Mechanical Translation and the Problem of Multiple Meaning †

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THE UNIVERSITY OF MICHIGAN undertook research, late in 1955, in the analysis of language structure for mechanical translation. Emphasis was placed on the use of the contextual structure of the sentence as a means of reducing ambiguity and on the formulation of a set of operative rules which an electronic computer could use for automatically translating Russian texts into English. This is a preliminary report on the latter phase of the problem, stating the results and suggesting a practical method for handling idioms and the problem of multiple meanings.

It was decided that the first work would be done on Russian texts in physics, both because of the interest in this field and because of the general availability of texts. Some work has already been done in this field.[1] If this work proves successful, it will form a basis for work in other scientific, technical, and military fields.

A text was selected from a Russian journal on experimental and theoretical physics.[2] It was chosen to present most of the expected difficulties; i.e., stylistic, orthographical, grammatical, etc. On the basis of this text a vocabulary was set up and fifteen rules were established. (Subsequent work has altered the rules slightly to remove such obvious faults as the occurrence of "the" before proper names.) It should be realized, of course, that neither the vocabulary nor the rules were in generally applicable form. The vocabulary was simplified by applying a "one form, one meaning" rule whenever possible. Thus, inflectional endings were stripped from most word stems although in some cases a word was listed with two or three specific endings. Most words were given their scientific meaning only. Some words, however, occurred in more than one sense, or were combined with others to form idioms; in which case more than one meaning had to be listed. Finally, the words were listed in conventional grammatical categories; i.e., verb, noun, adjective, etc.

In the long run, we expect that the concept of conventional categories will be completely abandoned. What we hope to have, instead, are word groups the interaction of which will provide the grammatical and syntactical information needed. The need for such grouping has been made apparent. [3]

The rules were developed empirically by analysis of the essential processes undertaken by a human mind in translating a foreign text. It was found that most of the rules involved either word order or the grammatical functions which in Russian are indicated only by case endings and which in English might be classified by inserting a preposition. In most cases the rules concerning word order were sufficient to eliminate the necessity of referring to endings. To test the adequacy of the rules, several volunteers who had no knowledge of Russian were asked to translate the original text, using only our rules and vocabulary.* Except for random, minor stylistic faults, it turned out that the resulting translations were clear and accurate. Being convinced that the rules are as complete as is practicable for the text, we are currently enlarging the vocabulary in preparation for future tests on different texts.

Perhaps the most significant result thus far is the success in handling multiple meanings,

[1] See K.E. Harper, "A Preliminary Study of Russian". Machine Translation of Languages, The Technology Press of the Mass. Institute of Technology and John Wiley & Sons, Inc., New York, 1955.

[2] Zhurnal Eksperimental'noi I Teoretichesk'oi Fiziki. Vol.26, No.2, pp. 189-207, Feb., 1955.

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[3] See V.H. Yngve, "Sentence for Sentence Translation", MT. Vol.2, No.2, Nov., 1955.

* The Russian text with the vocabulary and rules based on this text will be found on pp.48 to 49. A standard translation and a translation made with the help of the rules by a volunteer who had no knowledge of Russian are on pp.50 to 51.

which has given us an insight into the problem of idioms. Although the problem of ambiguity as exemplified by this situation was greatly reduced by the use of a highly specialized vocabulary, the situation still occurred and a means for solving it had to be found. Published results on this problem have, generally, involved either a post-editor or a separate idiom dictionary.[4] These methods seem undesirable particularly in view of the additional computer time required for translation. Consequently, a method was developed which, it is felt, is widely applicable. The assumption was made that the specific meaning of a word could be determined from its context. It developed that not only is this assumption valid, but in fact we need not consider sequences of more than four words. The method used is the following:

All possible meanings of a word are listed, consecutively, in the order (1), (2),...........(n). In general, in order to have corresponding meanings mesh, it will be necessary to list some meanings for each word more than once, and to include some blank translations. When a word with multiple meanings is encountered, the number (n) of meanings is noted and translation is postponed. Subsequent words are examined for the number of possible meanings of each, until a word (X) with a single meaning is encountered. If there is only one word in the sequence preceding X, then the first listed meaning is assigned to this word. If there is more than one word in the sequence preceding X, we determine (M), the minimum of all (n) noted in the sequence. Let us denote by (i) [A] the i-th meaning of a word A, and by 0 a blank (null) translation.

Given a two-word sequence, A B, we consider (M) [A] and (M) [B] . If neither of these are blank, we translate, assigning meaning (M) to each word. If either of these is blank, we consider (M-l) [A] and (M-l) [B] and apply the same test to these. In this way, we find the highest numbered meaning which is not blank for either A or B and assign this meaning to each.

Given a three-word sequence, ABC, we consider (M) [B]. If (M) [B] is 0, we consider successively meanings M-l, M-2,....., as above, and assign finally to all three words the highest numbered meaning which is non-blank for all. If (M) [B] is not 0, then if (M) [A] and (M) [C] are both 0, we assign meaning (M) to the three words; otherwise we search meanings M-l, M-2, ...of all three words, applying the above rule.

In a four-word sequence, ABCD, (M) [B] is again considered. The procedure followed is that used for a three-word sequence, except that (M) [D] must be considered along with (M) [A] and (M) [C] .

In all cases, if no translation is found by the above procedure, we assign to each word meaning (1).

By properly ordering the meanings for each word (listing some meanings several times if necessary), it has been found possible to obtain valid translations for over 96% of the two-word sequences [The two exceptions which occurred, по делу and цель в, were easily handled by separately listing дел in the form делу , and цел in the form цель .] and for over 90% of the three-word sequences which might occur. These figures are based on the possible sequences without reference to their relative frequency of occurrence in actual use. It is not known how the difficulties in "properly" ordering the meanings will multiply as the vocabulary is increased. With each new word (or meaning) added, the order of the meanings previously listed may have to be changed *so* as to maintain consistency as much as possible.

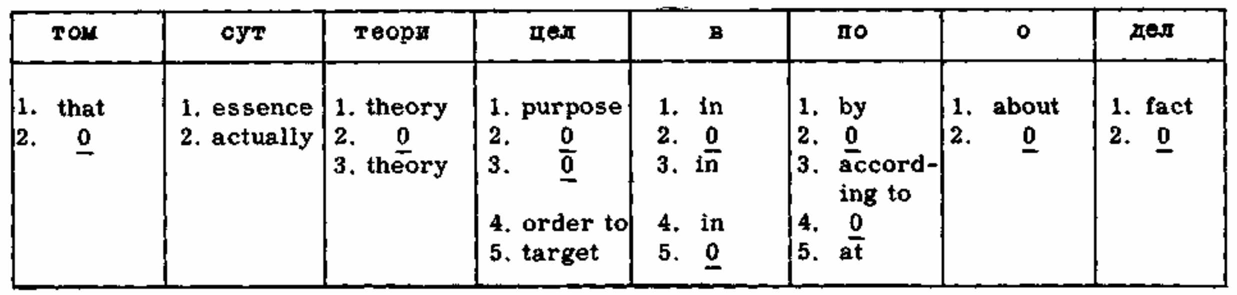
In this system an idiom is handled as merely an additional meaning which is possible. A study of the structure of three-word idioms showed that generally the second word had the least number of meanings. On this basis it was decided to assign to the second word the entire idiomatic meaning, and to supply corresponding 0 translations for the other two words. Thus, for example, the Russian idiom по сути дела ("actually") would appear as по = 0, сут = actually, дел = 0. (Note the dropped inflectional endings.)

To illustrate this method, let us consider the eight Russian words том, дел, сут, цел, по, в, о, and теори. From these eight words it is possible to form 56 two-word sequences and 336 three-word sequences. However, of these only 29 two-word and 106 three-word sequences are linguistically possible. It is assumed, of course, that the appropriate inflectional endings are supplied in each case. (The list of sequences, with translations, is available on request.) By working with these 135 sequences it was found that the arrangement of meanings given in Table I is the best possible. There seem to be no algorithms for ordering the meanings, other than that the idiomatic meaning, if any, be

[4] See, for example: "The Treatment of Idioms" by Y. Bar-Hillel, typewritten, 8 pages; "A Study for the Design of an Automatic Dictionary" by A.G. Oettinger, doctoral thesis, Harvard University, 1954.

the last meaning listed for at least one of the words.

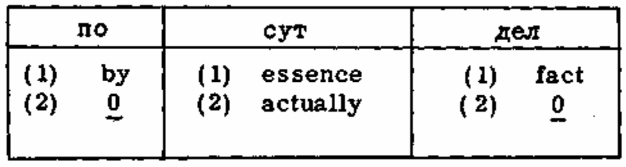
TABLE I



том	сут	теори	цел	в	по	о	дел
1. that	1. essence	1. theory	1. purpose	1. in	1. by	1. about	1. fact
2. 0	2. actually	2. 0	2. 0	2. 0	2. 0	2. 0	2. 0
		3. theory	3. 0	3. in	3. according to		
			4. order to	4. in	4. 0		
			5. target	5. 0	5. at		

It may be noted that on the basis of only the three words по, сут, and дел the shorter arrangement of meanings given in Table II suffices,

Table II



по	сут	дел
(1) by	(1) essence	(1) fact
(2) 0	(2) actually	(2) 0

It will be observed that there is a certain amount of redundancy inherent in this system. However, it is felt that this is a minor fault; first, because the percentage of redundant meanings in the entire vocabulary appears to be small (around five per cent) and second, because this plan does not require a separate idiom dictionary or other special devices which tend to increase computer translation time. Although further research is necessary for the complete development of this method, we believe that the theory used is valid and that it eventually will lead us to the solution of most multiple-meaning problems.

VOCABULARY AND RULES

NOUNS

Буссин	Boussinet
врем	time
времен	(1) time (2) the period
вычитани	subtraction
движени	movement
действительност	reality
дело	(1) fact, (2) 0
значени	value
значениями	values
интервал	interval
корреляци	correlation
Крутков	Kroutkov
малост	shortness
момент	instant
некоррелированност	uncorrelativity
обобщени	generalization
Орнштейн	Ornshtein
основани	reason
Планк	Plank
последействи	after-effect
предполозкени	assumption
промехутк	interval
приращени	increment
приращений	Increments
процесс	process
работ	work
рассмотрени	examination
результат	result
результатам	results
релаксаци	relaxation
сил	force
скорост	velocity
создали	(1) formulation (2) formulate
сравнени	(1) comparison (2) as compared
Стокс	Stokes
сут	(1) essence (2) actually
теори	(1) theory

(2) on the theory
(3) in the theory

течени - (1) course
(2) during the

удар - collision
уравнена - equation
ускорени - acceleration
Фоккер - Fokker
формул - formula
формулой - by the formula
функци - function
цел - (1) purpose
(2) in order to
частиц - particle
частот - frequency
частност - (1) particularity
(2) in particular
Эйнштейн - Einstein

VERBS

был — а — was
был — и — were
выражать - to express
оказыва - ется - proves to be
описыва - ет - describes
отсутству - ет - is absent
предполага - лась - was assumed to be
предполага - лись -were assumed to be
привед - ет - will lead
создать - to formulate
явля - ется - is

ADJECTIVES

больш - large
броуновск - Brownian
выражающ - expressed
гидродинамическ - hydromatic
законн - legitimate
корреляционн - correlated
мал - small
марковск - Markov's
меньш - smaller
небольш - small
независим - independent
некоррелированн - uncorrelated
несправедлив - incorrect
неупорядоченн - random
остающ - remaining
перв - first
подобн - such
полн - complete
пригодн - applicable
применим - applicable
протекакщ - taking place
различн - various
рассматриваемым - observed
сделан - made
случайн - random
справедлив - correct
сравним - comparable
том - (1) that (2) 0
указанн - indicated
упорядоченн - correlated
физическ - physical

ADVERBS

более - a more
больше — more
всё-таки - nevertheless
достаточно - sufficiently
правильно - correctly
после - after
поэтому - therefore
соотвественно - accordingly
статистически - statistically
также - also
точнее - more precisely
учитывая - by taking into account

MINOR PARTS OF SPEECH

а - and
в - (l) in, (2) 0, *(3)* 0
даже - even
для - for
если - if
и - and
к - to
когда - when
лишь - only
между - between
не - not
но - but
о - (1) about, (2) 0
однако - however
по - (1) by, (2) 0
порядка - within
при - at
с(о) - with
также - also
то - then
что - (1) that, .(2) that
этому - 0

ABBREVIATIONS

ДР - others
см - see
т.е. - i.e.

PRONOUNS

её - its
она - it

RUSSIAN TEXT

В первых работах по теории броуновского движения /1/ (см. также /22/) значения скорости частицы в различные моменты времени предполагались по сути дела статистически независимыми. Соответственно этому была применима формула Эйнштейна

$$M\ (x - x_0)^2 = 2 \qquad (1)$$

а также уравнение Эйнштейна-Фоккера-Планка, справедливое для марковских процессов. В действительности, однако, корреляция между значениями скорости отсутствует лишь при достаточно больших интервалах времени между рассматриваемыми моментами. Поэтому формула (1) оказывается несправедливой для малых интервалов времени (порядка времени корреляции для скорости).

В целях создания более полной теории, пригодной для меньших интервалов времени, были сделаны предположения (Орнштейн, Крутков и др., см. также /3/) о том, что некоррелированной случайной функцией является не скорость, а ускорение, т.е. сила. Точнее, некоррелированной предполагалась неупорядоченная сила, остающаяся после вычитания гидродинамической силы, выражающейся по формуле Стокса. Если, учитывая гидродинамическое последействие, упорядоченную силу выражать формулой Еруссине, то предположение о некоррелированности неупорядоченной силы приведет, в частности, к результатам работы. Физическим основанием предположения о некоррелированности неупорядоченной силы является малость её времени корреляции по сравнению со временем релаксации скорости для больших броуновских частиц (большая частота ударов). Для небольших частиц, когда время корреляции сравнимо с временем релаксации, подобные теории не применимы. Но даже если указанное предположение законно и теория правильно описывает процессы, протекающие в промежутки времени порядка времени релаксации (и больше), то она всё-таки является не пригодной для рассмотрения приращений скорости в течение времен порядка времени корреляции неупорядоченной силы.

STANDARD TRANSLATION

In the first works on the theories of the Brownian movement (see also #2) the values of the velocity of a particle at various instants of time were actually assumed to be statistically independent. Accordingly, Einstein's formula $M(x\text{-}x_0)^2= 2....(1)$ was applicable as well as the Einstein-Fokker-Plank equation, which holds true for Markov's processes. In reality, however, the correlation between the values of the velocity is absent only at sufficiently large intervals of time between the observed instants. Therefore, formula (1) proves to be incorrect for small intervals of time (of the order of magnitude of correlation time for the velocity).

In order to formulate a more complete theory which would be applicable for smaller intervals of time, assumptions were made (Ornstein, Kroutkou and others; see also #3) that the uncorrelated, random function is not the velocity, but the acceleration, i.e., the force. More precisely, it was assumed that the random force which remains after the subtraction of the hydrodynamic force, expressed by Stoke's formula, is uncorrelated. If by taking into account the hydrodynamic after-effect, the correlated force, is to be expressed by Bousett's formula, then the assumption of the uncorrelativity of the random force will lead, in particular, to the results of the work (perhaps he means to the satisfying results?). The physical reason of the assumption about the uncorrelativity of the random force, is the shortness of time of its correlation as compared to the relaxation time of the velocity of the large Brownian particles (high frequency of collisions). For the small particles, when the time of correlation approximates the relaxation time, such theories are not applicable. But even if the indicated assumption is legitimate and the theory correctly describes the process which takes place in the interval within the relaxation time (and longer), the theory still is not applicable for the observed increments of velocity during the periods within the time of correlation of the random force.

SIMULATED MECHANICAL TRANSLATION

In the first works on the theory of the Brownian movement (see also) the values of the velocity of the particle in the various moments of the time were assumed to be actually statistically independent. Accordingly, was applicable the formula of the Einstein and also the equation of the Einstein-Fokker-Plank, correct for the Markov's processes. In reality, however, the correlation between the values of the velocity is absent only at sufficiently large intervals of the time between the observed instants. Therefore, formula (1) proves to be incorrect for the small intervals of the time (within the time of the correlation for the velocity).

In order to create a more complete theory, applicable for the smaller intervals of the time, assumptions were made (Ornshtein, the Kroutkov, and others, see also) that the uncorrelated random function is not the velocity, and the acceleration, i.e., the force. More precisely, it was assumed that the random force, remaining after the subtraction of the hydrodynamic force, expressed by the formula of the Stokes is uncorrelated. If, by taking into account hydrodynamic after-effect, correlated force is to be expressed by the formula of the Boussinet, then the assumption about the random force will lead, in particular, to the results of the work. The physical reason of the assumption about the uncorrelativity of the random force is the shortness of its time of the correlation as compared with the time of the relaxation of the velocity for the large Brownian particles (large frequency of the collisions). For the small particles, when the time of the correlation is comparable with the time of the relaxation, such theories are not applicable. But even if the indicated assumption is legitimate and the theory correctly describes the process, taking place in the interval of the time within the time of the relaxation (and more), then it is, nevertheless, not applicable for the examination of the instants of the velocity during the period within the time of the correlation of the random force.

INSTRUCTIONS: 0 blank translation

("ending" means entire ending - not just final letter.)

1. Compare word with dictionary: If there is exact equivalence, translate. If there is multiple meaning, then this will be true for several consecutive words. In this case, choose the highest meaning common to all of the words. E.g., if there is a sequence of two words, the first having two meanings and the second three, then choose the second meaning for both.
2. If there is no exact equivalent, then remove as many letters from the end as is necessary to obtain a correspondence, and translate using the following rules. If there is no rule applicable to the ending, translate the word and ignore the ending.

RULES: The placement of "the". Place "the":

1. Before all nouns after a punctuation mark and before all adjectives when they begin a sentence.
2. Before nouns preceded by minor parts of speech and before adjectives also preceded by minor parts of speech except не .
3. After the verb, if the noun follows the verb or it is separated by one word.

Nouns preceded by adjectives:

1. If the adjective ending is ые , ых , их, и, then the noun is plural: otherwise sing.
2. If the word preceding the adjective is a noun, and if there is no punctuation mark between the first noun and the adjective, then place "of the" before the adjective.

Nouns preceded by pronouns:

1. Precede the pronoun by "of".

Nouns preceded by nouns:

1. If there is no punctuation mark between the nouns, then preface the second noun by "of the".

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