MATHEMATICAL LINGUISTICS — A New Discipline

By A. Craig Reynolds, Jr.

Ladies and gentlemen, it is with the greatest humility that I address you. It is obvious from the Chairman's introduction that I am no linguist, but rather that I have a deep and abiding interest in the problems of communication between human beings, be the differences between them those of separate languages — your problem — or those of separate disciplines, my problem today. This is going to be a severe problem in getting across to the linguists the viewpoint of the physical scientist and the mathematician. I have listened to a great number of the terms of my own field being used in a, to me, somewhat unrecognizable fashion. I am certain that you are going to listen to precisely these same terms and they are also going to appear to be unrecognizable. I hope that at the end of the paper we will be able to clear up any semantic barrier that may exist between us with respect to the words such as : "function, operation, structure," etc.

The advent of large scale computing machines of the digital variety in the past decade has introduced a new problem in communications and, paradoxically, a possible solution to a problem as old as the human race. The new problem contains within itself the elements of the solution of the old problem, namely communication across language barriers — the translation problem. The prospect that thus unfolds has intrigued and stimulated numerous individuals, myself included. Your Chairman has actually participated in a successful experiment that demonstrated that the use of machines for translation — mechanical translation — is not only theoretically possible but practically attainable. The purpose of my talk is to acquaint you with the nature of the problem, the physical realities within which the solution must and can be found, and, I hope, stimulate your interest in participating in the brutal drudgery required to arrive at final answers.

First, let us define digital computing machines and their method of operation. Fundamentally all digital machines are discrete rather than continuous in their steps of operation. They perform their operations in steps of multiples of a basic unit rather than in a continuous fashion. Their fundamental operations, for our purpose today, are only three in number. A digital machine can add two quantities, subtract one quantity from another, and can shift a sequence of symbols from one position to a second position. They are very stupid. They can perform these operations only in the sequences prescribed by the operator or programmer of the machine. Dr. Garvin can bear witness to this. When he wrote down one sentence that he wanted our mutual friend, Pete Sheridan, to place on the IBM-701, Pete would immediately generate some five 8-1/2" x 11" closely written sheets of mathematical symbols that had to be translated into the machine programming sequence.

The manufacturer of the computer may aid the programmer by providing certain sets of sequences built into the machine that will be of assistance in the solution of particular classes of problems, and to date, such sequences have always been directed at the field of the physical sciences and mathematical solutions. They have not been particularly patterned for the problem that we are discussing today, that of mechanical translation. The sequences that were built into the 701 to assist in the solution of arithmetic problems merely got in the way of the programmer when he attempted to use that machine for the totally unforeseen purpose of mechanical translation, the translation, in this case, of Russian into English.

The utility of the sequences provided may determine the selection of a machine to do a job. However, once a job has been defined, the sequences required for its efficient solution can be readily built into a computer. The major challenge confronting an individual desiring to use a computer is the efficient choice of sequences of the fundamental operations required to arrive at a solution. This is the challenge before linguists desiring to use computing machines for translation from one language to another. In other words, what are the sequences the linguist requires for this purpose of utilizing machines for translation? The mathematician does not know, and I am reasonably certain, after the discussions that I have heard in the last two days, that the linguist, at this point, would be hard put to it to define just precisely which sequences would be of assistance to him. The work can, however, be done within the proper framework of analysis.

It is certainly not obvious that all mathematical problems having a numerical solution can be solved by a sequence of the fundamental operations. It merely happens to be true. It must be noted that the truth depends upon the problem being contained within the framework of a deductive logic, i.e., an axiomatic and tautological system, and at this point, I want to acknowledge the groundwork that was laid for me by the three previous speakers on this panel, in completely ripping apart the arguments that can lead to mechanical translation. In this, I find myself in complete opposition to them. Problems of inductive logic are presently beyond the capabilities of computing machines. It might also be noted that these problems are beyond the ability of philosophy or metaphysics to define within a bounded framework at the present time, and I think that this was admirably pointed out in Professor Juilland's talk this morning. Fortunately, the problems of translation from one defined language to a second can be deductive in nature rather than inductive, if poetry and similar communication of an emotional nature is not considered. The utilitarian value of mechanical translation fortunately lies outside the emotional field. I might add the corollary to this: insofar as we propose to use machines for the purpose of translation, the problem of meaning is also completely beyond the purview. We are concerned only with form, structure, and operations. These are the defining framework within which mechanical translation is possible. Recent investigations into the operation of the nervous system also clearly indicate that sequences of the fundamental operations defined for the computer are adequate descriptions of the operation of the autonomous nervous system. I have participated in putting experiments defining the problems of neural physiology on a computor on which we actually set up neural patterns to see if a learning process could take place. The answer is "yes". Since this is so, we do have a description, possibly not the correct description. This is a metaphysical argument as to correctness. The fact is that we have a *modus operandi.* Programs we could put on the machine showed that the three fundamental operations were all that were required to make a neural map exhibit a learning pattern. Now an efficient multi-lingual person has incorporated the processes of translation into the autonomous nervous system in such fashion that translation amongst the languages in which he has expert knowledge becomes completely automatic, and I might add that one of the finest examples of this was the simultaneous translation system that was set up at Nuremberg and the United Nations, demonstrating the fact that these sequences can become automatic. The operations of the translator's mind in accomplishing the translation can therefore be described in terms of the elemental operations of a computer. That this has not been done to date in no way detracts from the fact that it can be done.

The question that naturally arises at this point is whether or not an adequate analysis and symbolism exists to cover the diverse fields of mathematical solutions, operations of the nervous system, and translation from one language to another. The answer fortunately is "Yes". The required basis is found in the discipline known as mathematical logic. The founder of the analysis was George Boole, a mathematician of the nineteenth century. His work has had an enduring and fruitful effect on not only mathematics but also philosophy and metamathematics. His writings are still amongst the best for an introduction to the subject. It can be correctly stated that without his work no large scale computer would exist today in its present form, nor would computational procedures exist in their present form today, nor physical analysis.

The exploitation and extension of the work of Boole has led to the present existence of the school of mathematical logic. It has also led to a new philosophy of the organization of the nervous system. It is basic to an understanding of mathematical processes. It underlies the operation of modern computers. It can be shown to be the foundation upon which the successful demonstrations of machine translation in the past few years have been built, not only in this country, but also in Europe and in Russia.

It is my thesis that a new and fruitful wedding can be made between the disciplines of mathematical logic and linguistics. The economic need for mechanical translation can be demonstrated in all the various branches of science. The military need is obvious to all. The solution lies in the joint effort of the linguist and the mathematical logician to exploit our present mechanical knowledge to the fullest. The contribution to humanity can be immense. Can our respective disciplines be so married?

My answer is that they can. I sincerely hope that they shall be.

BIBLIOGRAPHY

Mechanical Translation—
Vol. 1, #1, 2, 3, Vol. 2, #1.
Massachusetts Institute of Technology,
Cambridge, Massachusetts, 1954–55.

Machine Translation of Language—
Locke, W. N. and Booth, A. D.,
John Wiley & Sons,
New York, New York, 1955.

Communication Theory—
Jackson W.,
Academic Press, Inc.,
New York, 1953.

The Logical Syntax of Languages—
Carnap, R.,
Humanities Press, Inc.,
New York, New York, 1951.

High Speed Computing Devices—
Engineering Research Associates,
McGraw-Hill Book Co. Inc.,
New York, New York, 1950.

Introduction to Mathematical Thought—
Stabler, E. R.,
Addison-Wesley Publishing Co.,
Cambridge, Massachusetts, 1953.

Laws of Thought—
Boole, G.,
Dover Publications, Inc.,
New York, New York, 1953.

DISCUSSION

A. C. REYNOLDS: I should like to make a correction in regard to *Biametrika;* the correct dates are 1951 and 1954.

ROBERT P. STOCKWELL: Can the speaker expound briefly this model of the nervous system which showed the machine having accomplished an act of learning? Is it too complicated to discuss at this point?

A. C. REYNOLDS: Unfortunately I'd have to go into the theory of binary arithmetic, mathematical logic, and then show how the neural nets were constructed. It is complicated. In this particular case we were presenting to the machine a sequence of letters which preferentially we wanted it to learn on a statistical basis, from numbers of presentations to respond only when the letter "F" or the letter "H" was presented to the machine, a very simple learning problem.

EDMUND S. GLENN: Here again we are in a field where there has been much needless controversy, often because our purposes were not always defined. "Translation" is a word with many different meanings, and some of the controversies were due to the fact that some people were using this word with one meaning, and others were using it with a different meaning. In the experiments which were quite successful, we dealt with scientific texts which were rather restrictive in their cultural import, the restriction being that the men uttering the original and the men receiving the translation may not have spoken the same language in the linguistic sense, but they were speaking the same language in the scientific sense. Where you deal with such questions as statements of an extremely general nature involving differences in language, say from Russian to English, differences in culture, as from Russian to some type of Anglo-Saxon culture, in addition to differences of field, then you have some complex practical problems. The fact that we can, practically, in the near future, make scientific translations should not let us forget that in the latter case, the difficulties may be compounded.

PAUL L. GARVIN: I think one of the very important functions of research in machine translation in relation to linguistics is that machine translation is one of those outside criteria by means of which you can measure the preferability of one solution over another, because — and I'm partly speaking from experience and partly from inferring theoretical possibilities — it seems to me that it may become quite obvious that of two solutions, one is more readily transposable into mathematical logic and computer operations than another.

A. C. REYNOLDS: I would like to add that the machine can be a tremendous tool to the linguist. There were several statements made yesterday with respect to a complete analysis of the English language. I assume that the audience here is not familiar with the recent experiment that was performed on the Sperry-Rand Univac. For centuries, scholars have struggled with the problem of constructing a complete and encyclopaedic concordance of the Bible. That this goal was never attained was purely due to finite limitations on the human brain and the ability of the human animal to keep working for too many years, actually. Such a concordance was deemed desirable by the publishers of the Bible in this country and the King James version was placed completely on tapes. As a result of the fundamental operations available to the machine, a complete concordance excluding only such words as: "the," "a," "and," some fourteen common words, has been attained with the printed output from the machine tabulating the word, the phrase in which it appears, over the entire length of the phrase, enclosed within the particular punctuation marks selected, the book, chapter, and verse. For the first time, such a complete concordance is available. What does this mean so far as the linguist is concerned? If one is concerned with statistical distribution of phrases, of lexical units if I use the term correctly, this is the fashion in which it can be accomplished. The important thing is that the program is already constructed. It makes no difference now the program is constructed whether you want to tabulate this on the level of *The New York Times, The Daily Mirror, The Washington Post,* whether you take a translation of *Buddenbrooks,* for example, and find out what the occurrence is, in a literary translation from German into English. The program exists and insofar as one wishes to utilize it, one can conduct these very studies that were discussed yesterday and appear to be a pressing need for the English language. This is also of extreme importance for translation, because the machine is indifferent to the language which is put into it; it will correlate any set of symbols in the fashion prescribed according to that program. We now have the tool for analysis of distributions of words and phrases and the types of phrases in which they appear, all available for use in mechanical translation.

L. E. DOSTERT: The word just used by Mr. Reynolds, "correlation" is a flash of light on the whole problem, because really the only reason we think "translation" is that we are lingual, so to speak. The machine is not, so that all you have to do, really, in translation, is to achieve a correlation of symbols, and that makes a very significant difference in respect to the problem of meaning.

RALPH D. WINTER: I'm sure there are a lot of things you'll never be able to translate by machine, but it occurs to me that the kind of thing you can't translate by machine, say poetry, and things highly charged with political or emotional overtones, are almost always the things with which the ordinary human translators also have great difficulty. Even to transpose the Good Samaritan parable into modern English might mean to construct an entirely different story. Of course the machine couldn't easily be taught to do this, but neither can a human being.

A. C. REYNOLDS: This question has arisen many times with both linguists and engineers. One can go back to one's school days when Latin was studied and take the pony for the *Aeneid,* with one page in Latin and the direct translation on the following page. Yet from those direct translations transposed into another cultural context have come some quite beautiful but widely divergent interpretations of the *Aeneid.* The interpretation still lies with the human being. What we propose to give in mechanical translation is raw material from which the human being can derive the necessary semantic inferences and use the necessary connotations, references to the culture, and thus tie it into something he understands now. The machine will never be able to do this; we will never be able to put cultural context into a machine.

ROBERT L. LADO: You use the term "learning" for the machine, and of course the word "learning" is common stock and I wonder what you mean by it in relation to the choice between "F" and "H". By "learning" I seem to understand that the subject reacts in such a way that he now does something else without my turning any particular screw in his head by giving him experience. I can't quite interpret this in terms of the machine.

A. C. REYNOLDS: I was hoping someone would ask this question. Actually, on a very high level of abstraction, the learning of a second language, is a question of learning, securing, putting into the nervous system, a new pattern. What we were trying to show was that in symbols which the machine could recognize through its sensing organs, it would learn to follow and respond favorably to a given pattern. We were testing a theory of synoptic connotations in the neural system. Insofar as on that level of abstraction we could talk about pattern recognition as being fundamental to the learning process, in this sense only, I use the word "learning" in connection with the machine. It's of interest, however, that in the paper yesterday of Professor Choseed, his entire paper could have been translated across the disciplines of linguistics into mathematics, in terms of "built-in sequences," "memory storage," "speed of recall," that is, "random access," a basic problem in machine operation, "shift operation," meaning the reconstruction of syntax which necessarily takes place in translating, and repetition. This last gives a difference in the efficiency of operation insofar as the more repetitive the material, the more firmly it is grasped, and the more automatic is the response to the material.

ROBERT L. ALLEN: Shannon and others have developed mechanical rats which can find their way through a maze by trial and error, and afterwards remember the way through. Is that the same principle at all?

A. C. REYNOLDS: This is not the same principle. The Shannon mouse experiment has clouded many discussions of the learning process. I won't go into the details of that; essentially, your description of the operation is correct, but to call it a learning process is totally incorrect. There is a machine, however, that does have another learning process that the Bell Telephone Laboratory has constructed. It's a very simple and stupid game, but the machine hasn't been beaten yet. It's the old game of flipping coins. You flip a coin and press a button to tell the machine this was a head. Or you just put in a set of sequences of heads or tails. The machine is built according to the mathematical discipline known as the "theory of games." It can learn sequences, and after the first few tries, it starts predicting what you are going to do. Its percentage is 60% for the machine and 40% against anyone who cares to play with it. The Bell Laboratory states that this is probably a weighted sample, because people who are consistently beaten by the machine won't go back any more.

L. E. DOSTERT: I would like to comment on something said by Mr. Winter a moment ago. I think his statement is highly subjective and characteristic of the way we react to so-called "poetic language." We think that it is more difficult to translate a line of poetry than a line of prose because we are thinking of its evocative significance to us. In other words, the machine is not reacting to poetry; it is only reacting to symbols. The poetry is what the human being, when struck with the symbol, responds with, so to speak; the poetry is not innate in the symbol. It is an interaction between the symbol and the human being. This, the machine obviously cannot translate. On the basis of the syntactic rules that were formulated for Russian, I have, as an experiment, tried to translate several lines from Milton's sonnet on his blindness, and I can assure you that what comes out is every bit as poetic — that is, to one who knows French and responds to the French symbol, as to one who responds to the English symbols of the original. So what the machine will never be able to do is to put poetry in the symbols, but it can certainly handle and manipulate the symbols.

DAVID A. REIBEL: I think I read about this in *Publisher's Weekly.* It was about the Revised Standard Version of the Bible, and the important thing was that they got not only the concordance but a printable text out of the machine. It could then be photographed and reproduced without any more editing and took some small amount of time like twenty-eight hours. This is useful for linguistics, but how much do they get per hour to use in the machine?

A. C. REYNOLDS: Let me rephrase that question. We computor engineers secured this concordance in some fourteen hours of running time on the machine, and some six months of key-punch operation of the programmers' time. The cost of a programmer can run between $400 and $600 per month. There were some ten or twelve people involved in the programming and the key-punch operation. The running time on the IBM machine cost $300 per hour. To have a set of biblical scholars repeat this process would be comparable in length of time to the length of time it took to produce the Revised American Standard Edition, and it would require a subsidy far in excess, by factors of many tens, of the total cost of the programming and the running time on the machine. The economics are all in favor of the machine. Do not be misled by the cost per hour; it is the quantity that comes out per hour that is the basic criterion. With the machine, the cost per word per hour was fractions of a mill as against whole pennies in any other process.

JACOB ORNSTEIN (Washington, D. C.): In reference to some remarks by Mr. Householder and Mr. Reynolds, I'm still obsessed by the cost of these things. The Josselson word list was done at Wayne in three years by a large staff with a Rockefeller grant. Who will finance these things?

A. C. REYNOLDS: Warren Weaver of the Rockefeller Foundation has been behind mechanical translation almost since its inception as an organized effort. The Foundations are interested in scholars who know how to use these machines. If the scholar is sufficiently intrigued by the prospect of solving his problems, he can get the money. He can also get his work done while he's still young enough to enjoy the results of it!

JACOB ORNSTEIN: Since most of this is now done by government subsidy, to what extent do you think private industry is prepared to back work of this sort?

A. C. REYNOLDS: As far as the chemical and petroleum industries are concerned, were it not for the scarcity of large scale computors, the necessity of adopting them to their everyday operations, and the military demands on them for the use of the machines to solve urgent problems in the nuclear field, private industry would be behind this. I have talked to enough industrialists to know this.

ROBERT L. LADO: Private industry has shown enough interest in a similar study of Cervantes, a concordance, to offer the use of the machines at no cost to a member of our staff at Michigan, and plans are going forward to see if that can be done.

A. C. REYNOLDS: A democracy sometimes works a lot more slowly. In the Russian press and journals recently there have been descriptions of their attempts at machine translation. They can put all the money they want into it.