SECTION III

INDIRECT ACCESS TO THE PRINTED PAGE

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AUTOMATIC MACHINE TRANSLATION: POTENTIALITIES FOR BRAILLE ENCODING

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The automatic transcription of contracted braille from uncontracted material shares many of the problems of the translation by machine of such languages as German and Russian. To the extent that the braille spelling rules refer to the conventional spelling of the original the problems are minor. But to the extent that the braille spelling rules refer to pronunciation, grammatical function, or meaning the problems are severe and can be attacked only with very sophisticated methods. In other words, going from a code (ordinary inkprint spelling) into braille is really a problem in translation.

There are available source documents in the form of punched paper tape that are by-products of the printing industry. It has occurred to many of us that these could perhaps be used to produce braille copies automatically. There is also the possibility of providing, from a typewriter keyboard, pulses corresponding to ordinary spelling, and then translating these into the correct contractions in braille. There are various other possible ways of tying the two systems of representation together.

The problem is made difficult by the nature of braille. Braille is in a sense based on spelling, but many of its rules refer not to the spelled form but to the underlying language. In other words, in a very real sense braille is a direct representation of the spoken language rather than a direct representation of the spelled form that we find in books.

In order to make the rules of braille easier many of the rules of ordinary spelling have been adopted, so that many words in braille are spelled exactly the same way as they are in a book. Since the purpose of braille is still to transmit information, however, I think it proper that the rules have been stated in terms of the underlying language. This is true as long as a human being transcribes the braille, because he can understand the language that is being encoded into braille and can very easily use rules couched in terms of the underlying language. However, given the problem of translating into braille from a representation equivalent to inkprint, or from the output of a typewriter keyboard, one faces a different problem. First of all, the spelling system of English is notoriously poor.

I think I can illustrate the sort of problems one faces by stating a couple of rules from the braille standard of some years ago. Rule 34 for Grade 2 braille has to do with contractions; it says, "Contractions forming parts of words should not be used when they are likely to lead to obscurity in recognition or pronunciation, and therefore they should not overlap well-defined syllable divisions." This rule is stated in terms of syllable divisions, something that is not explicitly represented in inkprint. "Word signs should be used sparingly in the middle of words unless they form distinct syllables. . . . Special care should be taken to avoid undue contractions of words of relatively infrequent occurrence." It goes on, ". . . when words occur at the end of a line, they must be at the end of a syllable." Here we have a rule for contracted braille stated not in terms of the inkprint spelling, but in terms of syllables, which are a feature of the underlying language. The question arises: Can one syllabify a word automatically? I think most of you know that this is very difficult. I have to look words up in the dictionary in order to separate them correctly at the end of a line. The difficulty is partly due to the traditional spelling of English, a heritage from past eras, and does not in many cases conform exactly to the pronunciation.

The next example is contained in Rule 23. According to this rule the contractions "to," "into," and "by" are always to be written close up to the word or that word which follows. It goes on, ". . . in such phrases as 'it was referred to yesterday,' and 'he was passed by when others were noticed,' the 'to' and the 'by' should be written in full and not contracted, as they refer to the preceding verb and not to the word that follows them."

In other words, if "to" or "by" are prepositions, as in "to the house," or "by the table," then one would contract the "to" or the "by" according to this rule, and write the contracted form without a space immediately preceding the next word. However, if "to" and "by" are adverbs, as in the case ". . . it was referred to yesterday . . ." and " . . . he was passed by when others were noticed," they are not contracted. There is no clue in the inkprint that these words are in one case prepositions and in the other case adverbs; they are not marked explicitly. One needs to have an understanding of the sentence in order to make that distinction, or else one has to have a method of grammatically parsing the sentence so that he can determine whether these words are prepositions or adverbs. This is a problem that has been faced in the mechanical translation of languages, and I shall say a little bit about it below.

The following sentence is actually syntactically ambiguous: "It was referred to the other day" (or, "It was referred, to the other day"). The first inkprint makes no distinction; one can *say* it either way, however, using a different tone of voice. The "to" in this sentence (as I read the rules of braille) would in one case be contracted and written next to the word; in the other case it would not be contracted. The resolution of such ambiguities is relatively easy for the person who reads the material, if he understands it. The resolution of such ambiguities would be very difficult, however, for a machine. It is also the sort of ambiguity resolution that the people working in mechanical translation of languages have been facing.

I shall give a brief summary of this work. The first hope was that one could put a dictionary into a computer. The computer would simply look up the words one at a time in the dictionary, finding equivalent words in the other language, and print them out. Such a dictionary would be easy to mechanize; the problems were involved primarily in the large size of the dictionary as compared with the relatively small size of memories. The most promising method of implementing such a thing would be to put the dictionary on magnetic tape available to the computer and arrange to look up the words in batches. I say this was a hope; there were many problems with it. First of all, especially in languages such as Russian which was given a lot of attention by people working in mechanical translation, it was realized very quickly that the size of the dictionary could be greatly reduced by not storing a whole word complete with its ending, but storing instead its stem separate from the ending. Then a program in the machine would take each Russian word, examine it letter by letter, split off any inflectional endings there might have been (e.g., case endings, verb endings), and look up the remainder in the dictionary. Then, having found the stem of the word in the dictionary, the machine could go ahead and interpret the remainder of the word as an inflectional ending and give it its appropriate meaning. Programs of this type have been written at a number of universities and at a number of industrial firms that have been working on this type of translation. I can report that the problem is effectively solved.

However, our hopes were really too high. The result of writing out just the words from such a dictionary look-up process was completely inadequate as a translation (and I mean *completely* inadequate). There are two main reasons for this. One was that if one looks up almost any word in a dictionary, one finds that it has several renditions in the other language. The other reason was that even if one could select the correct meaning of each of the input words and string these meanings together the word order would be wrong and in general a grammatically correct sentence is not obtained. In some cases the "translation" is so badly garbled that one cannot make any sense out of it even if the correct word is there. The problem was, what next to do?

The next step was to look at the output and see whether something more could be done. Certain rules were set up, ad hoc rules, which worked perhaps 80 percent of the time. Let me illustrate such a rule. The letter sequence d-e-r in German can be an article in front of a noun; it can be a relative pronoun; if it is an article it can be nominative, genitive, or dative. The translation of this three letter word would depend on its grammatical function. Thus, a very simple rule of thumb is: "If d-e-r follows a noun without a comma translate it 'of the.'" This rule will give the correct answer about 90 percent of the time; perhaps even 95 percent of the time. It is wrong when "der" is dative (and it could very easily be dative), but it is dative perhaps only 5 percent of the time. Thus the translation is wrong about 5 percent of the time. It sounds impressive, however, to have a rule that works 95 percent of the time. This is the type of rule that I call an "ad hoc rule." The rule is not really based on the structure of the language. In other words the case is not determined and the part of speech is not determined.

Many of the mechanical translation groups looked for and discovered a large number of such rules of thumb; they were able to make a fairly reasonable improvement in readability. Another example they found was this: "If there are three meanings for a word, and one is very frequent while the other two are not as frequent, then print the frequent meaning and forget about the others." Again the quality is improved because it is very difficult for the reader to be faced with three alternatives; he can read much more easily if he has only single words to consider. Choosing the most frequent meaning is more often right than not. This is also the kind of rule that is not really a "correct rule." On the average, however, it will work.

Mechanical translation people were quite optimistic about this procedure; they thought, ". . . it's just a matter of finding more and more of these rules; fixing up the order; eliminating more and more of the problems." Unfortunately, one can't go all the way with this approach. It becomes much too complicated, rules conflict with rules, and one never really knows what one has when it is done. I want to emphasize, however, that such rules will take care of perhaps 80 percent of the problems involved. This first 80 percent of the problem is easy to solve. It is the remaining 20 percent that is extremely difficult and that cannot be solved by such rules of thumb.

The next approach was to try and do it right: to find out what are the actual parts of speech of each word in the sentence. Let us try to find out whether it *is* a preposition or an adverb. Let us find out what *is* the subject of the sentence; what *is* the verb; what *is* the object; and so on. In other words, do a complete parsing of the sentence. Programs of this sort have been written and they are fairly successful, but a new batch of problems has shown up.

In general it is not possible to parse a sentence without knowing its meaning. This we found through experience. I suppose if we had thought about it we would have known, but we hoped that a simple parsing of the sentence would give us enough improvement in the output of the translating program to be useful. Take the sentence we used above: "it was referred to the other day," or, as it may be read, "it was referred, to the other day." It would appear that parsing would help. However, this sentence is ambiguous; it has two different parsings. In any given text this sentence would be unambiguous because of its context, because the person who reads it would understand what was meant very readily, and it would never enter his mind that the sentence was ambiguous. Unless he can understand the text too, he cannot do this. So the limitations on automatic parsing of sentences is just at that point where we need to understand the meaning of the sentence in order to resolve ambiguities. I can report to you that such ambiguities are a very frequent occurrence. A very large number of sentences are really ambiguous from this grammatical point of view. We are not bothered by such ambiguity when we read because we understand the meaning and it is this understanding of the meaning of the sentence that carries us through the ambiguities.

Our hopes have been dashed again. The essential limit of a program for parsing a sentence is just in this area which I like to call "semantics." A number of the groups working on mechanical translation are now facing up to the problem of semantics. This problem appears to be orders of magnitude more difficult than the syntactic problem. We have a few hunches, but I don't think we have the foggiest idea, really, of how to solve this problem. Nevertheless, most of the groups are working at it. They are trying ad hoc rules, and they are trying various other schemes. They have also tried schemes such as the following.

You all know that you can *row* a boat. Now, it turns out that there aren't very many other things that you *row,* other than boats. The word r-o-w is ambiguous: it could be a row (a brawl) or a row (of objects). In other words the meaning of this word or the solution of this ambiguity can be found partially but not completely. In the general case one must also take care of the meaning of the sentence. One way of doing this is to list in the dictionary that it is *boats* that you row and not other things. Much information of this kind in the dictionary might be quite useful in resolving ambiguities. There are other methods that have been proposed. One is to order the words in the dictionary in much the same way as they are in a thesaurus, by meaning categories with indexes and connections between words, and putting them into fields of knowledge and fields of interest much the same way Roget did in his Thesaurus. There are several other such schemes. In other words, we are taking the first faltering steps into the area of semantics.

Now, as to braille, I think that the complete and correct transcription of contracted braille, according to the currently accepted official rules of standard English braille, is not currently feasible. I want to be very clear about this; it is exactly what I mean. I say, "It's not feasible," but on the other hand it is. Attend very carefully to the qualification: it is more than "not feasible" vs. "feasible."

Automatic transcription is feasible if certain of the rules are compromised. The real question is, what is the degree of compromise that is necessary? I suggest that we work out the best compromises and standardize them into a new type of braille specifically for machine transcription. All the rules should be phrased in terms of the conventional spelling of the original text with no reference to pronunciation, grammatical function, or meaning. This "machine transcription braille" should conform *as closely as possible to the current practice* so that it could be read interchangeably with hand transcribed braille. Now this is precisely what is being done, except that we have not standardized our usage. The braille programs that we have now *do* operate with rules stated in terms of the traditional spelling. In other words, a pronunciation rule would be restated: "you will do such-and-such," instead of saying, "you do such-and-such except when you would pronounce it some other way" (you do such-and-such and list the exceptions). This is tantamount to restating the rule in terms of the inkprint spelling.

If we devise machine programs that actually are used for transcribing braille, a little thought should be given to stating these rules the way we really want to use them, while realizing that machine programs can be very easily changed to conform with any set of braille rules one might wish to use. I think it would behoove the people who are interested in what the machine produced braille is going to look like to look at the rules *as they are stated now,* and to the problem of restating these rules in some way so that machine programs can be written that will give the kind of braille they want. They must realize that it is impossible to program a machine to transcribe braille according to the rules as they now stand, because the criteria now put down have to do with the pronunciation, with the grammatical structure, or with the meaning of a sentence. These are problems that have not been solved even in the mechanical translation of languages. They are in fact extremely difficult problems.

I have one other comment. It would be a good idea to capitalize upon the rather wide availability of punched tape from the printing industry. I imagine that this has been suggested before. I feel that this material should be placed in a central repository so that people who want to make braille editions would have it available. There are other groups that are also interested in a centralized repository for this material. I would think it would be very wise to contact these groups and work with them. The other groups are primarily concerned with mechanical translation (who would like to have the material for translation) and the groups associated with information retrieval (or the automatic library). I don't know where the best place would be for such a center; possibly the Library of Congress. Publishers send copies there anyway for copyright purposes. Perhaps they wouldn't mind sending their punched paper tapes to the Library of Congress. I don't know; I presume that the Library of Congress is not set up for this kind of thing, that there would have to be something added. Perhaps it is unsatisfactory as a repository for other reasons; but I certainly feel that this should be explored, and it should be explored concurrently with other groups that are also interested, particularly the information retrieval people.

In concluding, I should like to consider a number of specific questions having to do with problems in applying the caveats I have discussed.* Among these I would include those dealing with (1) paper tapes, (2) contractions vs. syllable boundaries, (3) the anticipated or possible contraction in a revised and "computer-oriented" braille, and (4) the argument for complex translation programs versus the generation of a modified braille.

THE PROBLEM OF OBTAINING PUNCHED PAPER TAPES

This is an extremely difficult problem. I personally feel that the best solution, which perhaps is not feasible, would be to update the procedures in the printing industry. After all, the printing industry was mechanized about 50 years ago, when Monotype was really the last word in automation. It uses a player piano-like roll which is not quite as wide as that for the player piano. It is read the same way, with compressed air; it huffs and puffs and chugs along, and is not really in line with modern automation techniques. Monotype has served the printing industry admirably; I could imagine they would be loathe to change unless a very real advancement were achieved. There are people who are thinking in terms of computer programs to help correct errors. In fact there are some at MIT who are doing this sort of thing. If one can get the material that is to be published on tape and into a computer, then it is possible to write a program that will correct this tape to order. This has a very great advantage, namely that one does not have to proofread the material carefully once more. Once it is set, once it has been proofread, once it is correct—it is there, it is done. I feel that there is a great deal of room for advancement in this area.

CONTRACTIONS, SYLLABLE BOUNDARIES, AND THE COMPRESSION OF COMPUTER-ORIENTED BRAILLE

I think that there is no doubt that contractions across a syllable boundary could tend to slow a person up. I think the problem here is to state the rules in such a way that a machine can follow them; in other words, to state mechanical rules that will give braille that is readable. Probably a statistical approach here would do. If there is only one word out of ten pages that is going to slow up a reader, then it is not going to slow him very much overall. If one can state the rules in such a way that they do the right things

* The material in this section was prepared from the question and answer period following Dr. Yngve's paper—Ed.

effectively most of the time, then if a mistake is made once in ten pages, or a contraction is made across a syllable boundary, the risk is worth taking. Let us make a standard to do the contracting so that different people who have different programs can still produce the same braille. I think that once the reader is used to the results they might not slow him up very much.

My guess is that the degree of compression in braille would not be changed appreciably. This is only an impression, for I have not made a study of this. The size of a braille book is not likely to be increased by very much; perhaps by one page out of 100, or something like that.

There are two problems here. One is the physical problem of storing all the words. One would have for example the word "hothouse," in which the "th" should not be contracted, presumably. There are several ways of approaching this problem in a machine. One is to list all these words. This means merely looking up the word in the dictionary, seeing what list it is in, perhaps storing only one list, the smaller one. If the word is not in that list, then do the job the longer way. There is one problem here in that the list might require a fairly large storage. One way out is to store only the words one expects to run into frequently and not the others. Then the rule would be correctly followed most of the time. Another approach would be to look at the spelling and to make such rules as " 'th' after 's' should be contracted" (assuming that we find that this is generally the case), and for "hothouse," the "th" after a vowel perhaps would not be separated. In other words, it might be possible to state the rules in terms of spelling and yet have a fairly satisfactory result. Whichever way it is done, there is not too much difference from a machine point of view, except it is out of the question to list all of the words involved in some of these rules.

The other problem is that there are many of these words; with vocabulary one is dealing essentially with an open class. People can invent new words, for example, and when they have invented new words one wants the program to deal with them correctly. It is not feasible, however, to list words that haven't been invented or used.

LARGE COMPUTERS *VS.* MODIFIED BRAILLE

First of all, I agree 100 percent with the statement made here that the machine should serve man and not vice versa; this is in part my own motivation in working towards mechanical translation. Communication between different linguistic communities now goes entirely through people who are to some extent bilingual. If we had some machine aid in this area we could, I think, do something by machine which is quite a burden to people. I don't want to be misunderstood on this point: from one point of view, one must change the rules of braille if the job is going to be done by machine. From another point of view, the rules need not be changed. It depends on just what one means by the phrase "changing the rules of braille." If one lists all the words, and indicates how they are to be contracted, this is a rule. This is a different rule from the kind of rule that tells us, "You must not cross syllable boundaries." The result may be precisely the same, which is to the good if it is judged that the braille as currently written is the best.

In other words I am not proposing to alter the braille codes as they are currently written unless there are good reasons to do so from the point of view of the reader. But I am proposing that the rules be restated in a machine-usable form, as they are in fact now being applied by working programs. The other comment I would have is that such rules as the use of "to" contraction, and "by" contraction (in the case of preposition and not in the case of adverb) is something that is rather difficult to mechanize; it is not out of the question, but it would take a rather sophisticated computer program. We don't know quite how to do this completely adequately. If this rule were restated in some other way that would give the result intended (or very close to it), then I think we should do so, and we should say to ourselves, "This is machine braille that we are using."

AUTOMATIC BRAILLE REPRODUCTION

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During the past ten years some effort has been expended to produce braille by the application of the principles and techniques of automation. This effort was initiated, at least in the United States, by the Library of Congress; in 1954 the American Printing House for the Blind (APH) was selected to conduct an exploratory survey to determine the need and the areas for which research might result in an improvement in the quality of braille and the lowering of its cost. As a result of this survey, several definite projects were selected and approved by the Library for further research and development over the next three years.

Several studies were made in cooperation with the University of Kentucky to determine the optimum physical dimensions of braille. These studies were concerned primarily with interdot, intercell, and interline spacing.

Some effort was made to fabricate a braille book paper that would be attractive, have maximum classroom life, and optimum readability. Under this program an effort also was made to improve the braille plate embossing machines to increase operating speed and raise the level of accuracy of embossing. Special emphasis was laid on the need to lessen the variation in dot height.

Through a cost analysis of braille book production from editing through binding, it was learned that the braille plate making operation which includes embossing, proofreading, and correcting is the largest single item of cost in this operation. This is due primarily to the fact that most runs of braille are very small. The Library of Congress, for illustration, normally orders 28 to 30 copies of a book; for this number the plates alone account for over two-thirds of the total cost. The fact that plate making represents such a large part of book cost suggests that research in this area could be rewarding, and that the use of the recent developments in technology might result in lower cost for the plates.

A braille plate consists of a sheet of zinc, iron, or aluminum approximately .010 inch thick, 9½ inches wide and 25 inches long. This plate is folded to form a double sheet of metal 9½ inches by 12½ inches. It is then placed in a stereograph machine where it is embossed through both thicknesses, forming in effect a male and female die. After embossing, proof sheets are made from the plates and are checked for errors. The plates and the error sheets are returned to the operator for correcting. These three operations—embossing, proofreading, and correcting—each require about the same amount of time. The actual translation is done by the operator at the same time as the embossing.

A systems engineering approach to the braille plate making operation suggests that a three unit system consisting of an input unit for originating and verifying punched cards or tape, an intermediate unit (probably a computer) in which the actual translation would be accomplished, and a third unit from which the output of the computer would be used to control a braille plate embossing machine, could logically replace the present manual operation.

The input unit presents no problem since punched tape and card machines are in everyday use. The intermediate unit probably presents the greatest problem, since it involves the selection of the computer that is most practical for the purpose, and many factors affect this decision, two of the most important of which are the size of memory and the actual per word cost of operation. Although the output unit presents several problems too, there appeared to be advantages in early construction of this unit as it would prove the feasibility of automatic control of the embossing machine, the practicability of verifying, and could result in some immediate saving in plate cost.

In 1955 the construction of the first tape controlled braille plate embossing system was started in IBM's laboratory. This machine consists of a braillewriter/tape punch unit to originate the tape, a tape reader/braillewriter/tape punch unit for verifying and a tape reader/stereograph machine combination for the output. Tape control was selected for this first unit since both tape punch and read units are small and flexible, which resulted in the entire unit being a small efficient machine.

Through several years of use in production, this pilot project proved the feasibility of tape control of the embossing machine; further, that verifying could be used in lieu of proofreading. Actually the level of accuracy obtained through verifying proved to be higher than that obtained with conventional proofreading. The shape and height of the braille dots are also much better with the tape controlled unit, since corrections are not made on the plates as they are with the conventional system. Braille plate cost with this unit is slightly lower than with the manual operation, but probably not enough to justify the increased cost of the equipment.

The positive results obtained with the tape control embossing project encouraged further research on the translation unit, and in October 1958, IBM agreed to write a program for the IBM 704 computer to translate fully spelled input into Grade 2 braille. IBM also agreed to translate 12 books to determine if machine translation could afford the necessary degree of accuracy. It was also important to learn whether or not the machine could produce acceptable braille format. ('Format' means page number, correct number of cells per page, correct number of lines per page, etc.)

It was agreed that APH should select the titles to be translated so that they would present as nearly as possible the unusual situations encountered in applying the braille literary code in day-to-day production. Special consideration was to be given to unusual format, the author's unique style, and word usage. Among the books chosen were *How Big Is Big,* Kipling's *Jungle* books, *The Fanny Farmer Cookbook, Psychology for Living,* and *New Ways In Sex Education.*

The translation program was developed in the IBM Department of Mathematics and Applications in New York City. The actual work was done by Mrs. Ann Shack, working closely with the braillist at the APH. As we might expect, some of the situations that we felt would cause trouble failed to do so, while some of the simpler situations (simple at least from the standpoint of the manual transcriber) presented the biggest problems. For instance, one of these books, an elementary reader, *Up And Away,* has only a few lines on the page of the original inkprint edition, the type is large, and the lines are widely spaced. Normally the braille version of a book of this kind is written with twice the normal line spacing, and the lines on the reverse side of the sheet fall between the lines on the first side. This situation coupled with the fact that running headings are placed only on the numbered pages presented one of the toughest format problems the program had to solve.

The choice of the IBM 704 computer was based on the flexibility the machine affords and the fact that it provided the memory or storage capacity that the project seemed to require. Since the 704 used punched cards for both input and output, it was decided that the embossing machine at APH should be fitted up for card control as well as tape control, so that a conversion from cards to tape would not be necessary. This was accomplished by adapting an IBM 056 Verifier as the card reader input to the embossing machine.

A program was completed and machine translation of braille became a reality in April 1959. Several revisions were necessary, of course, before the program attained its present form, but in the Spring of 1962 the last of the 12 books was completed.

It should be emphasized that the program as written takes no liberties with the braille code, the only compromise being that words normally hyphenated at the end of a line with the manual system are not hyphenated with the automated system; instead the entire word is carried over to the next line.

When the first few books had been completed and it appeared that translation was feasible, APH decided with the help of IBM to adapt two more stereograph machines for card control. This was done because it had been found that to emboss a plate takes approximately five minutes, the equivalent of 12 plates an hour. This capacity was far too small and did not utilize the operator's time efficiently. With three output machines 250 plates can be produced each eight-hour day. This is roughly equivalent to one-half the total production of the Printing House.

The experience gained from these 12 books suggests that machine translation is not only possible, but it will prove to be faster and more efficient than the manual method; it promises to be entirely satisfactory. With a table look-up type of program, some up-dating will have to be done continuously. It is felt, however, that some procedure such as translating the first chapter, then reading the proof listing and making the indicated changes, will enable us to cope with any unusual style or word usage that is encountered in a particular book without making a complete retranslation necessary.

The accuracy of the complete system seems to be ensured by the fact that input cards are verified, that a proof listing will be read at least in part, and that the embossing machine incorporates the fail-safe principle, thereby practically eliminating machine errors. The only remaining factor that might make the system impractical is economic and APH has given this a great deal of serious thought. Whenever possible accurate records have been kept of each operation and we know within reason the cost of punching and verifying the input cards; we know, too, the cost of embossing the metal plates.

Some estimates of computer cost have been made; however, there are many factors affecting this cost other than the actual per word cost of the machine. Since a computer sophisticated enough to handle the braille program is not available in the Louisville area, it is necessary that the cards be sent to and from a computer installation in another city; that the job be fitted into the computer schedule and an operator familiar with the braille project be provided. Since this presents so many incidental problems, the best solution found so far is to have a member of the APH staff actually carry the cards to the computer (after arrangements have been made of course), translate the cards, and bring the output cards back to Louisville. It is obvious that this procedure is both time consuming and costly—so costly that it appears necessary that a computer be obtained for use at APH if machine translation is to be a production operation.

Since the cost of the computer is so indefinite, we might approach the economics of the automated system in reverse order. That is, we might take the cost of a plate with the manual system and substract from it the known cost with the automated system. The difference would then be the amount that could be allowed for the unknown operations. Following this reasoning, we find that the average cost of a braille plate with the manual system is $1.80; this is the cost of one numbered page of approximately 900 characters. With the proposed automated system it would cost 50 to 55 cents to prepare the input for a similar amount of material. While the cost of the output is approximately 15 cents per page, the metal costs 10 cents per page. These amounts add to approximately 80 cents. The difference between this amount and the present cost of the manual operation would then be $1.00 per page—the absolute maximum that could be allowed for the computer cost and still make machine translation economically feasible.

Pursuing this line of thought further, we find that APH produces approximately 120 thousand braille plates per year; it is estimated that this figure will reach 150 thousand plates within the next two years. Since, however, a sizable amount of this work consists of mathematics, music, foreign languages, and other technical publications for which programs have not been written and machine translation may not be practical, it seems reasonable to assume that one-half of the total could be done on the automated system. Then assuming that some 60 to 75 thousand plates could be machine produced at a $1.00 per page, we would have available 60 to 75 thousand dollars as a maximum we could spend for the computer, its maintenance, and its operation annually and still be within the present plate cost.

Personnel to operate the machine would probably cost 7 to 8 thousand dollars a year; maintenance 20 to 25 thousand dollars per year; and an additional 10 thousand dollars will be needed for power and air conditioning. If the installation cost can be written off a saving in plate cost of 20 to 25 thousand dollars a year might be realized. This is equal to a saving of 20 to 25 percent in the cost of the plates made by this process over those made in the conventional manner. It should be emphasized that these are only estimates; however, if these figures are reasonably accurate the use of machine translation could result in a saving.

Looking to the future: additional titles should be translated as early as possible, as there is much to be learned. A great deal was learned from the first 12 titles; we know of course that machine translation can be faster, probably more accurate, and far more flexible than the manual system, but the actual per plate cost and the percentage of the total work load that can be handled in this manner efficiently can only be proven in regular day to day operation.

Since a computer sophisticated enough to handle the project is not now available in the Louisville area, it seems wise to take steps to obtain one for use at APH. There are several colleges in Louisville, including the Speed Engineering School; possibly the computer needs of these schools can be pooled with APH, thereby providing computer time not now available and at a reasonable cost.

Constant development underway in the computer field suggests that machines of this type will continue to become smaller, less costly to purchase, and easier to operate. If we assume that these developments will result in a lower per word cost while the cost of labor continues to spiral upward, the use of the computer becomes more of a necessity than a convenience or a novelty if we are to meet the needs of blind people for adequate reading material.

ENHANCING THE AVAILABILITY OF BRAILLE*

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INTRODUCTION

The striking and woeful unbalance between the availability of printed and written material to the sighted and to the blind has inspired the study, design, and fabrication of systems and devices to enhance the blind person's access to the sighted person's world. The interest of Mechanical Engineering faculty at MIT in the problems of the blind was initiated by the biweekly Sensory Research Discussions originated and chaired since the fall of 1959 by John K. Dupress, Director of Technological Research of the American Foundation for the Blind. Initial investigations were unsupported and conducted entirely within the context of undergraduate laboratory and design project and theses work. Subsequently, a small grant from the American Foundation for the Blind made possible the fabrication of, and experiments with, several research devices. As of January 1961 the project has had formal support from the Office of Vocational Rehabilitation of the Department of Health, Education and Welfare. The contract funds several research and development tasks in the fields of sensory aids and prostheses

* The work reported has been supported primarily by the Office of Vocational Rehabilitation of the U. S. Government Department of Health, Education and Welfare under contract SAV-1004-61. Mr. John K. Dupress, Director of Technological Research, American Foundation for the Blind has inspired and encouraged our efforts, including his sponsorship of a small grant from the Foundation which sustained student work on the early stages of the investigation.

The project is undertaken in the context of our academic laboratory (the Engineering Projects Laboratory) and so benefits directly from the involvement of faculty, graduate, and undergraduate students. Professor D. M. Baumann has supervised the development of the Brailler and Typewriter Accessory assisted by graduate research assistants D. W. Kennedy and G. F. Staack, and undergraduates D. G. Eglinton, S. A. Lichtman, and J. A. Robertson. Professor E. E. Blanco and graduate student K. F. Johansen have participated in the development of the braille transducers, and freshmen A. S. Ivestor and P. J. Siemens have contributed significantly to the type compositor's tape to mechanized braille study.

in the Engineering Projects Laboratory at MIT. This paper is concerned with efforts related to braille.

BRAILLE TRANSLATION AND REPRODUCTION

Braille material is made available to the blind by means of press embossing of those textbooks and periodicals which warrant distribution in excess of several copies. Original braille transcriptions are produced as single copies, on braillewriters (such as the Perkins) and duplicated by recently developed vacuum forming plastic processes. However, it is generally accepted that these facilities for braille reproduction severely restrict the quantity and range of material in braille for the blind. Dedicated private and institutional efforts coupled with government subsidy make possible, through printing presses such as the American Printing House, Howe Press, etc., the reproduction in quantities incredibly small compared to inkprint productions of selected titles of text and recreational reading material. At the single copy braille transcription level, numerous volunteers translate printed material into braille for the benefit of students, professionals, etc. The actual total output of braille material is, of course, restricted first by the production capacity of existing presses, and second by the availability of geographically widely distributed volunteers (154 groups in all) who have the talent and time to prepare individual transcriptions. Efforts are under way to increase the efficiency of the machinery for braille press reproduction. Much could be done to encourage the training of volunteer transcribers and to provide devices which will make more efficient their efforts. The description in this report of the braille encoding typewriter accessory and the high speed brailler are examples of the latter.

In all these cases braille reproduction hinges upon the availability of a sighted reader who has the language and braille training and experience necessary to convert the visual printed letter, word, or page into its corresponding braille symbolism. One can divide the activity of this sighted braille translator into two steps: the visual reading of the inkprint pattern and the intellectual translation of that inkprint into corresponding braille symbols.

These two processes, pattern recognition and translation, are fields subject to extensive investigation quite apart from the problem of blind communication. The vast problem of our ever-growing store of library reference material, particularly in technological areas; the problem it poses of storage, referencing, and access; the problem of making printed symbolic material available directly to data processing equipment for correlation and analysis;

military and commercial problems of identifying particular patterns in a field of view for aircraft control, surveillance, and other reasons—all motivate a broad spectrum of generously funded activity in the pattern recognition or reading machine area. While progress is being made in this field we are still far from the point where a machine is a demonstrated and effective substitute for the human reader.

The second activity of the sighted braille transcriber is that of translation—conversion of the printed ink symbol into its braille counterpart. Goals other than blind communication again justify a substantial investment of time and money in this field. Language translation is an obvious example. The devising of computer programming codes which facilitate either input/output from the computer to its environment, or the manipulation of information inside the computer, are other examples of work in the translation area. Specific efforts are, of course, underway to devise and test the adequacy of computer translation of alphabetical word input to a computer into its corresponding Grade 2 braille.* These efforts illuminate the theorem applicable to all machine translation programs: only where clear unambiguous rules for the translation correspondence (no matter how complicated they may be) can be defined can the machine be expected to carry through the process. The braille translation work under way underscores the need for studies of the present ambiguities in the Grade 2 braille code. This is a separate investigation which has had some beginning scrutiny by the MIT group (3).

TYPE COMPOSITOR TAPE TO MECHANIZED BRAILLE SYSTEM

In the light of the difficulties of mechanizing pattern recognition, it seems appropriate to ask whether in the preparation of braille material it would be possible to circumscribe the need for interpreting and encoding, in machine-interpretable form, the information content of the printed page. Could this step be avoided the first and at present most intractable of the contributions of the sighted braille transcriber could be avoided.

In fact most printed material (which of course circumscribes all that material under any circumstances of interest for translation into braille) is at some time prior to its final inkprint publication encoded in a machine-interpretable form. This development comes about as a consequence of

* As for example the work of Mrs. Schack of IBM in the cooperative program between IBM and the American Printing House for the Blind; also Dr. Abraham Nemeth of the University of Michigan.

advances in the printing industry itself through which virtually all type composition is done automatically; and also as a consequence of the frequent desire to transmit editorial material by means of wire between a point of origin and the point of publication. Thus we have the Teletypesetter wire transmission system, and Linotype, Monotype, and Photon type composition. Each of these is a somewhat different process which poses a somewhat different problem in terms of utilization for blind communication. But all offer the intriguing possibility of capturing the content of the printed page in an encoded form directly digestible for further data processing, rather than reliance upon the sighted reader or waiting for the development of reading machines.

The system to be considered then consists of obtaining the material to be ultimately presented in braille in the form of type compositors' tapes, using these tapes as the input to a centralized data processing system which would edit, translate, and reproduce the information in a form suitable for wide scale distribution through the mails to individual blind persons and to libraries. Recipients would have transducers which would convert the distributed form of the material into the equivalent of embossed braille.

The feasibility of such a scheme depends, of course, upon the kind of material which the blind need and want and its availability in the form of type compositor's tape.

THE READING NEEDS OF THE BLIND

On the question of what the blind want there is unfortunately little in the way of systematically collected, unbiased data, although there are indications that this situation will improve. The blind's access to the printed page includes braille tactile input, aural inputs including "talking books" tape recordings, and listening to sighted readers.

In the way of specific data on the proportional use of these various techniques by the blind, a frequently cited statistic is that while the number of current titles available in both recorded and braille form are about the same (with the aggregate number of titles available in braille substantially larger) according to the records of the Library of Congress, only 3 percent of the 380,000 legally blind population in the United States borrowed a braille book from a library, whereas some 30 percent of the blind population took one or more recordings from a lending source.

The hazard of too literal an interpretation of this data is that first, neither the estimate for braille books nor for recordings represent the total use of either of these techniques by the blind. In the case of braille the figure does not include the vast amount of material made in small quantities for use in the elementary, high school, and college education of the blind as well as for professional activities, and the use by the blind of braille for their own personal notation and correspondence. In the case of recordings similar exclusions are obvious. The second reservation on casual interpretation of these figures is the influence of the type and total amount of material available for use by the blind. In the case of braille books, for example, the total annual production at the present time is something like 160,000 braille page plates per year, which roughly corresponds to half that many inkprint pages. Now a total of 80,000 pages a year represents very few books, implies very few titles, and implies a gross least-common-denominator basis for choosing titles. Beyond this, a typical press run is 28 to 30 copies, which considering the national distribution of the estimated 380,000 legally blind presents an incredible waiting list problem for the popular titles. Similar arguments could be mounted for restrictions on the availability of aural material. Thus, in considering the various means by which the blind can take advantage of existing sensory channels for communications purposes it appears unwise to attempt to draw exclusive recommendations between alternatives. Rather we should attempt to enhance the availability and efficiency of all demonstrably practical modes as well as to explore new alternatives.

The spectrum of blind individuals constitutes a microcosm of the total population. A wide range of ages and vocations, from the elementary school child learning to read, through high school and college training which in turn ranges from fields in which the assimulation of a great deal of straight copy is essential (as in the liberal arts) to fields in which symbolic representations and exceedingly concise presentations dominate as in the physical sciences.

A recent study (2) concerned primarily with blind college students' use of recorded textbooks provides some data on comparative uses of tactile and aural reading aids. Thirty-four percent of the students' queried (91 percent of the 402 blind in college known to be using "Recordings for the Blind") preferred recordings for all their reading; an additional 40 percent preferred recordings for long descriptive nontechnical texts; 91 percent preferred recordings for light reading. But in the very areas where braille texts are scarcest many students said they were desirable: the survey indicated a demand for braille texts in languages, mathematics, and complicated materials. About 60 percent found braille important in reading and learning formulae and the like. These preferences are at least in part due to the fact that a reader's comprehension increases as the amount of active participation in reading increases; thus the braille reader who must follow the text with his fingers finds it easier to comprehend than the passive listener who uses recordings. Also, it is easier for the user of braille to reiterate phrases he fails to grasp on first reading. For grade school children, where integration of blind and sighted children in public schools rather than the blind residential system is becoming more predominant, it is important to have a display of the text corresponding as nearly as possible to the books their sighted peers are reading.

Beyond educational reading needs there is the professional literature, scientific, medical, legal, or otherwise, whose availability to the blind is severely restricted due to the vast and growing amount of material and the small, varied, and unpredictable need of parts of it by individual blind persons. Then there is the wide range of recreational reading, including periodical and full-length books, informational reading including contemporary news media, etc.

The general lack of sociological data on the reading needs for the blind and the scope of the project at MIT has made it impossible to carry out any comprehensive study of these needs. But a study of the available literature, results of conferences (some of them held at MIT) concerning communications with and for the blind, conversations with numerous knowledgeable blind and those concerned with blind rehabilitation, have indicated that at the very least additional braille transcribed information is essential for the educational process from the elementary through the college levels, particularly those stages at which the child is actively learning to read and when the teenager or young adult is studying in a field which involves symbolic and concise notation, including at all levels those learning processes in which active involvement of the learner are essential. A second prime need is the whole field of professional journals which are essentially unavailable to the blind except through services of individual and cooperative volunteers. A third obvious though less numerous need is that of the approximately 3000 deaf-blind for whom the tactile input is the only communication channel.

THE AVAILABILITY OF APPROPRIATE TYPE COMPOSITOR'S TAPES

On the availability of type compositor tapes of material of especial interest to the blind, a partial survey of publishers has revealed that between 40 percent and 65 percent of the elementary school texts published by major houses are printed using either Monotype (the most common equipment) or other tape operated systems such as a modified Linotype. Beyond the elementary level use of Monotype dwindles, since it is a somewhat more expensive process than the widely used Linotype. But the exception to this rule is in the field of mathematics and science, the very area in which braille texts are most needed, texts are printed almost universally in Monotype. In the field of professional journals, those in scientific fields again use Monotype exclusively (one large publisher reported their intention of changing to the Photon method, another tape operated process).

The punched typesetting tape must be made available to the agency sponsoring the transcription into braille. The publishers surveyed uniformily expressed their willingness and ability to make the tapes available and to cooperate concerning copyright restrictions.* Since the tape is only used once in setting up galleys of the printed books and is then discarded there are no intrinsic technical reasons it cannot be used for an input to a transcription system.

An important obstacle to the Monotype-to-braille system is the multiplicity of differences between the printed product and the text contained on the tape. For example, many of the headings that appear in a printed book or magazine are set by hand and inserted into the galleys of text. Illustrations, displays, tables, and other visual aids are inserted later. In the case of braille transcription, these latter pose a special problem, for these displays must be presented in a modified form for the benefit of a blind reader. At present braille texts leave out all illustrations except those essential to the content; for these are substituted either simplified embossed line diagrams or brief descriptive paragraphs. In any case this material must receive special treatment.

Even within the textual material itself the Monotype tape contains many deviations. Errors in the tape are corrected directly in the galleys of type. Often unusual characters or special symbols will not be contained on the Monotype tape; later they are inserted in the galleys of lead. Last-minute changes in content of textbooks may be made by hand without using the Monotype machine. Taken together these differences comprise a very sizeable error. This error must not be carried over into the transcriptions made for the blind, but its correction may require much time and effort.

* Replies were received from Ginn and Company; Scott, Foresman and Company; Laidlaw Brothers; Row, Peterson and Company; and the U. S. Government Printing Office, as well as from the American Mathematical Society and the American Institute of Physics.

The Linotype source represents potential advantages relative to Monotype provided provision is made for the simultaneous generation of a punched tape on those Linotype machines which mechanically compose the tape while providing no permanent record. Wherever Linotype is used for remote or multiple type setting such a tape is prepared. However, in many of the older Linotype machines no such provision is made. Either the utilization of standard Teletypesetter equipment or a typewriter accessory, such as is described later in this report, could be used. The Linotype process has the intrinsic characteristic that since type is cast in a single slug comprising an entire line, errors are more awkward to correct than in a case of Monotype where single letters can be removed and replaced. Thus with Linotype once one has line-length slugs (or the tape equivalent of them) one is assured of the absence of typographical errors. Beyond this the Linotype is frequently used in conjunction with the Teletypesetter process by which means editorial material is set from a point of composition to a remote point of publication. In such cases the tape is a pluperfect edition of the final copy, since all typographical and editorial corrections have been made. Generally speaking Teletypesetter tape represents current periodical news and editorial commentary. While as a general rule most of the blind receive such information through standard radio, the deaf-blind could maintain contact with their contemporary world only were it practically possible to convert these Teletypesetter tapes into their braille equivalent.

MECHANIZED BRAILLE DISPLAYS

Large scale effective utilization of the type compositor's tape to mechanized braille system discussed in the previous section of the report implies the availability of simple, small, rugged, and reliable transducers with which the distributed medium can be interpreted by the blind as embossed braille. Beyond this use such transducers would be very useful in research investigations on variations of braille coding and presentation methods. There are, for example, ambiguities in the present Grade 2 braille code from a human interpretation point of view which suggest study quite aside from possible changes in the code which would facilitate machine interpretation and translation letter-by-letter into Grade 2. Actually the primary consideration of human interpretability is really inseparable from the secondary consideration of machine translation, since the complications and ambiguities in the code which slow down and frustrate the human reader are in many cases the same vicissitudes which make machine interpretation impossible. Thus while respecting both the evolution of contracted braille and the extensive study of it by teachers of and workers with the blind, it is deemed desirable on a research and investigatory level to explore advantages which might be derived from changes in the code or going beyond the present braille and considering quite different modes of presentation. Theoretical studies of such alternatives can postulate possible advantages, but the effectiveness of changes can be demonstrated only after patient, thorough experimentation leads to acceptance by the blind. The existence of mechanized tranducers would greatly facilitate the educational and psychophysical testing essential to the evaluation and acceptance of such variations.

Experiments at the MIT Engineering Projects Laboratory (MIT/EPL) have been carried out thus far on three transduction approaches, all based on punched tape as the information storage distributed or experimental medium. Fortunately the hole spacing on standard punched paper tape corresponds to cell spacing in braille symbolism. Thus the braille symbol to be "embossed" by the transducers can be punched into tape and used directly to position pins with heads shaped like the braille embossing, up to correspond to an active cell or down to indicate the absence of a braille "bump." Figure 1 illustrates the use of hemispherical-head pin elements in this approach. Figure 5 is an instrument using this principle in which the presentation is analogous to a standard page presented a line at a time. The tape feeds from left to right and is advanced one line segment by means of the lever shown. As an alternative, a continuous presentation scheme (see Figure 6) utilizing a belt has also been built. Figure 7 is the original device. A second improved model is just about completed. We plan to experiment with both these devices in order to understand more completely the kinesthetics of the blind person's hand and finger as he reads braille in order to shed some light on how the standard presentation, line by line on a fixed page, compares with the somewhat more passive continuous presentation.

Figure 3 illustrates a second technique for direct mechanical tape to braille output. Small ball bearings are entrained by holes in the tape, in this case a hole corresponding to the presence of a braille bump. An embodiment of this scheme is illustrated in Figures 8 and 9. The motion of the tape strips ball bearings from a hopper. The balls are restrained and the tape is supported (at the equator of the balls) by grooves in a magnetized supporting plate. A receiver and vibrator would return the balls to the supply hopper.

A third scheme which has had some cursory investigation is suggested in Figure 4. A tufted or flocked textile fabric would be arranged so that fibers could extend through the holes in the punched tape, thus providing a tactile stimulation. Samples of a number of textile fabrics have been investigated and additional inquiries as to suitable material, textures, fiber distribution, etc., have been made.

Finally, Figure 2 illustrates the use of air jets as the tactile stimulator.

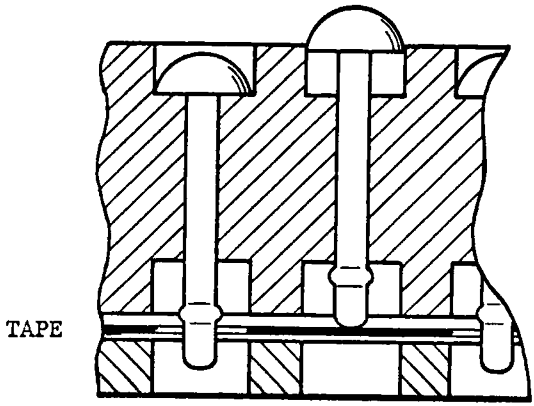

FIGURE 1 Basic Transducer Elements: Hemispherical Head Pin Elements

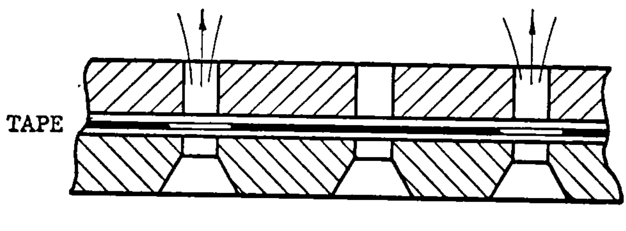

FIGURE 2 Basic Transducer Elements: Compressed Air Jets

FIGURE 3 Basic Transducer Elements: Spherical Elements

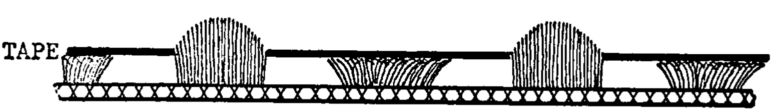

FIGURE 4 Basic Transducer Elements: Tufted Fabric

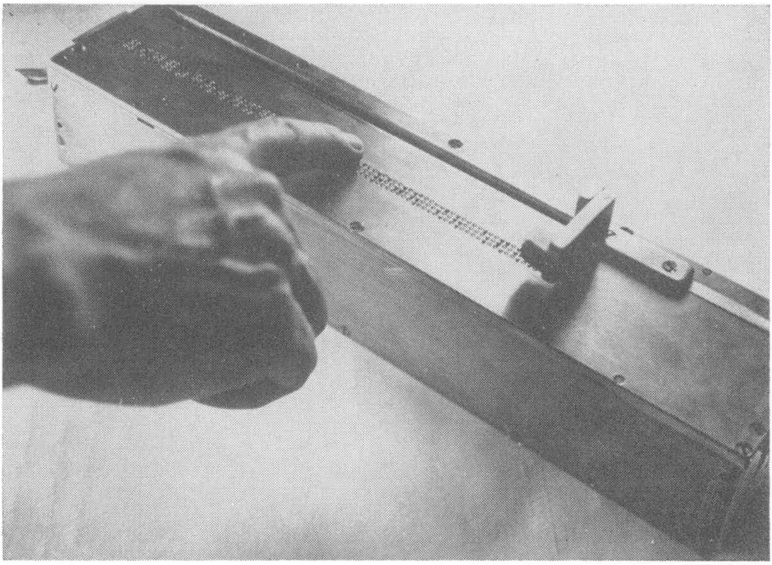

FIGURE 5 Line At a Time, Pin Element Tape to Braille Transducer

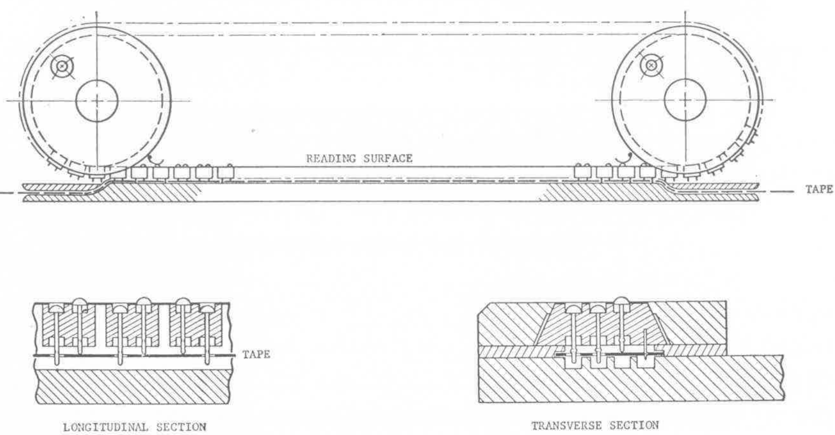

FIGURE 6 Belt Type Continuous Reader

An MIT/EPL Report by Lester Saslow, describes psychophysical research conducted using this stimulation technique (4). In Mr. Saslow's apparatus the air jets were controlled somewhat differently, but the tape could be used directly as a pneumatic valve as indicated. This scheme implies the availability of compressed air, which in turn requires additional machinery and input power and therefore contravenes to some extent our

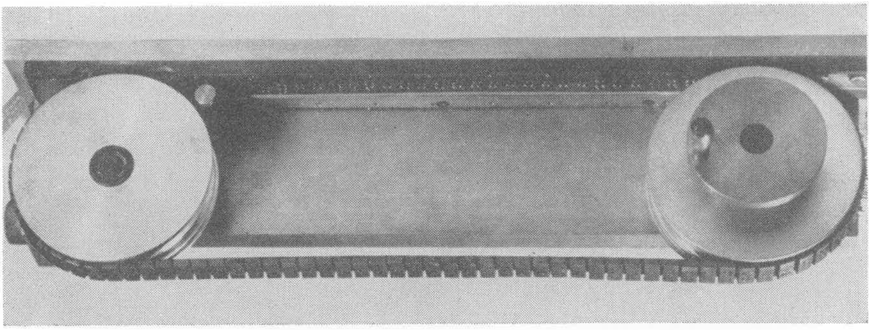

FIGURE 7 Continuous, Pin Element Tape to Braille Transducer

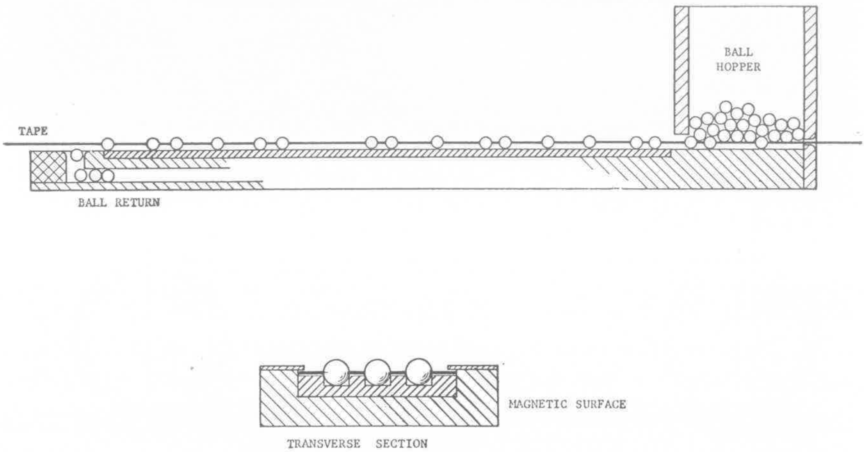

FIGURE 8 Continuous Ball Reader

original design goals of a simple, possibly portable, device. In this same regard it might be appropriate to observe that the IBM Belt Reader (1) in which pins were translated in a thick plastic belt for continuous presentation as braille involved considerable complication and complexity. A tape reader converted punched tape to electrical impulses which were processed and converted by electromagnets into a mechanical motion which, in turn, set up the pins.

HIGH SPEED ELECTRIC BRAILLE AND TYPEWRITER ACCESSORY

A complementary project in the Engineering Projects Laboratory MIT program considers the flow of typewritten correspondence, memoranda,

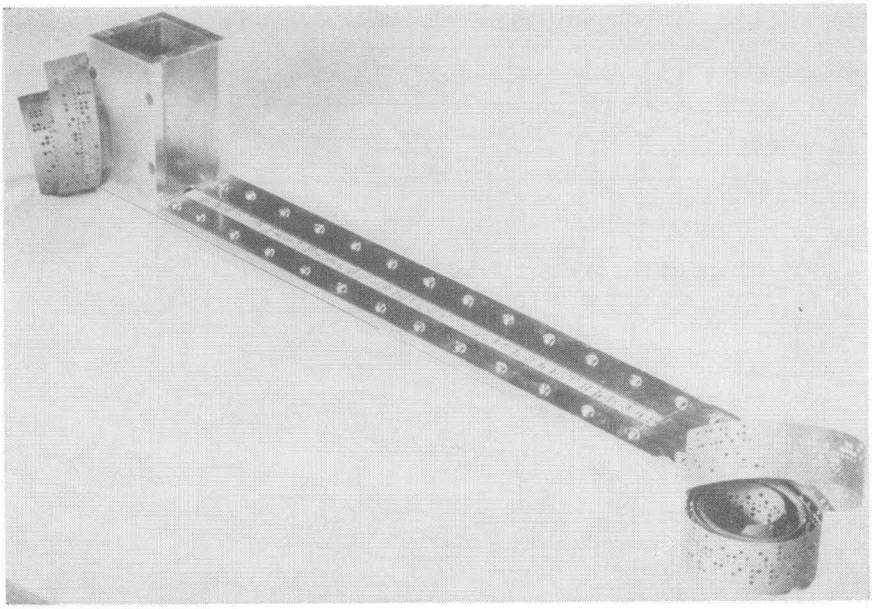

FIGURE 9 Ball Element Tape to Braille Transducer

reports, etc., which constitutes the life's blood of day-to-day office routine, from which the blind individual is either largely excluded, or in a restricted way cued belatedly through the generosity of aural or braille transcribers and the blind individual's persistence. To ameliorate this situation an accessory to any standard or portable typewriter has been designed and constructed which converts each key depression into the generation, simultaneously with the printed figures, of a corresponding encoded and amplified electrical signal.

The typewriter accessory will operate a high speed brailler, which is completely designed and partially fabricated. In order to operate at electric typewriter speed (120 words per minute), to compensate for the almost 2 to 1 line length magnification necessary in going from the typewriter to braille, and to provide for 7 cell combinations (as the "capital letter"), the brailler employs three light weight printing heads arranged in tandem, with the first head completing a braille line as the second head starts the next line (see Figure 10). Solenoid operated transposers (driven directly from the typewriter accessory or any other appropriately coded electrical input) set up the braille character in the heads, whereupon embossing takes place by platen movement. Figure 11 illustrates the

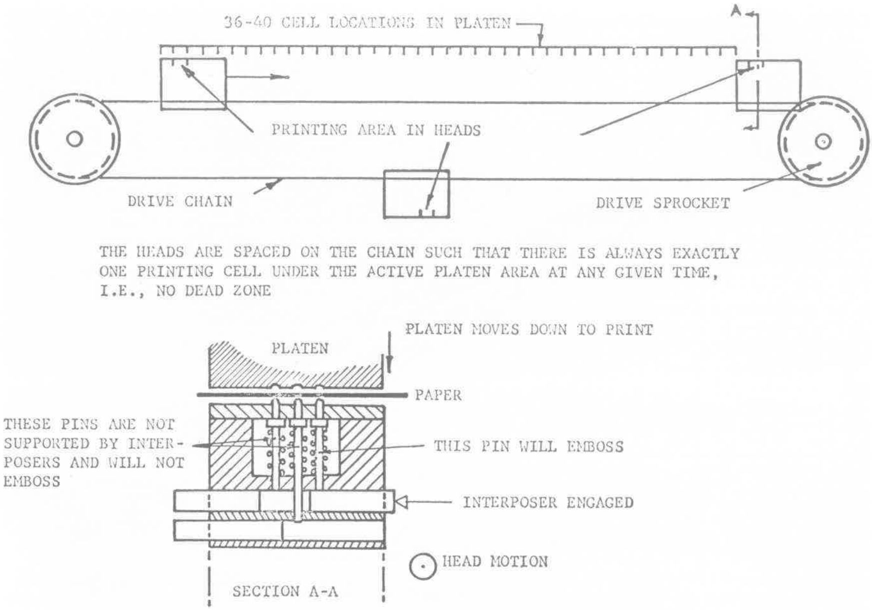

FIGURE 10 Operation of Heads and Transport Mechanism

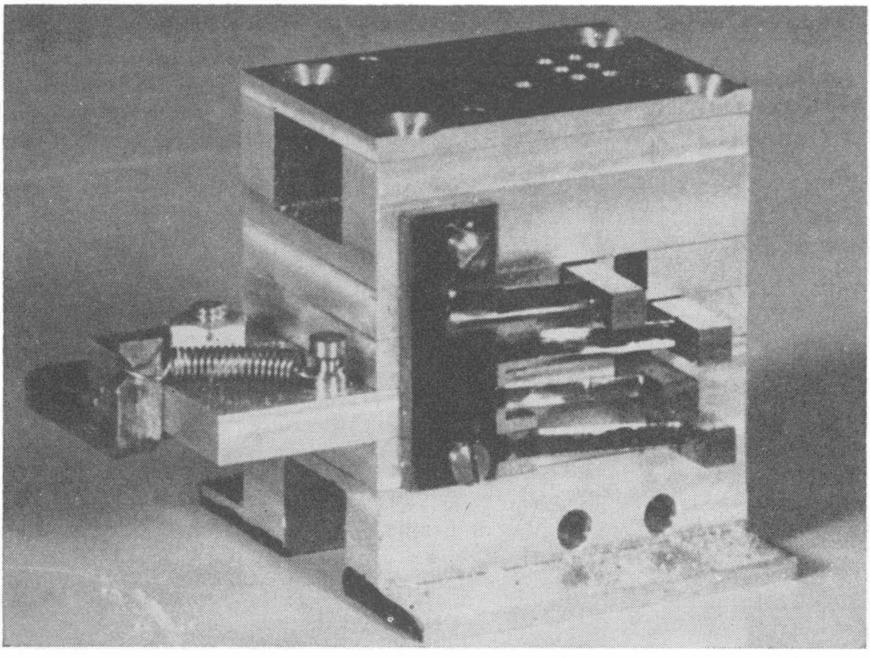

FIGURE 11 MIT Brailler Printing Head

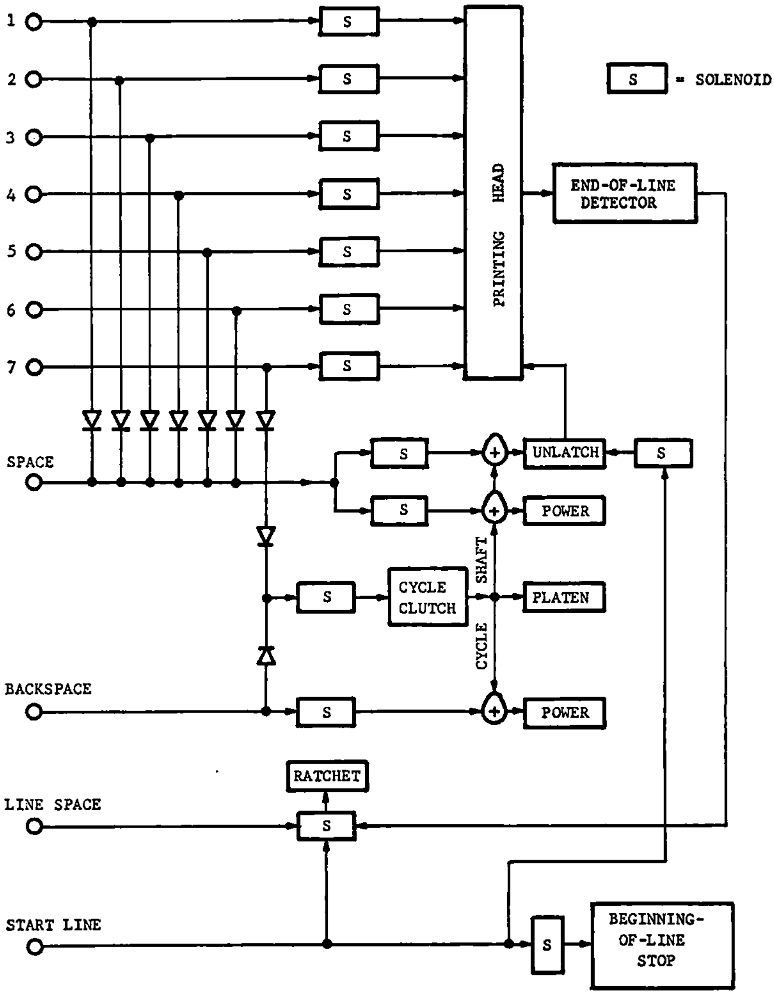

FIGURE 12 Block Diagram of MIT Braille Printer

braille head with the braille "cell" on the top surface indicating size. Figure 12 gives the over-all block diagram of the brailler while Figure 13 shows a partial assembly.

The typewriter accessory (see Figure 14) is mechanical, optical, and electronic, with plastic shutters transposed by key depression so as to obstruct 14 parallel light rays, whose impingement on photodiodes registers the signal. The encoding of the plastic shutters is accomplished by breaking off the appropriate blades on each shutter.

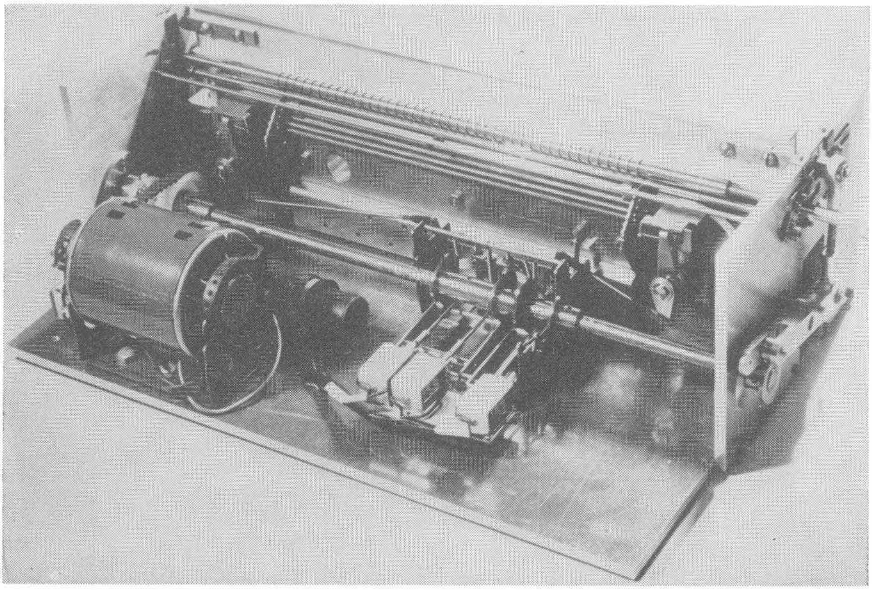

FIGURE 13 MIT Brailler: Partial Assembly

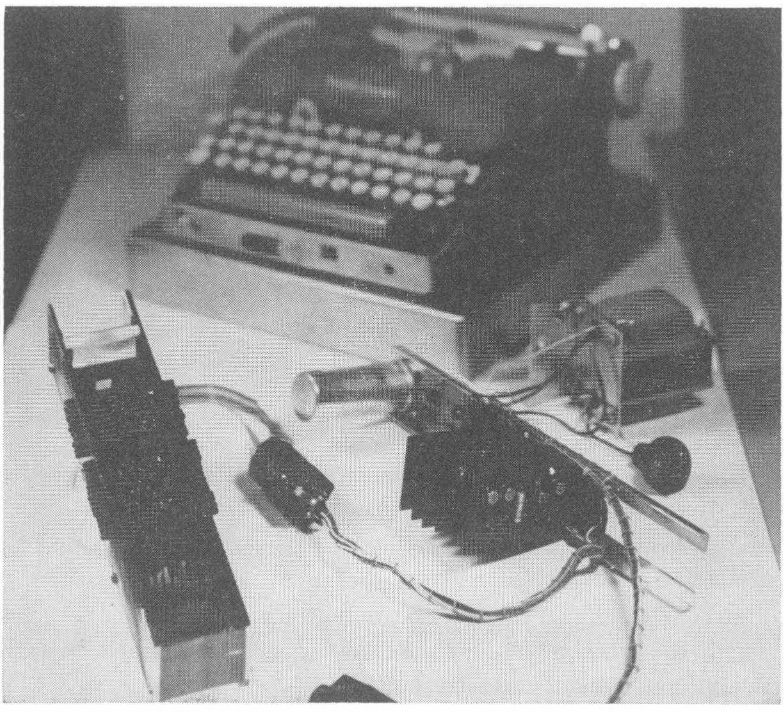

FIGURE 14 MIT Brailler Typewriter Accessory

While designed to augment each other, the typewriter accessory and brailler can also be used independently. Thus the accessory might be used for direct input for wire transmission, or the brailler used with separate key board (both one- and two-hand key boards will be designed), or as a slave to any other signal transmission system.

CONCLUSIONS

Research and development have been directed toward making braille more easily and more widely available. Consideration has been given to the blind person's particular needs for braille (as compared with aural transmission) in the learning process, in professional literature, and for the deaf-blind. The utility and availability of type compositor's tape as a source of braille translation and transcription has been explored. Problems involved in editing tape sources to achieve correspondence with inkprint text have been touched on and require further investigations. Mechanized braille displays for both system output and braille research have been devised. Refined models for psychophysical testing are under construction. A high speed electric brailler which will operate at electric typewriter speed from any of a variety of inputs has been designed and partially fabricated. An accessory for a standard or portable typewriter which simultaneously provides brailler input has been developed.

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