

It should be perfectly clear that the construction of a mechanical *syntactical analyzer* will pose tremendous hardware and programming problems, even after an operational syntax has been provided for the respective source language. But it might be worth while to construct this additional organ even for those languages where a simple word-by-word translation would be intelligible to a highly qualified post-editor. The more that is done by the machine, the less on the average will be the responsibilities of the post-editor. It is premature, at this point, to go into a discussion of the relative over-all effectiveness of the various combinations. Let me then conclude this part of the discussion by presenting a hypothetical output of a German-English translation machine consisting of a word-recognizer, a morphological analyzer, a syntactical analyzer, and a stem-dictionary. As a result of the morphological and syntactical analysis, each word is analyzed into stem and *operator* that contains the grammatical information about the specific form and function of this word in the given sentence. However, the operator is stripped of all those parts that are irrelevant for the translation into the given target language, such as person for verbs in the plural.

Let the original German sentence be:

Die Vergrösserung kann jedoch nicht beliebig gesteigert werden, da beim Mikroskop auf Grund noch zu besprechender Umstände eine untere Grössenschranke für die erkennbaren Gegenstände besteht.

The result of the grammatical analysis And rearrangement might look like this:

Die(Ar) Vergrösserung kann(AuPr) nicht werd(AuIn) gesteigert beliebig(Ad) jedoch, da(Co) ein(Ar) unter(Aj) Grössenschranke besteh(Pr) für die(Ar) erkennbar Gegenständ(Pl) beim Mikroskop auf Grund Umständ(PlGe) noch besprech(Gr),

using the following code for the purposes of this illustration only:

Ar—article	Ad—adverb	Ge—genitive
Au—auxiliary	Co—conjunction	Gr—gerundive
Pr—present	Aj—adjective	
In—infinitive	Pl—plural	

Some of the operators will be absorbed into the translation itself; the operator AuIn accompanying *werd* will simply cause the selection of the correlate *be* rather than *become.* Others will be transcribed without change, leaving it to the post-editor to perform the necessary transformation, which can be done, in general, in no time at all.

The machine output would then be:

the	increase	can	not	be	raised	any
	enlargement	may			increased	whatever
	augmentation	Pr			enhanced	optional
	magnification				auctioned	arbitrary
	exaggeration					at pleasure
						at will
						Ad

however	as	a	lower	limit of size	consist
yet	since	an		limitation of size	exist
nevertheless	when			limit of magnitude	persist
					pass
					be
					Pr

for	the	recognizable	object	at the	microscope	on	ground
		discernible	matter				motive
		perceptible	subject				reason
			Pl				estate
							sediment
							soil
							bottom
							foundation
							basis
							fundus

circumstance	still	criticize
condition	yet	discuss
	more	arrange
PlGe	in addition to	review
	else	
	however	Gr
	further	
	even	

There should be no difficulty in deriving from this array the following correct translation:

The magnification, however, cannot be increased indefinitely, since there exists a lower limit for the size of the objects that the microscope can discern, because of circumstances to be discussed further on.

(The post-editor will be warned that any preposition might have to be replaced by almost any other preposition, and the offered correlates are no more than suggestions which fit in many cases.)

The careful reader will have noticed the following: first, a whole word has disappeared from the original text, namely *zu.* This is not a mistake but the result of the syntactical analysis by which *zu besprechender* was recognized as a gerundive form. One can, of course, also envisage a less penetrating analysis by which *besprechender* would come out only as an adjective. In this case, *zu* will be kept and translated by *to.* The total result would be almost the same.

Second, in case the reader knows German, he might well have wondered whether *Grössenschranke* would be found in the dictionary. As a matter of fact, it was found there. But there are innumerable such noun-combinations which will not be found in any dictionary. *Oberbürgermeisterswitwenpension (pension of the mayor's widow)* is one of these, though such a word is, of course, unlikely to occur in scientific publications. There are again many proposed solutions of this particularly bothersome peculiarity of the German language. I shall indicate the conceptually simplest one, to be replaced *in praxis* by a quicker procedure. This procedure would be of essentially the same type as the suffix analysis, that is, letter after letter will be chopped off the tail, until the initial segment (in our example, probably *Oberbürgermeister)* is found to match a stem. The same procedure is then repeated for the final segment, with a dropping of *s, n,* or *en,* if necessary. In this example, both the *s* after *Oberbürgermeister* and the *n* after *witwe* will have to be dropped, before the three stems are identified.

Third, the reader who knows German might be appalled by the literal correlation of *auf Grund,* with the ten correlates of *Grund* and the thirty, or so, correlates of *auf,* of which by special convention only one was printed out. He knows that *auf Grund* certainly in this context but also in almost all other contexts, means just *because, on the basis,* or *on the strength,* and nothing else. And a human translator, who does not know German but knows how to use a dictionary, would find under the heading *Grund* that these are the correlates of the phrase *auf Grund.* In our example, an inability on the part of the machine to combine the two words *auf* and *Grund* into a phrase and the lack of a *phrase-dictionary* are only minor nuisances, and no intelligent reader will fail to come up with the correct translation. However, there are many instances where the phrases are so-called idioms, whose meaning, by definition, cannot be derived from the meanings of their components, relative to a given word-dictionary.

There is nothing surprising in the fact that a literal translation of a source language text, even if rearranged into target language word order, should at times be unsatisfactory. If there is anything surprising in this situation, it is rather the fact that literal translations, relative to given dictionaries, so often *are* satisfactory. This is due, of course, partly to the restriction to scientific texts and partly to the circumstance that most of the languages investigated so far have been Indo-European. Whatever the explanation for the adequateness in general of word-by-word translation, there will occur a sufficient number of cases where this type of translation will break down. The treatment of idiomatic sentences is doubtless one of the most serious problems of machine translation. To illustrate with a simple example: the German sentence, *Das gibt sich schon,* under literal translation will turn out as: *This gives itself already,* or any of its variants, none of which will be very revealing for someone who knows absolutely no German. He would hardly be able to arrive at the correct translation, *This will subside, in time,* perhaps not even within context.

Out of the many possible solutions of this problem, I shall again mention only one which, incidentally, coincides fully with the standard solution for human translation. In addition to the word (or stem) dictionary, a phrase dictionary will have to be constructed. One of the entries of this dictionary will be, for instance, *sich gibt, subsides.* The phrase dictionary will have priority over the word dictionary in so far as the latter will be consulted by the matching mechanism only after the search through the phrase dictionary has proved fruitless. There are many details in this procedure that need careful planning, but no more will be said about them here [7].

The major problem here, as everywhere else in machine translation, is to arrive at a good balance of the size of the phrase dictionary relative to the word dictionary. The more phrases in the dictionary, the easier the task of the post-editor and the greater the chances of arriving at a satisfactory translation, but the greater also the initial installation cost and the longer time required for the average matching.

The final proof of the pudding will, of course, be in the eating. The only really convincing argument for a skeptic will be the production of a satisfactory translation of a lengthy article by an honest man-machine partnership, in which either the quantity, or the quality, or both, of the man-hours spent on the translation is effectively reduced. This would be an important achievement even if the cost of the machine operation would, at the beginning, be much higher than the corresponding remuneration for the corresponding brain-power, provided that there be reasonable expectations for improvements in the near future. And there can be no doubt that the cost of a brain-hour will constantly increase, on the average, whereas the cost of an hour's work of an electronic-computer-like machine will constantly decrease, mainly due to a reduction in the initial installation cost but also to increases in storage capacities, reliability, and the like.

So far, it has been shown that an effective, high-accuracy, machine-post-editor partnership is theoretically possible and, for certain language pairs and for texts belonging to restricted fields, practically feasible. An operational grammar seems to be required for types of discourse not restricted to science and for pairs of languages whose syntactic structure is not very similar. The preparation of such a grammar is so far only a desideratum, though no very serious obstacles to its completion are in view. At least as important seems to be the preparation of a smoothly working word-and-phrase dictionary combination. Whether this can be produced so that the final output of the monolingual post-editor will not be worse, on the average, than the output of a human translator is a question on which the last word has not yet been said. One remark might be appropriate at this point. The possible failures of a machine-post-editor partnership will not be so apt to occur in cases where the machine output will look like such gibberish to the post-editor that he will be unable to produce any good translation—in these circumstances a bilingual editor might be called in for assistance, and the total combination still prove to be effective—but rather in those cases where the machine output will make sense but convey the wrong meaning. This will be outright dangerous when there is no possibility of finding out the impropriety of the translation by examining the context.

The machines we have been discussing so far are of the customary deterministic type, whose operation at each step is uniquely determined by the contents of their storage and the outcome of the preceding step. In addition, it was assumed that the internal memory span of such machines ranged over no more than a sentence. The second restriction is of a practical nature, since the gain to be expected from considering broader contexts seems to be slight in comparison with the increase in time and cost, at least for Indo-European and other major languages. The first restriction is a temporary one. Its abolishment would mean consideration of machines that "could learn from their experience" on a trial-and-error basis. It seems wise to postpone the treatment of such devices until a later date, since the general research into machines of this type has barely begun [8].

The restrictions just mentioned are both assets and handicaps of the machine. They enable it to perform effectively and smoothly certain vital operations within the complete translation process. As soon, however, as something goes wrong, the operation of the machine will become jeopardized. If, for instance, as the result of a misprint, a letter combination is recognized which does not match any entry in the dictionary, a machine of this type will be unable to find out what was the mispelled word. This does not necessarily imply that the machine will stop working until this misprint is corrected. One can envisage a set of instructions under which the machine would ring a bell to inform the operator that something is wrong, but would continue its work with the next sentence. Fortunately, and this forms a very important difference from the operations of machines engaged in computation proper, the sentences are regarded as entirely independent units. A machine of a learning type might be misled by misprints; a machine of the type envisaged here will not improve with experience but will not acquire bad habits either.

The situation will be worse, of course, if the misprint produces a different word. Should this other word belong to a different syntactic category—say, when *the* is misprinted as *she*—the syntactic analysis might be powerful enough to indicate that something is wrong, though it would not be able to tell exactly what is wrong. If, however, syntactic coherence is preserved—say, when *cat* is misprinted as *rat*—the machine will be unable to indicate that there is something wrong, and it is even likely that the post-editor will have greater trouble in detecting the misprint than the human translator. And this result is, of course, because typographical similarity is not invariant with respect to translation.

For an electronic "reader" even slight variations in font may pose problems that are trivial for the human reader. It must always be carried clearly in mind that the deterministic electronic computer of the present and of the near future is incomparably inferior to a human being, with respect to over-all performance in the totality of situations which they might have to face. It is only when the situations are naturally of a low degree of complexity, or are artificially arranged to be so, that the rigid mechanical brain can exhibit superiority over the flexible human brain. Fortunately for this problem, it seems that a sufficiently high proportion of the complete translation process is of this low complexity or can be reduced to it so that we can look forward to the utilization of machines to perform these routine operations. It is a major task to make certain that deviations from the conditions that make for the most efficient use of the machine will not lead to disastrous results.

In conclusion, let me state again that only specimens of the various dimensions of our problem were presented here. The topic is still in its infancy and I am not even sure that I have succeeded in covering the most important aspects. Only five years have passed since the application of electronic computers to translation were first considered [9], and the number of publications dedicated to this topic is still very small [10]. The progress made so far is sufficient to give hope that we may anticipate a new development which will free the human brain from the performance of another time-consuming, dull, routine operation which is an important part of translation as it is now handled.

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REFERENCES

A more complete bibliography, including abstracts of unpublished work, has been compiled and may be obtained, free of charge, by writing for "Mechanical Translation," Vol. 1, No. 1; Room 14-N307, Massachusetts Institute of Technology, Cambridge 39, Mass.

1. This based on unpublished work done by KENNETH E. HARPER of the University of California, Los Angeles.
2. These estimates are given by VICTOR A. OSWALD, JR., and RICHARD H. LAWSON in a paper, "An idioglossary for mechanical translation," to appear shortly in *Modern Language Forum.*
3. In accordance with an estimate of KENNETH E. HARPER [1].
4. This sentence is almost an exact quotation from the paper mentioned above [2].
5. Work in this direction is done at present by A. G. OETTINGER at the Harvard Computation Laboratory.
6. In "The present state of research on mechanical translation." *American Documentation, 2,* 229-237, 1953. *See also,* "A quasi-arithmetical notation for syntactic description." *Language, 29,* 47-58, 1953.
7. Slightly more is said in the paper, "Some linguistic problems. . ." mentioned in the previous note [6].
8. Some indications of the functioning of a non-deterministic machine are given by D. M. MACKAY in "Mindlike behaviour in artifacts." *British Journal for the Philosophy of Science, 2,* 105-121, 1951
9. The early history of machine translation is told in a memorandum, July 15, 1949, by WARREN WEAVER, Director of the Natural Sciences Division of the Rockefeller Foundation.
10. In addition to the papers mentioned in [9], only the article by V. A. OSWALD, Jr., and S. L. FLETCHER, Jr., "Proposals for the mechanical resolution of German syntax patterns," in *Modern Language Forum, 36,* 81-104, 1951, was directly provoked by machine translation. On September 11, 1953, David H. Shepard presented a paper, "The analyzing reader," before a meeting of the Association of Computing Machinery in Cambridge, Mass. The *New York Times,* January 4, 1954, published a news article on a public demonstration of machine translation which took place at the headquarters of the International Business Machines Corporation in New York. An electronic calculator, the result of cooperative research by IBM scientists and scholars of the Georgetown University Institute of Languages and Linguistics, was used to translate several selected Russian sentences into English.