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HISTORY AND PRESENT STATE OF MACHINE TRANSLATION

O. S. Kulagina

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An outline is given of the history of the development of work in the field of machine translation, a brief description is given of machine translation systems constructed and put into experimental testing in the USSR, and certain of the most interesting systems designed in other countries are also described.

The present article briefly presents the history of the development of machine translation (MT) and the present state of work in the given field is described.

In the quarter century of its existence machine translation has gone through several stages as a scientific discipline. The 1950's and early 1960's were a time of formation of MT and enthusiasm for it. These were years of the appearance of many working teams, the creation of the first experimental MT systems, and together with this the statement of many insufficiently sound evaluations and rash communications. This period of growth not only led to the wide development of theoretical investigation in the field of MT and the construction of a number of experimental systems, but also to the development of the first practically operating systems. In the USA in 1962 a decision was made to construct an operating MT system, and in 1964 under the control of foreign technology of the Air Force Foreign Technology Command began operation of the SYSTRAN system [46], effecting Russian-English translation of scientific and technical texts with human postediting.

After growth, a period of a certain loss of interest and the departure of many researchers from MT set in. This change is explained by reasons that can be divided into those internal or external to MT. Among the internal reasons it is possible to name the realization of how difficult the problem is, how deceptive the first successes, and, in particular, how fast the difficulties increase with the progress. An external blow was the decision of a specially created Commission of the National Academy of Sciences in the USA [1], which examined the situation of work in machine translation in the USA in detail, compared the time and cost of translations supplied by the SYSTRAN system with the cost of ordinary human translation, and arrived at the conclusion that for the low quality of the

machine result, MT with postediting is unprofitable. This decision was taken on the basis of the evaluation of work with essentially one system — SYSTRAN. The Commission considered that to obtain MT of satisfactory quality fundamental research should be developed at the junction between linguistics and mathematics. Concerning practically operating systems, it was found that semiautomatic translation, in which the machine operates as an automatic dictionary, giving the human translator the translation of the words not known to him, is more advantageous than poor quality machine translation.

The decision of the Commission had a fairly broad response in different countries. It was often lost from sight that the Commission's evaluations were made on the basis of only one MT system, which was very primitive and the pessimistic conclusions of the Commission were extrapolated to MT as a whole in a number of countries. The result was that the SYSTRAN system continued to operate, regardless of its unprofitability, but for many groups working in the field of MT and beginning to create systems of a higher level than SYSTRAN at that time, organizational and financial difficulties appeared. The Commission's report appeared in 1966, and the period of decline covered the end of the 1960's.

However, the 1970's marked a new growth in the field of MT. This is connected, first of all, with the fact that the existing groups continued to work and to forge ahead; second-generation systems were constructed (see below), giving a result of appreciably better quality than that given by the first-generation systems. Work was begun on third-generation systems. The revival of work in the field of MT is indicated, for example, by the establishment of an international MT group under the designation of "Leibnitz" [38], in which teams from France, Italy, Switzerland, and the Federal German Republic take part. The teams in this group are developing, in particular, methods for representing data about text at various levels, common to the different languages. This will allow common algorithms to transform from level to level and to economize work on the construction of these algorithms and their programming.

On the other hand, the new period of growth is connected with the fact that now MT is not alone. In contradistinction to the 1950's, when MT was, in fact, the only field in which natural language text was processed by machine, at the present time MT has a broad environment. First, work is being conducted on a broad front in the creation of various types of information-retrieval systems (IRS). In those IRS where the machine carries out any kind of transformation of the texts of documents stored in the system or the texts of queries, the same problems arise as in MT. Secondly, problems in common with MT arise in the creation of various kinds of "question — answer" systems (including those similar to Winograd robots), solvers of problems formulated in natural language, systems for communicating with the machine in natural language, and others, developed within the framework of work in artificial intelligence. We shall denote them AINL. These systems have in common with MT the presence of a language processor, i.e., of a converter, effecting analysis of natural language text in order to obtain a certain representation of this text, reflecting its meaning, and vice versa, the construction of a text from its representation. One of the essential differences of AINL from MT systems is that, as a rule, in AINL the range of initial permissible texts is strongly circumscribed both in subject (a narrow field) and in variety of permissible structures. In MT some restrictions are also introduced on the input material, since in MT systems are usually created for the translation of scientific-technical texts, and not for arbitrary texts, but in MT these restrictions are much weaker than in the AINL systems.

It has already been stated above that in the analysis of text the machine passes from the given text to a certain notation of the information, reflecting its sense and structure — in other words, to a certain representation of the text. At the present time it is generally accepted to distinguish three levels of representation: morphological, syntactic, and semantic (it is the convention to call each successive level deeper than the preceding one). Sometimes, as in the "meaning — text" model [33], superficial and deep sublevels are distinguished. It must be stated that in all the MT systems constructed and tested in the USSR up to now translation is conducted by individual sentences, the connections between sentences of the text are neglected, and, correspondingly, the representations of the different levels are constructed independently for the individual sentences.

The various MT systems and AINL systems employ various types of representation and differ in many parameters: in the maximum depth of representation used in the system, what data are taken into account, what requirements are imposed in the construction of a correct representation, what formalism is used to note the representation, etc. In particular, since in AINL systems strong a priori constraints are imposed on the structure of the initial texts, thereby many difficulties are eliminated from them that are encountered by MT, and because of this the possibility is created of descending in level faster. In such systems already a semantic representation of the text is often used which in MT systems carried out to the end and tested on machines in our country has not yet been achieved, although its use is planned in certain systems presently in development.

Following [2], we introduce the concept of generations of MT systems. This will facilitate the general description and comparison of systems.

As stated in [2], for first-generation systems such characteristics as binarity, absence of an independent description of the languages taking part in the translation, inseparability of analysis and synthesis (with the exception of morphological stages), the inseparability of the grammar from the algorithm proper, production of a single variant,

etc., are typical. Basically, such systems were constructed in the 1950's. Usually, in them the process of analysis was carried to the level of morphological representation, after which there began a fairly complex stage of transformation of the morphological representation of the input sentence directly into the morphological representation of the output sentence.

In the second-generation systems, which began to be constructed in the 1960's, the grammar was separated from the algorithm proper, the syntactic analysis and synthesis became independent, and single-variant production was replaced by multiple-variant production.

The basic effort in these systems was directed to syntactic analysis, with the purpose of constructing a syntactic representation whose basic part is the syntactic structure in the form of a dependency tree or a tree of constituents. The passage from first-generation systems to systems that have all the features of the second generation was effected progressively; i.e., there exist a number of systems that are intermediate.

The third-generation systems usually include such that attain the level of the semantic representation.

Let us list all those MT systems of the first and second generations (as well as the intermediate ones) that have been completely built and carried to machine validation in our country, i.e., those by means of which translations of sentences have been obtained from one language to another. As has been stated above, third-generation systems are only beginning to be developed.

1. An English — Russian system for translation of scientific and technical texts, made at the Institute of Precision Mechanics and Computers, and described in detail in [3]. A first-generation system. The first experiments in translation were made in 1955.

2. A system FR-I French — Russian for the translation of mathematics texts, made at the Institute of Applied Mechanics, Academy of Sciences of the USSR. A first-generation system. The first translations were obtained in 1956. Both a detailed description of the system and several hundred sentences translated by it have been published [4-7].

3. A system for English — Russian translation of mathematical texts, made at the Institute of Applied **Mathe**matics, Academy of Sciences of the USSR. This system represents the next step in comparison with the preceding. Experiments in translation were conducted up to the end of the 1950's. The system is described in [8]; the translation of 500 sentences is given in [9].

4. A system for Russian - Ukrainian translation, made at the Institute of Cybernetics, Academy of Sciences of the Ukrainian SSSR in Kiev. It was tested in three variants: a purely dictionary translation, dictionary plus morphology, and dictionary plus morphology plus elements of syntax; it is described in [10].

5. A system for Armenian — Russian translation, made at the Computer Center, Academy of Sciences of the Armenian SSR in the first half of the 1960's. It is described in [11-13], where there are the translations of 75 sentences. This system already had many of the features characteristic of second-generation systems: separation of the algorithm proper from the grammar and separation of analysis and synthesis. However, it conserved certain features of first-generation systems: single-variant operation and orientation of certain sections of the analysis to the output language.

6. A system for Armenian — Russian translation of mathematical texts, made at the Computer Center, Academy of Sciences of the Armenian SSR in the second half of the 1960's. It is described in [14-17]. The statements about system 5 also apply to this system.

7. A system for English — Russian translation of patent documentation, made at the Central Scientific-Research Institute for Patent Information and Technico-Economic Research. It is described in [18, 19]. In the latter publication the translation of a patent formula is given. A specific feature of the system is that it is designed for the translation of patent formulas and not arbitrarily composed texts in a given subject.

8. A system for English—Russian translation of newspaper publications, made at KBPA. In contradistinction to the other systems, it is not oriented toward scientific-technical texts, but political texts. In its basic components this is a first-generation system. The principal efforts made in it were to remove homonyms and to improve the choice of translation equivalents. The description and examples of translations are given in [20, 21].

9. A system for Russian — Georgian translation, made at the Institute of Control Systems, Academy of Sciences of the Georgian SSR [22, 23].

10. A system for English—Russian translation of scientific-technical texts made at the Computer Center of Leningrad State University. This system has all the characteristic features stated above of the second-generation systems. Experimental translations were begun in 1966 [26]. A very limited number of experimental translations

were done by this system: The author does not know of more than 20 translated sentences. A brief description of the system is given in [24, 25].

11. The system FR-II for the translation of mathematical texts from French to Russian, constructed at the Institute of Applied Mathematics, Academy of Sciences of the USSR, on the basis of experience with the development of the system FR-I. The second-generation system passed through the basic experimental testing; by its means, text in a total volume of about 30,000 words (1400 sentences) was translated. A detailed description is given in [27-32].

The first-generation systems operated unstably and gave a poor-quality result. Thus, for example, among the examples of translation given in the above-cited publications, the number of sentences translated with given errors (incorrect or imprecise transmission of the sense, grammatical errors in the output text) comprised about 60% of the sentences for FR-I, about 80% for the English — Russian system of the Institute for Applied Mathematics (where only very short sentences were correctly translated), and for the English — Russian KBPA system — 100% (to judge from the published examples, in the excerpts given in [20] there is not a single sentence that has been translated without error). We have mentioned above the SYSTRAN system, operating under the management of the Air Force Foreign Technology Command of the USA and giving Russian—English translation. Data are given in [37] about the following result of the evaluation of translation quality, supplied by this system: The post-editor corrected about 35% of the words in the translation obtained from the machine (the correction involved all sentences) and worked slower than a human translator working directly from the original text to clean copy.

| However, the construction of the first-generation systems allowed experience to be accumulated in the field of MT and the passage to the construction of second-generation systems.

Let us describe in somewhat greater detail the system FR-II, since in our country only this second-generation system was subjected to experimental testing on a fairly great amount of material.

Just as the system FR-I, whose further development it is, the system FR-II is designed for the translation of mathematical texts. In the first place, the dictionary of the system is designed for such texts, containing about 1500 French words and about 300 word-combination expressions, with their translations in Russian. The same concerns the grammar, but here the orientation to mathematical texts was expressed in the individual rules, while, as a whole, the grammar of the system was adapted to texts of a scientific and technical character.

As already mentioned, the system FR-II translated text by sentences. The translation of a sentence begins in the machine with access to the dictionaries of French words and expressions, which leads to the division of the original French word forms into roots and terminations, and the association to each lexical unit (word or expression) of the ensemble of attributes occurring in the dictionary article found for this lexical unit.

In the stage of morphological analysis the word endings are found in tables of endings, and information is established concerning the forms of the words (for example, the number of nouns, the tense, declination, person, number of verbs, etc.). If for a certain word in the dictionary a suitable root has not been found or a false root which has led to the appearance of a termination not provided by the corresponding table of terminations, then for such a word, not contained in our dictionary, it is determined from the ensemble of letters at the end of the word to which classes of words it may belong, and certain other attributes are established, in order that subsequently the words not found in the dictionary, participate in the analysis equally with the found words.

Before syntactic analysis of the sentence begins, complex verb forms are combined.

The syntactic analysis in the system FR-II is the most complex and ramified stage, which is a characteristic of second-generation systems. Its purpose is to construct for the sentence to be translated one or several dependency trees, reflecting the superficial syntactic relations among the words. The number of superficial syntactic relations used by us is 62. The dependency trees constructed by the machine satisfy definite requirements on a correctly constructed syntactic structure.

In general terms the process of syntactic analysis consists in the following. First, for the sentence to be analyzed a certain set of possible or potential syntactic connections, in general redundant, is constructed. At the instant that potential connections, are established only the attributes of the given word pair and their relative positions in the sentence are taken into account, while the context is neglected. In other words, potential connections are established for all those cases where there exists a pair of word forms that according to the laws of French grammar can be connected in some sentence. The question is whether this pair of word forms should be connected in the translated sentence; i.e., the question of which of the potential connections should enter into the tree of syntactic structure of the analyzed sentence is solved by the application of filters to the original redundant set of connections, taking into account the requirements on correctly constructed syntactic structures.

The filters used in this are very diverse. Some of them have a fairly general character. These include, for example, the requirement of projectivity with specified exceptions. Other filters represent particular rules, concerning

a definite combination of connections over a consecutive word form with definite attributes. For example, there is a group of filters that takes into account the classes of words whose representatives appear between the words connected by a given type of connection and eliminates the syntactic connection between the words under consideration if certain disjunctions appear between them. There is also a group of filters that takes into account agreement of definite subordinates to a common governing word, a group of filters taking into account the need for the presence of definite subordinates, etc. The majority of filters are applied many times, since the set of connections is changing all the time. If by virtue of a certain condition the incompatibility of two syntactic connections is established, then the principle of selection is as follows: That connection is conserved which is the only one possible for its subordinate. This principle is based on the fact that finally we want to obtain a tree of syntactic connections.

The application of filters either leads to obtaining a single tree of dependency or to obtaining such a set of potential connections that it cannot be further reduced by the available rules. In this case the trees contained in the resulting set are constructed. We qualify this, in that although at the given point the algorithm is designed to construct all the trees contained in the set, in reality this is not done. To economize machine time a definite limit is placed on the number of variants constructed. The experience shows that this restriction operates only on fairly long and involved sentences, since the method of filters delays the enumeration of variants until the application of the filters has strongly reduced the number of potential connections, and thereby the enumeration.

Each of the constructed trees is subsequently processed independently and gives its variant of the translation.

The dependency tree constructed in the analysis is subjected to transformation in order to reconstruct the syntactic structure so that it is possible to construct a Russian sentence from it. In other words, those syntactic constructions that are permitted in French but not in Russian are reconstructed. They are replaced by suitable Russian constructions.

The reconstructed dependency tree proceeds to the input of the syntactic synthesis, in the process of which information is established about the forms of Russian words and their order in the Russian sentence. Information obtained in the analysis and the transformations is used here, as well as data obtained from the Russian part of the dictionary, where the Russian roots and the accompanying characteristics are stored.

Then in the stage of morphological synthesis the required forms of the Russian words are constructed and the current variant of the translation is printed. After this, the machine proceeds either to the next variant of translation of the same sentence, if it exists, or to the next sentence.

Let us now consider the question of the quality of translation given by this system FR-II.

We have made two collective evaluations of the quality of translation. Both mathematicians and linguists basically concerned with MT or related problems, took part in this. In all, 33 people took part in the first one, in which a total of 670 sentences were evaluated; i.e., for each participant there were about 20 sentences; 18 took part in the second, evaluating 530 sentences, i.e., about 30 sentences each. Only 1 person took part in both evaluations.

The texts translated by the machine were taken from books by Bourbaki, Picard, Cartan, from the abstracts journal "Bulletin Signalétique," etc.

The evaluation was conducted in the following way. The evaluator was given the machine printout, containing the French sentences and for each of them one or several Russian translations. If there were several translations, the evaluator took one of them after a rapid examination - the one that appeared to be the best. The chosen or unique translation was evaluated for several parameters: comprehensibility of the Russian sentence, its grammatical correctness, and the adequacy of the translation. At the same time, those evaluators with a knowledge of French first evaluated the comprehensibility and correctness of the Russian without reading the French sentence, and then the French sentence was read in order to evaluate the adequacy of the translation. Since not all the evaluators knew French, in the first series 436 sentences were evaluated for adequacy and in the second, 438. The evaluations were done by a three-grade system for all parameters, i.e., "very good," "average, there are incorrect points," and "poor."

The table presents the percentages of sentences receiving a given grade, where the "very good" grade appears at the left, "average" in the second position, and "poor" on the right.

I should also like to note the following: Very few sentences obtained a very good grade for comprehensibility and at the same time poor from the viewpoint of adequacy. For example, there were only 7 such sentences out of the 436 in the first group. In other words, errors of transmitting the sense do not conceal themselves in sentences that are easily understood by human beings. The presence of errors in the transmission of meaning by the machine is clearly indicated by the fact that a human being has difficulty understanding the Russian text.

TABLE 1

	First group			Second group		
Comprehensibility	**63,5**	**25,0**	**11,5**	**61,8**	**25,5**	**12,7**
Grammatical correctness	**49,2**	**32,2**	**18,5**	**54,7**	**33,6**	**11,7**
Adequacy	**60,7**	**25,6**	**13.7**	**68,1**	**23,7**	**8,2**

For comparison, we present the evaluation of the results of the Russian — French translation system made at Grenoble during 1961-1967 and tested on the IBM 7044 in 1967-1971. This is the only published evaluation made on a three-grade system analogous to the above. In the book [38] the comprehensibility of the translations supplied by the machine has been evaluated as follows: 50%, "very good"; 28%, "average"; and 22%, "poor." The evaluation was made on a material of about 15,000 words, i.e., about the same volume of material as in the first group for the system FR-II. On a larger material (in all, a volume of 400,000 words of text was translated by means of the Grenoble system) the following evaluation was obtained in dividing the sentences into two classes: 61%, understandable; 39%, incomprehensible.

Two of the systems listed above – the French – Russian system FR-II and the English — Russian system developed at KBPA serve as a basis for constructing practical operating systems for machine translation that should be built in 1980 at the All-Union Center for Translation of Scientific-Technical Literature and Documentation.

At the present time, in our country work is proceeding on the development of two third-generation translation systems. At Informélektro a system for French — Russian translation is being developed and at the Moscow State Pedagogic Institute for Foreign Languages, an English — Russian translation system [34-36].

Let us dwell briefly on MT work conducted in other countries. Aside from the above-mentioned SYSTRAN system, there are two other systems which have been reported to be in practical operation. These are the Russian-English translation system at the Euratom Information Center in Ispra (Italy) and an English — Russian system for the translation of technical information by the Logos Development Corporation (USA). No detailed descriptions of these systems nor adequate descriptions of their results have been published in adequate volume. To judge from comments, these systems, like SYSTRAN, give a cheap production of low quality.

Let us list the most interesting of the systems under development or machine testing and improvement at the present time. All of them are either second- or third-generation systems or intermediate.

1. A Russian — French system for translation of scientific-technical text, developed at Grenoble University in France under the leadership of B. Vauquois [38].

2. An English — French system for the translation of technical text, developed at the University of Montreal in Canada under the leadership of R. Kittredge [39].

3. The MIND system, developed at the Rand Corporation (USA) under the leadership of M. Kay, is a general-purpose type, tested in English — Korean translation [40].

4. A system developed by Y. A. Wilks at the Artificial Intelligence Laboratory of Stanford University (USA) (preference semantic system), used for English — French translation [41, 42].

5. A system for Russian — German translation, developed at the University of the Saar (Saarbrucken, Federal German Republic) under the leadership of G. Maas, A. Rotkegel, and G. Zimmerman [43].

Greater detail about these systems and also a number of other MT systems or AINL systems close to them and their comparison can be read in the survey [37].

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