MECHANICAL TRANSLATION

DEVOTED TO THE TRANSLATION OF LANGUAGES WITH THE AID *Of* MACHINES

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News

Rockefeller Foundation support for MT

The Editors are happy to be able to announce a grant of $3,000 from the Rockefeller Foundation to provide partial support for this journal over the next three years starting June 1, 1955. It is anticipated that this subsidy plus a modest subscription fee will permit us to publish three numbers a year, continuing our policy of serving as a vehicle for communication between those interested in the application of machines to translation. Pertinent papers, bibliography, and news items will be welcomed.

Appointment

J. W. Perry has been appointed Director of the Center for Documentation and Communication Research of the School of Library Science, Western Reserve University, Cleveland, Ohio. Perry was one of the earliest workers in the field of mechanical translation, which he views as a special case in the broader field of information organization, selection, and retrieval by machine, to which he is now addressing his efforts.

Seminar

MACHINE AIDS AND MATHEMATICAL ACCESSORIES IN LINGUISTIC RESEARCH will be the topic of a seminar at the Linguistic Institute this summer at the University of Chicago. The subject of mechanical translation and kindred matters will constitute a part of the subject matter to be covered.

M.I.T. Project

Four linguists have joined the M.I.T. Research Laboratory of Electronics. JOSEPH R. APPLEGATE comes from the University of Pennsylvania, where he has done a descriptive grammar of Shilha, one of the Berber dialects. A. NOAM CHOMSKY comes from the Society of Fellows at Harvard University and from the University of Pennsylvania. He has been working on problems of methodology in linguistics. FRED LUKOFF comes from the University of Pennsylvania, has prepared a textbook *Spoken Korean* and has recently written an English course for Koreans. BETTY JEAN SHEFTS comes from Yale University. She has specialized in German, and has just completed a comparison of Panini's analysis of Sanskrit with modern grammatical analysis. They will work on mechanical translation with Victor H. Yngve under a grant from the National Science Foundation.

MT Book

Machine Translation of Languages was published on May 27 by the Technology Press of M.I.T. jointly with John Wiley & Sons. It was edited by W. N. Locke and A. D. Booth.

There is a foreword by Warren Weaver and an historical introduction by Booth and Locke, followed by fourteen chapters, the first of which is a major historical document for MT, Weaver's 1949 memorandum, *Translation.*

For the complete table of contents see Bibliography, Item 55, at the end of this issue.

Photon Printed

This issue has been produced without the use of metal type in any form, as an experiment and as a demonstration of the possibilities of the PHOTON, a new photo-composing machine developed by the Graphic Arts Research Foundation of Cambridge, Mass. The machine has a conventional typewriter keyboard plus a number of other keys permitting the operator to choose from a total of 1,408 characters in a variety of type styles whose negative images appear on a rapidly revolving disk. The large variety of size of characters results from

the use of automatically controlled turret lenses providing magnification from point size 5 to 36. As the operator presses a key, information concerning character, font, and type size is recorded in a register. An automatic justifying apparatus warns the operator when enough words have been recorded to complete a line of predetermined length. Then, while the operator types in the succeeding line, the previous one is imprinted on film by means of a flash lamp which projects the image of each character in succession from the whirling disk, through the appropriate lens until the line is completed. The film then moves to the next line leaving space between lines as preset by the operator.

After a strip of film is obtained a paper proof is taken, corrections are made by stripping in pieces of film with corrected text where necessary. As the long strips of film, corresponding to galleys are corrected, they are cut up into pages. A negative is made from them and mounted in a mask. From the negative an offset plate is made, put on a press and copies are printed.

It was decided to try printing this issue of the Journal by PHOTON for two reasons: first, a greater variety of composition forms is available at less expense than by metal typesetting; second, and more important, the PHOTON is a completely electrically controlled printing device which might eventually be connected directly to the output of a translating machine when it is desired to print multiple copies of translations. The addition of facsimile equipment will be necessary to provide for the reproduction at the output of material in the original which is unnecessary or impossible to translate: illustrations, diagrams, and formulas.

Mechanical determination of the constituents of german[1] *substantive compounds*

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The MT process comprises four distinctive sub-processes called the *input,* the *identification* of input forms, the *translation process proper* and the *output.* Initially certain linguistic phenomena seemed likely to prevent the complete mechanization of the identification process. The problem is the following.

Identification presupposes a record of things remembered, with which everything to be identified is compared. An essential feature of all MT systems will be the "mechanical memory" which corresponds to the bi-lingual dictionary plus the knowledge at the disposal of the human translator. The head entries of this memory will consist of individual free and bound forms and idiomatic sequences. All input units whether they be words, portions of words, or groups of words will first have to be identified with their "memory equivalents" before their "output equivalents" can be determined mechanically.

Many important languages include large numbers of compound words which, though they are mostly of low frequency, are essential for understanding the context in which they occur. These compound words are made up of a comparatively small number of constituents, many of which also occur as free forms of higher frequency. German examples of the latter are *Hoch* (high) *and gefühl* (feeling) in *Hochgefühl* (exalted feeling) and *mittag* (noon) in *Nachmittag* (afternoon); *Nach* (after) in *Nachmittag* is an example of a very high frequency constituent.

It is natural to think of economizing coding and access time by excluding large and, in fact, continuously increasing numbers of compounds from the mechanical memory, and adding instead the comparatively few constituents which are *productive*—that is, are found in more than one compound—and do not occur as free forms. An example is German *seitig* (-sided) in *einseitig, zweiseitig,* etc., (one-, two-sided, etc.). Constituents which also occur as free forms are entitled to a place in the mechanical memory a priori. Such an arrangement would permit the identification of compounds by means of the mechanical identification of their constituents. This would result in a welcome reduction of the size of the mechanical memory. It is true that the matching of each compound would be replaced by the matching of its two or more constituents, and the design of the matching mechanism would have to include provisions for the dissection of compounds into their constituents. Nevertheless, because of the comparatively low frequency of most compounds, dissection would not be very frequent and would be amply compensated for by the reduction in the size of the mechanical memory and the resulting decrease in access time.

There are, however, two problems which complicate the situation. One is the fact that the semantic content of many constituents differs according to whether they are bound or free forms. The second is that the conventional written form of the majority of the compounds of certain important languages lacks graphic indication of the "seam" between their constituents. Moreover, many compounds permit more than one dissection into constituents identifiable in the mechanical memory. In most cases, however, only one of these is linguistically correct, whilst those in which two dissections are linguistically permissible are extremely rare coincidences. Numerous examples demonstrating these phenomena will be found below.

These complications are such that it seemed at first impossible to create a mechanism which would supply only correct dissections in every case. No wonder Professor Victor A. Oswald, in his paper *Microsemantics* read at the first CONFERENCE ON MECHANICAL TRANSLATION at M.I.T. in June 1952, stated: "We know of no mechanical process by which this could be accomplished, but an intelligent . . . pre-editor could indicate the dissection for any sort of context." The only alternative to the intervention of a human agent seemed to be the inclusion in the mechanical memory of *all* compounds of the source language, an alternative hardly relished by any linguist or engineer. Nor is it humanly possible, as will be seen as soon as we consider the phenomenon of *unpredictable compounding,* customary

[1] This paper is a revised version of my *Studies in Mechanical-Translation, No. 7,* September 3, 1952.

in many languages and particularly extensive in German, whose vocabulary is continuously being replenished by this method. Unpredictable compounds can not be coded into the mechanical memory. If no mechanical solution can be found for the problem of the *linguistically correct* determination of the constituents of compounds, then human intervention can not be eliminated from the identification process of MT.

In the following I shall show that there actually is a very simple mechanical solution to the problem presented by unpredictable compounds.

1. *Ascertainable and Extemporized Substantive Compounds.*

For MT purposes we distinguish two kinds of substantive compounds which we abbreviate to "SC":

Ascertainable SC—that is, those which are long established and, therefore, can be located in German dictionaries. Examples are *Kleiderbürste, Hochachtung, Gehwerk, Nachgeschmack, Buchstabe, Hochzeit, Unternehmer, Gegenstand,* etc. They could all be entered into the "capital memory." But, as we shall see, a large number of these ascertainable SC can, without sacrificing source-target semantic clarity, be mechanically synthesized out of "memorized" constituents.

Extemporized SC—that is, those which are the result of new free composition, for example *Marsuraniummonopolskandal.* Their potential number is practically infinite. They can, therefore, not be entered into any memory.

2. *The "X-Factor" In German Substantive Compounds.*

A number of SC are characterized by what I call an "X-factor." It is this occurrence of X-factors which presents the main difficulty in the mechanization of the determination of the constituents of SC. X denotes a letter or letter sequence which could be part of the preceding as well as of the following constituent of a SC. See the following examples, some of which have not yet occurred:

The "t" in Wachtraum which is either *Wach/traum* (day dream) or *Wacht/raum* (guard room).

The "er" in *Bluterzeugung* which might be either *Blut/erzeugung* (blood production) or *Bluter/zeugung* (the begetting of children suffering from haemophilia).

The "in" in *Arbeiterinformationsstelle* which is either *Arbeiter/informationsstelle* (workmen information office) or *Arbeiterin/formationsstelle* (female worker formation office; wrong dissection).

The "ur" in *Literaturkunde* which is either *Literat/urkunde* (man of letters' document; wrong dissection) or *Literatur/kunde* (knowledge or textbook of literature).

The problem becomes more complex when two or more "X-factors" occur in one substantive compound. For example, *Kulturinfiltrierung* which is either *Kult/ur/infiltrierung* (cult earliest infiltration), *Kult/urin/filtrierung* (cult urine filtering; a semantically impossible interpretation) or *Kultur/infiltrierung* (culture infiltration). Such coincidences are comparatively rare, for formal and semantic reasons, and some of the dissections which are possible in terms of forms listed in the dictionary are not likely to prove correct for formal and/or semantic reasons. Thus one would rather say *Allmähliche Durchdringung einer Kultur* or *Beeinflussung einer Kultur* (gradual penetration of a culture) than *Kulturinfiltrierung.* One will find *Arbeiterinnenformationenstelle* (office for the military formations of female laborers) instead of *Arbeiterinformationsstelle,* and *Literatenurkunde* (document of men of letters) instead of *Literaturkunde* because *Arbeiterin* and *Literat,* though they are substantive forms listed in the German dictionary, would not be used as first constituents in these compounds. And *Dichterinbrunst* can only be *Dichter/inbrunst* (poet's fervour), but hardly *Dichterin/brunst* (a poetess' male-animal-like sexual excitement).

Nevertheless, since the only basis for the mechanical determination of the constituents of a SC is the occurrence or non-occurrence of the memory equivalent of an input form in the MT memory, such cases have to be considered in the solution of the problem.

In order to meet these conditions, a solution is suggested here for the mechanical determination of the "seam" or junction between every set of two constituents of a compound. This solution requires a special memory apparatus based on the following considerations:

The primary aim of all translation is access to the meaning of a foreign text. In MT

the primary aim is *quick* access to the meaning. Access time depends largely on storage economy. If in matching every input form the whole store of entries has to be scanned, then access time will play a great role. But if, through the exhaustive utilization of all distinctive graphic features of the different types of source forms (letter sequence, capital initials, occurrence or absence of space, punctuation marks, conventional diacritic marks, etc.) and through the use of a *categorized* storage system, the different types of source forms can be directed to specific sections of the storage system, then the dependence of access time on storage economy decreases in proportion to the increase of categorization.

Consequently, full utilization of all distinctive graphic features of the source text and a categorization on different levels of the storage system are important requirements of this scheme. In planning the contents of the memory I have given precedence to source-target semantic requirements over storage economy wherever possible.

3. The Capital Memory.

One of the facts on which this solution is based is the conventional capitalization in German of the initial letters of all forms occurring immediately after a final punctuation mark, and of the overwhelming majority of German substantive forms and of a number of other forms in all positions (for examples see below). The graphic distinctiveness thus enjoyed by German substantives not preceded by a final punctuation mark makes it easy to direct them immediately to a special memory. But since substantives also occur as first words after a final punctuation mark, certain measures have to be taken to make sure that *all* substantives reach their matching centre via the shortest possible route.

These measures are the dissection of compounds, economy of access time, and considerations of source-target semantics. They make it necessary to divide the German MT memory into a number of sub-memories. One of these sub-memories is the capital memory for the treatment of all substantives.

At this point, it is desirable to consider German words beginning with a capital letter in some detail.

Words With Initial Capital Letter.

The following German forms have initial capitals:

a) After final punctuation marks (period, question mark, exclamation mark, the colon preceding direct discourse) *all* first words.

b) In all positions:
   1. All forms of pronouns used in address instead of *du,* and, in letter writing, all pronouns (including *du)* referring to the addressed person.
   2. All adjectives derived from personal names by the suffix *-isch.*
   3. All adjectives, pronouns and ordinal numbers in titles and in historical and geographical names.
   4. All invariable word forms with the suffix *-er,* derived from place names of provinces or federal states.
   5. All substantives with the exception of certain petrified forms and certain forms used in idomatic expressions.

All words with initial capital letter, other than demonstrative adjectives, pronouns, non-adjectival adverbs, prepositions, conjunctions and interjections are directed to the capital memory. (In a separate paper[2] I have discussed how they are sorted and how those not directed to the capital memory can, immediately after input, be directed to their specialized memory.)

Special provision has to be made for cases of initial-capital words after final punctuation marks which may belong to more than one form class. A striking example is *Dichter ist der Hahn geworden* which could mean either "The faucet has become *tighter"* or "The cock has become a *poet."* The ambiguity is here due to antiposition which, though not a feature of the normal word order, is fairly frequent in German.

All substantives with initial capitals are treated in the capital memory. Those without initial capitals are, through the combination of this fact with their letter sequence and with the fact that they are preceded by certain types of words, highly distinctive. They can be dealt with by mechanical processes tailored to the different problems they present.

All other initial-capital words directed to the capital memory are first matched there—that

[2] This subject is treated in some detail in my chapter "The Mechanical Determination of Meaning" in *Machine Translation of Languages,* New York (John Wiley & Sons), 1955.

is, if they occur also as constituents of SC. If, however, no match is found there, they are passed through the remaining memories in a fixed sequence.

4. The Contents of the Capital Memory.

Certain forms are not included in the capital memory, though they may begin with a capital letter. They are:

a) Extemporized SC.
b) Ascertainable SC whose target meaning is inferable from the meaning of the target equivalents of their constituents. For example, *Hochland,* composed of *Hoch* (high) and *land* (land). The target meaning of *Hochland* is "highland."
c) All unproductive constituents which do not occur as free forms; if all ascertainable SC in which they occur are listed in the capital memory. For example, *Ohn* in *Ohnmacht* (fainting fit).

Most capitalized forms are included in the capital memory, as follows:

a) All non-compound substantives.
b) Every SC constituent which:
   1. Occurs as a free substantive form. For example, *Zeit* (time) in *Hochzeit* (wedding).
   2. Occurs as a free, though not substantive form, if not all of the ascertainable SC in which it occurs are entered into the capital memory or if it is still productive. An example is, *Hoch-* in *Hochzeit. Hochland* will not be "memorized" because its target meaning "highland" is inferable from the meaning of the target equivalents of the constituents, "high" and "land." An example showing the continued productivity of such forms is "grass" in *Grossneptunien* (the world empire on the planet Neptune).
   3. Does not occur as a free form, if not all of the SC in which it occurs are "memorized" or if it is still productive. This rule takes care of all compounding forms such as *Geschichts* (history) in *Geschichtsunterricht* (teaching of history), or *Ur* in *Ureinwohner* meaning "aborigine" (this *Ur-* is not of the same origin as the free substantive form *Ur* denoting the European buffalo) as against *Ohn* in *Ohnmacht.*
c) All ascertainable SC whose target meanings cannot be inferred from the meanings of the target equivalents of their constituents because the juxta-position of those meanings:
   1. does not make sense. For example *Mitgift* (dowry) composed of *mit* (with) and *Gift* (poison).
   2. makes the wrong sense. For example, *Hochzeit,* composed of *hoch* (high) and "Zeit" (time), together "high time," but actually meaning "wedding" or "nuptials." An example showing that the difference can sometimes be very great is *Unternehmer,* composed of *unter,* meaning "under," and *Nehmer,* meaning "taker," the combined form actually means "contractor" or "employer," not "undertaker."
   3. permits multiple interpretation because of the multiple meanings of the target equivalent of at least one of the constituents. For example, *Ein* in *Einverständnis* may mean "in" as in *Eingang* ("ingoing"—that is "entry, entrance") or "one" as in *Einklang* ("unison"). In *Einverständnis* (agreement) it means "one."

5. Source-Target Semantics in the Planning of the Capital Memory.

The rules stated and exemplified in 4 and especially in 4c will prevent a large number of potential source-target ambiguities and nonsensical target results. But there is another potential cause of source-target semantic difficulties. Many SC share a first or second constituent which has only *two* possible meanings, one characteristic of one group of the SC concerned and the other characteristic of the other group. The most satisfactory solution of this problem is as follows:

a) If the target meanings of all SC involved can be inferred from the meanings of the target equivalents of both their constituents, then we enter the smaller one of the two groups of SC into the memory unless the constituent or constituents concerned are still productive in one of their two meanings. If both groups happen to have an equal number of members, then we choose either one or the other group for "memorization."
b) If the target meanings of one group cannot

be interred from the meanings of the target equivalents of *both* their two constituents, then this group is entered.

c) In all these cases we enter the two constituents of that group of SC which are not "memorized," and the constituent which both groups share is entered into the capital memory with that meaning in the first position it has in that group of SC which are not "memorized," (see e). For example, *Brech-* in *Brecheisen* (break-iron, i.e., crowbar) and *Brechstange* (break-stick, i.e., crowbar), etc., means "break," whereas in *Brechdurchfall* (vomit-diarrhoea), *Brechweinstein* (vomit-tartar, tartar emetic), etc., it means "vomit." If the group of SC in which *Brech* means "break" is the smaller one, then we enter all SC of this group and enter the constituent *Brech* in the sense of "vomit" in the first position.

d) If, as far as such cases are concerned, a constituent also occurs as a free form—that is, if its free form is identical with its compounding form, then there are the following two possibilities:

1. The free form has only that one of the two meanings of its compounding form, which the latter has in the group of SC not entered. The treatment of this case is identical with that of a free form which has the same meaning or meanings as its graphically *identical* compounding form *none* of whose SC are entered, as for example the free form *Arbeiter* and the compounding form *Arbeiter-* or *-Arbeiter.)* In both these cases only the free form needs to be entered. The graphio-mechanical arrangements in the input and matching system and in the capital memory, required to make this possible, will be discussed elsewhere.
2. The free form has both meanings of its graphically *identical* compounding form or it has more or entirely different meanings. (The question of the common or different origin of the free and the compounding form plays here no role whatsoever.) Here both forms have to be entered. This situation is exemplified by the free substantive form *Ur,* the two graphically identical composing forms *Ur-*[1] and *Ur-*[2] and the SC containing these composing forms. The free form *Ur* means "aurochs" (primitive European bison) and occurs as a constituent (*Ur-*[1]*)* only in one SC, *Urochs* (aurochs). The free form of *Ur-*[1] belongs to the poetical style and is not commonly used. Wherever else *Ur-* occurs in an SC, it will be first understood to be "Ur-[2]." "Extemporizers" will, therefore, avoid forming new SC with *Ur-*[1]. They will use the more common synonym *Auerochs* (or, rarer, *Urochs)* instead. Since *Urochs* is thus the only SC in which *Ur-*[1] (aurochs) will occur, it will be entered into the capital memory in order to avoid confusion with the highly productive *Ur-*[2]. *"Ur-*[2]*"* occurs in a number of ascertainable SC and is still productive. It means "original, earliest, first." The target meanings of one group of the ascertainable SC containing it can not be inferred from the meanings of the target equivalents of their constituents, as, for example, *Urkunde* (document), *Urteil* (judgment). Thus, as far as the problem of *Ur-*[2] itself and the group of SC containing it is concerned, the procedure described above, especially in b, will take care of it. But for the solution of the problem presented by the contrast between *Ur-*[2] and the free form *Ur* certain graphio-mechanical arrangements are necessary. These can be understood only after a description of the matching procedure has been given and they will be discussed in a separate paper. I should like to say here, however, that these graphio-mechanical arrangements and the solution of the *Ur* vs. *Ur-*[2] problem based on them are remarkably simple.

e) The target meanings of extemporized SC are mostly inferable from the meanings of the target equivalents of their constituents. These constituents are not likely to carry meanings they do not have as free forms or as components of ascertainable SC. But they may carry a meaning occurring only in SC which are "memorized." Therefore, wherever this is the case, the criterion for the choice between the two groups of compounds described in a) can not be their size, but must be the continued productivity of one of the two mean-

ings of the constituents concerned. The group of compounds none of whose constituents is still productive will be coded into the memory. The other group will be excluded and the still productive constituent or constituents will be coded only with the meaning characteristic of this group—which is the meaning in which the constituent or constituents concerned are still productive. Also, if a group of compounds, which has to be "memorized," because the meanings of their target equivalents can not be inferred from the meanings of the target equivalents of their constituents, has a constituent which is still productive, the constituent has to be "memorized" too.

6. *All Possible Types of German Substantive Constituents*

We shall now break down German SC, into all possible types of constituents relevant for their determination. Substantive constituents not accompanied by an "X"-factor, I call "trunk" or "T," the left trunk "LT," the right trunk "RT." If the left constituent contains an "X"-
factor, it will be denoted by "LTX," the right constituent containing an "X"-factor by "XRT."
If the left or right constituent occurs in the capital memory, their notation will have the prefix "p" (possible), if they do not occur, it will have *Senn*
the prefix "I" (impossible). Theoretically sp
ing, this gives us the following types of substantive constituents.

Left	*Right*
I. PLT	I. PRT
II. ILT	II. IRT
III. P(PLTX)	III. P(XPRT)
IV. P(ILTX)	IV. P(XIRT)
V. I(PLTX)	V. I(XPRT)
VI. I(ILTX)	VI. I(XIRT)

Of these the left and right forms under VI drop out at once because substantive compounds which have the form "I(ILTX) plus I(XIRT)" or in which either the first constituent has the form "I(ILTX)" or the second constituent the form "I(XIRT)" are linguistically impossible *in all languages*. Consider, for example, the following monstrosities concocted from
English material: "literatuin" ("literatu-" from "literature" and "-in" from "aspirin, insulin, etc.") and "reecutive" ("re-" from "resumption, resource, etc." and "-ecutive" from "executive"). "I(ILTX) plus I(XIRT)" would then be the English substantive compound "literatuin-reecutive." If the right constituent is the possible "executive," then we get the impossible "literatuin-executive"; if the left constituent is the possible "literature," we would arrive at "literaturereecutive."

7. *All Possible Types of Substantive Compounds With Two Constituents.*

Consequently we need consider only the first five alternatives for both the first and the second constituent. This gives us the following 25 theoretical combinations. (For semantic reasons the examples given are partly unlikely to occur.)

I.

1. PLT *Senn*	plus PRT *idyll*	Alpine herdsman's idyll.
2. PLT *Senn*	plus IRT *dustrie*	*An impossible compound.* The trunk *Dastrie* from *Industrie* (industry) does not occur.
3. PLT *Senn*	plus P(XPRT) *inschrift* (Cf. 11a)	*Senn, inschrift* (inscription), *Schrift* (writing) and also *Sennin* (Alpine herdswoman) occur.
4. PLT *Senn*	plus P(XIRT) *industrie* (Cf. 12)	Alpine herdsman's industry. The trunk *Dustrie* does not occur.
5. PLT *Senn*	plus I(XPRT) *ingabe* (Cf. 11b)	*Ingabe* does not occur, but *Senn, Sennin* and *Gabe* (gift) occur.

II.

6. ILT *Insul*	plus PRT *halt*	*An impossible SC. Halt* occurs but *Insul* does not occur.
7. ILT *Insul*	plus IRT *dustrie*	*An impossible SC.* Neither the trunk *Dustrie* of *Industrie* nor the trunk *Insul* of *Insulin* occurs.
8. ILT *Insul*	plus P(XPRT) *intoleranz* (Cf. 16a)	*Insul* does not occur, but *Intoleranz, Toleranz* and also *Insulin* all occur.
9. ILT *Insul*	plus P(XIRT) *industrie* (Cf. 17)	*An impossible SC.* Both *Insulin* and *Industrie* occur, but neither *Insul* nor *Dustrie* occur.

10. ILT plus I(XPRT)
Insul *ingabe*
(Cf. 16b)
Neither *Insul* nor *Ingabe* occur, but *Insulin* and *Gabe* (gift) occur.

III.

11. P(PLTX) plus PRT
Sennin a) *schrift*
b) *gabe*
(Cf. 3 5)
Sennin, Schrift (or *Gabe)* all occur. Also *Senn* and *Inschrift* occur, but *Ingabe* does not occur.

12. P(PLTX) plus IRT
Sennin *dustrie*
(Cf. 4)
The trunk *Dustrie* does not occur, but both *Industrie* and *Senn* occur.

13. P(PLTX) plus P(XPRT)
Sennin *inschrift*
Alpine herdswoman's inscription. But also *Senn* and *Schrift* occur, though *Senninin* and *Ininschrifl* do not occur.

14. P(PLTX) plus P(XIRT)
Sennin *industrie*
Alpine herdswoman's industry. *Senn, Sennin* and *Industrie* all occur, but *Dustrie* and *Inindustrie* do not occur.

15. P(PLTX) plus I(XPRT)
Sennin *ingabe*
An impossible SC. Senn, Sennin and *Gabe* occur, but neither *Ingabe* nor *Senninin* nor *Iningabe* occur.

IV.

16. P(ILTX) plus PRT
Insulin a) *toleranz*
b) *gabe*
(Cf. 8 & 10)
Insulin tolerance or insulin gift. *Intoleranz* occurs, *Ingabe* does not occur; the important fact is, however, that *Insul* does not occur.

17. P(ILTX) plus IRT
Insulin *dustrie*
(Cf. 9)
An impossible SC. Both *Insulin* and *Industrie* occur, but neither *Insul* nor *Dustrie* occur.

18. P(ILTX) plus P(XPRT)
Insulin *information*
Insulin information. *Insulin, Information* and *Formation* all occur, but *Insul, Insulinin* and *Ininformation* do not occur.

19. P(ILTX) plus P(XIRT)
Insulin *Industrie*
Insulin industry. Neither *Insul, Dustrie, Insulinin* nor *Inindustrie* occur.

20. P(ILTX) plus I(XPRT)
Insulin *ingabe*
An impossible SC. Insulin and *Gabe* occur, but neither *Insul, Ingabe,* nor *Insulinin* occur.

V.

21. I(PLTX) plus PRT
Steinin *schrift*
Steinin does not occur, although *Schrift* occurs. But both *Stein* and *Inschrift* occur.

22. I(PLTX) plus IRT
Steinin *sel*
Both *Steinin* and *Sel* do not occur, but *Stein* (stone) and *Insel* (island) occur.

23. I(PLTX) plus P(XPRT)
Steinin *inschrift*
An impossible SC. Stein, Inschrift and *Schrift* occur, but neither *Steinin* nor *Ininschrift* occur.

24. I(PLTX) plus P(XIRT)
Steinin *insel*
An impossible SC. Stein and *Insel* occur, but neither *Steinin* nor *Ininsel occur.*

25. I(PLTX) plus I(XPRT)
Steinin *ingabe*
An impossible SC. Stein and *Gabe* occur, but neither *Steinin* nor *Iningabe* occur.

Of these 25 combinations 2, 6, 7, 9, 15, 17, 20, 23, 24 and 25 are linguistically impossible. Of the remaining 15 combinations, 3 and 1la, 4 and 12, 5 and 11b, 8 and 16a, and 10 and 16b represent the same SC; 3 and 11a present, moreover, two possible dissections of the same SC (i.e. *Senn/inschrift,* Alpine herdsman's inscription, and *Sennin/schrift,* Alpine herdswoman's writing). Thus only 5, 8, 10, and 12 can be ignored. This leaves us with the following eleven possible types of SC:

1, 3, 4
11 a & b, 13, 14
16 a & b, 18, 19
21 and 22.

Of these eleven types only two types with an identical graphic form, 3 and 11a, are ambiguous. From the point of view of the matching mechanism these two types are only one type, so that only *ten* types remain. Thus only in *one* out of *ten* possible types will the matching mechanism have to supply a double answer. (But see "Compounds With An X-Factor," section II, below.) In all other cases the answer will be unique. Furthermore, since all the unique answers and the one double answer are obtained in one to four matching steps, the remaining ten types present only four possible matching situations with which the design engineer has to deal. For these I refer to Section 10, below.

8. Matching Procedure for Substantives Which Have A Complete Memory Equivalent And For Substantive Constituents.

As we have seen in 4, only free substantive forms and productive substantive constituents are entered into the capital memory. Substantive constituents which also occur as free, though not substantive, forms are entered only as compounding forms. Thus the "substantivized" adjective *Rot (Das Rot der Vorhange passt nicht zur Farbe der Teppiche* "the red of the curtain does not suit the colour of the carpets"), the compounding forms *Rot (Rotstift,* red crayon), *-gelb-* and "grün" *(das Rotgelbgrün der bolivianischen Handelsflagge* "the red-yellow-green of the Bolivian merchant flag"), and *Mit-* in the sense of "co-" *(Mitarbeiter, Mitbesitzer, Mitbürger,* co-worker, co-owner, co-citizen) etc., will be entered, but not the free adjective forms *rot, gelb, grün, hoch,* nor the free preposition form *mit.* These will be entered in their own specialized memories. On the other hand SC like *Mitgift* and *Mittag* would be "memorized."

The capital memory is subdivided into sections characterized by the number of component minimal symbols (space and letter symbols) of entries. Thus entries with five minimal symbols will be in the five-symbol section, entries with four symbols in the four-symbol section, and so forth. Within each section the order is alphabetical. The input mechanism counts the minimal symbols of each form fed into it and directs those forms which have not previously been directed to other memories[2] at once to the capital memory section indicated by the number of symbols.

Such an arrangement will go far to cut down the access time: substantives are checked only against the capital memory, and within the capital memory only against memory equivalents with the same number of letters. If the memory counterpart of a substantive form does not occur in the section characterized by the number of its symbols, the matching mechanism ignores the last symbol and checks the remainder against the section with the next smaller number of symbols. This process is repeated until the first agreement is found. The sequence of symbols previously ignored is then fed back as a new input and subjected to the same process until the memory equivalents of all substantive components have been located. The constituents established by this process are individually translated in their original sequence.

All substantives not found as complete entries or determined through the matching process described above appear on the target side in their original form.

In the following each completed matching procedure will be called "one matching step."

9. Matching Procedure For Mechanical Determination Of Constituents Of All Substantive Compounds.

I. Left To Right Matching.

P(PLTX)

A. If RT has no memory equivalent, *(Sennin/* IRT P(PLTX) IRT *dustrie, Schülerin/vasion,* cf. 7/12), then the matching mechanism feeds back LT *(Senn, Schüler,* male student) and XRT *(Industrie, Invasion)* and determines the memory code for LT and XRT.

P(ILTX)

B. If RT has a memory equivalent, *(Insulin/* PRT P(ILTX) PRT *toleranz, Insulin/gabe,* cf. 7/16), then the matching mechanism feeds back LT *(Insul)* and,

ILT

1. if LT has no memory equivalent, *(Insul/* P(XPRT) ILT P(XPRT) *intoleranz, Insul/ingabe,* cf. 7/8,10), then the matching mechanism supplies the memory code for LTX *(Insulin)* plus RT *(Toleranz, Gabe).*

PLT

2. If LT has a memory equivalent, *(Stein/* P(XPRT) *inschrift,* cf. 7/21), then the matching mechanism feeds back XRT *(Inschrift)* and,

PLT

a) if XRT has no memory equivalent, *(Senn/* I(XPRT) PLT I(XPRT) *ingabe, Wäscher/inzeichen,* cf. 7/5), then the matching device supplies the memory code for LTX *(Sennin, Wäscherin,* laundress) plus RT *(Gabe, Zeichen,* mark).

PLT

b) If XRT has a memory equivalent, *(Senn/* P(XPRT)
inschrift, cf. 7/3 and 11a), then the matching mechanism has to supply two answers: the memory code for
LTX plus RT *(Sennin/schrift)* and for LT plus XRT *(Senn/inschrift).*

II. Right-To-Left Matching.

Note: *Left-To-Right* matching presents the simpler engineering problem. *Right-To-Left* matching has the advantage that it tackles first the final constituent which can only be the compounding form of an existing or non-existing (cf. "-nahme" in "Landnahme" land taking) substantive and contains all the grammatical information there is about the SC in which it occurs.

ILT
A. If LT has no memory equivalent, *(Insul/* P(XPRT) ILT P(XPRT)
intoleranz, Insul/ingabe, cf. 7/10), then the matching device feeds back LTX *(Insulin)* and RT *(Toleranz, Gabe)* and determines the memory code for LTX and RT.

PLT
B. If LT has a memory equivalent, *(Senn/* P(XIRT) PLT P(XIRT)
industrie, Schüler/invasion, cf. 7/4), then the matching mechanism feeds back RT *(Dustrie, Vasion)* and,

P(PLTX)
1. if RT has no memory equivalent, *(Sennin/* IRT P(PLTH) IRT
dustrie, Schülerin/vasion, cf. 7/12), then the matching mechanism supplies the memory code for LT *(Schüler, Senn)* plus XRT *(Invasion, Industrie).*

I(PLTX)
2. If RT has a memory equivalent, *(Steinin/* PRT
schrift, cf. 7/21), then the matching mechanism feeds back LTX *(Steinin)* and,
a) if LTX has no memory equivalent, I(PLTX) PRT
(Steinin/schrift), then the matching device supplies the memory code for LT *(Stein)* plus XRT *(Inschrift).*
b) If LTX has a memory equivalent, P(PLTX) PRT
(Sennin/schrift, cf. 7/11), then the matching mechanism has to supply *two* answers: the memory code for
LT plus XRT *(Senn/inschrift)* and for LTX plus RT *(Sennin/schrift).*

10. Number of Matching Steps Necessary for Mechanical Dissection of Substantive Compounds with Two Constituents.

The matching mechanism always determines first the longest memory equivalent. We are here concerned with the number of matching steps of only those SC which do not occur in the capital memory. We distinguish the following possibilities:

a) No constituent occurs in the memory.
b) Only one constituent occurs in the memory.
c) Both constituents occur in the memory.

Those with only one or no constituent occurring in the capital memory are at once directed to the output print system and put out in their source form as are all other words not found in the memory.

For SC both of whose constituents occur in the capital memory we distinguish between:

a) Compounds without an "X"-factor.
b) Compounds with an "X"-factor.

In the following only "left-to-right" matching will be considered.

The examples represent *types* of compounds. They need not actually occur.

Compounds Without An "X"-Factor

For compounds without an "X"-factor (i.e. *Nach/geschmack,* "after-taste," *Senn/idyll,* "Alpine herdsman's idyll"; cf. 7/1) we receive a unique answer after the last letter (in right-to-left order) of the second constituent (that is, the *g* of *-geschmack* and the *i* of *-idyll)* has been ignored by the matching mechanisms—that is, *after the first matching step.* The determination of *Nach-* and *Senn-* as largest memory equivalents—that is, as first constituents—determines *-geschmack* and *-idyll* as second constituents.

Compounds With An "X"-Factor

I. Compounds Always Yielding A Unique Answer

A. After The First Matching Step

Compounds yielding a unique answer after the *first* matching step because the form with first trunk plus "X" *(Steinin-* in the following examples) does not exist.

The following facts can be ignored by the machine and the memory designers:

1. The second trunk exists:
Steinin-schrift (Cf. 7/21. Solution: *Stein/inschrift,* stone inscription.)

2. The second trunk does not exist:
Steinin-sel (Cf. 7/22. Solution: *Stein/insel,* "stone island.")

B. After The Second Matching Step

Compounds yielding a unique answer after the *second* matching step because the *second trunk (-dustrie, -vasion* in the following examples) does not exist.

The following facts can be ignored by the planners:

1. The first constituent has only one "X"-factor:
Sennin-dustrie (Cf. 7/4. Solution: *Senn/industrie,* "Alpine herdsman's industry.")
2. The first constituent has two "X"-factors: *Arbeiterin-vasion* (Solution: *Arbeiter/invasion,* "workmen's invasion.")

C. After The Third Matching Step

Compounds yielding a unique answer after the *third* matching step because the first trunk *(Insul-* in the following examples) does not exist:

1. There is only one "X"-factor between the two trunks. The following facts can be ignored by the planners:
   a) The second trunk can not have an "X"-factor prefix *(-ingabe* in the following example does not exist):
   Insulin-gabe (Cf. 7/16b. Solution: *Insulin/gabe,* "insulin gift.")
   b) The second trunk can have an "X"-factor prefix *(-intoleranz* in the following example exists):
   Insulin-toleranz (Cf. 7/16a. Solution: *Insulin/toleranz,* "insulin tolerance.")
2. There are two identical "X"-factors between the two trunks. The following facts can be ignored by the planners:
   a) The second trunk *(-dustrie* in the following example) does not exist:
   Insulin-industrie (Cf. 7/19. Solution: *Insulin/industrie,* "insulin industry.")
   b) The second trunk *(-formation* in the following example) exists: *Insulin-information* (Cf. 7/18. Solution: *Insulin/information.)*

D. After The Fourth Matching Step

Compounds yielding a unique answer after the *fourth* matching step because the form with "X"-factor plus second constituent *(-ingabe, -inindustrie, -ininschrift* in the following examples) does not exist:

1. There is only one "X"-factor between the two trunks:
Sennin-gabe (Cf. 7/5. Solution: *Sennin/gabe,* "Alpine herdswoman's gift.")
2. There are two identical "X"-factors between the two trunks. The following facts can be ignored by the planners:
   a) The trunk of the second constituent *(-dustrie* in the following example) does not exist:
   Sennin-industrie (Cf. 7/14. Solution: *Sennin/industrie,* "Alpine herdswoman's industry.")
   b) The trunk of the second constituent *(-schrift* in the following example) exists:
   Sennin-inschrift (Cf. 7/13. Solution: *Sennin/inschrift,* "Alpine herdswoman's inscription.")

II. Compounds Yielding A Double Answer After the Fourth Matching Step Unless the "Ur"-Problem Solution Is Incorporated In the Matching Mechanism.

Compounds all of whose trunks *(Literat* and *Welt* in the following example) and forms with *trunk plus "X"-factor* as well as *"X"-factor plus trunk (Literatur* and *Urwelt* in the following example) occur in the capital memory, but whose left trunk *(Literat)* does not occur as a left constituent of SC, would, unless the "UR"-problem solution (cf. 5/Db) is applied, yield a *double answer* after the *fourth* matching step.

Such compounds are, for formal and semantic reasons, rare coincidences:

Literatur-welt:

Solution a) *Literatur/welt,* world of literature—correct dissection.

Solution b) *Literat/urwelt* literary man's primeval world—wrong dissection.

Since *Literat* cannot be a first constituent, the *Ur*-problem solution is applicable and a *unique answer* will be supplied by the matching mechanism after the *third* matching step: the compounding form *Literat-* will not be found in the capital memory.

The case of the following Russian example is similar:

rybo-lovu

Solution a) *:rybo/lovu,* to a fisherman—correct dissection.

Solution *b) :ryb/olovu,* to the tin of the fishes—wrong dissection.

Both trunks *ryb* (genitive plural of *ryba,* fish) and *-lovu* (compounding form meaning "to a catcher"; cf. *ptitse/lovu,* to a fowler, and *kryso/lovu,* to a rat-catcher), and also the composing form *rybo-* (a trunk-plus-"X"-factor form) and the free form *olovu* meaning "to the tin" (an "X"-factor-plus-trunk form) will occur in the capital memory. The connective vowel *-o-* is an "X"-factor. But the trunk *ryb* cannot be a first constituent and the compounding form *ryb-* will, therefore, not be found in the capital memory. Consequently, the matching mechanism will supply a unique and the correct answer after the third matching step.

III. Compounds to Which the "Ur"-Problem Solution Cannot Be Applied and Which, Therefore, Always Yield a Double Answer After the Fourth Matching Step.

For compounds in which two dissections are formally correct and semantically valid, the "Ur"-problem solution is not applicable. These will, therefore, always yield a double answer after the fourth matching step. Such composita are, however, extremely rare coincidences:

1. "*Sennin-schrift*"

   Solution a): *Sennin/schrift,* Alpine herdswoman's writing (cf. 7/11a).

   Solution b): *Senn/inschrift,* Alpine herdsman's inscription (cf. 7/3).

2. "*Wacht-raum*"

   Solution a): *Wacht/raum,* guard room.
   Solution b): *Wach/traum,* waking dream, daydream.

In such cases the MT mechanism will supply *two alternative translations.*

11. The Mechanical Dissection of Substantive Compounds With More Than Two Constituents.

The solution for the mechanical dissection of SC with two constituents includes the solution for the mechanical dissection of SC with more than two constituents. For the matching mechanism such composita are nothing but SC with two immediate constituents, namely the largest first signal sequence which has a memory equivalent, plus the rest. Once the longest first signal sequence with a memory equivalent is established, the matching mechanism feeds back the rest, and the procedure is repeated until all constituents are determined.

Let us assume that all non-compounded constituents of *Grieselbärintelligenzexperiment* occur in the capital memory. The first longest signal sequence with a memory equivalent established by the matching device will then be *Griesel-* (grizzly), and *Bärintelligenzexperiment* will be fed back. Note the "X"-factor *-in-* after *Bär. Bär* means "bear," *Bärin* "female bear." The first longest signal sequence now established will be *Bärin,* and *-telligenzexperiment* will be fed back. Since no portion of this rest can be found in the memory *(-telligenz* does not exist), the matching device will feed back *Bär* (cf. 9/I), locate its memory equivalent and feed back *Intelligenz-experiment.* It will now establish *Intelligenz* as the first longest signal sequence occurring in the capital memory and *Experiment* as the last constituent. Solution:

Griesel/Bär/Intelligenz/Experiment,

Grizzly bear intelligence experiment.

12. Vocabulary Research: Lexical Information Required.

The solution suggested in the preceding pages for the mechanical determination of the constituents of *all* substantive compounds indicates the type of qualitative and quantitative lexical information required for the planning of the capital memory and the matching mechanism. The most important points of this information are:

1. How many and which non-compound substantives, substantive compounds and non-substantive forms belonging to the general language, or only to a specialized language, are eligible for the capital memory?
2. How many and which ascertainable SC can be "synthesized" without any loss in source-target semantic clarity?
3. How many signal number sections will be necessary? What will be the number of source forms in each section?
4. How many and which eligible forms *are unproductive, have been productive,* are *still productive: are* or *are not "X"-factor forms;* have *non-distinctive, distinctive* or *both types* of *composing forms;* can only occur as *left constituents* (cf. *Lehr-),* or only as *right constituents* (cf. *-lehre, -kandidat, -nahme),* or as *both*

(cf. *Arbeiter-, -arbeiter)*; which forms cannot, or are not likely to, occur as *constituents* of *proper names* of *source language origin* (cf. *Erziehung,* education, *Verwundung,* wounding, *Tisch,* table, *Sessel,* chair, etc., etc.); which forms only occurring as *right* constituents *are not listed in dictionaries* (cf. *-nahme)?*

5. In how many and which cases do the *free* and the *non-distinctive* compounding forms have the *same, different,* or only *two meanings,* one carried only by the free, the other only by the compounding form?
6. In how many and which cases does the compounding form have the *same meaning* in. *all* SC in which it occurs (cf. *Arbeiter-, -arbeiter)*; when does it have *two meanings, one* associated with *one,* the *other* with a *second group of SC* in which it occurs?
7. How many and which SC *permit double dissection?* To how many and which ones can the *"Ur"-problem solution* be *applied,* i.e.:
   a) How many and which "X"-factor forms have a "possible" trunk or an "impossible" trunk?
   b) How many and which "X"-factor forms occur with the same "X"-factor?
   c) How many and which "X"-factors occur?

I may add here that some "X"-factors are, for morphological reasons, of frequent occurrence (for example *-er-, -in-* and *-ur-);* others, for formal and semantic reasons, are rare (for example the *-t-* in *Wachtraum).*

"X"-factors can be easily located in the vocabulary by determining whether, after one or more final or initial letters of a productive or potential substantive constituent are dropped, the remaining letter sequence represents another productive or potential substantive constituent. Examples are the finals and initials in *Wacht* (guard), *Wach-* (waking), *Traum* (dream), *Raum* (room), in relation to *Wachtraum; Traum* (dream), *Trau-* (wedding), *Mahnung* (exhortation), *Ahnung* (foreboding), in relation to *Traumahnung* (dream foreboding); *Lehrer* (teacher), *Lehr-* (teaching), *Erzeugnis* (produce), *Zeugnis* (certificate), in relation to *Lehrerzeugnis* (teacher's certificate); *Bärin* (female bear), *Bär* (male bear), *Instinct* (instinct)—containing an "impossible" trunk *-stinkt*—in relation to *Bärinstinkt; Kultur* (culture), *Kult* (cult), *Urwelt* (primeval world), *Welt* (world), in relation to *Kulturwelt* (civilized world).

8. Since all German words after a final punctuation mark have a initial capital letter, vocabulary research will also have to determine all ascertainable substantives whose graphic form—apart from the initial capital letter—is identical with that of a form belonging to another form class.
9. Another important category which should be established in the course of this vocabulary research is all two-initial-letter combinations possible in the source language and the size of the membership in each combination group. To go beyond the second initial letter would not be practical because three-letter words are frequent. The membership of each signal-number section of the capital memory could then be further subdivided into groups of source forms with the same two-initial-letter combinations. The matching mechanism would then compare each source form only with those memory equivalents in the signal-number section concerned which have the same two-initial-letter sequence. This procedure would further reduce access time to a degree where it would be negligible from the MT point of view.

13. Conclusion

The mechanical identification—demonstrated here for the German language—of all compounds which are not included in the mechanical memory and lack graphic indication of the boundaries between their constituents is, of course, applicable to other languages. Only minor modifications in the mechanical design and in the programming will be necessary to take care of differences in the graphic distinctiveness of form classes, such as the absence of the capitalization of substantives, other than proper names, in non-initial positions. Other minor adjustments in this scheme will make it possible to eliminate from the mechanical memory most free and bound forms of dual nationality which has been treated separately.

The importance of the mechanization of this part of the identification process of MT lies in the fact that it solves the problem of unpredictable compounds and makes possible a substantial reduction in the size of the mechanical memory with a resultant decrease in access time. The compound effect of these results in the lowering of the cost of MT is obvious.

translation of russian technical literature by machine notes on preliminary experiments*

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The Russian alphabet, the Russian words encountered in scientific and technical material and the Russian grammar differ greatly from their English counterparts. In order to read scientific or technical Russian, it is necessary to have the meaning of a large number of Russian words stored in the memory. In translating Russian, the corresponding English words must be supplied by the memory accurately and quickly.

Automatic electronic equipment can be designed so as to have a memory capacity sufficient for translating Russian scientific and technical material. Machine memory, supplemented by appropriate selecting mechanisms, provide the basis for effecting word-by-word translation of Russian.

Preliminary experiments have been performed in which machine translation was simulated. One person copied the individual words from samples of Russian text on separate pieces of paper and the writer took the words at random and supplied separate translations for each word. The text was then recreated by restoring the words to the order in the Russian original. The crude translation so obtained was then evaluated by persons having scientific background but no knowledge of Russian.

The results obtained were unexpectedly good and justify the conclusion that even this most primitive form of machine translation enables persons knowing no Russian to understand, to a surprising extent, the subject matter of the Russian original. This understanding is far better than would be provided by numerous index entries to the text material. In fact, some sentences were understood with complete accuracy.

These experiments indicate that a practical, experimental approach to further development of machine translation should yield very useful results. The quality of translations produced by machine can be greatly improved by designing the machine system so that at least the simpler principles of Russian grammar are exploited. How to do this to best advantage is a problem which will require considerable experimentation.

introduction

English-speaking scientists who undertake to learn to read scientific and technical papers in the Russian language encounter a number of difficulties. The most obvious of these is the alphabet which consists for the most part of strange, exotic looking letters.

Mastery of the alphabet does little more than open the door to further difficulties. Although an Indo-European language, Russian is a member of the Slavic group. The words that constitute the backbone of the Russian language bear so little similarity to corresponding English words that a heavy burden is imposed on the memory when acquiring the vocabulary needed to read scientific and technical material. It is true that the purely technical and scientific terminology of modern Russian is, in large degree, derived from the same basic words—Latin, Greek, German or French—as are the corresponding English terms. However, in adopting words of foreign origin, the Russian language employs numerous suffixes, which, though used for the most part in a logical fashion, nevertheless require considerable effort to impress on the memory.

Finally, the grammar is a source of so many difficulties that it often becomes a barrier to learning to read the language.

Grammar difficulties are not due to a lack of logical structure in the Russian language. On the contrary, the basic rules of Russian grammar can, to a large degree, be stated in a simple, straightforward fashion. Inflectional endings play a dominating role in Russian grammar; they alone account for much of the discouragement one so often encounters.

In spite of some strange grammatical features, the basic structure of sentences in Russian and English is similar. Perhaps the most important similarity is the word order, which is so nearly the same that, once the corresponding English words have been written under the successive words in a Russian sentence, very often no rearrangement is needed to produce understandable English sentences and minor rearrangement suffices to provide good idiomatic English.

When the Russian endings are not taken into account, a word-by-word translation often proves deficient with respect to simple English connec-

*This is a slightly revised version of a paper originally written in September, 1952 and given limited circulation in mimeographed form. Mr. Perry was then with the Center for International Studies at M.I.T.

tives such as "of" and "to." In spite of these shortcomings word-by-word translations of Russian technical material have a surprisingly high degree of intelligibility, as will be evident from the experiments described below.

experimental method and results

In these experiments, paragraphs were selected at random from Russian texts on physics, chemistry and astronomy. The lines in the paragraphs were numbered as were also the words in each line. Each individual word in the Russian text was copied on a separate piece of paper along with the two numbers which identified the line and the position of the word in the line. The slips were then shuffled so as to place them in random order. Randomizing the Russian words had the purpose of preventing the writer from interpreting the meaning of the word in the light of the context. After this had been done by an assistant who knew no Russian, the writer supplied one, or if necessary more than one, English word as a translation for each Russian word on an individual basis without knowing how the Russian sentences had been worded. This operation of translating individual words one by one could be accomplished by an appropriately designed automatic electronic machine in whose memory units a Russian-English dictionary in properly encoded form had been recorded.

The numbers on the slips were next used to sort the individual words back into the original order (work slips arranged in order are reproduced below in an appendix). The English words were then copied off to produce the equivalent of a machine translation.

In the all important step of supplying an English translation for individual Russian words, no consideration was given to inflectional endings, with exception of certain irregular verb forms whose frequent occurrence would justify their being included in the dictionary as separate entries. The participles of verbs were also treated as though they were separate dictionary entries.

No consideration was given to case endings of nouns, pronouns and adjectives, nor to the tense endings of verbs. This means, first of all, that no distinction was made between the singular and plural of nouns. Furthermore the translation provided no hint that a Russian noun in the genitive case stands in a dependent relationship to another noun. Thus the phrase струйки фонтана was interpreted after machine translation as "little jet fountain" rather than as "a fountain's little jets," a more appropriate translation, which would have required account to be taken of the fact that фонтана was in the genitive singular case. The writer's assistants also pointed out that the interpretation of the machine translation would have been simpler if the plural of nounshad been indicated and if it had not been necessary to rely on the context to select those nouns which indicate the means or agency used to accomplish various actions. Interpreted in terms of Russian grammar, this latter observation means that it would be advisable for machine operations to take the instrumental case into consideration.*

In spite of these limitations—and other less obvious ones—the rough translations exhibited a high degree of intelligibility. To establish this point, two of the writer's assistants who had had training in physics (Miss Patricia Fergus) and chemistry (Mrs. Anna M. Reid) were requested to edit the rough translation produced by simulated machine operations so as to indicate how they would interpret its meaning. The results of their editorial interpretations are presented in the pages which follow, along with a rather literal translation of the Russian text prepared by the author as a check.

discussion of results

The practical usefulness of machine translation is, of course, the most important point we have to consider. As is evident from the results, such translation, even in a primitively simple form, provides an astonishing degree of insight into Russian technical and scientific material. Such insight is more than sufficient to allow decisions to be made as to the pertinency of a document to a given study. At the very least, therefore, machine translation provides a basis for selecting out documents to be investigated in further detail.

*K. E. Harper documents this conclusion in his paper "The Mechanical Translation of Russian—A Preliminary Report," *Modern Language Forum*, Vol. 38, No. 3-4, pages 12-29 (Sept.-Dec. 1953). See also his chapter "A Preliminary Study of Russian," in *Machine Translation of Languages*, Ed. by Locke, W. N. and Booth, A. D., Technology Press and John Wiley and Sons, 1955 (New York), pages 66-85.

SAMPLE I — PHYSICS

Пьезоэлектрические и пироэлектрические явления. Поляризация кристаллического диэлектрика может происходить не только под действием электрического поля, но в случае некоторых кристаллов (из числа не имеющих центра симметрии) поляризация может быть вызвана механическим, а также и термическим воздействием. Электрическую поляризацию кристалла, вызванную его растяжением или сжатием, называют пьезоэлектрическим эффектом, а поляризацию, происходящую при изменении температуры, называют пироэлектрическим эффектом.

— K. A. Putilov Kurs fiziki (Moscow) 1943, p. 150

imulated machine translation

Piezoelectrical and {thermoelectrical / pyroelectrical} phenomenon.

Polarization crystalline dielectric (noun) is able occur not only under action electrical field but in case certain crystal {from / of} number not {having / possessing} center symmetry) polarization is able to be {called forth / caused} mechanical {and / but} also and thermal action (on). Electrical polarization crystal {called forth / caused} {it / his / its} {pulling apart / tension} of compression {call (verb) / name (verb)} piezoelectrical effect {and / but} polarization {occurring / taking place} {at / during / near} change temperature {call (verb) / name (verb)} {thermoelectrical / puroelectrical} effect.

machine translation

Edited by Miss Patricia Fergus

PIEZOELECTRICAL AND THERMOELECTRICAL PHENOMENON. Polarization of a crystalline dielectric can occur not only under the action of an electrical field but in the case of certain crystals (a number of which do not possess center of symmetry) polarization can be caused by mechanical and also by thermal action. Electrical polarization of a crystal, caused by its tension or compression is called piezoelectrical effect and polarization taking place during a change in temperature is called thermoelectrical effect.

direct translation of russian original

J. W. Perry

PIEZOELECTRICAL AND THERMOELECTRICAL PHENOMENA. The polarization of a crystalline dielectric may occur not only under the influence of the electric field, but in the case of certain crystals (from the group not possessing a center of symmetry) the polarization may be caused by mechanical, and also even by thermal action. The electrical polarization of a crystal, when caused by its being under tension or compression, is called the piezoelectric effect, and polarization, occurring on change of temperature, is called thermoelectrical effect.

SAMPLE II — CHEMISTRY

Осахаривание клетчатки начинает применяться в технике. Для этого отбросы деревообделочных заводов нагревают под давлением с 0,1%-ным раствором серной кислоты; полученный таким путем сироп перерабатывают на винный спирт. По другому способу осахаривание производится на холоду действием очень крепкой (уд. вес 1,21) соляной кислоты. После удаления кислоты остается твердый продукт, применяемый как кормовое средство.

– B. A. Parlov Kurs organicheskoy Khimii (Moscow) 1943, p.253

simulated machine translation

Saccharification cellulose begin {use (verb) / employ} {in / into / at} {technology / technique}. For what waste product {wood processing / wood working} {plant (industrial) / factory} heat (verb) {under / below (preposition)} pressure. {with / from} 0.1% solution {sulfuric / sulfate} acid; obtained such {means / way} syrup {process (verb) / convert (verb)} {on / at} {wine (adj.) / tartaric} alcohol. {According to / Along / In accord with} other process saccharification {accomplish / carry out} {on / at} cold action very strong (sp. weight 1.21) {salt (adj.) / hydrochloric} acid. After removal acid, remain (verb) solid product being used {as / how} {food (adj.) / forage (adj.)} {medium (noun). / means (noun).}

machine translation

Edited by Mrs. Anna M. Reid

Saccharification of cellulose begins to employ technique. For that, the waste products of wood processing plants are heated under pressure with a 0.1% sulfuric acid solution. The syrup thus obtained may be converted on to wine alcohol. According to other processes, saccharification may be accomplished by cold action of very strong hydrochloric acid (sp. gr. 1.21). After removal of the acid, the solid product remaining is used as a food material.

direct translation of russian original

J. W. Perry

The saccharification of cellulose is beginning to be employed in technology. For this purpose, waste products of wood-working plants are heated under pressure with 0.1% solution of H_2SO_4; the syrup obtained in this way is processed into alcohol. According to another process the saccharification is carried out in the cold by the action of very strong (sp. gr. 1.21) hydrochloric acid. After removal of the acid there remains a solid product, which is used as a feed stuff.

SAMPLE III — MATHEMATICS

На рис. 12 вычерчены параболы, по которым движутся тела, брошенные со скоростью 10 м/сек под углами к вертикальной линии в 15°, 30°, 45°, 60°. Так располагаются струйки фонтана, выбрасываемые по всем направлениям из точки А. Огибающая всех этих струек, нанесенная на чертеже пунктиром, тоже парабола. Это и очертание головы кометы.

– S. V. Orlov Priroda komet (Moscow) 1943, p. 50

simulated machine translation

{On / Onto / At} Fig. 12 {traced / mapped out / drawn} parabola {according to / along / in accord with}

which move {thrown / deserted} {with / from} velocity 10 m./sec. {under / below}

angle {to / toward} vertical line {into / in / at} 15°, 30°, 45°, 60°.

Thus {locate / place (verb) / distribute} {groove / little jet} fountain {being ejected / being thrown out}

{according to / along / in accord with} all direction {of / from} point A. {Deflecting / Bending}

all these {groove / little jet} {applied / brought / plotted} {on / onto / at} {sketch / drawing / plan} dotted

line also parabola. This and {is (in fact) / are (in fact)} {outline / contour / form}

head comet.

machine translation

Edited by Miss Patricia Fergus

On Fig. 12 a parabola is drawn according to which a body moves, thrown with the velocity of 10 m/sec and making angles of 15°, 30°, 45°, 60° with the vertical line. Thus a little jet fountain is being thrown out in all directions from point A. Deflecting all these little jets, plotted on the graph, the dotted line also forms a parabola. This is, in fact, the outline of the head comet.

direct translation of russian original

J. W. Perry

In Fig. 12 are plotted the parabolas, along which bodies move when ejected with a velocity of 10 m/sec at angles of 15°, 30°, 45° and 60° to the vertical. Thus are distributed a fountain's little jets, when they are ejected in all directions from point A. The envelope of deflection of all these little jets has been plotted on the sketch as a dotted line, and it is also a parabola. And this is in fact the contour of the head of a comet.

Obviously, such further investigation may require the services of a skilled translator to assure that obscure—though important—points are not misunderstood.

The first example (see page 17) provides an instance in which misunderstanding regarding an important point crept into the machine translation. In editing Sample I (Physics), Miss Fergus made the first sentence read "Polarization of a crystalline dielectric can occur not only under the action of an electrical field but in the case of certain crystals (a number of which do not possess center symmetry) polarization can also occur by mechanical and also by thermal action." The italicized parenthetical statement is somewhat erroneous and would be better translated by "from the group not possessing a center of symmetry." The error was the result of the rather uncommon use of the Russian word число to mean "group" instead of "number." To eliminate this type of error, some of the rarer meanings of words would have to be included in the machine output.

Close inspection of the other examples of machine translation reveals similar misunderstandings, which do not, however, invalidate our previous conclusion that machine translation can provide an astonishing degree of insight into Russian scientific and technical material.

As already noted, machine translation could serve the very useful purpose of facilitating selection of documents pertinent to a given subject or problem. It is possible to imagine a system which would index Russian material without translating it and in this way provide a basis for machine searching by recently developed automatic equipment. To set up such a system, a list of key Russian words and phrases would have to be drawn up and these encoded so as to constitute an indexing system. The translating machine, when it encountered a key word or phrase would perform two operations simultaneously. One would be the translation of the word or phrase into English, the other the encoding of the key word or phrase so as to convert it into an index entry appropriate for machine searching operations. Once such a system was set up, it would permit a large volume of Russian material to be analyzed and correlated without the help of persons having the scientific and linguistic training necessary to read and understand Russian scientific and technical literature.

Another point to be remembered when estimating the value of a machine translation is its usefulness to a human translator as a rough draft from which he can prepare a completely accurate translation of documents whose importance warrants such attention. A rough draft prepared by machine translation can save much time and effort on the part of human translators.

The crude examples of machine translation presented above were produced with only a minimum of use of Russian grammar, namely the addition of a parenthetical notation—e.g. "noun," "verb," "adj."—to an English word to indicate the part of speech of its Russian counterpart. Such grammatical identification can be readily accomplished in machine translation, as the Russian language is so constructed that it is easy to distinguish between nouns, verbs, adjectives and other parts of speech. The young ladies who edited the crude translations remarked that it would have been helpful if more grammatical notations could have been included.

Many possibilities of exploiting the Russian grammar to improve the quality of machine translation await exploration. In particular, the elaborate Russian system of inflectional endings provides a wide range of leads to the structure and meaning of Russian sentences. When investigating these possibilities, the most practical approach would be to establish by experimentation which features of grammar can be most advantageously incorporated into a machine translation system.*

It is perhaps obvious that advantage is gained when the time and effort involved in using the output of a translative machine are decreased, but the expense of increased complexity of design and increased maintenance cost must be borne in mind. It would be easy to go beyond the point of diminishing returns in developing elaborate machines and elaborate machine translating methods, which might produce translations of better literary quality, but might fail to provide a profitable return on the increased investment.

*Much work has been done in this direction since the present paper was originally written. See especially Oettinger, A. G., *A Study for the Design of an Automatic Dictionary*, Harvard thesis 1954, also Harper, op. cit.

A good starting point for investigating the possibilities of exploiting Russian grammar to improve machine translation might be furnished by the more than 700 example sentences which which the writer used to illustrate the different points of grammar in his book Scientific Russian, Interscience Publishers, New York, 1950.

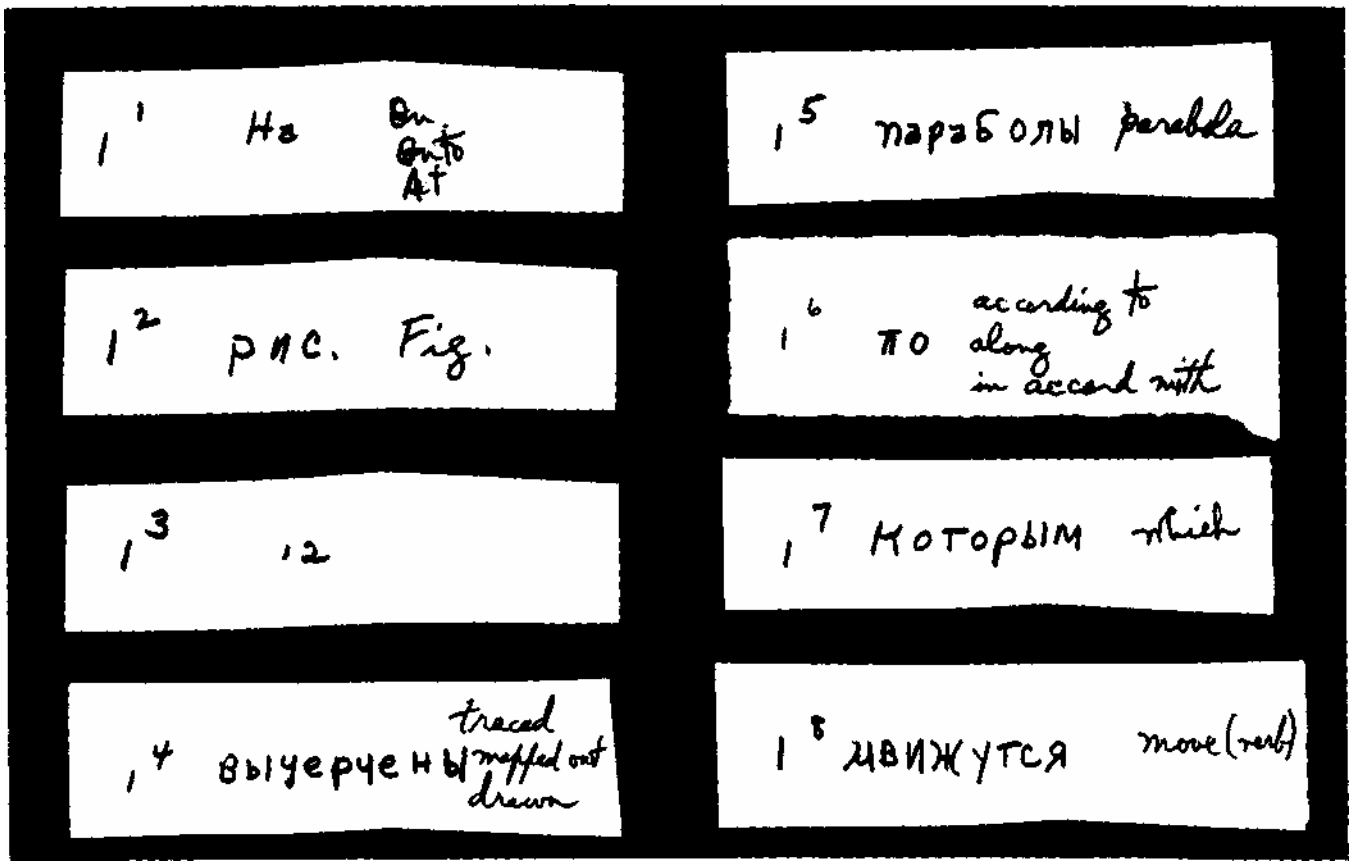
Certain news reports may have given the misleading impression that digital electronic equipment already in existence would be well suited for translating scientific and technical Russian. Discussions with experts in digital electronic machines indicate on the contrary that present machines would be grossly inefficient if used for translating but that techniques and sub-assemblies used in constructing digital computers can doubtless be used to construct a practical translating machine. Further investigation of the methodology of machine translation appears advisable before undertaking to design a translating machine. However, such an investigation, in order to remain within the realm of the practical, should take into account the limitations imposed by the present state of development of automatic electronic equipment.

conclusion

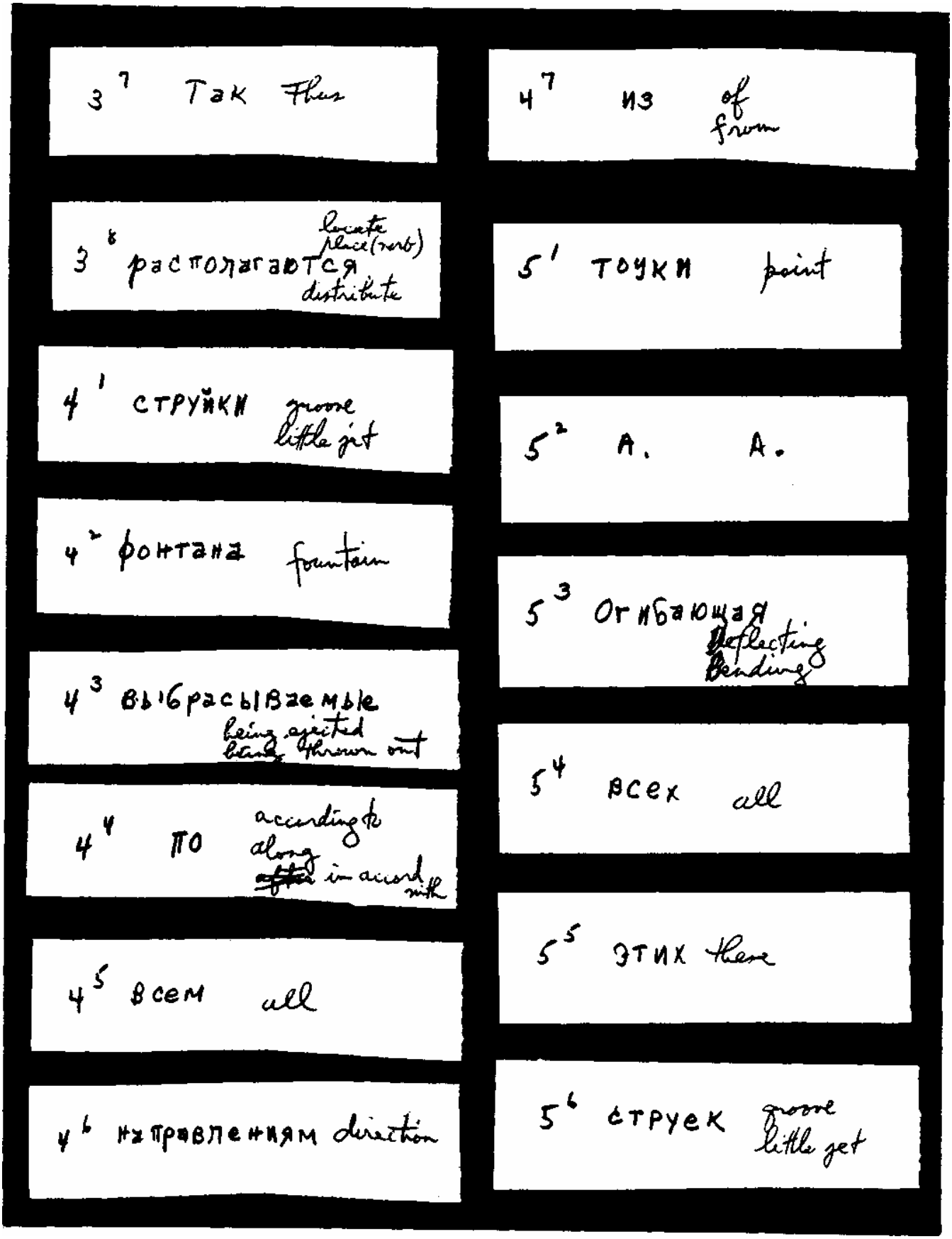
Preliminary experiments indicate that it is possible to apply machine methods advantageously to the problem of translating Russian scientific and technical material. Even the crude translation produced without systematic exploitation of the Russian grammar provide a surprising degree of insight into the subject matter of scientific and technical material. An important problem awaiting investigation is how best to exploit the possibilities inherent in the Russian grammar while still remaining within the realm of the economically feasible.

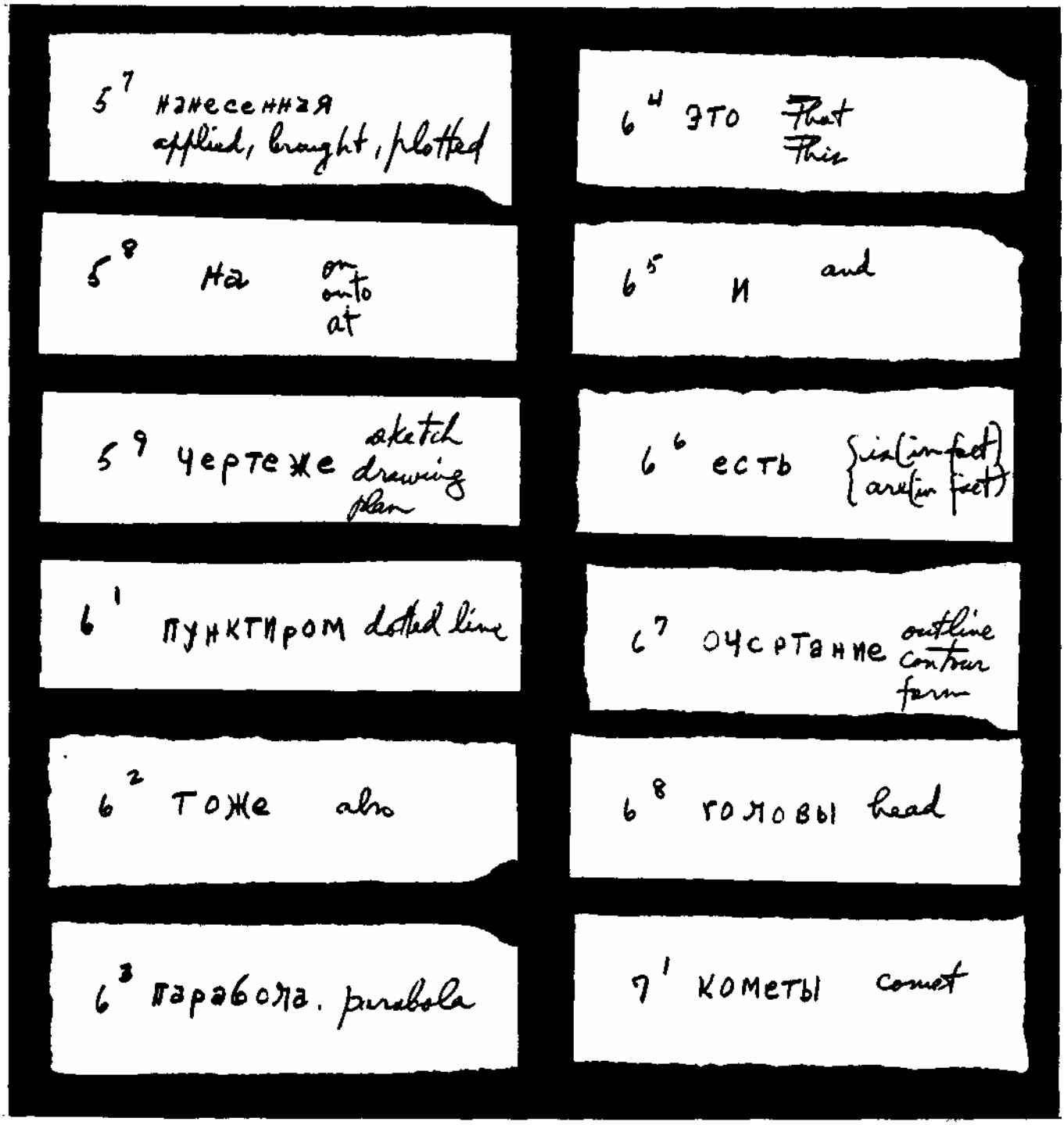
appendix—work slips from sample III

(The numbers refer to the arrangement on the original Russian page where the first line contained eight words and the last, only one.)




2 1 тела body
2 2 брошенные thrown deserted
2 3 со with from
2 4 скоростью velocity
2 5 10 10
2 6 м/сек м/sec.
2 7 под under below
2 8 углами angle
2 9 к to toward
2 10 вертикальной vertical
3 1 линии line
3 2 в into in at
3 3 15° 15°
3 4 30° 30°
3 5 45° 45°
3 6 60° 60°


3⁷ Так Thus
3⁶ располагаются locate place(verb) distribute
4¹ струйки groove little jet
4² фонтана fountain
4³ выбрасываемые being ejected thrown out
4⁴ по according to along in accord with
4⁵ всем all
4⁶ направлениям direction
4⁷ из of from
5¹ точки point
5² А. А.
5³ Отибающая Reflecting Bending
5⁴ всех all
5⁵ этих these
5⁶ струек groove little jet


5⁷ нанесенная applied, brought, plotted
5⁸ на on onto at
5⁹ чертеже sketch drawing plan
6¹ пунктиром dotted line
6² тоже also
6³ парабола. parabola
6⁴ это That This
6⁵ и and
6⁶ есть is (in fact) are (in fact)
6⁷ очертание outline contour form
6⁸ головы head
7¹ кометы comet

bibliography

Anthony G. Oettinger 49
"The Distribution of Word Length in Technical Russian" *Mechanical Translation,* Vol. 1, No. 3, pp. 38-40 (December, 1954).

6486 words of text were obtained from four articles of technical Russian. The frequency of words of different lengths in terms of letters is given.

V. H. Y.

T. M. Stout 50
"Computing Machines for Language Translation" *Mechanical Translation,* Vol. 1, No. 3, pp. 41-46 (December, 1954).

This article is intended to suggest some of the linguistic problems to the engineer and to explain some of the engineering ideas for the linguist. It includes discussion of the language problem, coding, input and output devices, storage, dictionary search and multiple meaning.

V. H. Y.

A. C. Reynolds, Jr. 51
"The Conference on Mechanical Translation" *Mechanical Translation,* Vol. 1, No. 3, pp. 47-55 (December, 1954).

The papers given at the conference held at M.I.T. June 17-20, 1952, are reported on and evaluated by an engineer. Many of these papers are abstracted in MT, Vol. 1, No. 1, and some appear in a more or less revised form in *Machine Translation of Languages* (abstract 55).

Fred Lukoff

Peter Sheridan 52
"Research in Language Translation on the IBM Type 701" *IBM Applied Science Division Technical Newsletter.No. 9,* pp. 5-24 (January, 1955).
This paper describes the manner in which the 250 word Russian-English lexicon and 6 syntactic rules provided by linguists at Georgetown University were programmed on the IBM 701 computer for the demonstration of January 7, 1954. This is the demonstration that has been widely reported in the press.

V. H. Y.

Victor H. Yngve 53
"Machines for the Translation of Languages" *Journal of Communication,* Vol. V., No. 2, pp. 35-40 (Summer, 1955).

The technical developments which make the building of machines for translating both possible and desirable are discussed. A brief report is given on research in progress in the field of mechanical translation, especially linguistic work. Some speculations on the sociological effects of the new machines are also made.

Fred Lukoff

Kenneth E. Harper 54
"Translating Russian by Machine" *Journal of Communication,* Vol. V., No. 2, pp. 41-46 (Summer, 1955).

This is a brief, non-technical presentation of some of the problems and methods of mechanical translation. It discusses how computing devices can be used and how grammatical information can be extracted from inflections and from the relative positions of words. Some possible ways of refining rough translations are also discussed.

Fred Lukoff

Machine Translation of Languages
Edited by William N. Locke and A. Donald Booth
The Technology Press of M.I.T. and John Wiley & Sons, Inc., New York, Chapman & Hall, Ltd., London (May 1955).

This first book to be published in the field contains fourteen essays representing the latest thinking of nearly everyone who has been active in mechanical translation. The table of contents follows:

Foreword: The New Tower - Warren Weaver
Historical Introduction - A. Donald Booth and William N. Locke
1. Translation - Warren Weaver
2. Some Methods of Mechanized Translation - R. H. Richens and A. D. Booth

Machine Translation of Languages (Cont.)

3. The Design of an Automatic Russian-English Technical Dictionary - Anthony G. Oettinger
4. A Preliminary Study of Russian - Kenneth E. Harper
5. Some Problems of the "Word" - William E. Bull, Charles Africa, and Daniel Teichroew
6. Speech Input - William N. Locke
7. Storage Devices - A. Donald Booth
8. The Georgetown-I.B.M. Experiment - Leon E. Dostert
9. The Mechanical Determination of Meaning - Erwin Reifler
10. Model English - Stuart C. Dodd
11. A Practical Development Problem - James

V. H. Y.