

A Revised Design for an Understanding Machine*

by Ross Quillian, Research Laboratory of Electronics, Massachusetts Institute of Technology

This paper argues that machine translation programs will be able to solve certain problems, e.g., the resolution of polysemy, only by storing the meaning of natural language words in a medium and a format providing properties similar to those of human "understanding". It also maintains that all human meaning may be exhaustively represented in terms of readings on a practically infinite number of calibrated standards, or, alternatively, by elaborate constellations of readings on a very small number of "element" standards. It is proposed that representing the meanings of natural language words in terms of such constellations is to represent them in a medium appropriate to serve as a mechanical equivalent of human understanding, at least for the purposes of mechanical translation. Such representation of meaning would also permit the overall body of semantic information to be stratified in accord with the dimensional complexity of concepts. This would allow encyclopedic amounts of information about the meaning of each natural language word to be stored in memory for use when a decision dependent on "understanding" arose, while at the same time only very brief summational symbols of this information would ordinarily be adequate as a translation interlingua. Several general characteristics of such representation and storage of semantic information, and some of the standards possibly usable as element standards, are described.

1. The Nature of Semantic Understanding, and Its Indispensability in Machine Translation

This paper will attempt to outline a way of representing any given unit of semantic content in a form which would maintain an invariance during combination. This is not generally the case for the representation of meaning in natural languages, but would appear to be the case for the way meaning is represented in what we call human "understanding" of language. For example, while there is essentially nothing of the English symbol, "death", left in the English symbol, "murder", every English speaker can tell us that the concept represented by the first word is a part, but not all, of the concept represented by the second word. Thus a representation of the meaning of natural language words in a form manifesting such invariance would in at least one aspect be equivalent to an understanding of them.

Moreover, it is proposed that any fully automatic, high quality translation program¹ is going to have to

use some such representation of meaning in an interlingua-like manner, because effective translation from one natural language directly into another, without utilizing an understanding of the meaning being dealt with, involves virtually insurmountable difficulties. I maintain that human translators do not translate "directly", and that really good mechanical ones cannot hope to either. To see one reason for saying this we shall for the remainder of this section look at the problem of polysemy, or the fact that most natural language words have more than one meaning, between which any translating mechanism must constantly decide.

The resolution of a polysemantic ambiguity, by whatever method of translation, ultimately consists of exploiting *clues* in the words, sentences or paragraphs of text that surround the polysemantic word, clues which make certain of its alternate meanings impossible, and, generally, leave only one of its meanings appropriate for that particular context. The location and arrangement in which we find such clues is itself a clue, or rather a set of clues, which we may call syntactic clues. The direct language₁-to-language₂ approaches to mechanical translation are able, to a greater or lesser degree, to exploit clues which either are grammatical, or else are the result of established idiomatic phrases in the text. By reacting differently to where such clues are found, direct approaches can also exploit their locations or syntax. However, such approaches are not in general able to utilize semantic clues, and this, I maintain, is due to a restriction

* This paper is a revision of a paper originally submitted to the University of Chicago in partial completion of the requirements for a Master's degree in communications. A summary of an earlier version was presented at a colloquium, "Semantic Problems in Language", held at Cambridge University, September 9 and 10, 1961, under the auspices of the Cambridge Language Research Unit. Work on the present version was supported in part by the National Science Foundation, and in part by the U.S. Army Signal Corps, the Air Force Office of Scientific Research, and the Office of Naval Research. The author wishes to thank all those who have offered helpful comments and aid, especially Drs. Jeanne Watson Eisenstadt, Hans Mauksch, Edward Stankiewicz, Victor Yngve, and Carol Bosche.

¹ Bar-Hillel, Yehoshua, "The Present Status of Automatic Translation of Languages," in Alt, F.L., *Advances in Computers*, Academic Press, New York (1960), pg. 94.

inherent in the direct method itself.

For example, suppose we want to program the machine to choose whether the word “bank” refers to the kind of bank within which rivers flow, or to the kind in which money is kept. (For simplicity, let us pretend that “bank” has only these two meanings.) We note that if any one or more of the following words occurs in the text surrounding the occurrence of “bank” it will contain information useful in resolving the polysemy: account, bankruptcy, fee, buy, currency, check, dollar, spend, bribery, profit, sell, salary, expenditures, paid, income, savings, interest, loan, etc. Since these words contain no common element in either their spelling or in the way they will be placed in a sentence, it is hard to imagine how, as long as we work directly with the words themselves, we can ever program a computer to utilize the clues they contain for resolving the polysemy of “bank”. However, the words do contain a common element, namely some reference to money, but this is clearly and solely a part of their semantic content, or meaning. Any English speaking human, upon encountering a sentence containing both “bank” and one or more of these clue words, will use the clue word’s semantic content, if necessary, to help resolve the meaning of “bank”. It is in fact no trick at all to construct sentences in which there is no other imaginable way to resolve the polysemy, simply because there is no other clue available, e.g., “He got a loan from the bank,” “The interest is lower at the bank,” and so on. Giving a computer the ability to resolve polysemy, then, would seem to depend on finding some way of allowing it to utilize such elements as “a reference to money” or, more generally, of making the meaning of words accessible and manageable. How might this be accomplished?

Imagine we had a medium in terms of which we could represent any conceivable human concept. Thus, for example, we could represent the meaning of each of the possible clue words listed above as expressions in our medium. Moreover, imagine that this medium had the further property that any given piece of meaning which was represented in it, would always be expressed in a partly invariant form, no matter what it happened to be in combination with at the time. This is the situation with chemical notation, where carbon, for example, is always represented in a chemical formula by the symbol “C”, no matter what the compound is which the formula refers to. In our case, invariance would mean that, in the representations of the meanings of each of the clue words, their common reference to money would always appear in a partly constant form, no matter what *other* meaning it accompanied. If we did have such a medium, we could build a complete automatic dictionary relating the words of English to representations of their various meanings.

Then the first step in the translation of an English

sentence: into some other natural language would be a straightforward “word to concept” type translation of each word of the sentence into the stored representations of its various meanings. This would leave us, in the case of a sentence containing, say, our word “bank” but no other polysemantic words, with two representations in place of “bank”, and one in place of each other word. From there the machine would be programmed to utilize clues in the words surrounding “bank” which might be helpful for deciding which of that word’s two meanings was appropriate in this case. In programming the machine to do this now, however, the programmer would be in a far stronger position than he was in trying to work directly with natural language words. For, if he could imagine any semantic clues which would be helpful to resolve the polysemy, he would now be able to program the computer to search for and utilize these. Thus, in our example, a reference to money is one such semantic clue, and one which, should it appear in the sentence, could be exploited no matter what word it occurred in, whether one of those on our list or not. The clue might of course appear and yet not be the deciding factor, but this is a question of considering other clues as well, and only strengthens the point we are making.

In practice we will also want to make our semantic representations show any useful grammatical or syntactical clues the original text had, and often it will be most fruitful to exploit some combination of grammatical, syntactical and semantic clues. The point is not that having a semantic medium would in itself resolve polysemy, but only that it would make a solution possible, by giving us access to a whole range of relevant clues which we did not have access to before. Surely any problem can only become simpler if we vastly increase the number of clues available to choose from in solving it.

This seems to me a crucial advantage over those other approaches to mechanical translation which, lacking any manageable representation of meaning, have to proceed as though the only clues that are useful in resolving polysemantic ambiguities are those in grammatical features and their locations, or else in established idiomatic phrases. That human beings do not so limit themselves, but also utilize semantic clues extensively, would appear obvious from the fact that people are able to understand language that is full of grammatical and syntactical errors.

Thus I conclude that having a way of representing concepts which would provide the two properties specified would be of value to mechanical translation, and shall devote most of this paper to specifying how such representation might be achieved. During the following presentation we shall frequently notice the close functional similarity between the representation and storage of information to be outlined and human understanding, and that, therefore, a computer utilizing such information would seem to be best viewed

as one simulating the human understanding process: an understanding machine.

2. A Definition of Human Meaning

One prerequisite to storing meaning as specified above is having a definition of human meaning which will satisfy our intuitive understanding of just what this nebulous phenomenon is. Obtaining such a definition will occupy us during this section. Let us approach the problem by considering first the *totality* of information on the basis of which a person acts at any particular moment, including both the information which he is consciously aware of having, and that which he has but is in greater or lesser degree not conscious of having. We shall think of this information as flowing into whatever center or centers there may be in the person which direct his action. It flows in from exteroceptors connected to the outside world, from interoceptors and proprioceptors describing conditions within his body, and also from his "memory". The information from "memory" provides him with such notions as that of a constant, expanded space, in which objects are located. It continuously enlarges his perceptual world to include some "knowledge" of things which he is not actually sensing at the moment. At any one instant these several flows of information combine to produce a broad, rushing stream of input to what for convenience we will simply call the person's "action direction center".

Now some of this information input—if not all of it—becomes transformed into "meaningful" information before or as it reaches the person's action direction center. We may ask: What is the nature of the transformation it undergoes in so changing from raw sensory input into meaningful information?

It has already been realized by at least some writers² that the operation which is performed on a bit of sensory input as it becomes meaningful perception is one of its being *related* to other information. This process of "becoming related" to other information seems to me to be usefully viewed as two simultaneously occurring processes. First, the bit of information may be said to be *combined with* other information which is flowing in at approximately the same time, thus creating the celebrated "gestalt" of perception. Secondly, the information formed into such gestalts can be considered to be *compared to* yet other information which in general is not part of that flowing into the action direction center at that moment.

To illustrate the way meaning can be viewed as obtained by this second process, comparison, let us imagine a subject scanning down a list of random numbers, counting all the sevens he finds. In other words he consciously or sub-consciously gets, from time to time, a meaning we may express as "here's a seven" and increments his count by one. Such recogni-

tion becomes understandable if we say that the subject's receiving the above meaning depends upon his comparing the visual sensory data he gets from looking at the list to a pattern represented in his head, a pattern somehow resembling the sensory data he has when he actually views a seven. If his incoming sensory data matches this standard within a certain tolerance, he perceives the meaning stated above; if not, he passes on. (Actually his standard needs to be invariant under changes such as differing angles of view, but this needn't concern us.)

Now suppose the list of numbers happens also to be handwritten, and that our subject has written some but not all of the numbers himself. As he scans the list he also picks up some half-awareness of which numbers are in his own handwriting and which are not. This element of meaning too, clearly may be seen as depending on his comparing the incoming sensory data to a complex set of patterns he has of his own handwriting, and then responding one way to good enough matches, and another way to those not good enough.

We can go on adding bits of information contained in the list of numbers—e.g., they may be written in different colors, or with different type pens, or they may fall into certain sequences, and *for each element of information added, the question of a subject getting meaning or not getting meaning is totally resolvable into whether or not he performs some appropriate comparing process.*

Let us focus on the fact that each such comparing process is dependent on the possession by the subject of a *mental standard* in order for him to have something to compare his sensory input *to*. Conversely, a subject who has never seen my handwriting simply does not have the standards which are necessary to identify it from among others, and hence cannot perceive this particular meaning.

The point of the italicized sentence above is one on which our entire case rests, so let me give more examples. Imagine a subject who looks at a painting, and recognizes it as a Van Gogh. The point I am making is that we can now say: the way in which this subject got this meaning from this stimulus was by comparing his sensory input from it against a vague mental standard which in some way represented the subject's impression of Van Gogh paintings. The subject will also know various other things about the picture, for example that it was rectangular—and again, we can say that the way he perceived this was by comparing it to some kind of mental standard he has of rectangles, without which he couldn't have perceived that unit of meaning. Suppose the subject also knows the picture contained the color orange—we can say that he can only know this by virtue of having some kind of standard for orange in his head.

I think a little reflection should convince the reader that *no matter what* meaning we imagine *any* subject

² Boring, E. G., *The Physical Dimensions of Consciousness*, Century Company, New York (1933), pp. 222-229.

to perceive in any situation, we can always view that meaning as based on his comparing his sensory input against appropriate mental standards. The fact that such a view of meaning may be highly artificial and in fact useless for many problems, such as those considered in neuro-perceptual research, does not mean that it may not be the appropriate approach for our particular problem. For the moment all that is proposed is that any meaning *can* be viewed as acquired by some comparison process. It doesn't matter whether the sensory input comes directly from the stimulus, or whether it comes from associations which the subject himself produces. For example, suppose the picture above vaguely reminds the subject of a farm on which he grew up—we can still maintain that the neural activation (produced by his memory) which contains this information would be simply meaningless noise to him unless he had some kind of mental standard representing some aspect of the farm on which he grew up to compare it to. Nor does the subject's awareness or lack of awareness of having any particular meaning have anything to do with our ability to say, as regards its meaning, that this can be viewed as dependent on his comparing neural input to an appropriate mental standard.

The objection has been raised that some stimuli simply activate certain sensitive receptors, just as a tuning fork is set in motion by sound of a certain pitch, and that people probably obtain some meaning in an analogous, "direct" way. But, even this case is describable as the tuning fork comparing each sound striking it to a standard sound it has represented, and responding differently to these stimuli in accord with how closely they match this standard.

From all the above, I conclude, again, simply that some comparing process may be said to occur whenever something in any sense becomes meaningful to anyone. The first implication of this which I want to consider is that if we could describe all the mental standards which it is possible for anyone to have, we would have at least a start toward describing all the meaning possible for him. The obvious practical objection to such an approach (and the reason its value is very limited in mechanical pattern recognition) is that, since we have been allowing the mental standards to be defined ad hoc as needed, there is a practically infinite number of them, one for each of the different units of meaning people may have. We shall deal with this objection soon, but first let us make our notion of these standards more precise.

To do this it will be helpful to notice that comparing something to some standard is the general case of what we ordinarily call measurement. Since we are most familiar with the special case of scientific measurement, where the standard used is external and relatively constant, looking at that case will facilitate our understanding of measurement in which the standard used is a purely subjective, relatively non-

constant one. For example, in scientific measurement, if all that we discriminate when we compare some data to some standard is that the data either matches the standard adequately or does not, we say we have only a dichotomous scale. If, however, our discriminations are made more precise, then we come to discriminate between different degrees of divergence from the standard, noting that some just miss matching it, while others fail by differing degrees. We then often standardize these degrees of divergence and at some point assign a zero point and numbers to them. As refinements are made we say we have created rank ordered, interval, and ratio scales, and we speak of numerical measurement. The difference, therefore, between a scientist's assigning something a quality "intuitively" by observation, and measuring it quantitatively, is not a difference in the *kind* of operation he performs, but only a difference in whether the standard he uses is internal or external, and in how precisely he considers it calibrated. Clearly the same may be said of all meaning formation.

This all sounds rather simple, but the literature on perception still seems full of statements which assume that the assignment of discrete "qualities" to a perceived object is some mysterious operation, which only people can perform, that is not to be in any way associated with quantification. Let us understand clearly that precisely the same kind of operation is involved when, for example, we note that the temperature of the water in a pool is "68 degrees", as is involved in our noting that the stroke of a man swimming in it is "awkward". These judgments may *to an equal degree* be considered the result of comparing observations to a standard. The fact that in the first case the standard is a much more constant one than in the second does not alter the process by which meaning is gained.

Measurement, therefore, we may take to be in its broadest sense the correct term for all comparing, and, in accord with our previous conclusion that all perception of meaning is dependent on comparison, we may now state that all possible human meaning depends on certain measurements having been made (or, if not actually made, simulated) by humans. In fact, for the purpose of arriving at a definition of meaning, we can concentrate exclusively on the measurements themselves, and forget about the material which is measured, because in this case the material measured is by definition raw neural input before it becomes meaningful by being compared to something else, i.e., neural input totally unrelated to our understanding of colors or tones or shapes or anything. Eliminating raw sensory data leaves us with the definition we have been seeking: *The universe of human meaning is composed entirely of measurements on mental measuring standards.* While we shall of course never be able to prove that this statement is "true", I do not believe the reader will be able to imagine

anything which he would want to call meaning which cannot be expressed as measurements on scales, albeit in a trivial manner. This statement implies that all the information which can be communicated by any imaginable language may be expressed as measurements.

Before trying to use our definition let us notice another important fact about measurement in general. If we want to be in a position to record data on some variable, but do not know in advance how developed a scale—from dichotomous to ratio—will be used to obtain the data, we can nevertheless *insure* our ability to record it by setting up a precise ratio scale on which to record whatever measurements are made. Thus, if we have a chart showing a full ratio scale on which to record, say, a measurement of water temperature, we can record any exact measurement made of water temperature by making a mark at the correct point on the scale. At the same time, if the information we receive is simply that the water is “below freezing”, we can also represent this, *in exactly its own degree of precision and ambiguity*, by marking in the whole area of our numerical ratio scale which lies below the freezing point. (This ability to represent ambiguity accurately by the use of “area” measurements will be extremely important for us later.)

Applying this idea to our definition of meaning, we can gain in precision, while losing nothing, by stating that all possible human meaning may be viewed as due to measurements made by humans on ratio scales, as long as we remember that subjects frequently use their scales only grossly, and without specifying where their zero points are. In theory each such scale can be thought of as a continuum, extending to the limit of its possessor's perceptual ability at either end, and having as many points between as he can discriminate. This gives us a picture of a person's total ability to assign meaning to sensed objects, what we might call his total meaning space, as made up of a vast repertoire of ratio scales. We may think of him “having” such potentially applicable scales in somewhat the same sense that one is said to “have” certain moves in chess at any particular moment of play. To look at these scales from a physicalistic point of view, each one may be described as some aspect or dimension of the world, one which a given subject at any particular moment may or may not be making a measurement on, or, what is the same thing, one to which he may or may not at that moment be sensitive. Therefore we will say that the correct name for such scales is scaled sensitivities, although for brevity we shall continue to refer to them simply as scales.

3. From Scales to Element Scales

To see how the conceptual machinery assembled so far may be utilized to build a working representation or meaning we need to notice yet one more thing

about measurement in general. Once we set up some standard, say a standard of length such as a 12-inch ruler, we can show the length of an object we have measured to someone else with no need to show the object itself to him. In this case, we just show him our ruler, with a mark on it denoting the length of whatever we have measured. Or, if he has a similar ruler, he doesn't even need to see ours, he just simulates our mark on his ruler, and we both then have a conception of the length.

This suggests a way to view human communication within the present framework. If a person's ability to perceive meaning consists of a repertoire of scales he possesses to measure things on, and his perception of meaning consists of activations or readings on these scales, then consider two such subjects. As long as their repertoires contained at least some scales in common, one of them could understand the other's meaning to the extent that he could activate similar measurements on similar scales. In order to understand a message, a receiver would *simulate* a pattern of readings its sender had had. Learning to understand a language would consist of learning which readings on which scales should be activated in response to each word of that language. From now on we shall assume that this kind of process is what happens when communication takes place, and consider the task of equipping a computer with an “understanding” to begin with the following three steps: First, to establish an adequate repertoire of scales. Second, to code the meanings of the words, of those natural languages which we wish to be able to inter-translate, into the appropriate readings on these scales. Third, to store all this information in permanent memory, forming a kind of semantic dictionary.

However, as previously made clear, the number of scales, as long as we allow each to be defined ad hoc as needed, appears to be essentially infinite. If there were no way to cut this number down to a reasonable size *without* losing any of the information representable by the larger number, our approach would be worthless. Fortunately, there is a way to do this. The answer lies in the fact that the scales of human meaning, as we have defined them so far, are not mutually exclusive, but instead overlap each other in information content. For instance, in the previous example of the subject looking at a Van Gogh painting, the information involved in his perception that the stimulus contains orange, and that it contains a rectangle, are both *part* of the information contained in his perception that it is a Van Gogh painting. Perceiving it as a Van Gogh painting is, in short, a more inclusive perception, depending on the possession of a more dimensionally complex scale, than is his perception that it contains orange, or that it is rectangular.

Allport has most appropriately referred to this fact that human meaning is simultaneously present in different, overlapping levels by stating that meaning is

present at different “wholeness levels”.³ We shall adopt this term, and speak of “higher” wholeness level scales accordingly as they are relatively more inclusive than “lower” wholeness level ones. That is, moving down in the wholeness level of scales means to take narrower and narrower aspects of the world singly, and moving up in the wholeness level of scales means looking at information which may be seen as composed of combinations of readings on many lower level ones. The wholeness level of a scale would directly reflect its dimensional complexity.

Now, natural language words refer to concepts (or scale readings) of various wholeness levels, generally levels a good deal *above* the lowest level at which people understand the words’ meanings, so that people are able to view practically any concept represented by a word as a composite of lower level scale readings. I propose that we build up the entries in our computer’s store of semantic information as composites of readings on low level scales, and that *if, in fact, these scales can be defined at the lowest level at which people understand the meaning of language, then our representations of meaning will have the second property originally specified for them: that of always being represented in a partly invariant form*, no matter how they are combined with other representations to make up compound meanings. This of course will make all the meaning in a compound concept mechanically recognizable and usable. Just as the presence of any chemical element, or combination of elements, in a chemical compound is generally not directly discernible by looking at the natural language name of that compound, but is manifestly so in its chemical formula, so the presence of lower level meaning is not directly discernible by looking at the natural language names of meaning compounds, i.e., at words, but becomes manifestly so in their representation as combinations of lowest level scale readings.

(We shall argue in section five that defining our element scales at the lowest possible wholeness level will also mean that only a very small number of element scales—my guess is 50 to 100—will be necessary to exhaustively represent all concepts. However, working with such a small number of elements will also mean that very large constellations of readings will be needed to represent some meanings of words, in order to keep the amount of information in our representations the same as in the meaning of the words they stand for. It will become clear in the final section, however, that nowhere near all the readings comprising the computer’s understanding of a meaning need always be handled during translation.)

Perhaps the way we want to view the domain of meaning can be clarified by looking more closely at the analogy between the situation we are now considering and that faced in chemistry. The chemist has a

vast domain of variation in physical composition to deal with. If he decided to categorize this domain at, say, the wholeness level at which we ordinarily experience it, he would need millions of categories, for we discriminate millions of different kinds of materials in our physical world. The chemist chooses, however, to categorize at a much lower wholeness level, that of the periodic elements, and succeeds in representing and differentiating each of the millions of kinds of physical materials that we perceive, with only one hundred two variable categories, and a syntax for showing arrangements of them. Any physical compound is representable as a constellation of readings on those elemental variables, a constellation in the form either of a chemical formula, or of a diagrammatic illustration showing the way the readings are combined. The invariant capital letters appearing in these representations tell us which variables are relevant, and their variable subscripts tell us what the readings on those variables are, for the particular material represented.

The chemist’s conceptual tool, the list of elements and its syntax, is able to represent any variation in the universe of chemical makeup just as exhaustively as could a complete listing of all the names of chemical compounds in all the world’s languages. In fact, more exhaustively, since it can represent any imaginable chemical compound, as well as those actually found in nature.

I choose to believe that the universe of human meaning is composed the same way as the universe of chemical composition, insofar as it also can be exhaustively described by constellations of readings on a small number of variable elements, i.e., on scaled sensitivities defined at a single very low wholeness level, plus a syntax for building up combinations of such readings.

Our first reaction to this analogy with chemistry may well be an uneasy feeling, engendered by the fact that the chemical representation of a compound does not give all the information about it. For example, it does not state its melting point. But, this has not been claimed; what has been said is that the chemical element representation gives all the information about variation of chemical *composition*; the descriptive names for chemical compounds don’t give their melting points either, and it is only the compositional information in all possible such names which is of a sort translatable into constellations of readings on chemical elements. The notion of a melting point is obtained by going *outside* the universe of chemical composition; our universe shall be no less than *all* notions expressible in language, so that, at least in theory, we needn’t worry about information which is outside it, and the analogy holds exactly.

Offhand it strikes us that there must be fantastically more information in such a universe of meaning than in that of chemical composition. This is true, even

³ Allport, Floyd H., *Theories of Perception and the Concept of Structure*, John Wiley and Sons, New York (1955), pg. 555.

though in building a store of semantic information the relevant variance in our universe is only all the meanings of words in isolation, i.e., *before* they modify each other in text, which makes the amount of information our store must contain seem slightly less overwhelming. Still, this store must represent meaning in a *medium* that is capable of precisely representing any meaning that might arise, just as the periodic elements do for any conceivable chemical composition. As a first step toward creating such a medium, *let us define the element scales of human meaning, at any given time, as those formulated at the lowest possible wholeness level which is at that time capable of being articulated with the given units of meaning.*

What this definition means operationally is that the primitives of our semantic medium are to include only dimensions that people treat as unidimensional, of which "length", "time", and "hue" may be taken as current examples. It should be noticed that even though it was initially convenient to describe our position by using the notion of individual bits of sensory data, this concept is *not* utilized in the above definition of element scale dimensions. For my part, I suspect that Piaget's interpretation of such dimensions as groupings of behavioral operations⁴ is a more fruitful approach to what exists within such dimensions than is afforded by notions of individual bits of sensory or perceptual data. But in any case, this whole philosophical issue is outside the scope of this paper. Here we simply assume that whatever internal structure our element scales have remains effectively constant within adult conceptions of the world. A persuasive argument for this assumption would seem to be implied in Piaget's many demonstrations of the "equilibrium" and "stability" of adult conceptions of such dimensions.⁵

Our definition also seems to raise some question for natural language text, because the given units of meaning in such text are of several simultaneous wholeness levels (words, phrases, sentences, etc.). But, clearly we will want to store meaning in our dictionary in blocks which correspond in wholeness level to the smallest units at which it is given, namely words (or morphemes) and idioms. (How to move up from units of meaning at the wholeness level of morphemes into units at the wholeness level of phrases and so on is outside the scope of this paper; here we are concerned only with the provision of an appropriate material for such combining. However, I might note that rules governing changes occurring in meaning as words are combined into phrases, etc., must be discoverable, since *people* must have such rules, or they could neither formulate nor understand sentences which they have never seen before. Some of the work

⁴ Piaget, Jean, *The Psychology of Intelligence*, paperback edition: Littlefield, Adams and Co., Paterson, NJ. (1960), pp. 32-50. A similar approach is also advocated by Ceccato (see refs. under footnote 6).

⁵ See, e.g., Piaget, Jean, *The Construction of Reality in the Child*, Basic Books, Inc., New York (1954), Chap. I.

of Ceccato and his co-workers at Milan⁶ appears to constitute a beginning toward such rules.)

Another question raised by our definition is whether or not the meaning of words is stable enough to be coded, since the meaning of a given word is rarely if ever exactly the same for any two people. However, for translation, which is the immediate aim of our present approach, we can and must always have a one-to-one correspondence between one sense of a word and one constellation of scale readings, since we want to handle only the sharable, communicable meanings of text, not the idiosyncratic responses it may evoke in a particular translator or reader. This of course does not mean that our representations should not contain the connotative, ambiguous, or subtle meanings of a word, as long as these are an accepted part of its meaning. The various standard "dictionary" meanings of words, therefore, provide us with a stable basis on which to move back and forth between words and their meanings, as these are represented by constellations of our lower level scale readings.

To see how elements like those defined above might provide a potential "understanding" interlingua, suppose we simply stored in a computer the information that each English name for each chemical compound was to be associated with its chemical element representation. Thus "water" would be associated with "H₂O₁". For words such as "steel" we would have to utilize subscripts with area readings, and other ways of showing the degree to which the compound's composition was ambiguous. Also, we would soon need a more expressive syntax in order to accurately specify relationships between elements. Nevertheless, it seems clear that we should be able to build a complete "dictionary" relating each compound name to its chemical composition. Also, it is clear that we could do the same for the words specifying chemical compounds in any other natural language, such as, e.g., German. Then we could program the computer to go from an input of the German name for a compound to its chemical composition on one pass, and on another to select, from the chemical-composition-to-English dictionary, the entry with the best matching meaning, thus providing an English word for output. (If these were no English entry adequately matching the one in the interlingua, then two or more English entries, which when combined would produce an adequately matching entry, could be automatically selected. This would provide the word stems for an output *phrase* stating the meaning of the input expression.)⁷

⁶ Albani, Enrico; Ceccato, Silvio; and Maretto, Enrico, "Classifications, Rules, and Code of an Operational Grammar for Mechanical Translation," in Kent, Allen (Ed.), *Information Retrieval and Machine Translation*, Interscience Publishers, Inc., New York and London (1960), part 2, pp. 699 ff. See also Technical Report RADC-TR-60-18 of the Centro De Cibernetica e di Attivita Linguistiche, University of Milan, Italy, *Linguistic Analysis and Programming for Mechanical Translation*, Giangiacomo Feltrinelli, Milano (1960).

⁷ This selection process is discussed more explicitly in an earlier version of this paper, "The Elements of Human Meaning: A Design for an Understanding Machine" (mimeographed, 1960), pp. 31-37. Copies available from the author.

This is basically the method here proposed for all machine translation, with the elements of chemistry replaced by the elements of meaning, and with at least three more steps added: One for combining and altering meanings according to the way their words are combined into sentences by the input text. One for attempting to resolve the polysemies of the input words. And one for generating appropriate output sentences with the word stems provided.

The three tasks confronting a person wishing to equip a computer with understanding can now be amended to read: First, he must establish an adequate medium of *element* scales for the representation of meaning, and an intraword syntax for building up constellations of readings on those scales. Second, he must code the meanings of natural language words into such constellations. Third, he must arrange all this information into a semantic "dictionary". We shall discuss these tasks in turn in the next three sections.

4. A Medium for Semantic Information Storage

Before we try to select dimensions that might serve as element scales of our medium, let us clarify two requirements which such scales must meet, and one which they do not need to meet.

In the first place, the element scales must allow constellations of readings on them to represent all the different meanings which natural language words represent. More significantly, these constellations must be differentiated from and related to one another at least as precisely as any writer of text will expect a reader to consider their referent concepts differentiated or related. This is essential if constellations are to be combined with and translated into one another appropriately. However, we should remember that this does not mean that the representations in our semantic dictionary need to be related to each other in the same ways that aspects of the real world are. In other words, there are vastly more relationships contributing to the variations between actual perceptions made in the real world, and hence perhaps to the meanings of sentences, than there are contributing to the variance represented by the sum of all single word pictures of that world.

This fact is crucial for us, because it means that someone constructing a semantic dictionary will never need to know anything except what is already a part of some accepted body of knowledge, scientific or commonsense, at the time that the dictionary is constructed. Coding the meaning of words into such dictionaries is purely a matter of recognition, not one of actual measurement, as is science itself. This will best be clarified with an example.

As we shall see presently, three proposed element scales in our repertoire are hue, brightness, and saturation of color. This means that we will need to code the meaning of a color name, e.g., "yellow", as a con-

stellation of three area readings, one on each of these element scales. Doing so allows us to differentiate this representation from all other representations in our semantic dictionary, and relate it to them, as precisely as contemporary writers using "yellow" can expect their readers to differentiate or relate its meaning from or to all other meanings. But now consider the case of devising a semantic coding medium *before* anyone had sorted out the various dimensions of color vision. In this case we might very well, in our ignorance, have constructed a single scale to account for color, one which confounded hue, brightness and saturation. Then we would have had to assign a calibration scheme to this spectrum, and code the meaning of "yellow" as the reading(s) that appeared at the yellow area(s) on it. This strikes us as crude, but it would be entirely adequate for an understanding machine, because under these conditions no one would *write* any text which assumed the readers understood the separate dimensions of vision, the physical correlates of these, or precise ways of measuring them. *In such text no resolution of polysemy, nor accurate translation, nor other function contingent on understanding would ever depend on its readers possessing such knowledge.*

In actually choosing element scales, we shall always be in a position exactly like this hypothetical one, for our knowledge is always subject to change as more fruitful and precise ways of dimensionalizing and measuring it are discovered. The important point is that this doesn't matter; the best we can do will always be at least good enough to permit understanding and translating of contemporaneous text. I believe that much criticism claiming that mechanical understanding is impossible has failed to understand this situation. Perhaps I should also point out that, should our computer possess *more* semantic knowledge than a writer has, or dimensionalize this knowledge *more* precisely than he does, this will in general not affect the translation process at all, since during translation the text gives rise to questions to be answered by the computer's understanding, not vice versa.

What I wish to do now is sketch the main features of my own efforts toward constructing a semantic medium, and at the same time speculate about what additional element scales would be needed in order to make this tentative medium universally applicable. So far only scattered words have been coded into this medium, on an exploratory basis. Moreover, all my efforts so far have been directed toward representing natural language concepts as constellations of readings on its tentative element scales, and relatively little thought has been given to insuring that these scales rigorously meet our theoretical demand that all element scales be defined so as to have the least possible dimensional complexity. Thus what follows is in no sense intended to present a final repertoire of elements, but only to provide the reader with a some-

what more concrete picture of what such a medium might look like.

First of all, this medium's *scale readings* are all either numerical points, or ranges, or a symbol meaning simply "some reading on some scale."

Secondly, its *syntactical symbols* for combining such scale readings (note that this is an intra-word syntax, in respect to natural language words) include primary logical operations, the relations "greater than", "less than", and "equal to", and brackets. A syntactical convention prescribes that all readings be assembled into "rows" of readings, each of which represents either something someone takes to be a unit, or something someone takes to be a relationship between such units. (Although arrived at independently, these rows turn out to correspond fairly closely to the "correlata" and "correlators" postulated by Ceccato.⁸ This representation of meaning, then, may be viewed as one similar to Ceccato's "correlational net", but with two important differences. First, that in our representation what is put into each of the boxes of the net (rows) is not simply a natural language word or a predefined relationship, but rather a large body of information, all represented in terms of readings on element scales. Second, that in our representation differing numbers of rows are associated with each concept represented, so that it may take one or a great many rows to represent one meaning of one word.

Thirdly, there are *the element scales themselves*. Since my sympathies are primarily phenomenological, I shall first mention five scales of an especially abstract nature, and then pivot the rest of the discussion around the human senses, attempting in passing to indicate how several types of concepts not ordinarily thought of as sensory can be viewed in terms of combinations of such variables. The five abstract scales are: a dimension called "Number", representing the real number continuum, one of "Correlation" (in the statistical sense), one of "Makeup" (representing the notion of whole-to-part or whole-to-aspect), one of "Similarity", and one of "Derivative" (in the mathematical sense). This done, let us now turn to visual sensation, where basic dimensions are generally agreed upon.

Most writers can expect their readers to view (but not necessarily to be able to describe) color concepts as modifiable in, and hence for our purposes as made up of, three dimensions; hue, brightness, and saturation. We add each of these to our repertoire as element scales. It would seem that the meaning in *any* words which describe and differentiate colors, light and dark, and so on, should be capable of being coded into constellations of readings on these scales.

Another kind of discrimination of visual sensation people can make is between different times at which pieces of it occur. For this we have a time scale in

our repertoire. There is also a scale to represent distance, or length, with a variable superscript so that it can be made to represent additional, orthogonal spatial dimensions when needed. This distance scale alone, then, can expand into an infinite number of scales. However, for coding anything except certain mathematical terms, we will only need to apply superscripts 1, 2, or 3 to it, so that for practically all purposes we have added only three spatial dimension scales to our repertoire. We shall speak of all element scales as substantive, even though in another sense time and length can be viewed as lacking content.

Another kind of discrimination people at least pretend to be able to make of their visual sensation is between the probability of some part of it occurring or not occurring, so that "degree of existence", i.e., probability, is our next element scale. The meaning of a word like "exist", for example, is presently coded with a maximum positive reading on this scale. Multiple readings on this scale are used in building up constellations representing concepts of alternative situations. Such constellations are necessary to handle the meaning of words dealing with unrealized potentials, counterfactual conditionals, goals, etc. A related element scale is called "degree of awareness", needed for representing the degree to which something is said to be consciously vivid to someone.

As will be explained in the next section, visual shapes are to be coded as patterns, together with readings on particular element scales whenever such substantive content is also part of the meaning of the word being coded. At this point I for one begin to be unable to think of discriminations of visual sensation that can *not* be viewed as made up solely of readings, or patterned constellations of readings, on the dimensions mentioned above. I am not altogether sure there is not some meaning which depends on other kinds of distinctions of visual sensation, but I would be surprised if we had to add more than *a few* scales beyond those named above in order to represent all the meaning people have regarding purely visual data.

Now, most of the scales here assembled for visual meaning are also used in coded meaning pertaining to other sense organs. Readings on the "time" and "awareness" scales, for instance, obviously will serve as well in constellations pertaining to auditory meaning or to some other kind as in combinations pertaining to visual sensation. In order to code all the meaning related to hearing, in fact, I believe we only need to add two more scales to our repertoire: one representing variations of pitch, and one representing loudness. I believe the other phenomenological dimensions of sound, such as tonal volume and density, now can be reduced to patterns of pitch and loudness, although, as discussed earlier, it is of no great consequence for this particular discussion whether they can be or not; we only need do as well as it is known how

⁸ Op. cit., pp. 713 ff.

to do. Harmonies, melodies, etc., are to be coded in essentially the same manner that visual shapes are, namely, as patterns of readings.

For gustatory sensation also, the phenomenological dimensions are fairly well agreed upon. Four more element scales would seem to be required: sweetness, sourness, saltiness, and bitterness. In combination with the scales already in our repertoire, these scales should enable us to represent just about anything any language is now able to say about taste proper.

But what about other senses, such as olfaction, for which there is as yet almost no agreement on basic phenomenological dimensions? For these we must either adopt one of the available sets of proposed basic dimensions, or else isolate some workable set ourselves. There are several ways this might be done. One would be to use some factor-analytic technique; another, which would work directly from the natural language words to be coded, is sketched in an earlier version of this paper,⁹ and Goodman's "ordinal quasi-analysis" offers a logically more rigorous method for discovering the linear orderings into which phenomenological data fall.¹⁰

However we decide to arrive at a set of scales for these areas, we will do well to keep the requirement set up earlier clearly in mind: our final element scales must permit us to code all meanings such that they are differentiated from and related to one another at least as precisely as the most exacting writer of text is going to expect his readers to view them. It seems clear that the kind of elements we have mentioned above, hue, brightness, etc., could facilitate just such coding. And it seems to me almost equally clear that in sensory areas such as smell, carefully chosen sets of tentative basic dimensions can permit our medium to reflect a knowledge of the subject matter at least as precise as that which humans have for understanding text.

As previously noted, a semantic dictionary can store knowledge only about the meanings of *isolated* words or idioms. However, it is this paper's contention that storing the meaning of a word as we have been describing is to store it in a form which will permit mechanical modifications to accurately reflect changes occurring in the concept as the word representing it is found placed in phrases, sentences, and larger units of input text. Placing a concept on areas of element scales differentiates it correctly, it is maintained, from *all* other correctly coded concepts, and shows *some* of its relations to other concepts. Additional relationships must be added to represent its full meaning; again, element scales are only an attempt to provide a medium in which such relationships can be represented in an appropriate notation. (Work currently

under way involves recoding into COMIT¹¹ concepts already coded in my semantic medium, in order to facilitate testing the feasibility of mechanical modification procedures for reflecting combinatory effects on meaning.)

To return to our enumeration of exteroceptor sense scales, some tentative set of basic dimensions will have to be used for cutaneous, as well as for olfactory sensation. How many scales can we expect to add to our repertoire in equipping it to deal with all meaning related to these two senses? I should think there can hardly be more than 25 distinguishable dimensions of skin sensitivity and smell.

Some set of tentative element scales will also have to be used to deal with meaning based on proprioceptive and interoceptive sensation. It is largely from this kind of sensory data that the person builds up his notions of emotion, fatigue, etc., and partly from it that he builds up notions of muscular activity. Natural language names for emotions typically refer to *patterns* of such experience and behavior, just as words for shapes refer to patterns of vision and words for melodies to patterns of sound. I think that we will find that there are not more than about a dozen distinguishable dimensions of interoceptive and proprioceptive awareness, but let us figure 25 to be safe. Adopting each of these as an element scale, then, would bring our repertoire to something like 75 scales altogether. What other element scales are we going to need?

I choose to believe that all concepts representable by language can ultimately be defined in terms of readings on a set of dimensions not much larger than, and roughly of the same sort as, those just outlined. This assumption means that although adequate specification of the meaning of concepts will frequently require very large constellations of readings, we will not need to add very many more element scales as primitives. This assumption will not be shared by a good many readers, and certainly need not be shared before a reader can believe that *many* concepts may be usefully coded in terms of a medium such as we have outlined.

5. Coding Concepts into the Semantic Medium

To begin with, let me reemphasize that the job of representing the meanings of words as constellations of scale readings should not be confused with the scientist's job. What one must have to code the meaning of words is *not* a knowledge of the way every word's meanings actually measure out into sensation, but only a consistent representation of what such words *communicate* to other people, in terms of ambiguous measurements on element scales. Of course, concepts whose precise relative position on phenom-

⁹ See reference under footnote 7, pp. 22-24.

¹⁰ Goodman, Nelson, *The Structure of Appearance*, Harvard University Press, Cambridge, Mass. (1951), pp. 203-214.

¹¹ The COMIT system was designed and programmed at M.I.T. as a joint project of the Research Laboratory of Electronics Mechanical Translation Group and the Computation Center. For further information, contact V. H. Yngve, COMIT, Room 20D-102, M.I.T., Cambridge, Massachusetts.

ological dimensions has been empirically established must be coded into scale readings in accord with this knowledge. This is the case, for example, with the relative placement of color names on the dimension of hue. But with any concept for which this is not the case, we only need to place its readings onto a scale in accord with the way some intelligent speaker would place them, *relative to other concepts' readings on that scale*, in order to make a computer "understand" that piece of the concept's meaning the same way the speaker does.

It should also be obvious that in coding we will make constant use of area readings, because the meaning of words is generally not precise. In fact, a reading will often cover the entire positive or negative half of a scale, or both, indicating simply that *some* measurement within the area covered is a part of the meaning of the word being represented. Ambiguity also exists regarding which scales are involved in the meaning of a word, and for this, as well as for arranging the readings within rows into subgroups, we must utilize all the flexibility which our syntax allows.

The next thing to be said about coding is that not all natural language words are to be coded as scale readings at all, many instead being, in whole or in part, operations on other scale readings. Examples of English words which simply operate on other scale readings include "very", which moves a given reading further away from the scale's normal point; "slightly", which does the opposite; "precisely", which does the opposite. The fact that natural languages do contain words of this sort, whose meaning in a phrase would seem to be appropriately reflected only as operations *on scale readings*, is taken as further evidence that scales are in fact the appropriate primitives for a medium designed to represent concepts so that they will combine in the way that human concepts do during the understanding of sentences.

Another of the most important jobs for our syntactical symbols will be to represent the meaning inherent in concepts of shape, most typically represented linguistically as a part of the meaning of nouns. From our viewpoint all of the meaning of a noun is built up by a subject's lumping pieces of dimensional meaning together into a unit. Which pieces he lumps together is at least to some degree his decision; the stimulus field rarely if ever completely dictates what he is to take as a unit. The reader interested in this notion may see Bruner¹² for a discussion of how certain dimensional meanings are taken to be "criterial" to the existence of an object, i.e., to be part of the necessary composite making up that object, while other dimensional meanings, not criterial for that particular object, are seen as attributes which examples of it may or may not have. However, *the way* in which such criteria are combined is itself usually

¹² Bruner, Jerome S., Goodnow, Jacqueline J., and Austin, George A., *A Study of Thinking*, John Wiley and Sons, New York (1956), pp. 25 ff.

criterial. In other words the meanings of nouns, as we said, generally include the specification of certain shapes, i.e., patternings of dimensional readings.

Representations of such patterns in our semantic dictionary may be constructed either as batteries of dimensional scale readings, or else with some algebraic notation which would allow readings on various spatial, temporal, or other substantive scales to be plugged into a neutral, purely relational description of a pattern. The meanings of time-spanning patterns, such as melodies, are to be coded the same way as shapes, since the temporal dimension is treated no differently than other scales. The same is the case for all concepts referring to patterned events, such as that of the word "handshake". The meaning of all verbs implying activity are from our point of view considered to be statements of change, which again are for us a type of pattern in a series of measurements.

Obviously much of the current work on pattern analysis is relevant to representing the meaning of visual patterns, but it would be a great error to suppose that our job is the same as that of pattern recognition itself, because, for one thing, language normalizes all configurational meaning for us. Thus, we don't describe the appearance of a chessboard we are looking at as 64 slightly differing four-sided figures, but rather as 64 squares. Even if we do give a full verbal description of the chessboard as it actually appears from some particular angle of view, we shall have to build up that description from words which, individually, present whatever information they contain in normalized form. Thus the biggest problem of pattern recognition doesn't exist for a translation medium. This is one example of a fact stated more generally earlier: the variance in the universe of meaning that is presented by single words is only a microscopic part of the variance in the real world itself.

Nevertheless, just coding all the *normalized* patterns which are a part of the meaning of natural language words is no small job—consider for instance all the shapes inherent in the meaning of a word like "automobile". (By this we of course do not mean all the different shapes which automobiles can take, a range which does not add to the meaning of the word, but, on the contrary, increases its ambiguity. What we do mean is the knowledge people have about the shapes of tires, pistons, sparkplugs, doors, etc., which are contained in what is ordinarily assumed to be an understanding of "automobile".) Complete representations of the meanings of words like this would be very large indeed, and we must now consider the problem this raises.

6. The Structure of a Semantic Dictionary

The over-all arrangement of the entries in a semantic dictionary is too large a topic for us to more than touch on in this paper, but we must at least do that,

to permit an accurate understanding of such an information store. As we have mentioned, the complete meaning of many words is indeed enormous, with, for instance, one meaning of a word like “science” being no less than all of science. Readers of text are likely to have to call on parts of this information to understand text, to resolve polysemies in it, and so on. An understanding machine, like a human, need not *do* anything with or to such information upon encountering the word “science” in a text, but we should prefer that such a machine, again like a human, be able to ask itself, for example, whether some concept is or is not a part of the meaning of “science”, and get a correct answer.

This implies that we will eventually have to pack truly astronomical amounts of information about the meaning of many words into our dictionary. But I believe the disaster of becoming hopelessly cumbersome which this seems to imply can still be avoided, by thoroughly utilizing the overlappingness of words’ meanings. For example, a constellation representing the meaning of a word like “wheel” needs to be set up only once, even though that concept is a part of thousands of higher level concepts. This is because the one complete constellation representing “wheel” would be placed in some fixed location, and, in the representation of any higher level concept, a symbol naming this location could be used as a pronoun for it. Thus such a pronoun for the meaning of “wheel” might appear four times in the constellation representing the meaning of “chassis”. In turn, this representation of the meaning of “chassis” would itself be represented (in still higher level constellations such as that representing “automobile”) by a pronoun symbol stating its location. To look again at the representation of wheel, this constellation could itself be made up in part of pronoun symbols referring down to lower level locations, where words like “hub” and “circular” might be represented. Stratifying a complete semantic dictionary in this way could vastly reduce its redundancy, with a corresponding reduction in its over-all size, although of course at the expense of speed in scanning or reproducing that meaning of a word which lay at a great distance beneath its “surface”. When very “deep” information about the meaning of a word *was* needed, it could always be fetched or scanned by following location symbols down through various levels of the dictionary. However, we could almost always get along *without* exploring all the actual details of a word’s meaning, partly because people only create text which requires a certain limited “depth” of understanding, and partly because the clues we would search for could *themselves* be defined in terms of location symbol pronouns, thus directing that searches be conducted only at the appropriate level of words’ meanings.

This kind of structure would be our computer’s version of a trick used constantly by humans, that of

summarizing large amounts of information under more manipulable tags—which is what makes man into, among other things, a symbol-forming animal in the first place. It is the sort of arrangement by which computers and people, can manage to possess much fuller understanding of the meanings of words than they actually handle, except when more depth of understanding is explicitly needed.

Any ordinary natural language dictionary utilizes the same principle in that it defines the meaning of words in terms of other words. In such dictionaries this strategy succeeds in reducing the size of definitions, and might seem to imply that we should be able to search back through successive definitions to reproduce as complete an understanding of a concept’s meaning as we wished. The reason that it is not possible to do so is that ordinary dictionaries generally define words not in terms of less dimensionally complex words, but indiscriminately in terms of higher, equal, or lower level ones, subtracting from and altering these, as well as simply adding them, in phrases, in order to establish the meaning of the word being defined. Our computer, armed with equipment allowing a precise specification of meaning, and defining all words in terms of lower level meanings, should allow us to trace meaning up and down at least as reliably as this can be done in any human’s understanding.

Now, there is actually no reason why the machine’s fund of knowledge need be stratified only as we have specified, viz., in accord with the way natural language words indicate. That is, not only could a block of readings equal to the meaning of a lower level word be displaced out of a constellation down to some lower level, but so could any arbitrary block of readings we chose. Whenever a block of readings was displaced from a constellation, a symbol indicating the location it was moved directly to would be left in its place. This location symbol would specify both the level and the location within that level that the block was moved to, the level being completely determined by the number of readings in the block, while its location within the level is arbitrary. Information could be moved to varying depths by repeated displacements. Decisions about what to displace to what depth could be made in accord with the likelihood of the information’s being needed for a certain use of the semantic store. Thus, we (or, ultimately, some heuristic subroutine) would probably want different kinds of information up close to the surface representations of words for resolving polysemies than would be wanted there for expressing meaning into some particular output language. Just what to put at what depth is a complex problem indeed, with any one complete solution, for a semantic dictionary as a whole, being the equivalent of giving the computer a psychological “set”.

This completes our sketch of an “understanding” machine; I hope there is enough here to give the

reader a basis on which he can build up some impression of what at least the semantic memory in such a device might look like. I trust that it is clear that actually building such a memory involves a gigantic amount of work, and very tedious and dirty work at that. But nothing in what has been proposed would appear to be really beyond the reach of a concerted

effort. For information retrieval, and for social science, the implications of having a computer program able to reproduce the essentials of human understanding of language would seem to be of no small importance. And for mechanical translation, if we really want fully automatic, high quality translation, I can see no other choice.

Received March 1, 1962