M I N U T E S

WORKSHOP ON CULTURAL EVOLUTION

held at

Center for Advanced Study in the Behavioral Sciences
Stanford, California

November 24-25, 1975

JOSHUA LEDERBERG - CHAIRMAN

D R A F T

MINUTES

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First Day, November 24

The Chairman, Joshua Lederberg, opened the meeting and outlined the objectives of the Workshop on Cultural Evolution.

Philip Morrison then described the purpose of the series of Interstellar Communication Workshops. He pointed out that we now have techniques that will permit us to see if we can communicate with beings on other planets. One major consideration in deciding whether to attempt such communication is the likelihood we attach to the existence of intelligent creatures in our galaxy with whom we can communicate. We assume that such other creatures would be much like ourselves and would reside on a planet much like Earth. We don't know whether another such planet exists. We know that there are 200,000,000 sun-like stars in our Galaxy; perhaps many of them have planets although we do not have a good theory of the origin of solar systems.

Morrison then asked what hypotheses can we make about the existence and nature of other creatures in our galaxy with whom we can communicate? What is the nature of the evolutionary processes which would lead to their existence? What would such creatures be like? For lack of imagination we assume that we are seeking terrestrial beings who are like us. That is, we consider the likelihood of the evolution of mammals, primates, and beings that can invent radio telescopes. What are the conditions of time and environment under which such beings would evolve? What is the number of cultures in our galaxy which engage in radio communication across interstellar space, and what is the likelihood that we will be able to detect one of those cultures?

One perspective on this question is that radio communication seems like a chance invention, even in our scientific history. Hence, it might seem altogether improbable that it would be invented by some extraterrestrial species. One might even speculate that there are other and better possible ways to bridge interstellar space. There is little we can do to evaluate this, given our present knowledge.

Another perspective on the likelihood that an extraterrestrial culture will invent radio communication is that it is inevitable if they reach a level of intellectual development comparable to ours. The history of the invention of radio communication suggests that this is so. In the early 1930's, Jansky, of Bell Labs, was studying the noise background at the radio-frequencies at which inter-continental communications systems were then being developed, for purely economic reasons. The band in question was to be used for HF communication because, by chance, legislation required other radio users in the post World War I era to use other bands and this one was available. But HF was not considered suitable for high powered long distance communication. It turned out that lightning is a source of noise, and that the center of the galaxy is a source of noise. Thus radio astronomy was started - and ignored by the profession with the exception of one famous amateur until it had a rebirth after World War II as the result of new and powerful techniques.

However, one could also take the view that given the knowledge we had in the 1880's of Maxwell's equations, and given the discovery of radio, there are many ways that we could have chanced upon the discovery of radio astronomy. One of those chance discoveries was bound to have occurred within a short time after the formulation of Maxwell's equations; if Jansky had not done his work, the discovery would have been made in some other *a priori* improbable manner.

Morrison concluded by proposing that all of evolution, not just the evolution of radio astronomy, might be viewed as a series of successive approximations rather than as a straight line. Given enough time and the existence of certain environmental characteristics, complex structures will form and some will survive and provide a basis for the development of more complex structures. There may be many ways in which the precise details of an evolutionary process occur, just as there are many ways in which radio astronomy might have been invented. Which one occurs may not be terribly important. That certain endpoints are reached in the process, such as the emergence of a species that invents radio astronomy, may be inevitable, however, given enough time. If evolution is viewed as a series of successive approximations of this kind, then we see that it is very difficult to predict a particular course of evolution, although we can explain post hoc the development of existing species and their technologies. It is this inability to predict the course of evolution that makes it difficult to attach values to equations, such as Drake's, which deal with the likelihood that there exist extraterrestrial cultures with whom we can communicate by radio astronomy.

Lederberg then discussed the reasons why it was considered important to consult specialists with the background of this group. He said that Philip Morrison had summarized very cogently most of the working assumptions of those currently engaged in work on interstellar communication. He stressed that these are primarily physical scientists who would benefit from the views of experts in the biological and social sciences on questions of the evolution of intelligence and technology.

Lederberg then called on Carl Sagan to explain the Drake equation for the number of civilizations in the galaxy. He urged the social and natural scientists present to question the cultural and sociological assumptions on which the Drake equation is based.

Sagan stated the Drake equation:

$$N = R_* f_p n_e f_\ell f_i f_c L$$

where:

N is the number of technological societies in the universe capable of radio communication,

R_* the rate of star formation,

f_p the fraction of stars having planets

n_e the number of suitable planets per ecosphere

f_ℓ the fraction of suitable planets on which life starts

f_i the fraction of life starts that evolve into intelligence

f_c the fraction of intelligent civilizations that attempt communication,

while L is the characteristic lifetime of a civilization.

Sagan stressed that the uncertainties attached to the terms having to do with biological and cultural evolution far exceed the uncertainties attached to the terms of the equation which may be evaluated by the physical sciences. He said that these who have studied the Drake equation have speculated that a value of 10^{-2} for $f_i f_c$ would not be unreasonable. One of the major questions, therefore, is whether this value is in fact reasonable. He then raised the following issues concerning the biological terms of the equations:

1. We do not define intelligence, except to say that we mean the kind of intelligence that could lead to invention of radio astronomy - whatever that may imply.

2. We are not sure what temperature conditions will support life.

3. We need about 5 billion years for intelligence to develop if we are guided by what occurred on Earth. Therefore, B or A stars with lifetimes in the tens of millions of years are not likely to have life-supporting planets.

4. Many stars are older than ours and may have been long-lived slow burners. So we might expect many of the stars in existence now to have planets that sustain life.

5. The lifetime of cultures is a critical factor. Technological societies may tend to destroy themselves rapidly. However, N and the lifetime of cultures may not be independent. For example, as N increases, perhaps the amount of interstellar communication also increases; thus both N (at any given time) and the lifetime of cultures may increase due to the communication between emergent civilizations and cultures who have learned how to keep from destroying themselves if they transmit this information across interstellar distances.

6. We may get some ideas about search strategies by developing estimates of the values of the terms in the equation. For example, if N is small, this would warrant use of more powerful equipment. If N is large, this would warrant search with existing technology. If N is very small, search would be unwarranted.

Kevles thought it would be good if we could more confidently estimate N. There ensued an extensive discussion about the conditions under which life evolved on the primitive earth. Sagan felt it probable that a 1% amino acid solution, "Knorr's Chicken Soup", would have been produced by natural phenomena and that this evolved into living structures. The amount of time required on Earth for such evolution to occur appears to have been a few hundred million years or less. McCarthy thought the most important time-scale was that required for the development of sexually reproducing organisms. Lederberg thought that we understand the genetics of this, but not of life's origin. Sagan agreed that the origin of the genetic code is an unsolved problem. He added that the origin of an oxygen atmosphere might have been a critical event in the evolution of higher life; this must have required the prior evolution of photosynthetic plants.

Sagan pointed out that here on Earth there has been little opportunity to observe independent emergences of intelligent species. In the absence of the concrete example of several emergences of intelligence on earth, Sagan thought the following alternate lines of speculation might be advanced:

1. Once life emerges, all else that we have seen on Earth is inevitable, given enough time.

2. The number of independent events that must occur to produce technological man is so incredibly great that it is unlikely that more than one such species would emerge.

3. We are not talking about just one sequence of events (the sequence that actually occurred to produce man). We are talking about all of the possible pathways to the development of man. There are many possible sequences of events that could lead to the development of man and hence the likelihood that man would emerge is very great.

Sagan then explained the principle of mediocrity. Given an optimistic estimate of the rate of emergence, in our galaxy, of technological cultures, by which we mean those that develop radio astronomy, we need to recall that we emerged just about 20 years ago; hence we are very backward. What has happened on Earth is unlikely to be in a major way different from what has happened elsewhere. Given statistical sampling theory, it is reasonable to assume that Earth is not terribly far from the modal level of development. But when we consider the time scale on which we think about the development of planets in our galaxy and how far man has advanced in a mere 200 years, we see that it is very unlikely that other cultures would be at exactly our stage of development. Therefore most who have reached the level at which radio astronomy is possible will also have advanced beyond this level. Of course, technological cultures may not really last that long before self-destructing. They may only last a few decades. Or, it may be that a few technological cultures learn how to avoid self-destruction and last for a very long time.

Sagan concluded that in any case, communication is made difficult for us by the following considerations. Cultures near to us in distance, and thus likely to contact us, are not likely to be similar to us in level of maturity. They are likely to be far more advanced. Perhaps we could not decode their signals or they might be uninterested in us. On the other hand, cultures a long way from us are the ones with which exchange of messages would be difficult, and two-way communication might be utterly impossible, but among those are ones likely to be not too far beyond our level of development.

Morrison said there is a third possibility: our being in the line of sight of two communicating cultures. But it is very unlikely that this would be so. And even if we were, it is unlikely that we could decode their communication given our state of immaturity.

Following Sagan's presentation there was a long discussion on the conditions thought to produce technology. In particular, much attention was given to the role of conflict and war. The discussion was free-flowing and inconclusive. The search for a direct relationship between the occurrence of war and the emergence of technology led to the following difficulty: discovery of scientific principles is probably largely independent of the development of that technology which is accelerated by wars. Furthermore, Morrison thought the development of war-related technologies may inhibit other technological developments. Clark emphasized that climate and environment were major causal factors in the evolution of technology.

A number of considerations were raised about the effect of war or conflict on the emergence of intelligence. Lederberg thought war was a major factor. It seems to require rapid invention. Strategy discussions that are connected with the planning of warfare tend to involve a kind of verbal competition that is highly inventive. But Kevles thought investments in new knowledge or technology merely required expectation of a higher benefit than investment in something else would give; these could include economic and other kinds of benefit as well as military.

Teuber thought developments in a number of areas, including neurophysiology, had been seriously retarded by World War II. Other stimuli, too, may cause advance in one area and retardation in another. It is wrong to ponder too deeply the influence of so-called critical events. For example, the importance of what might have happened had the Greeks lost at Marathon has probably been greatly overemphasized. Some developments that subsequently occurred might, to be sure, have been prevented, but others of similar type that did not happen could also have been stimulated.

Teuber agreed with the idea that there are multiple pathways to a given evolutionary end. What is important is whether there is evolutionary pressure tending to produce it. The details of a given course of evolution are mere incidents; had they specifically not occurred, others would have, to lead to essentially the same result. For example, some organs have polyphyletic origins. The eye has been invented at least three times. The cephalopod eye, and the insect eye, as well as the eye of vertebrates have totally different, independent evolutionary histories, but these histories have converged to the same result. The neural networks in each of these eyes are shockingly similar. Indeed, Teuber thought that any life-form evolving in an environment where the optical spectral band is important would develop a light-sensing organ with similar nerve structure. Nevertheless, octopi and vertebrates cannot see the same things. Octopi cannot distinguish mirror images. So different evolutionary pathways cannot be expected to produce identical results.

Lederberg returned to the narrower subject of military stimulus of rapid technological progress. He insisted that much of our present technology has directly or indirectly resulted from military needs. Oliver was unconvinced; he felt that even if Lederberg's point be conceded, the acceleration of technological development resulting from military needs would be negligible on a geological time scale. McCarthy thought Bacon's insights into the relation between technology, science, and progress were a critical event in producing our technological society which demonstrably did not occur in other cultures. Billingham thought that Bacon's work was merely an example of something bound to happen sooner or later, which perhaps happened later. Campbell thought technology was necessary to survival and that the environment was a major stimulating factor. Lederberg thought that intraspecific conflict makes special demands on organisms that their battle with the environment does not: the difference is between intelligence against intelligence on the one hand, and intelligence against mere non-intelligence on the other.

Clark wanted to know whether a general rule for all civilizations was being discussed. Stull asked what was the importance of such a basic biological trait as territoriality in producing intraspecific conflict and what factors might be expected, on some arbitrary planet, to make territorial behavior an advantage which natural selection would favor. Campbell thought territoriality was not basic, but resulted from the primary need to compete for resources. Not all species are territorial; alternate ways of allocating resources might be possible.

Ammerman thought that the importance of military stimuli to technological development might vary from one culture to another. Lederberg asked if we knew of historical examples of protracted conflict not associated with technical advance. China and Mesopotamia were proposed as examples by McCarthy in the sense that while some technological evolution did occur, the idea of progress and technological advance was not present. But this interpretation was rejected in the subsequent discussion. Kevles thought that the diversity of climatic conditions was a major factor, which, combined with others - such as competition for resources - would result in the actual development of anything possible. McCarthy thought commercial competition was important, but Lederberg said commerce is nothing but warfare within the framework of a social compact. McCarthy conceded that military conflict might be important, but wondered whether the time scale might not be a million years rather than ten thousand.

Following the lunch break, Lederberg directed the afternoon's discussion to the topic of "What conditions produce intelligent life and what kinds of intelligent life might evolve".

Campbell cited the echinoderms as an extreme example of what happens in a very stable environment - no evolution at all over indefinitely long time scales. When the environment becomes heterogeneous instead of homogeneous, and time-variable instead of constant, changes occur, and such environmental fluctuations may be looked upon as ultimately responsible for the emergence of intelligence.

Eisenberg asked that it be assumed for the sake of argument and simplicity that intelligence corresponds to brain size, and that solely mammalian evolution be considered. We are then confronted with some interesting data. Because of continental breakup, certain groups of mammals were isolated from one another. For example, in Australia, Madagascar and pre-Pliocene South America there was development of many mammalian species, independent of that which took place on the contiguous land masses. On none of the isolated land masses did there develop mammals with large cranial capacity. We see this today in the mammals of Australia and Madagascar. This was also true in South America, although the development of those species was interrupted in the Pliocene when the northern and southern continents were joined. For example, carnivores on the North American land mass developed rapidly in cranial capacity. Ungulates on the then-isolated South American land mass did not develop in cranial capacity, but only in body size. When the two land masses were joined, the South American ungulates did not possess the ability to defend themselves from the predators which migrated into their territory. Only the mammals on large contiguous land masses developed both large bodies and large cranial capacities. Hence, it is not inevitable that mammals will evolve large cranial capacity. Rather, this development seems to depend on the complexity of the environment in which they occur. And environmental complexity requires a large contiguous land mass.

Morrison pointed out that more time might have produced evolution of each group. He proposed that the complexity and size of the land mass might not be an absolute determinant of the emergence of intelligence. It might affect only the rate of such evolution.

Eisenberg replied that Morrison was advancing a theory while he was presenting data on the only experiments (the isolated areas of Australia, Madagasdar, and South America, and the large continental land mass) of which we know. He granted the possibility of Morrison's view, but pointed out that Earth has not been the site of enough experiments to test Morrison's hypothesis. He suggested as an alternate hypothesis that it takes a critical area, implying competition among a critical minimum number of species, before intelligence can emerge.

Morrison said that if he claimed the rate of evolution was a constant per species per year, that was consistent with Eisenberg's hypothesis. Eisenberg agreed. Ammerman pointed out that evolutionary rates might critically depend on the life span of the animals in question. Campbell pointed out that life span is a characteristic of a species which is surely a product of natural selection and the interaction of the genotype with its environment. Ammerman said this might be related to the length of the day and year; Morrison said that we don't believe day or year lengths would vary by much more than a factor of two, whatever that might imply with respect to animal life spans.

McCarthy asked for the evidence supporting Campbell's claim that the life span is adapted to the manner of life of the species. Campbell conceded that indeed it was possible to find examples of two different species occupying the same ecological niche, but having different life spans and reproductive intervals. Lederberg pointed out that we only poorly understand aging patterns in various species and their biological foundations. Morrison said that the reproductive interval in mammals was always between about one year and twenty, and this distinguished mammals from, say, the insects. Eisenberg replied that among mammals, on the average, the larger the animal is, the longer its potential life span. Morrison said that it is important to distinguish between life span and reproductive interval - the time from egg to egg. In determining evolutionary rates it is the latter which is important. Morrison repeated that for mammals this varies within well-defined limits, approximately from one year to twenty, and said that there must be some reason for this. Eisenberg said that there is a rough correlation between reproductive potential and rate of aging - rapidly reproducing species tend also to age rapidly. Furthermore there is a weak correlation between reproductive interval and brain size. Ammerman asked whether these results might be planet-dependent or could be universally expected. Morrison responded that if elsewhere reproductive intervals were 100 or 1000 times longer, complex life systems would be unlikely to have evolved yet. Ammerman then asked whether mutation rates might be planet-dependent. Sagan said it was his understanding that the primary cause of mutations was interactions among genes of different kinds, and hence this was itself subject to control by natural selection. Lederberg thought that so many factors entered into the determination of life span that it was not likely to be a primary determinant of the evolution rate.

McCarthy then raised the issue of whether the intellectual structure of a problem-solving animal was determined by the problems it faced, or whether that intellectual structure determined the nature of the problems that the animal chooses to deal with. He contrasted the motivational structure of human beings with other animals, say dogs or apes. For example, a dog will seek food, manifest curiosity about another animal, etc., whenever there are proximal stimuli to remind him of them. However, by contrast, man internalizes his purposes and problems and preserves them for years, or even generations. He makes internal models of his external world, embellishes these models, and passes them on to the following generations. We can see different motivational structures in different societies and even between adults and children. If we suppose that a species develops intelligence as a result of competition for survival, must it also develop the kind of motivational structure that leads to science, or art, or interstellar communication?

Morrison thought that this sort of distinction was invalid. What we mean by intelligence is the ability to construct internal models of the situations which an individual encounters, that it might better deal with them. Should organisms with this ability be produced by natural selection, it is difficult to imagine that they would not try to construct internal models of all phenomena they encountered, including the sky. Clark pointed out that man's great advantage over other animals is language - his ability to communicate abstract concepts. This ability developed only perhaps 50 to 100,000 years ago. Before that, communication was on a lower level, though obviously much more advanced than that which is observed between groups of chimpanzees. Evidence Clark cited for the communication of abstract ideas included ritual burial by Neanderthal man. Lederberg said that the great increase in hominid cranial capacity long antedated the developments that Clark was concerned with; something else must have caused it. The increase in cranial capacity was thus a developmental overshoot that made the development of language possible.

Morrison pointed out that Turing had shown that once yes-no choices can be recognized in large number, one can map any mathematical computation onto this "straight tape", given enough time. Once a system capable of conceptualizing internal models of phenomena has evolved, it is only a matter of time before it also develops better models for its communications. That is, overshoot is built into such a system.

Bracewell said that, viewed as gesturing with the tongue, language was a natural evolutionary product of gesturing with the hands. Campbell said the doubling of brain size over the past several million years could be accounted for by the increase in association areas and memory banks for dealing with the environment in symbolic terms. Thus the evolution of language has taken place over at least one or two million years, but reached its present "flowering condition" only very recently. As far as motivation is concerned, Campbell felt we were very little different from the chimpanzee. Brain differences between man and chimpanzee involve primarily the cortex, which is the area of the brain concerned with conceptualizing sense impressions and not with motivations. Furthermore, all animals have the ability to model internally the environment; ours is merely more highly developed. Chimpanzees already are probably able to build models a thousand times more complex than most other animals. Campbell concluded that he thought it was proper to understand the evolution of the brain as a slow development, with it having no more hardware than necessary at any particular time. There were no overshoots and therefore no mysterious developments which produced them.

Lederberg asked Campbell to clarify his picture of the evolution of language and the brain with dates.

Campbell started by pointing out that communication in chimpanzees comes from the limbic system and is largely an involuntary expression of emotions. Communications, such as gestures under voluntary control, come from the cortex. Therefore language starts with gestures. McCarthy asked what might the limits be in teaching chimpanzees American sign language; he claimed that we see here an ability which wild chimps may not use. Clark pointed out that it had been possible to teach very complex behavior, including what amounted to making and intelligently using a knife, to orangutans by having them observe humans do the same. Sagan said that since what we seem to have in chimps is an ability to express abstract thought, which, however, they do not develop on their own, perhaps we have exterminated all primates with greater ability, and let survive only those with abilities we cannot recognize as similar to our own. Clark said that it is extremely important to realize the chimp and other apes evolved in the forest where there is an abundant supply of plant foods, while man evolved on the dry savannah. On the savannah there was a vastly greater opportunity for experimentation, and much greater evolutionary pressures forcing new adaptations. Lederberg returned to the question of whether apes indeed possess symbolic and learning abilities they never use in the wild.

Eisenberg disputed the assumption that animals that have developed in the forest have developed relatively little compared to man. He argued that in order for animals to survive in the woods, to live well and breed and reproduce, they must learn a great deal. The forest, and for that matter the seas, are not a Garden of Eden and require an incredibly high degree of evolutionary adaptation. The issue, rather, is the kind of adaptation that occurs; certainly chimps use whatever abilities they have, but to solve the problems they must to survive, and not to play the games that we care to teach animals in captivity.

Clark said that only the hominids seem ever to have developed a systematic tool-making ability. Chimps and other animals merely use tools. McCarthy asked whether the difference might not be social. For example, we teach a chimp society something new, and they may retain it and pass it on to new generations. Discussion ensued on whether chimpanzees spontaneously teach sign language to other chimps; it was not clear to what degree this has yet been observed.

Lederberg then repeated his request for a cultural and biological history of language with dates. Campbell said that as he understood it, the brain started to take off about 3 million years ago, having previously been more-or-less chimpanzee-sized (~450 cc). The earliest cultural evidence appears between 2.6 and 1.8 million years ago; the actual date is uncertain. This evidence is the first stone tools; there may have been perishable manufactured tools (wood and bone) long before this date. There must be a link between increasing cranial capacity, as evidenced by tool manufacture, and language. Language must have started with gestures. One could then learn to draw attention to his gestures by making noises. Once this has been done, you are using your vocal cords in a voluntary way. Sound can then begin to take over, especially since you can make noises in the dark. Thus there was a slow switch from gesture to vocal communication generated by the cortex. Eisenberg thought that surely vocal communication antedated gestural. Campbell agreed, but said this was merely involuntary expression of emotion. Eisenberg said that dueting and antiphonal calling in marmosets, for example, required voluntary control. But Campbell said that his distinction was between communication generated by the limbic system and the cortex; Eisenberg accepted the idea that the former preceded the latter.

Eisenberg then made the assertion that surely some of the hominids' increased cranial capacity was related to a general increase in motor coordination. The "text book idea" that man is a puny beast is simply not true. He is a fantastically powerful and coordinated organism, especially in the hands and limbs. He has subtle and accurate motor control which gives him great physical ability. He has independent control of his fingers. He has motor control of vocalization. He has a very complex feedback system which enables him accurately to determine the course of projectiles, with a little practice. These possibilities seem to allow for an extremely rapid rate of cultural evolution. The complexity of our tools has increased at a very great rate in the last several thousand years.

Campbell and Eisenberg agreed that initially all primates developed a large brain to cope with an arboreal environment. Eisenberg pointed out that other diurnal, arboreal animals like squirrels have large ratios of brain size to body mass. Campbell pointed out some of the complexities of the arboreal environment: three-dimensionality, complexity of structure, and the existence of things of varying degrees of hardness, such as branches and leaves. But Eisenberg emphasized that the arboreal environment cannot be responsible for man's superb motor control, and Campbell agreed. No monkey or ape can control a thrown projectile the way a man can. The independent control of fingers is unique to man.

Oliver asked for clarification of the importance of this discussion to the development of language. Did cranial capacity increase as a result of the survival value of communication? Eisenberg said increased cranial capacity received its impetus from motor control and the need for increased locomotive and perceptual abilities in man's environments. But Sagan asked if this implied enhanced linguistic abilities; after all, the motor and language areas of the brain are different. Clark pointed out that the increased rate of evolution of the brain which set in some 3 million years ago was correlated with increased use of tools. Complexity of tools and complexity of brain development are demonstrably related. Sagan objected that this does not mean one caused the other. Clark said he envisioned a feed-back mechanism going on during this entire period. Lederberg asked how often does this happen. What was inevitable in Africa didn't happen at all in South America. Winograd pointed out that the picture must be viewed as a whole; no individual factor, such as tool use, can be singled out from the social structure, communication, and all the rest. Lederberg was not satisfied by this; he still wanted to know how often this was likely to occur.

Stull said that maybe we could determine the answer to Lederberg's question if we could identify the selective pressures which produced hominid evolution. Eisenberg said this was more difficult. In horse-evolution and proboscidean-evolution there was also an increase in brain size. And we might well ask ourselves why an elephant has such a large brain. Sagan asked whether the ratio of brain to body size had increased in these cases. Eisenberg said it had. McCarthy said from the computer-science point of view, only brain size should be important. Was a large brain needed to control a large body? Eisenberg said that even if the answer to this should be yes, the elephant has an abnormally large brain in terms of its body size. And a 50-ton whale has a very much larger brain than a 50-ton shark. It was concluded that the brain-to-body size ratio is probably a good rough measure of intelligence.

Lederberg asked if the discussion could return to the isolation of those selective factors responsible for increasing intelligence. Campbell pointed out that there is a continuum among primates. Chimps are on the verge of man's abilities in many respects, including their social organization, tool-making, and communicative abilities. If man were to be exterminated, chimps could move onto the savannah and develop true intelligence in but a few million years.

Stull asked whether a planet must have a savannah environment for intelligent species to develop. Wolfe asked whether we could consider not just the savannah <u>per se</u>, but the role of climatic changes in general and the importance of such factors as the tilt of our spin-axis with respect to our orbital plane and plate tectonics.

Sagan said that the tilt of the axis of Mars varies from nearly zero to 34°, because it is pumped by Jupiter. Were it not for our moon, which damps this effect, the tilt of our axis would vary nearly as much and climatic fluctuations on earth would be much more violent on a time scale of hundreds of thousands of years. Plate tectonics seems to be a function of the mass of the planet; however, plate tectonics on the earth may have developed only a few hundred million years ago. To the extent that plate tectonics produces vulcanism and causes changes in the earth's albedo, it may cause climatic change. Campbell said the savannah was not special. What was crucial was that an animal which was well adapted to life in the complex forest environment proved pre-adapted to an ecological niche on the savannah and was successfully able to invade it. This opened many new possibilities. Coming onto the savannah from the forest was the critical event. Lederberg asked whether this was not an unlikely event in the history of a planet. Campbell said he thought not; any animal was likely to expand its range into new environments given that amount of preadaptation necessary. Thus what appears most important in stimulating evolution is the presence on a planet of a large diversity of environments which are readily accessible to the inhabitants of each.

Lederberg commented that everyone seemed to believe, that given a reasonable planetary environment and sufficient time, the evolution of intelligence was inevitable. He asked if there was anyone who took a contrary view; he thought that George Gaylord Simpson at least had believed this was so improbable, "perhaps it didn't even happen here". Stull asked whether it had not been agreed that if there is a planet with few diverse environments or perhaps a very constant climate, intelligence might not emerge, or if it did, it would be on a much longer time scale. Morrison agreed that a planet covered entirely by water was unlikely to evolve a civilization which would build radio telescopes.

McCarthy concluded the discussion before the break by asking whether the kinds of species and cultures that develop might conceivably be very different from ours. For example, highly seasonal intelligent animals, for example, ones which hibernate for a long time and must gather and store supplies on which to live during those times, might develop as more cooperative and unified animals than we are. Whatever they did, they would all do; they would be more business-like, less individual and less inventive. This would suggest that they would not invent means of interstellar communication. There is a second example of a particular adaptation which could lead to cultural differences. A species might emerge, which, like the frog, had to radiate out to new territories to survive. Frogs need to hop over dry land in order to find new ponds; many die in the process, but frogs survive as a species because a few make it to other sources of water. As soon as the number of frogs becomes quite large relative to the volume of water in which they live, frogs begin this process of migration. If people or some other intelligent beings had to live around some kind of oases which tended periodically to vanish, they would also be likely to develop a strategy for survival which included some kind of periodic migration, despite great hazards, over inhospitable territory in quest of habitable territory. Such a species might develop more and more complex means of migration and survival in the inhospitable areas, and thus become highly adapted to space travel; indeed, they might be violently expansionist.

After the break Lederberg asked whether he correctly understood that everyone believed that a combined probability like 10^{-2} were reasonable to assume for the evolution of intelligence and technological civilization over time periods on the order of 2 to 4 billion years, given the origin of life. Campbell said he could accept this, if Lederberg included in the origin of life the rise of cellular life; non-cellular animals might evolve very differently. Nobody else disputed Lederberg's probability estimate; however, the negative opinion of George Gaylord Simpson was discussed at length. Ammerman pointed out that when he framed that opinion, in the early fifties, much less was known about such things as the evolution of the hominids and the social structure and communicative abilities of chimpanzees which members of the present workshop were relying upon to support their view that the evolution of intelligence was probable. At that time man appeared terribly unique; today this is no longer true, and it is easy to imagine how other lines could have led or might yet lead to intelligence and civilization. Campbell agreed that certainly the study of primate behavior since 1960 had drastically changed man's picture of himself in relation to other animals; previously we had seemed so utterly different that our evolution must have been very improbable. That no great gap exists implies our evolution was not at all an unusual occurrence. Eisenberg agreed, but said that this argument has other consequences. For example, as we now understand things, man is not the only intelligent animal to have evolved on earth. There are also small cetaceans, and perhaps chimpanzees and elephants. But only one has a technology. Was there anything inevitable about our developing technology? Clark felt that it was the combination of our manipulative ability with intelligence that was crucial. Campbell agreed and said it came back to the concurrence of forest environments in proximity to the savannah. Eisenberg asked for clarification; were people saying that it was of importance that cetaceans don't manipulate things, and that while elephants do, they nevertheless seem to have no need for tools? Clark said that to start off with, efficient bipedal locomotion freed the forelimbs for experimentation with implements. The use of implements proved valuable to survival and generated a feedback whereby brain size increased, motor coordination was improved, and the erect posture further developed. Eisenberg asked how often this could be expected to happen in the evolution of life on other planets. Why couldn't it stop at the elephant stage; they, after all, have wonderful manipulative ability. Clark pointed out that the elephant's implements are used for a single purpose, but man's tools are used for a great variety of purposes as circumstances demand. Lederberg asked how old cetacean intelligence was. Eisenberg said older than human. Lederberg concluded that the pace of human evolution was more rapid and the cetaceans seemed to be going nowhere. Teuber cautioned against looking too closely at recent forms. He pointed out that early Cetacean brains were related to those of the ungulates, while that of the early horse, Eohippus, was almost identical to the opossum's. Ungulate, and, especially, opossum brains have evolved little in the past 60 million years, but the changes in cetacean and horse brains, which are well evidenced by the fossil record, have been enormous when this entire period is considered. Campbell said he would not expect a manipulative species to develop in a marine environment. Eisenberg could not accept this because it was based on the false assumption that that environment was homogeneous; there are currents and different temperature and pressure regimes which make it very exciting. But, Campbell said, there is nothing in that environment that favors the development of limbs and manipulative organs.

At this juncture, Lederberg suggested that our review of our past had provided some useful perspective on how intelligent beings evolve. He proposed that we now put ourselves in the position of extraterrestrials and try to speculate about their technical capabilities and their attitudes. Will they beam messages to us? Will they listen to us? What cultural gaps will there be between them and us? What are the implications of these gaps for our efforts?

Sagan asked why, if they are so advanced, other cultures haven't reworked the whole galaxy in such a way that their presence is apparent. It was suggested that if they had, we wouldn't know--we would assume any such reworking was a natural happening. For example, if gravitation were created by another culture, how would we know? We would be too ignorant to recognize any sophisticated reworking. We would not recognize their artifacts any more than ants in a suburban swimming pool would recognize the artifacts of human civilizations around them.

A similar question, said Sagan, is why there are no extraterrestrials on the Earth. It has been argued in the scientific literature that this could not be true unless there are no extraterrestrials. If there are advanced civilizations, they would have come here recently enough for us to be aware of it. Teuber said you cannot take absence of evidence for evidence of absence. Sagan agreed that there are alternate explanations, such as the difficulty or impossibility of interstellar flight. A second possibility is that technological societies may have a short lifetime and are therefore rare. A third is that there are lots of intelligent cultures throughout the galaxy, but we may not be aware of them because of some intergalactic ethic that one should not disturb emergent cultures. Finally, the evidence may be all around us, but we merely have not looked for it, much as we never looked for pulsars until we discovered them quite by accident. Sagan concluded that from none of these possibilities does it follow that we should not search; rather, given any one of them, we should.

Kevles asked if it follows that as a biological organism develops a progressively larger brain, that brain will be addressed to the same sort of conceptual notions we possess. Development of the kind of technological civilization we have requires similar notions of space and time. Might not the perception of what we call three-dimensional space and time be different, given a different evolutionary history for the "grey matter"? But perhaps it wouldn't be different, if the same types of sensory apparatus - visual, auditory, alfactory, etc. - evolved. Could anyone say anything about the relation between the physiology of the brain and the concepts we possess?

Morrison thought that hardware designs would be independent of the concepts used to describe nature, since after all, its laws work the same way, however we describe them. Stull thought Kevles had raised a serious question. He thought it might be significant that we appear able to communicate with chimpanzees, but not with dolphins, which appear more intelligent than chimps, but the evolution of which is far removed from that of the primate line. He asked whether we have merely gone about communicating with dolphins in the wrong way, or whether our failure might be due to some fundamental physiological difference resulting from our different evolutionary histories. Sagan thought that the investigators of dolphin behavior had simply failed to perform experiments designed to test the idea that the dolphin communicates abstract thoughts and to decipher the mode thereof; he attributed this failure to their captivation by interesting "anecdotal material". But he added that he had not kept up to date in this area in the past four or five years. Eisenberg said he could accept the idea that the paradigms we conceptualize are determined by the way we sense our environment. With respect to the dolphin, the problem has been understanding what they are attempting to represent by their vocalizations. Everyone got thrown off the track by their tendency to mimic. But a new idea now being checked out is that dolphins have no word, say, for shark, but rather transmit the sound pattern identical to the sonar echo one would get from a shark. Now this, if it turns out to be true, is a brilliant insight. It is very difficult for a human used to thinking in his own paradigms to realize that a dolphin could conceptualize the world in such a way. And that man can do this makes one very hopeful that he can also figure out how to understand intelligent extraterrestrial life forms who also do not share our concepts and paradigms.

Lederberg felt that we should consider what another civilization would be like, especially in view of the fact that they might be thousands of years ahead of us. Kevles said it would depend on their relation to death. Lederberg said it was likely that we can, in the near future, eliminate death as a biological necessity. What would be the impact of this on a culture's attitudes? Kevles thought that mortality was the source of the psychological drive to know. Lederberg thought there would always be a zone of ignorance which cultures would want to eliminate, however advanced they were; for example, no amount of theorizing can reveal the natural history of the universe. Campbell thought advanced civilizations might be reluctant to disseminate information which might be dangerous to less developed societies, or which might, in the hands of those societies, become dangerous to themselves.

Campbell then pointed out that we are not motivated to transmit; therefore, we perhaps shouldn't assume others would be motivated. Morrison replied that at some future time, should a passive search for radio signals yield negative results, we might indeed decide to transmit.

Kevles returned to his point that it would have a major impact on our conciousness if we were to abolish death, and asked what implications that would have. Campbell said we would still have to get resources and feed ourselves; therefore our position wasn't likely to change very much. Lederberg disagreed. He thought the impact would be enormous. Oliver wondered whether abolition of death would end progress; he claimed it is the young generation which always changes things. Lederberg said it would still be important to listen even if only a small fraction of civilizations are sufficiently motivated to transmit.

Lederberg asked what might be the impact upon us of discovering radio signals from extraterrestrial intelligent life. Oliver said he thought this could easily be exaggerated, and Morrison pointed out that it would probably be a long time before the message could be decoded and understood. People thus could gradually become accustomed to the idea of the existence of a civilization more advanced than our own before the full extent of the gap between the two should be realized. Oliver thought that the discovery of an advanced culture might refute the pessimistic beliefs of many that our own society cannot possibly survive. Lederberg wondered whether the realization that "it is all in the library" somewhere might not have a demoralizing effect on research scientists. Morrison replied that all scientists today must face the possibility that somebody has already solved the problem they are working on, or will do so before they can; however, this does not deter research. Whatever may be known, there will be new possibilities; also whatever we may think we are learning from extraterrestrials will have to be checked out experimentally.

Kevles drew a distinction between advancement of knowledge and technological advance; the latter could be stimulated by acquisition of new knowledge. Sagan asked again whether everybody really believed 10^{-2} for the combined probability that first intelligent life and then technological civilization would appear, given life's origin on a planet. The participants indicated that they did.

Lederberg then adjourned the discussion for the day.

Second Day, November 25

Lederberg began the second day's discussion by asking the workshop members for advice on: (1) what should be the future inputs from the social sciences into a SETI program; (2) what we might be able to say about the behavior of extraterrestrial civilizations, bearing in mind that we can't base too much of this upon our own behavior; (3) what this might imply in the way of detection strategies; and (4) what degree of search effort was warranted. To facilitate the discussion, he requested some further consideration of the likely number of technological civilizations.

Oliver discussed the relation between the number of civilizations and their longevity. He distributed plots of the mean separation of advanced cultures as a function of mean longevity for values of the combined probability factors in the Drake equation of 1, 10^{-1}, and 10^{-2}. He showed that the separation is not a sensitive function of the longevity since it varies as the cube root of the number of civilizations until one considers distances greater than the thickness of the galactic disk, whereupon it begins to vary as the square root of the number of civilizations. A mean longevity of 10^9 years implies a mean separation of 50 to 60 light years; a mean longevity of 10^6 years implies a mean separation of 700 to 800 light years. The number of two-way communications which can occur goes up both as the longevity and as the reciprocal of the separation, which, in turn, varies inversely with longevity. Therefore for mean lifetimes on the order of millions of years, the possible number of two way exchanges becomes quite large.

Teuber asked if the effects of feedback possibilities such as assimilation of emergent civilizations by those more advanced were being considered. Lederberg replied that this would be of consequence only if transmitting sites were extinguished. Teuber said it might make a difference to search strategies if we could make the assumption that similar rather than dissimilar types of signals would be coming from different locations. Sagan asked Teuber if what he was worried about was decoding strategy. Teuber replied that the sending civilization has an enormous task in deciding what we can detect and evaluate; what they do depends on what assumptions they are likely to make about us, but these could depend on their own nature.

Stull questioned the use of longevity of a civilization in the Drake equation. He thought that intelligence might be the same kind of advantageous adaptation as giant size, which is likely to recur repeatedly, though it be wiped out from time to time. If this is true, the age of the galaxy might be a more appropriate time factor than the longevity. Sagan replied that if the re-emergence time is 10^9 years, the difference will be but a factor of 5, while if the re-emergence time is 10^8 years, the difference will still only be a factor of 50. Thus the number of galactic civilizations might be increased by a factor of 10, which does not make an important change in the probability of interstellar communication. Furthermore, depletion of easily mined resources by a previous civilization might make re-emergence of technological civilization unlikely. Oliver, however, thought that the re-emergence time could be as low as 10^7 years, and if there were enough tectonic activity to bring to the surface new mineral deposits in this length of time, re-emergence would imply that interstellar communication is substantially more probable. Lederberg claimed that to adopt so short a time scale postulated the survivability of species closely related to the intelligent form, such as Earth's primates, which could rapidly develop intelligence; he thought this unlikely and a 10^7 year time scale overly optimistic. Stull disagreed, and emphasized that the entire evolution of the hominids from p primitive mammalian forms had taken place in only approximately $5x10^7$ years. Sagan conceded that re-emergence might increase the number of civilizations by a factor of 100; however, so might a colonization scenario.

Oliver commented that he thought the fraction of stars which are good suns should be in the Drake equation, since small M stars, for example, probably can't support life on any planets they may have.

Sagan, Oliver, Lederberg, Teuber, and Bracewell discussed the relation between the likely number of strong sources and search strategy. Sagan described the observations he and Frank Drake were making of external galaxies with the Arecibo radio telescope in order to search a very large number of stars at one time for very powerful signals. They had so far obtained negative results; however, it was premature to attach a meaning to these. The experiment had not yet been concluded nor all the data reduced. Furthermore, failure might only mean that Drake and Sagan were looking at the wrong frequency or using insufficient sensitivity to detect a weak transmitter in fact present, or that transmitters in external galaxies do not happen to be beamed in our direction, while transmitters in our own might be. Campbell thought that negative results in this experiment should not be considered discouraging since we have not yet even detected pulsars in M31 (the nearby galaxy in Andromeda), and we would expect these to be far more readily detected than civilizations. Furthermore, he thought that if, as believed by some participants, civilizations are altruistic, they would probably transmit only within their own galaxy.

Billingham said Seeger had made calculations of detection probabilities given some number of civilizations. He asked Seeger to outline his results.

Seeger said that if one assumes civilizations are uniformly distributed at random in our galaxy, in association with certain classes of stars, one can calculate out to what distance it is necessary to search in order to have a certain confidence (p_c) that one has tested the assumptions that there are N sites in the galaxy transmitting a given equivalent isotropic radiated power (EIRP = $P_t g_t$). This distance is proportional to the square root of the product of the number of receiving dishes used and the equivalent isotropic radiated power transmitted. The accompanying figure illustrates the situation for the ranges $10^3 \leq N \leq 10^9$ and $10^3 \leq P_t g_t \leq 10^{13}$ watts. Conversely, one can estimate the range of assumptions testable with a given number of dishes. In closing, Seeger remarked that increasing the observing time in a given direction by a factor of sixteen would only double the range.

Ammerman asked whether, since a civilization may not remain at the same level of technology, it might be interested in interstellar communication for only a limited portion of its lifetime. Lederberg thought that if this should be true, it might be wise for us to transmit rather than receiver. Kevles suggested doing both, provided there is no resource problem. Oliver replied that it is much easier to receive first, and transmit only after exhaustive listening has yielded negative results.

Eisenberg questioned Morrison's idea that anything which can happen will happen. He emphasized that there are many possible outcomes of organic evolution, and that the assumption a technological civilization must emerge was unwarranted by the evidence and bordered on theological conviction. He wanted to know if the real motive of the proponents of the interstellar communication idea was to do radio astronomy. If that were true, why was the rationale of looking for intelligence needed to sell radio astronomy? It has always been well funded. Kevles replied that the motivations for funding astronomy have always been navigation and God; formerly it was a real God, today it is a metaphorical one. Eisenberg thought politicians might be credible enough to believe there is a big voice in the sky which might save us, but that scientists ought to be clear on what they were doing. Sagan said that certainly there were theological overtones to the interstellar communication idea, but it was more than that. He, at least, thought that it did have a sound scientific basis.

Campbell commented on the subject of altruism. He said it does indeed seem to be characteristic of advanced social animals. Furthermore, some evolutionary theories predict that altruism should be genetically selected. Therefore at least the postulate of altruism for extraterrestrial civilizations was not without scientific basis. However, he questioned whether altruism would often extend outside the social group with which an organism is involved. Sagan said those societies which can communicate do have a genetic affinity; Campbell replied that he obviously meant cultural affinity. Ammerman added that it was dangerous to infer genetic parallels from cultural and vice versa.

Kevles said that he would prefer to transmit. This involves faith, but should be done whatever the probabilities might be of receiving an answer. Seeger replied that when one is exploring new territory and does not know what he might run into, it is wise to exercise a certain amount of caution.

Campbell made the point that any higher social organism must have an exploratory drive. This can be safely postulated; indeed it is a much better assumption than altruism. Ammerman said that our curiosity does not reflect our real technology. For example, climbing Everest involves little technology. Interstellar communication curiosity may be incident to a particular stage of technological advance; it might give way to other kinds of curiosity with further change in technology. Lederberg thought the exploratory drive might be suppressed once a planet was totally inhabited because he thought it would then lose its value. Bracewell added that some exploratory success was necessary to stimulate the exploratory drive.

At this point Lederberg recessed the meeting for coffee.

After the break, Lederberg said that he wanted each of the participants individually to summarize their opinions on the issues, including their assessment on whether we should transmit or receive.

Eisenberg thought we should try to use our cortex so we think we have a hopeful future and not a gloomy one. Therefore interstellar communication is a worthwhile pursuit, but we should probably listen before we transmit.

Herbig thought a man set in the middle of a strange jungle with lots of noise would be quiet until he had surveyed the situation; he would have no idea of what might emerge from the bushes. Therefore, we should listen only. Furthermore, that is cheaper. He said he was still trying to decide what his position should be. He thought that if we could better evaluate the Drake equation terms, this decision might be easier. However, he thought that further meetings would not be of value in this respect. He said that the participants in this meeting tended each to have their own favorite scheme, but not many solid proposals to take care of those terms which can be evaluated, such as star formation and the existence of planets. But this would not help if the other terms must remain highly uncertain; therefore, it comes down to a matter of personal conviction.

Teuber said that careful scrutiny of strange radio sources was important. In spite of the enormous uncertainties in the Drake equation terms, it was his personal conviction, at least, that we should listen. He emphasized that we are not motivated exclusively by reproductive drives or hunger and recalled an experiment with a monkey which was allowed to choose its reward for successfully performing a task. The monkey, which was enclosed in a cage, repeatedly chose to open a window which showed a toy train moving, rather than the two alternatives, which were a picture of a "monkey lady" and a banana. Whether we find anything or not, to search is important to us; to explore and seek new understandings is really among our most powerful innate drives, and we should satisfy it.

Campbell likened the interstellar communication discussion to a discourse on whether God exists - there seemed to be very little hard evidence by which one could be guided. But this was no reason for discarding the idea. He expressed concern that were a message received, the Pentagon might clamp down on the information. His own impulse was to explore the universe, and he felt strongly that an effort should be mounted. However, he said he was not optimistic about the contents of any message which might be received. It probably wouldn't be helpful at all; still we should search for it.

Ammerman said he was struck by the importance of the longevity term in the Drake equation. He emphasized that we have no idea what the value of this might be. We should explore further such questions as "Does technology level off or does exponential growth continue?", and "Will other civilizations maintain their interest in transmitting?" A starting point would be to develop a good theory about the evolution of hominid culture.

Kevles said he looked on the matter as a religious man. He noted that everybody's assumption seemed to be that a search was worth conducting if it appeared that life were common. However, he thought it would be equally worthwhile should we not be convinced of this, and a null result would be very important. The justification of the experiment is that it is a very special test of whether we are alone. We have a drive to know and this is a legitimate kind of thing to learn, since it is intrinsically worth finding out. Only if we can demonstrate that one of the Drake factors is <u>zero</u> should we not go ahead with the search; this, of course, is impossible, since we are here. He thought it would be wrong to try to sell the program on the grounds of learning something or gaining some benefit; its justification is that we are trying to find out things, and this is enough.

Oliver said that various myths and motivations had carried man through some difficult times - life after death was an example. Some people are now very pessimistic about the future of civilization; humanity needs a new frontier. If we do learn how to manage our planet and control society, it will still be important for us to know what is "out there". Therefore the question is not whether we search, but when. If civilizations live long enough for their mean separation to be small, it is reasonable that a "galactic club" of communicating civilizations exists. If it exists, it is reasonable that it might expend at least modest efforts on recruiting new members. Therefore, we should make at least modest efforts to detect signals that may have been transmitted for our benefit.

Harlan said that he had been practising listening and not signaling. He felt he had little expertise to contribute in this area. However, he thought that advanced civilizations could decide interstellar communication was unproductive. He pointed out that the Chinese long felt that barbarians were unimportant; this might be the attitude of an extraterrestrial civilization towards us. We should not transmit. It has often been disastrous for a culture to meet with one technologically more advanced than itself. But we should listen. We should learn what we can about the universe; it is our destiny.

Clark thought that more effort should be put into the determination of whether technological civilizations elsewhere are probable. He thought that no particular reasons <u>for</u> the emergence of technology and intelligence had been convincingly identified, though all seem convinced that there were no viable arguments that these should not develop. He thought also that it would be of great value if we could say something about likely climatic conditions on other planets.

This completed the comments of workshop invitees, and Lederberg adjourned the meeting.

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Enclosures:
1. Agenda
2. List of Attendees

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