North American AstroPhysical Observatory (NAAPO)

Cosmic Search: Issue 3
(Volume 1 Number 3; Summer 1979)
[Article in magazine started on page 21]

MINDS AND MILLENNIA:
The Psychology of Interstellar Communication

By: Michael A. Arbib

If we establish communication with a civilization even as close as 100 light years from Earth, the round-trip time for a message and its reply is 200 years. What will be the psychology of a civilization which can engage in a meaningful conversation with this sort of delay? How is such a conversation to be established? What should the content of such a conversation be? These are the questions which motivate our title: "Minds and Millennia: The Psychology of Interstellar Communication".

Arbib engaged in interspecies communication

Intelligence and Language

There seems to be general agreement that a civilization which engages in interstellar communication must have achieved the technological capability for radio astronomy, and it is felt that radio astronomy cannot be developed without a solid underpinning of physics and applied mathematics. Thus, while there may be many types of intelligence which do not achieve mastery of the physical sciences as we know them, it does seem reasonable that those intelligences with which we communicate will have a certain amount of basic mathematical and physical knowledge in common with us. This commonality will in fact be the key for the strategy for establishing communication.

However, let us first focus upon the nature of mind, and the role of language. One of the fascinations of the question of the possibility of interstellar communication is that it forces one to look at old philosophical problems from a new perspective. We do not abstract from the nature of human thought in building a philosophy of mind, so much as we try to build a science of mind which is rich enough to embrace not only human minds, but also the still somewhat limited minds of computers, and a whole range of possible minds that we might encounter elsewhere in the universe.

What, from this perspective, constitutes intelligence? It seems to me that the crucial aspect is to be able to adaptably, flexibly, and predictively "model" the environment — representing aspects of current experience in such a way that one will be able to handle oneself better in novel situations in the future than one could have without the current interactions.

However, even among terrestrial organisms, intelligence is by no means limited to humans — dogs can certainly learn from experience. What does seem to be a turning point in evolution on this planet is the development of a separable symbol system for non-hereditary, non-imitative transfer. With language, we can tell people about situations they have not yet encountered, and tell them how to react. For other animals, non-hereditary transfer seems to be based on imitation — the infant either imitates an older animal, or gains experience from play.

One of the most important aspects of language is that it frees us from the here and now. It also frees us from what is definitely the case. It must be able to express temporal relations: after you have seen such-and-such then you may do so-and-so; it must include a denial: no, it is not the case that such an approach will be effective; and it must include quantifiers: the ability to assert that some things have one property, and that all things have another property. We cannot build a technology on a scientific basis without the ability to make and test hypotheses and look for unifying laws — and the very nature of a hypothesis is that it describes a wide range of circumstances and may not necessarily be true.

It is for this reason that one needs a language made of symbols which can be rearranged in arbitrary fashion, thus transcending imitation or the transmission of pictures of actual events. The trouble with pictures is that they are too literal to communicate general truths: imagine a picture which adequately conveys a theorem about polynomials, or which conveys the negation of a statement. However, the fact that we need a language that transcends literal or pictorial representation of that which is, does not deny that pictures can enhance a symbolic message. For example, in addition to communicating mathematical statements to a creature on another planet, we might also find it worthwhile to establish a picture of our stellar environment as seen from space, and thus provide a clear indication of our location in the universe.

"Another intriguing question raised is the question of how intelligent we really are..."

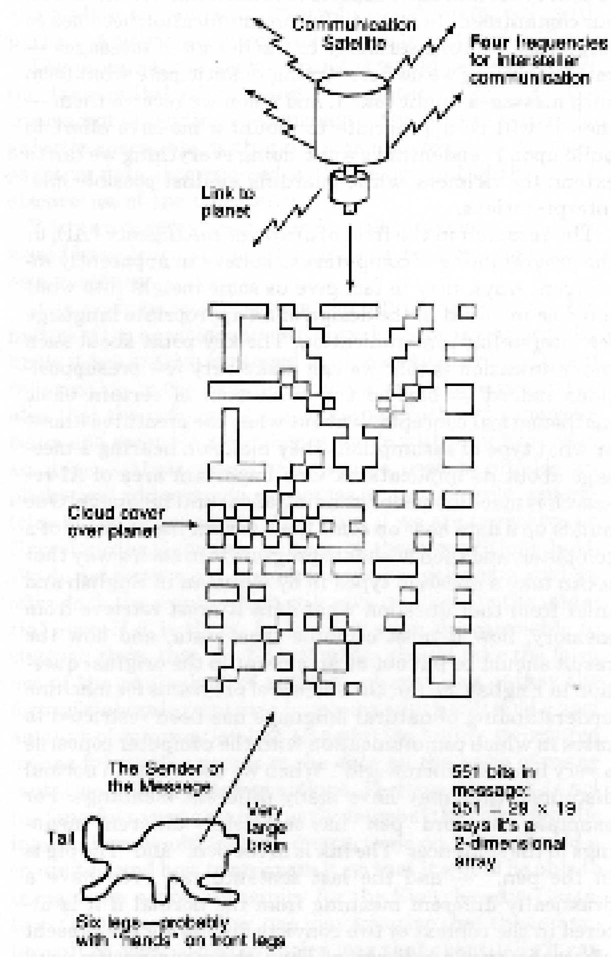
The last comment suggests that our communications with intelligences elsewhere in the universe should contain a combination of symbolic messages and transmission of pictures — whether two or three dimensional. This raises the question of the likelihood that a creature who has evolved on another planet along completely separate lines will share the sense of sight. Perhaps such a creature would be like a blind man yet endowed with the ability to hear radio waves — having no distance sense which gives him a clear spatial map of the world, although he has directions of maximum sensitivity. However, the frequency of convergent evolution on Earth does suggest that visual perception is likely to be a component of the sensorium of an intelligence, no matter where it had evolved. The visual system of the octopus and the visual system of man are very similar, and yet their evolutionary history on this planet is far apart. The ability to locate objects in space, and maintain a map of the object's position in the brain (in the general sense of the physical substrate of the mind) argues for the evolutionary advantage of developing the ability to sense the reflected energy of the local star on an array of receptors.

We seem to have established that any intelligence with which we are likely to establish communication will have vision, language, and a sophisticated knowledge of applied mathematics. Unfortunately, though, we do not know how different the language of such creatures may be. Here on the planet Earth, the question of whether or not whales and dolphins are intelligent creatures with an advanced language of their own is still highly controversial. The fact that they live in a marine world must greatly condition what intelligence they have. If indeed they do have language, the words they use will be different from ours. What may seem an obvious concept to them may be a very complicated concept to us. We often forget that language works so well for us because we can plug it into a substrate of experience that we share with other humans. The simple phrase "you know" often works wonders — but it is unlikely to convey any information to an intelligence which has evolved along different lines. One of the problems that we must face, then, in the next section is how to design a message which not only will work irrespective of the language of the receiver, but which will work even when the concepts of the receiver's language are in many ways different from ours.

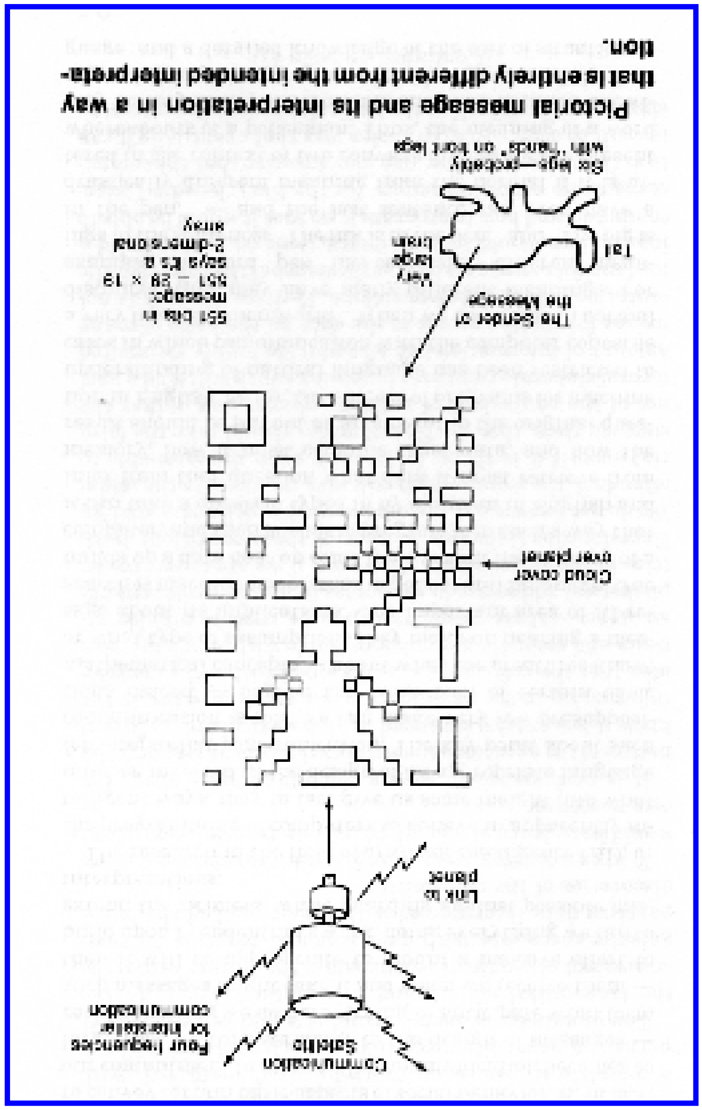
Will the intelligence we talk to be natural or artificial? In some sense, I suspect that the question is meaningless. If we generate a message of significance sufficient to beam it to the stars, it will not be the product of any single human mind. Rather, it will reflect the whole network of knowledge of many humans, and — given the current state of our technology — it will be a network enhanced by a man-machine symbiosis, in which sophisticated information retrieval and data-base management systems are part of the production of the message. The resultant message will be one that many intelligent individuals can *comprehend*, but which will transcend what any single individual can *create*. The problems of communication on such a scale will probably depend little on the 'proportion' of organic intelligence that enters into the composition of the messages; and the divergence of evolution may well be so great that when it comes to inter-species empathy, we may find that we have far more in common with an anthropomorphic robot than we may have with many of the organic beings in the universe. However, we may hope that in any case the richness of ideas that we can share not only about the physical universe but also about the diversity of social structure in the universe is sufficiently rich to justify and sustain an exciting interchange.

A Language for Interstellar Communication

We have already suggested that pictorial information will not be sufficient for interstellar communication, and that a rich symbol system based language will also be required. However, before saying something more about such a language, we should say something about how much we can indeed hope to convey through a picture. A picture has been designed by Frank Drake* (*See "A Reminiscence of Project Ozma" by Frank Drake in **COSMIC SEARCH**, Jan. 1979.), for transmission to an extraterrestrial civilization. His pictorial message consisted of a string of 551 0's and 1's. It was assumed that the mathematical ability of the receiver would be such that he would notice that 551 was the product of the two primes 29 and 19. The fact that it could be broken down into a two-dimensional array but not into an array of any other dimension was meant to suggest to the receiver that in fact he display it two-dimensionally. Displaying it as 19 rows of 29 columns each would yield a far less meaningful pattern than that we have displayed in the figure as 29 rows of 19 bits each. Drake's intention was to design the picture in such a way that no intelligent species could fail to appreciate the message it contained. Let us now see how we might read off some of the information that has been packed into this small message. At the bottom left-hand corner, we can see the sketch of the creature which sent the message — and we may conclude with some confidence that it has a very large brain, six legs, and a tail. Somewhat above it we can see that the picture is cut almost in two, and it seems reasonable to infer that this suggests that there is a heavy cloud cover over the planet cutting the species off from outer space. We may then recognize above the cloud cover a communication satellite with beams radiating out from it. The beam back to the planet links the creatures with their satellite, while the four beams radiating upward either suggest that the communication is on four frequencies, or that communication on two frequencies is being spread out in all directions.



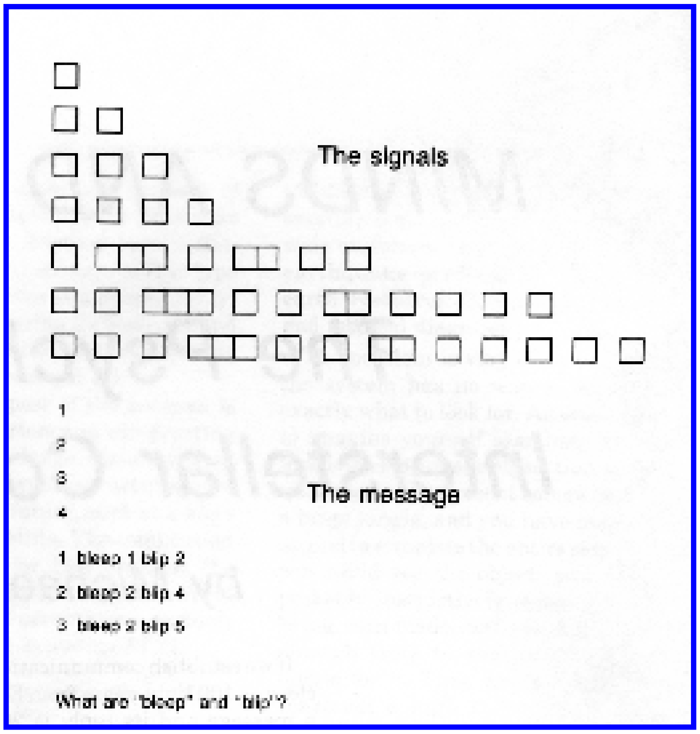
Pictorial message and its interpretation in a way that is entirely different from the intended interpretation.



This last ambiguity indicates how difficult it is to be sure just which aspect of a picture is meant to convey what information. However, there is an even greater argument for the ambiguity of the message that a single picture may convey to an alien intelligence. This is that the picture we have been discussing is Drake's picture upside-down! If in fact you turn the picture the other way, you will see that the "communication satellite" turns into a biped — and this was meant to show that the intelligent species were somewhat man-like in shape. The "creature" — now at the top right-hand corner of the picture — was in fact meant to be the symbolic representation of the carbon and oxygen atoms. Each is represented by a nucleus with two inner electrons, and then with four and six, respectively, electrons in the outer shell. The point of all this is that while there may be some chance of Drake's message being deciphered by an intelligence that expects any biped-like shape to be an intelligent being, it is very unlikely indeed to succeed with six-legged but large-brained creatures with tails. The challenge in defining interstellar communication, then, is to devise messages which cannot be so readily misconstrued.

"No single message ... can reliably convey the meaning of a given set of symbols."

We have already mentioned one reasonable suggestion — that high resolution sequences of pictures — such as a cosmic zoom showing the neighborhood of the planet which is transmitting the message — can play a valuable role. Nonetheless, it seems that much information can only be conveyed when words are available to present hypotheses, or to emphasize which aspects of the picture are truly worthy of attention.



The problem, then, is to establish a vocabulary of symbols and their meanings in which such communication can proceed. Let us suppose that the message consists of a string of pulses (as in Morse code) which may either follow immediately one upon the other, or may be separated by intervals of silence. Let us assume that the message is broken up into sentences — sequences of pulses separated by at most short pauses — with long pauses used to mark off one sentence from another. Suppose, then, that you were to receive the sequence of sentences indicated at the top of the accompanying diagram. The first four sentences—the sequence could be continued further as a safety factor — rapidly convey the idea of counting: 1, 2, 3, 4, ... With this, you may attain a reasonable degree of confidence that the message has told you that the code for a number is just the corresponding number of pulses separated by short pauses. Thus, when you turn to the next three "sentences" of the sequence you have some confidence in the interpretation that the messages take the form: 1 bleep 1 blip 2; 2 bleep 2 blip 4; and 3 bleep 2 blip 5. Your problem, then, reduces to interpreting "bleep" and "blip". Some reflection may lead you to the conclusion that "bleep" stands for "plus", while "blip" stands for "equals". However, this may not be true. It may be that our creatures write their mathematics backwards, and that these sentences should really be read from right to left rather from left to right, so that the correct interpretation of the three messages is: 2 minus 1 equals 1; 4 minus 2 equals 2; and 5 minus 2 equals 3. However, if the messages following were of the kind: 2 blap 2 blip 4, 2 blap 3 blip 6, 5 blap 3 blip 15, and so on, it would become far more likely that "blip" did indeed stand for "equals" rather than "minus", while "bleep" stands for "plus" and "blap" stands for "times".

The moral is clear. No single message or small set of messages can reliably convey the meaning of a given set of symbols. However, if we send enough examples of how symbols are to be used, using different symbols in different contexts, then it becomes more and more likely that the web of usage will trap the symbols in a single meaning. There has been surprisingly little work on the development of a string of messages which will build up an unambiguous interpretation for a sufficiently rich set of symbols and words. The only example that I know of that has been worked out in immense detail is contained in the book "LINCOS" by Hans Freudenthal, a Dutch mathematician, which was published in 1960. However, I know of no attempt to build misinterpretations of the system of the kind provided in the previous figures. In any case, Freudenthal's achievement remains impressive, for he was able to build a vocabulary through sequences of examples of the kind shown in Figure 2 [i.e., Frank Drake's picture (above on the right in rotated and non-rotated views)] which was rich enough to express basic concepts of Newtonian physics and of relativity theory, as well as to express the concept of truth and of falsehood, and to convey certain basic aspects of social behavior. If, in fact, our commitment to interstellar communication becomes so large that we turn seriously to the design of messages — rather than, as we do here, trying to anticipate what form such messages might take if and when we receive them — then it will be appropriate to mount a massive effort to build upon Freudenthal's work, doing everything we can to extend the richness, while guarding against possible misinterpretations.

"The trouble with pictures is that they are too literal to communicate general truths."

The research in the field of *artificial intelligence* (AI), or the programming of computers to behave in apparently intelligent ways, may in fact give us some insight into what must be involved in the design of an appropriate language for interstellar communication. The key point about such communication is that we can make very few presuppositions indeed — beyond the possession of certain basic mathematical concepts — about what the creatures know, or what type of assumptions they make on hearing a message about its implications. One important area of AI research is machine understanding of natural language. One builds up a data base on some topic within the memory of a computer, and then wishes to program it in such a way that it can take a question typed in by a human in English and infer from that question what data it must retrieve from memory, how it must combine those data, and how the result should be put out as an answer to the original question in English. So far, the success of programs for machine understanding of natural language has been restricted to cases in which communication with the computer concerns a very limited "microworld". When we use words in normal discourse, they may have many different meanings. For example, the word "pen" has completely different meanings in the sentences "The ink is in the pen," and "The pig is in the pen," — and the last sentence can even have a drastically different meaning from the normal if it is uttered in the context of two convicts discussing the present whereabouts of a policeman. Thus, the meaning of a word may be very hard to infer unless one has a detailed knowledge of the syntax or grammatical structure of the language, and a detailed knowledge of the sort of situation — in other words the "microworld" — that the sentence is about. A computer program for understanding English sentences only works if it is provided with a full specification of grammatical structure and a full specification of the very limited world to which the sentences may refer. We may expect, then, that our interstellar communication must start by spelling out in inordinate detail the conventions for structuring the strings of our language, and the topics about which we will communicate.

However, rather than try to get away with the type of brief ambiguous expressions that work well in normal human discourse, we will probably build a language which — while using high-level constructs to refer to earlier discourse so as to keep the length of individual sentences within bounds — will be structured to reduce ambiguity. One may think of a mixture of the language of legal documents and the language of algebra to get an approximation to what such a language would look like.

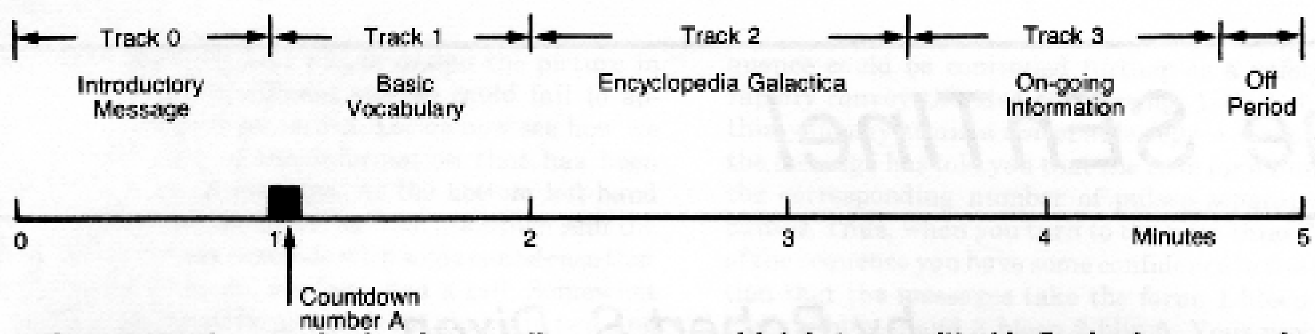
One of the dominant themes in current research on linguistics — the structure of language — concerns the search for a "universal grammar". However, in the context of our present topic, this search for universal grammar is very parochial indeed. It is not a search for a grammar which applies to all languages throughout the universe — rather it looks for commonalities amongst all human languages, in the hope that this will give us some insights into the structure of the human brain which all of us share due to our common evolutionary heritage. Thus, unfortunately, it is not clear that the science of linguistics as it is currently developed has too much to offer us. Intriguingly, we must look back to the 16th and 17th Century for descriptions of mythical voyages to the Moon and other planets for attempts to build a language which is indeed truly universal. This search for a so-called "universal character" was centered on the idea that one could symbolize an object or a property in such a way that the symbol contained within its structure all that one needed to know about that which was symbolized. Fortunately, or unfortunately, we now know so much more about the objects of our world — and infer much about the objects of other worlds — that we cannot believe in the existence of such symbols. If we wish to keep our symbols of manageable size, then they must in some sense be short and arbitrary — as many of the words of the English language indeed are — but able to refer to bodies of accumulated knowledge stored elsewhere in our dictionaries or encyclopedias or libraries. It is the intermingled development of such symbols together with the information to which they refer that we must now turn.

Structuring the Message

Suppose, then, that we — or whoever is creating the interstellar message — have designed a language which appears to be sufficiently universal that it can be comprehended by an intelligence which has some form of language and some mathematical ability of its own. Suppose, too, that we have designed a sequence of statements which make the items of the language almost impossible to misinterpret. It might seem that the appropriate way to start a conversation going, then, would be to provide the sequence of statements which serves to teach the receiver this new language, and then — having established the language — use it to provide instructions upon how to send a reply, and then give the questions to which a reply is sought. However, a little reflection shows that this is not a good way to proceed. While we cannot guarantee that a communicating intelligence would use the following strategy, we now present a strategy which does seem likely.

The first consideration to bear in mind is that the recipient or receiver may only sample the message for a short period of time. If he were to come upon the message long after the transmission of the basic vocabulary, there would be little chance of comprehension. The other point is that even with optimistic assumptions the round-trip time for a communication may be 200 years and delays of this kind suggest that a strategy of sending a question and then sitting back while waiting for a reply is ill conceived.

Instead, then, we suggest the following. Approximately every five minutes a short message is sent of so regular a structure that anyone hearing it will be convinced with high probability that they are listening to the product of some intelligence, rather than some natural phenomenon. The message might be a "number beacon" like that whose initial segment is given in Figure 2 [see Frank Drake's picture above (in rotated and non-rotated views)] which is sufficient to establish not only the intelligence of the transmitter, but also to establish the basic number system which will be used.



Structure of one unit of an interstellar message which is transmitted in 5 minute segments. The first minute (Track 0) establishes the basic number system and is repeated exactly from one 5 minute period to the next. The second minute of each 5 minutes (Track 1) starts with a countdown number and gives basic vocabulary, with a new lesson every 5 minutes until the basic vocabulary is built up in perhaps a month. The third minute or so of the 5 minute period (Track 2) contains sections of a basic encyclopedia or Encyclopedia Galactica which might require 10 to 100 years to transmit with a new edition coming out each century. The remaining time of the 5 minute period (Track 3) contains on-going information.

Let us call this "number beacon" Track 0: exactly the same message will be transmitted on Track 0 for the first of every 5 minutes, as shown in Figure 3 [centered above]. Let us call the second segment of each 5 minutes Track 1. Track 1 is to be devoted to basic vocabulary, and would build up the knowledge of a language such as LINCOS on which further communications are based. It might be that a month would suffice to build up the basic vocabulary of the interstellar language, and so each segment on Track 1 would start with a number A which indicates how many more segments on Track 1 are required to complete the basic vocabulary lesson. We would quickly notice that immediately following the Track 0 standard message came a number, and that this number decreased by 1 every time. It would thus be reasonable to infer that some countdown was taking place, and that the basic vocabulary lesson would be reinitiated as soon as the count passed 0. This would thus give us the confidence to hold on until the Track 1 cycle started again, knowing that we could then proceed to gain our basic vocabulary. Presumably, the Track 1 cycle would include a general description of the other features of the message, and instructions on how to acquire even further information.

Track 2 would contain the basic encyclopedia — it might have something like a 10 or even 100-year cycle time — but given the time-scale of the communication this is not an unreasonable time to wait. During this period, we would gain an appreciation of the type of intelligence with which we were communicating, and would learn much about their sciences and culture. We might think, then, of Track 2 as being the transmission of the *Encyclopedia Galactica*, with a complete transmission every hundred years, say, with perhaps a new edition coming out each century!

The remainder of each 5 minutes would be reserved for the transmittal of on-going information (Track 3), the equivalent of sending the journals of the culture across the galactic space, but with questions and requests for comparative data interspersed with the account of the latest discoveries of the transmitter.

Within a century, then—and possibly much sooner—we would have learned enough to initiate transmission of our own response.

It is perhaps worth saying something more about the nature of the encyclopedia. An encyclopedia as we normally know it has entries arranged in alphabetical order. To find information in the encyclopedia one must have firstly the idea that the information is contained within the encyclopedia and secondly a number of words with which to index an item — these words can then be used to provide alphabetical addresses to get access to possibly relevant entries in the encyclopedia. However, if we are to receive an Encyclopedia Galactica neither of these conditions hold. We do not know what is stored in the Encyclopedia, and we often lack the words which will give us access to the material even if it is there. It does not seem unreasonable to suggest, then, that the Encyclopedia should take the form not of the equivalent of written volumes, but rather the form of elaborate computer programs which will hold a vast amount of information but also provide highly structured means for getting access to the data on the basis of many tentatively formulated questions. Perhaps, then, it is not too fanciful to imagine that early stages of the Encyclopedic information would include instructions on how to build a computer, and how to program it, so that it would be able to serve as an active repository for the Encyclopedia Galactica. Going even further, one may imagine that the computer will be constructed in such a way that eventually it can simply program itself on the basis of the incoming interstellar message, without any further direct intervention on the basis of the recipient. The computer need not only contain dialog enquiry programs to give us access to the sort of information that a written encyclopedia would contain, but could also contain simulation programs. It might even contain world models of a kind far transcending those currently studied by the Club of Rome, and it would be by the studying of those models under varying input conditions as tested on the computer that we would be able to make projections about the fate of mankind under varying types of decisions on the form of international relations. Of course, one might become very paranoid, and imagine that the computer we are building is the artificial intelligence which will succeed us as the next highest form of intelligence on Earth (recall the novel "A for Andromeda"!).

"One of the most important aspects of language is that it frees us from the here and now."

Another intriguing question raised by the proper structuring of such a message is the question of how intelligent we really are — even when we join our minds together in symbiosis with sophisticated computers. To take a homely example: a number of scientists have discovered that chimpanzees can indeed be taught a simple 'language', and construct quite complicated sentences by putting symbols they are taught together in novel ways. In fact, we have not yet exhausted the complexity of what a chimp can learn, and it may well be that they can come to greatly transcend their current apparent limitations. However, there is little evidence yet that chimpanzees can create a language nearly as complex as that which they can learn — though, again, it may take many generations of training chimpanzees and then letting them live together with young chimpanzees before we can explore the justice of this claim. Have we, then, reached a 'regenerative stage' when — at least in symbiosis with our machines — we are capable of understanding anything which any intelligence can understand, or are there new levels which are blocked to us, and which we may be taught in a passive way as the chimpanzees are now taught, but in which we can never aspire to be creative?

In any case, if we are going to receive communications from a civilization which is hundreds of thousands of years old, we may well expect that they will have notions which far transcend anything which we can now imagine. To many readers, the idea that the interstellar message should provide instructions on how to assemble a computer which can then answer many questions in a flexible way seems to come right out the the pages of science fiction. Yet, in fact, we are within the first 50 years of the existence of general-purpose computers on our planet. In other words, such an idea may seem incredibly old-fashioned — perhaps even lost in the mists of primeval history—to the transmitters. If communication is established, we may be in for a lot of surprises.

The Nature of the Conversation

What does one say in a dialog in which each question must wait 200 years for an answer, and the "conversation" may extend over millenia? Are we to imagine that dialog must fail, as we become passively overwhelmed by the flood of information which "gives us all the answers"?

To answer these questions we must realize that we are in fact at this very time receiving messages from intelligent civilizations, messages transmitted hundreds or even thousands of years ago. By these messages, I refer to such documents as the American Constitution, the writings of Newton or Euclid, the corpus of Greek philosophy, and the Bible. What is important about these examples is that they do not, in fact, "give us all the answers". Nonetheless, they are rich mines of information, and provide a basis for an on-going process of *interpretation* — just think of the disciplines of constitutional law, philosophy, and theology.

What this means is that knowledge is not simply a pile of pieces of data, to which one may turn for the answer to any given question. Rather, it provides a source of ideas, with which we must struggle in determining what to do in a particular situation.

To take one example: We have suggested that one of the most valuable things that we can learn from the Encyclopedia Galactica is a route to world stability. Yet what if we receive a message from an alien intelligence telling us that they have found that the key to social harmony is for adults to live together in groups of 12 — with four of each sex! When we turn from physics to sociology, we may find that much of the information is conditioned upon a biology with a completely different evolutionary history to our own. Trying to understand why groups with four of each of the three sexes help these creatures may give us insight into new ways of organizing our own society. But it is in no way a strategy which can be plugged in for any human society.

"What does one say in a dialog in which each question must wait 200 years for an answer . . ."

Bearing this in mind, the leisurely pace of interstellar communication becomes in fact appropriate — it gives us time to assimilate the messages that we receive, and accommodate to them, providing grist for our own theories which we will use to guide our own actions. We can expect, then, that it will require the wisdom of many humans to transform the interstellar message into prescriptions for courses of action. In the case of purely physical projects — such as the description of a new energy source — the implementation of suggestions contained in the interstellar message may be relatively direct. But, as we have already seen, the use of sociological insights may require a drastic transformation. It is perhaps to be expected that, in the nature of humankind, many 'false prophets' will arise once we receive such messages, who will forcefully argue for the adoption of various social structures long before they have been transmuted into a form adapted to human needs and, history. But the give and take between fashionable cult and accumulated wisdom has always been part of the human condition, and there is no reason to expect that to change, no matter how much of the galactic wisdom should one day come to be ours.

Arbib engaged in interspecies communication

Michael A. Arbib is Professor of Computer and Information Science and Director of the Center for Systems Neuroscience at the University of Massachusetts, Amherst. Born in 1940, he received a Bachelor's degree from the University of Sydney, Australia, in 1961 and a Doctor's degree from the Massachusetts Institute of Technology in 1963.

Arbib's primary research interests lie in the mathematical study of computation and control on the one hand, and in the study of brain theory and artificial intelligence on the other hand. However, he has maintained an interest in the problems posed by interstellar communication ever since taking part in a series of lectures given at NASA's Ames Research Center in Moffett Field, California in the summer of 1970. The present article is the revised text of a lecture given as part of a lecture series on "Our Galactic Heritage" at San Jose State University and San Francisco City College in May, 1976. Readers wishing an elementary introduction to some of the concepts of computers and artificial intelligence discussed in the present paper may consult Arbib's book "Computers and the Cybernetic Society" (Academic Press, 1977).