Engineering and Science

The Brain of Pooh: An Essay on the Limits of Mind

The inviolate principle of causality—that a precisely determined set of conditions will always produce precisely the same effects at a later time—underlies our entire scientific perception of the universe. And yet in the smoothly flowing channels of natural causality there has always been in our conception one seemingly irrational, unordered, swirling eddy—the human mind. Increasingly now we cannot avoid this vortex, nor can we continue to skirt around it, for herein is the ultimate perceiver and herein form the shapes of surmise. And so, as in our dreams where we are surprised by that which we ourselves have conjured, the perceiver must in wonder inquire "How do I perceive?" and the mind ask "What is thought?"

The great discoveries in genetics and our enlarged understanding of the biochemistry of heredity have led to increasing discussion of the possibility of the designed change of human beings—not only of the repair of overt genetic defects but also of the longer range enhancement of the capabilities of man. Naturally, much of this discussion has concerned the improvement of man's finest and most precarious quality, his mind.

To consider this issue in any serious way one must first inquire as to what qualities of mind are considered to be genetic in origin (and are thus susceptible to genetic modification) and to what extent these qualities limit the performance of man—and what might be the consequence of their modification.

In a philosophical sense such an endeavor—man trying to improve his own capacity—is clearly a bootstrap project, an adventure in positive feedback. And yet this is what we have done all the way from the jungle. What we consider now is but an extension, albeit in a new dimension.

What can we honestly say about the mind from our present knowledge? I do believe that such a presentation can be useful in the same sense that the 16th century maps of the world were useful, essentially as a rough chart of what it is we need now set out to learn, bearing in mind that the enterprise may well require as many years as were needed to fill in those ancient maps.

Further, in this *special* case there is special merit in such a projection of knowledge that we may hope to have concerning the human brain and thus concerning its, and our, future potential. For this effort to see how our brain came to be and how it might be advanced can serve to provide us a valuable perspective in which to view our present reality, in which to see more clearly our present limitations and, therein, the origins of some of our most basic dilemmas.

The very opening lines of *Winnie-the-Pooh* provide my theme.

> Here is Edward Bear, coming downstairs now, bump, bump, bump, on the back of his head, behind Christopher Robin. It is, as far as he knows, the only way of coming downstairs, but sometimes he feels that there really is another way, if only he could stop bumping for a moment and think of it.

Now Edward Bear or Winnie-the-Pooh as he was known to his friends was of course a bear of very little brain. But nonetheless I often think that these opening lines constitute a splendid parable to man and his whole scientific enterprise—that we perforce go bump, bump, bump along the paths of scientific discovery when had we but the acumen, the brain power, we could immediately deduce from the known facts the one right and inherently logical solution. This seems particularly true in biology wherein all extant phenomena have for so long been subject to and ordered by the harsh disciplines of natural selection, and wherein the right answer, when we find it, always does seem so inevitably right.

And yet of course we don't have the acumen and we can't immediately deduce the right solution because, like Pooh, our brains too are really very limited compared to the complexity about us and the frequent immediacy of our tasks. And in simple fact what else can we sensibly expect when we are apparently the first creature with any significant capacity for abstract thought? Indeed, even that capacity developed primarily to cope with stronger predators or climatic shifts, not to probe the nature of matter or the molecular basis of heredity or the space-time parameters of the universe.

A physicist friend of mine frequently remarks on how much more difficult it seems to be to teach a 17-year-old a few laws of physics than it is to teach him to drive a car. He is always struck by the fact that he could program a computer to apply these laws of physics with great ease by Robert L. Sinsheimer

"When we've mutated the genes and integrated the neurons and refined the biochemistry, our descendants will come to see us rather as we see Pooh: frail and slow in logic, weak in memory and pale in abstraction, but usually warm-hearted, generally compassionate, and on occasion possessed of innate common sense and uncommon perception."

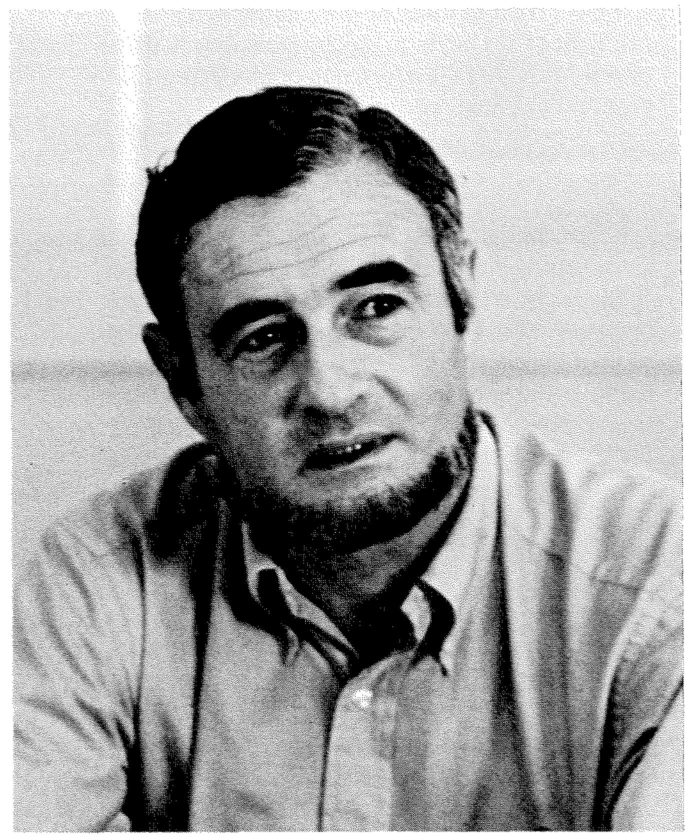
but to program a computer to drive a car in traffic would be an awesome task. It is quite the reverse for the 17-year-old, which is precisely the point. To drive a car, a 17-year-old makes use, with adaptation, of a set of routines long since programmed into the primate brain. To gauge the speed of an approaching car and maneuver accordingly is not that different from the need to gauge the speed of an approaching branch and react accordingly as one swings through the trees. And so on. Whereas to solve a problem in diffraction imposes an intricate and entirely unfamiliar task upon a set of neurons.

I think the computers first made us aware of one of the more evident limitations of the biological brain, its millisecond or longer time scale. Computers flashing from circuit to circuit in microseconds can readily cope with the input and response time of dozens of human brains simultaneously or can perform computations in a brief period of time for which a human brain would need a whole lifetime.

Similarly I believe that we will come to see that our brains are limited in other dimensions as well—in the precision with which we can reconstruct the outside universe, in the nature and resolution of our concepts, in the content of information that may be brought to bear upon one problem at one time, in the intricacy of our thought and logic—and it will be a major contribution of the developing science of psychobiology to comprehend these limitations and to make us aware of them, to the extent that we have the capacity to be aware of them.

For I think it is only logical to suppose that the construction of our brains places very real limitations upon the concepts that we can formulate. Our brain, designed by evolution to cope with certain very real problems in the immediate external world of human scale, simply lacks the conceptual framework with which to encompass totally unfamiliar phenomena and processes. I suspect we may have reached this point in our analysis of the ultimate structure of matter, that in various circumstances we have to conceive of a photon as a wave *or* as a particle because these are the only approximations we can formulate. We, and I mean we in the evolutionary sense, have never encountered and had to cope with a phenomenon with the actual characteristics of a photon.

And likewise with the subnuclear particles. I was intrigued to learn that the latest attempt to formulate a theory of subnuclear particles is a bootstrap or self-consistent field theory, which as I understand it is a bit like saying it is there because it is there and it has to be



Robert L. Sinsheimer

there. To my mind this is in effect a bold attempt to adapt the concepts available to the human mind to an intractable and perhaps unimaginable reality.
As Einstein so well said, "The most incomprehensible thing about the universe is that it is comprehensible."

Similar problems of concept may well arise on the vast scale of the universe or, more to the point, in the intricate recesses of the mind. Our problem will be somehow to shape a mirror to the mind such that we can comprehend its reflection.

I have tried to think how we might approach this problem of the limits to thought inherent in the structure of our brain and therefore potentially extensible by genetic modification.

One approach would be comparative or phylogenetic. If we could trace the detailed chemical and structural changes in the central nervous system as evolution has progressed through the vertebrate species, and if we could correlate these changes with the changes in the reactive and conceptual capacities of these species, we would have one basis for future extrapolation.

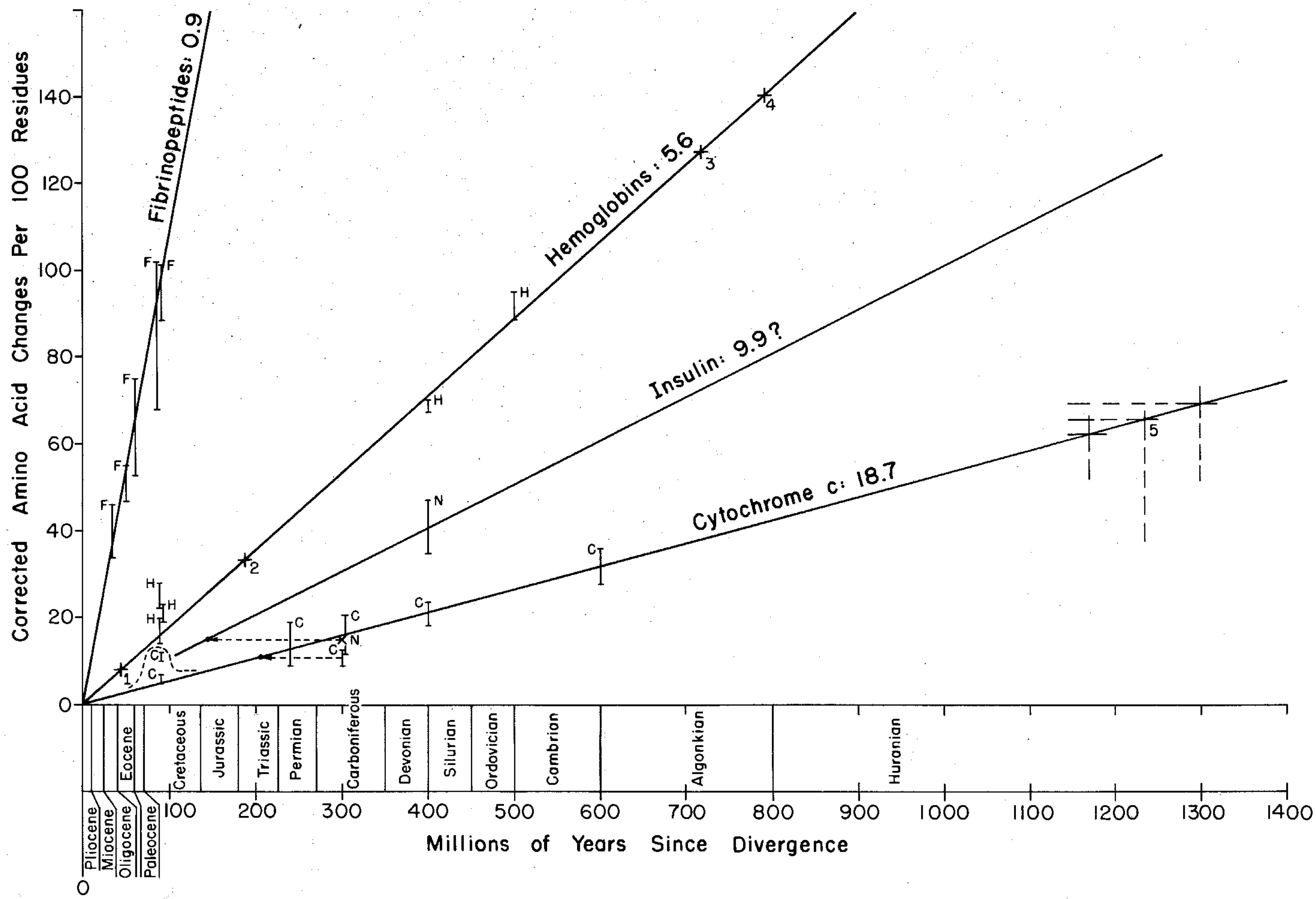
Now the comparative approach to phylogenetic evolution has been somewhat in disfavor in this recent era of biochemical ascendance, and for good reason. The biochemistry of all living creatures is really so similar. Hardly anyone would venture to suggest the differences between man and monkey are a consequence of a novel and major innovation in biochemistry. Indeed the biochemistry of man and a yeast cell are astonishingly similar. It is evident that almost all of the most basic processes of biochemistry must have been elaborated in some very remote time of evolution.

Rather, then, the differences between man and monkey must derive largely from some elaborations of structure, and thereby function on a cellular and multicellular level and primarily in the central nervous system. And these innovations must have arisen through the usual genetic mechanisms. How many genetic changes were there, literally? It's clear they did not require any major addition to the genome. The haploid DNA content of man and monkey is identical within the precision of measurement—a few percent.

Our abilities to compare and homologize or differentiate the DNA's of different species—say, man and monkey—are as yet very crude. The DNA-DNA hybridization experiments of Roy Britten and D. Kohne indicate that, on an average, the DNA sequences of man and monkey are highly homologous. Comparative measurements of the thermal stability of human DNA, chimpanzee DNA, and test-tube hybrids of these DNA's suggest that in the fifteen or so millions of years since these species have diverged there have developed about 1.6 nucleotide changes per 100 nucleotide pairs, or about 5 changes per 300 base pairs—which is equivalent to 100 amino acids of protein sequence. Since, because of redundance, about 20 percent of random nucleotide changes will not result in an amino acid change, we might expect a mean evolutionary distinction between these two species of about 4 amino acids per sequence of 100 in the absence of selective bias.

However, the interpretation of such homologies has since been complicated by the recognition that these experiments as they have been performed to date can only concern or involve certain fractions of the DNA, specifically those fractions that are made up of large families of molecules, or closely related sequences represented literally tens or hundreds of thousands of times in the genome. These represent about 40 percent of primate DNA. Under the conditions of these experiments, sequences represented less often simply never find a partner with which to hybridize in any reasonable time. The existence of these large families of closely related sequences, which may in total comprise some half of the genome, is both a surprise and a conundrum in itself, but in addition it does at present clearly limit the quantitative significance of statements about DNA homology between species, for we can say as yet very little about the possible homology of the less frequent DNA species.

Studies of the available rates of genetic mutation, as evidenced by changes in the amino acid sequences of particular proteins, suggest that the time of divergence of man and present-day monkeys from a presumed common ancestor *has been sufficient* to allow significant changes. The observable changes in amino acid sequence in any special protein are of course strongly biased by possible, and generally unknown, selective pressures that limit permissible change. Thus the alpha hemoglobin in the gorilla differs in only one amino acid from that of man. And that of the chimpanzee is identical to that of man. In an over-all sense, the rate of acceptable mutation in the globins is only about 1 amino acid per 100 residues per 6,000,000 years. For other proteins, such as cytochrome c, the allowable rate proves to be even less: 1 in 21,000,000 years. But a more accurate measure of the *possible* rate of amino acid replacement *may* be obtained from the fibrinopeptides which appear to serve no other function than to be excised from fibrinogen, when it is converted to fibrin in the formation of a blood



The number of changes in amino acids between the same protein from two different species is plotted here against the time in the past at which the two species' ancestors diverged. The unit evolutionary period is the average time required for one difference to show up per 100 residues. Molecules such as cytochrome c, which interact closely with other macromolecules, have longer unit evolutionary periods than such non-specific proteins as the fibrinopeptides.

Adapted from R. E. Dickerson and I. Geis, *The Structure and Action of Proteins,* Harper & Row, 1969.

clot, and then to be degraded. In these the apparent rate is 1 amino acid change per 100 residues per 1.2 million years. These numbers are in reasonable agreement with the averaged estimate from nucleotide change—approximately 4 replacements per 100 amino acids per 15,000,000 years.

It is thus possible to suggest that in the last several million years a considerable number of the proteins of man could have undergone mutational changes in one or two amino acids. But a *major* change in a particular protein would be highly unlikely—at least by the mutational processes leading to the changes so far studied.

Now of course the body undoubtedly has mechanisms whereby the consequences of even a single amino acid change in a strategic protein can be greatly amplified. But the conclusion I tend to draw from this admittedly loose argument is that the genetic distinction between a man and a monkey is, in a quantitative sense, not a great one. Hence, there is a greater chance that in time we will

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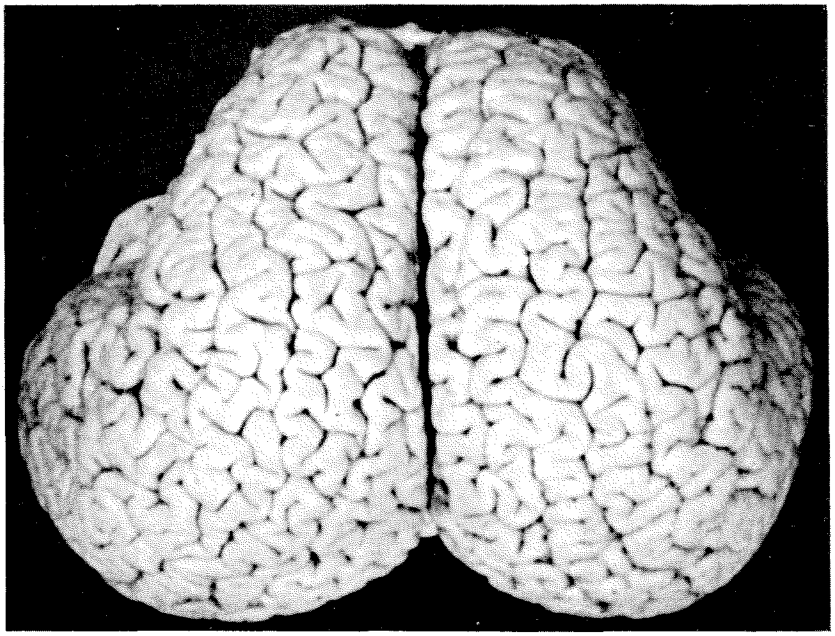

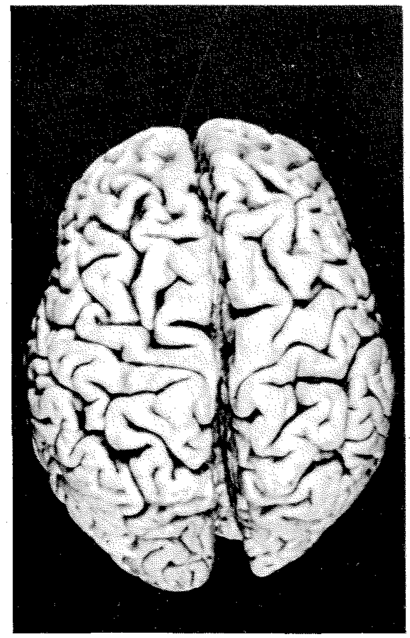

Brain size is a rather crude indicator of brain capacity, and man's (right) is by no means the largest at 1,450 grams. For instance, the brain of the dolphin weighs 1,700 grams, and that of the adult fin whale (left) weighs 6 to 7 kilograms.

be able to define and understand this change and conceivably recapitulate it in the laboratory. In this connection it would certainly be of great value to have phylogenetic comparisons of specific brain proteins as well as of hemoglobin.

In addition to his enhanced capacity for conceptual thought, man exceeds other primates in his enlarged consciousness, his power of speech, and undoubtedly in such underlying functions as memory and capacity for numeration. What changes provide the bases for these qualities?

If we compare the brain of a man and, let us say, that of a rat, we find the rat brain weighs a little over 1/1,000th that of the man: 1.6 grams vs. 1,450 grams. Yet the rat is a rather complex organism. It can learn intricate mazes; it can fight or defend itself; it reproduces; it has, particularly in the wild, quite intricate behavior. After observing a rat for a while, one begins to wonder what the other 99.9 percent of the brain is doing in man. If one compares the volume of the cerebral cortex, the ratio becomes even greater: 5,000 to 1 (500 cubic centimeters to 0.1 cubic centimeter).

"One of the most obvious distinctions between man and the lower animals is in the quality and quantity of his consciousness. Man can escape from the here and now; he can compare alternate responses and originate new actions by internal imagery."

Of course size of brain is a rather crude indicator. The brain of a chimpanzee weighs 450 grams, that of a man 1,450 grams. A dog has 80 grams of brain, a rabbit 10. But the brain of man is not all that extraordinarily large. The brain of the dolphin weighs 1,700 grams. It rivals that of man in structural complexity and proportions. What is it doing? The brain of an elephant weighs 5 kilograms, a whale 6 to 7 kilograms.

If we examine animals at various levels of phylogenetic development, one trend is, clearly, that more and more information is brought into the central nervous system. Thus, in man somewhat over 2,000,000 sensory fibers bring information to the brain, about half through the cranial nerves (optic, auditory, etc.) and half through the spinal cord.

If we compare man with the rat, we find that 12 times as many sensory fibers enter the spinal cord and 10 to 12 times as many fibers carry auditory and visual information. But most of this increase in informational capacity has already developed by the evolution of the primate. The principal difference between the primate and man appears to be in the elaboration of structures for the analysis and integration of the sensory input. If we compare the number of cells in area 17 of the visual cortex in man and in the macaque, or of the areas 17, 18, and 19 of the visual cortex in man and the orangutan, or the number of cells in the auditory cortex in man and the chimpanzee, we find large increments in man over the primates. And, of course, even larger differences are found in the volumes of the frontal cortex, the functions of which are still disturbingly poorly understood. We are only now, in experiments such as those of David Hubel and T. Wiesel, beginning to learn some of the ways in which networks in these areas of the cortex analyze the sensory input in monkeys; we have no information yet as to how these means of handling sensory data may differ between the lower primates and man.

	Sensory Fibers into Spinal Cord	Auditory Fibers	Optic Nerve Fibers
Man	1,000,000	30,000	1,000,000
Macaque	550,000	30,000	1,000,000
Rat	80,000	3,000	80,000

A better indicator of brain capacity is the amount of information brought into the central nervous system. A comparison of man and the rat shows that 12 times as many sensory fibers enter the spinal cord and 10 to 12 times as many fibers carry auditory and visual information.

	Man	Primate
Cells, Area 17, Visual Cortex	540,000,000	150,000,000 (Macaque)
Cortical Surface, Area 17	26 cm²	18.7 cm² (Orangutan)
Cortical Surface, Area 18	39 cm²	14.5 cm² (Orangutan)
Cortical Surface, Area 19	39 cm²	14.2 cm² (Orangutan)
Cells, Area 41, Auditory Cortex	100,000,000	10,000,000 (Chimpanzee)

The principal difference between the primate and man appears to be in the elaboration of structures for the analysis and integration of the sensory input. Large increments in man over the primates are shown in this comparison of the number of cells in area 17 of the visual cortex in man and in the macaque, or of the areas 17, 18, and 19 of the visual cortex in man and the orangutan, or of the number of cells in the auditory cortex in man and the chimpanzee.

One of the most obvious distinctions between man and the lower animals is in the quality and quantity of his consciousness. Man can escape from the here and now; he can compare alternate responses and originate new actions by internal imagery. In the nature and origin of consciousness is one of the most profound of mysteries. What determines the modality of consciousness? How do certain stimuli cause pain, others color, others tone or taste? What defines the spectrum of color sensation? Why are there no more colors or no other tones? Clearly there are structural and very likely chemical, and therefore, genetic, bases for these phenomena.

There are individuals, for instance, who are genetically insensitive to pain. In some instances this defect is peripheral. The nerve receptors in the skin which are usually considered to be the sensors of pain are lacking. In others the sensory cells and sensory fibers, at least as far as can be seen, appear to be intact, and the defect may be central—an indifference to pain. An interesting point is that these people, lacking a sensory modality, do not appear to know what pain is. It is absent from their consciousness, which thus seems, in part at least, discrete. It is of interest that such people often can distinguish temperature quite normally but there is no pain associated with hot or cold. This condition is most often disastrous to the individual. It is also of great interest that in two cases siblings from first-cousin marriages have shown this trait, suggesting that it may be a consequence of a fairly simple genetic alteration.

Now I personally rather doubt that we have the conceptual capacity to really comprehend the origin of consciousness; but I do expect that we will learn that consciousness of various modalities may be associated with circuits of the brain connected in diverse ways, possibly with diverse chemical transmitters and effecters, all programmed genetically, and that by modifying these programs we may indeed in a true sense expand consciousness into unknown sensations and into undreamt intensities. If this sounds absurd, consider that many

Continued on page 36

The Brain of Pooh

Continued from page 13

vertebrates have no color vision at all. By changing their genetic program an entire new sense has been added. We might be able to build chemical switches into various sectors of consciousness so that pain specifically could be turned off for surgery or a widened sense of taste or color turned on for enjoyment.

Conceivably new receptors—for electric fields or radio waves, for ionizing radiation or what have you—could be developed to go with new modalities of consciousness.

Whatever may be the basis of conscious thought, it is clear that much of the operation of the brain cannot be brought to consciousness; it is, somehow, inaccessible or screened. There is very likely much merit in the automation of many activities. Yet, as we know, conflicts and distortions on the subconscious level can produce grave disturbances of the psyche and are most difficult to detect and analyze. If more of the unconscious could be made at least selectively accessible, it could be a very considerable boon.

Of course one of the major distinctions of man is his ability to communicate, particularly through speech. Remarkable as this capacity is, it must be recognized that it is a limited device.

There are very real limitations of language and communication. Can we truly express everything we experience or conceive in speech? There are problems of precision, of connotation, and of association. We frequently have to coin new words for new concepts, and still it is difficult to convey their meanings to others, The expression of feelings and emotions is particularly difficult and seems to interweave several dimensions of emotionality. One can sum up a whole complex of emotions by an analogy (such as an Oedipus complex or a messianic complex) which is extremely hard to decompose analytically in words.

The average person is said to know some 20,000 to 60,000 basic words (dependent somewhat upon the definition of "know") and perhaps 100,000 derivatives of these. In ordinary speech he uses 2 to 3,000 basic words; in ordinary writing, maybe 10,000. (This difference between stored information and effective information is curious. It is of interest that there is a similar difference between the over-all sensory input—2 to 3,000,000 fibers—and the over-all motor output—about 350,000 fibers in man.)

The rate of direct communication is typically about 150 words per minute. These it may be estimated contain at most 2,000 bits of information. Of course that depends a little upon the speaker.

Speech is probably genetically one of the newest of nature's inventions and obviously one of major importance for the development of inter-individual communication, the consequent development both of group behavior and properties, and the transmission of knowledge and culture from one generation to the next. Yet there is no reason to believe this relatively recent innovation is perfected. Indeed, as we have indicated, there is good reason to believe speech is a very imperfect device for communication.

If we could manage a significant improvement in the potential precision and speed of our vocal communication, this could be of major consequence. We could, for instance, use many more of the potential phonemes and thereby markedly increase the potential information density.

I think it is interesting that our friend Pooh, although of little brain, used language with considerable precision and economy—as in the time he was hanging onto a balloon suspended in the air and, wanting down, he asked Christopher to shoot the balloon. So Christopher aimed very carefully and fired.

> *"Ow!"* said Pooh.
> "Did I miss?" Christopher asked.
> "You didn't exactly *miss,*" said Pooh, "but you missed the *balloon.*"

One well-known indicator of the limitations of our capacity for speech is our frequent inability to bring to mind the right word for an object or a person or a concept. Pooh also suffered from this all-too-human failing—as when Christopher says:

> "One well-known indicator of the limitations of our capacity for speech is our frequent inability to bring to mind the right word for an object or a person or a concept."

> "What do you like doing best in the world, Pooh?"
> "Well," said Pooh, "what I like best—" and then he had to stop and think. Because although Eating Honey *was* a very good thing to do, there was a moment just before you began to eat it which was better than when you were, but he didn't know what it was called.

I am of course assuming here that our command of language and indeed the structure of language, whatever language it is, are at least in large part a consequence of genetically determined neuronal structure. I think this is very reasonable. And along these lines I would like to return to the concept I developed earlier—that we can learn to do certain things rather easily because, in effect, approximate programs for these operations are built in.

Could we not extend this? Could we not build in through the proper circuitry certain packets of knowledge so that every generation need not learn these anew, such as a language, or a periodic table, the Krebs cycle, etc. Migratory birds evidently have genetic programs that enable them to recognize stellar constellations. Other birds innately recognize rather complex songs. It does not seem inconceivable.

This is only an extension, although certainly in another dimension, of the wise ideal so well expressed by Whitehead, who wrote: "It is a profoundly erroneous truism—that we should cultivate the habit of thinking what we are doing. The precise opposite is the case. Civilization advances by extending the number of important operations which we can perform without thinking about them."

Statistically at least it is clear that there are changes in the human brain with aging. There are times of optimum ease of learning such matters as language or mathematics. There are optimum periods for creative work, and these seem to differ in the different sciences. In early childhood there are critical periods for mastering certain skills, and if these are past, the effect may well be nearly irreversible. Also we know there are at various times in life irreversible hormonal influences on parts of the brain. We know the number of cells in the brain does not increase after six months or a year of age and, indeed, decreases after 30 to 40 years of age.

If we understood these matters, we could perhaps control these factors. We might keep open and extend critical

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periods of learning. We might learn to reverse untoward hormonal effects or even to increase the number of brain cells and thus permit continued increase of information and counteract senility.

Matters of learning clearly involve the intake of information and the storage of memory. We do not understand these matters well. Numerous studies of varied design indicate that the rate at which we can abstract information from our sensory presentation—visual, for example—is highly limited by a narrow channel capacity. Various studies have been made and, despite some variation of interpretation, there seems to be a general agreement that while some 40 to 50 bits of information may be taken in visually in a flash and held for somewhat less than a second, at the most 10 bits of information per second can be abstracted from a presentation and used to control an output or relayed to a memory bank.

This channel capacity is certainly a major parameter in the determination of the speed and quality of the working of the brain.

The limited capacity of the brain to abstract information from a visual display underlies the McLuhan fallacy and explains why people still read books. Could this rate of information-handling be markedly increased? If so, we could enter the McLuhan era.

Further, it seems likely that the limitation upon the bits of information we can process at one time is related to a deeper question. How many data can we hold in our mind at one time, how many can we bring to bear upon a particular conceptual problem? Surely this is limited, and this in turn restricts our ability to cope with problems of great complexity except by over-abstraction and over-simplification. Conceivably we might be able to increase this quantity.

Now, of course, it is easy to list various qualities and suggest independently improving this or that one. But properly one needs to consider and needs to be able to consider the effect of changing any one facet of intellectual performance upon an individual's whole personality. Personality is like a network with more-or-less-balanced tensions and strains; modification anywhere can affect the whole. Consider what one might first think to be a purely mechanical element such as memory. Upon reflection, memory is easily seen to be a central element in the whole cerebral process. With a little reflection I think it becomes obvious that the quality of memory, its extent, its rapidity, its precision and acuity must influence the whole life pattern through our perception of and response to any situation.

We know all too little about memory. It has become known that there is a short-term memory for the relatively brief storage (on the order of seconds) of information, and a longer term, more enduring memory, of a qualitatively different nature. I suspect that we do not yet begin fully to grasp the significance and function of these distinct memories. As we learn more about the roles of these separate memory systems, we may find that the existence of erasable short-term memory provides an essential gap that permits a distinction between our internal and external worlds. It provides a transient recording that permits us to respond to the immediate yet not to be constantly overwhelmed by the immediate, so we may select from it the important and the general. Without such a buffer we could not plan, we could not withdraw sufficiently from immediate reality.

It is even possible that our sense of time and of time passing is related to the rate of decay of our short-term memory. In our subconscious and in our internal world there is little sense of time. A past event can seem as real as the present. Drugs which affect our sense of time may do so through their effects upon these processes.

If these speculations have any validity, then the ability to alter physiologically or genetically the rates and extent of these processes of memory could have profound effects upon our perception of the world.

I might insert at this point that to a biochemist one of the major impediments to research upon many of these questions is the existence of the so-called blood-brain barrier. This is a poorly understood physiological mechanism that stringently restricts the transport of foreign substances into the central nervous system. Presumably this was designed to provide a specific neuronal environment and to protect the brain against physiological vicissitudes and not just to frustrate biochemists. But certainly one major contribution that genetics could make would be to alter this barrier—optimally, perhaps, by incorporation of some biochemical switch whereby it could be opened or closed so as to permit biochemical investigation.

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Another and different approach to the potentials inherent in further development of the brain is by a consideration of the attributes of individuals with special gifts of one character or another. It is clear that, presumably by genetic circumstance, individuals arise with marked asymmetries of talents. It is also clear that in accord with the concept of interdependence of various cerebral functions the hypertrophy of one talent is often accompanied by major, even disastrous, consequences to others, although we are at present unable to trace the causal connections.

The so-called idiot savants who have a general mental age of two or three years but can, with great rapidity, perform extraordinary numerical feats are an extreme example. One of these, given the series 2, 4, 16, immediately continued to square each successive number into the billions. Similarly, given the numbers 9-3, 16-4, he proceeded to do square roots of numbers into 3 and 4 digits.

Another class of feeble-minded individuals is known with extraordinary talents of mimicry.

Of a less drastic and more desirable nature are the special talents we associate with musical genius, such as a Mozart who composed significant works at the age of four, or artistic genius, or literary genius, or extraordinary skill at chess. There are individuals who are extraordinarily articulate; there are others with extraordinary ability in three-dimensional visualization and spatial orientation far beyond the corresponding talents of normal people.

The capacities of these individuals indicate levels of achievement that could become commonplace, beside which we may feel like Pooh who was somewhat weak in this matter of spatial orientation and symmetry.

"I *think* it's more to the right," said Piglet nervously. "What do *you* think, Pooh?"

Pooh looked at his two paws. He knew that one of them was the right, and knew that when you had decided which one of them was the right, then the other one was the left, but he could never remember how to begin.

"Well," he said slowly—

A particular case of an extraordinary development of the faculty of memory has recently been described in considerable detail by A. R. Luria in the book *The Mind of a Mnemonist.* This analysis is of particular interest because Luria is especially concerned not only with this unusual mnemonic talent but with its consequence for the whole personality of the man who had it.

This man's memory in truth could not be saturated and was apparently imperishable. He could quickly, in two or three minutes, learn a table of 50 numbers or a list of 70 words which he could then repeat or just as easily present in reverse order, or, if given an intermediate word, go forward or back from this. He memorized a nonsensical formula

$$N \cdot \sqrt{d^2 \times \frac{85}{vx}} \cdot \sqrt[3]{\frac{276^2 \cdot 86x}{n^2 v \cdot \pi 264}}\ n^2 b = sv\ \frac{1624}{32^2} \cdot r^2 s$$

in a few minutes, and when asked 15 years later, without warning and with no intervening exposure, he was able to reproduce the earlier test situation and the formula without error. He literally never forgot or lost anything once committed to memory.

Indeed this was a problem for him as a professional mnemonist. He would give several performances in an evening, quickly memorizing, for example, tables of numbers that persons from the audience would write on a blackboard. But since it was the same blackboard in each performance, he could see in his memory all the earlier tables as well as the present one he was supposed to reproduce and would become confused. He claimed that at one time he tried writing things down he did *not* want to remember. He thought that if he wrote them down he would know he did not have to fix it in his memory, but this did not work. Ultimately he claimed he developed an ability willfully not to remember.

As Jerome Bruner suggests in his foreword to this book, it is as though the metabolism responsible for short-term memory was defective in this man and everything experienced was transferred into the long-term memory.

This man's world was one of intense visual imagery. He was never able to develop and grasp or project ideas and generalities. He was, in effect, overwhelmed by an endlessly increasing store of perceptions.

As another corollary, the man had significant difficulty in distinguishing between the internal and the external world. He had great difficulty in planning. He could not withdraw enough from the immediate reality. Furthermore, his sense of time was often faulty. For this man the past was as real as the present. He had no childhood amnesia and seemingly could remember impressions to very early childhood.

This man was also remarkable in another way. He had a strong synesthesia. As I have pointed out, to most of us our senses are quite distinct. Sight, sound, taste, smell, touch, pain are all uniquely stimulated, except when under the influence of certain drugs which appear to facilitate sensory interaction. In this man almost all the senses seemed fused. Every sound also had an image in color, often a taste and a touch and a smell as well. (It is conceivable that this effect is also related to a short-term memory defect. The persistence of a sensory input may permit it to spread and involve other perceptual centers.) He said, "I recognize a word not only by the images it evokes but by a complex of feelings the image arouses. It is not a matter of vision or hearing but some over-all sense I get. Usually I experience a word's taste and weight, and I don't have to make an effort to remember it. But it is difficult to describe. What I sense is something oily slipping through my hand. Or I am aware of a slight tickling in my left hand caused by a mass of tiny lightweight points. When that happens I simply remember without having to make the attempt." "Even when I listen to works of music I feel the taste of them on my tongue. If I can't, I don't understand the music. This means I have to experience not only abstract ideas but even music through a physical sense of taste."

I think it is obvious that for such a person the world would be a very different place than it is for us.

His strongest reaction was imagery. He lived very much in a world of images. Obviously this could create very serious problems. For some words, for example, the images the sound of a word created would fit its meaning, but for others there would be a conflict and confusion. Many words we know have multiple meanings (fast, for example). This

"We are the victims of a variety of emotional anachronisms, of internal drives no doubt essential to our survival in a primitive past, but quite unnecessary and undesirable in a civilized state."

created great difficulty for him. He could not comprehend metaphors at all.

"Take the word nothing. I read it and thought it must be very profound. I thought it would be best to call nothing something. I *see* this nothing and it is something. If I am to understand any meaning that is fairly deep I have to get an image of it right away. So I turned to my wife and asked her what nothing meant. But it was so clear to her that she simply said nothing means there is nothing. I understand it differently. I saw this nothing and thought she must be wrong. If nothing can appear to a person then it means it is something. That's where the trouble comes in."

It's interesting that Pooh had the same difficulty with abstractions—as when Christopher says:

"... what I like *doing* best is Nothing."

"How do you do Nothing?" asked Pooh, after he had wondered for a long time.

"Well, it's when people call out at you just as you're going off to do it, What are you going to do, Christopher Robin, and you say, Oh, nothing, and then you go and do it."

"Oh, I see," said Pooh.

"This is a nothing sort of thing that we're doing now."

"Oh, I see," said Pooh again.

There is one other aspect of this man's unusual mental and psychical structure that should be mentioned. His poor distinction between external and internal reality was perhaps reinforced by an extraordinary control over his autonomic functions. He could increase his pulse rate from 70 to 100 by imagining he was running and then reduce it to 64 by imagining he was lying quietly in bed. He could raise the temperature of his right hand by two degrees and then later lower that of his left hand by one degree. How did he do this? He said, "There is nothing to be amazed at. I saw myself put my right hand on a stove. Oh, it was so hot. So naturally the temperature of my hand increased. But I was holding a piece of ice in my left hand. I could see it there and began to squeeze it and of course my hand got colder."

He claimed also to be able to alter his sensitivity to pain at will. "Let's say I'm going to the dentist. You know how pleasant it is to sit there and let him drill your teeth. I used to be afraid to go but now it's all so simple. I sit there and when the pain starts I feel it. It's a tiny orange-red thread. I'm upset because I know that if this keeps up the thread will widen until it turns into a dense mass. So I cut the thread, make it smaller and smaller until it's just a tiny point and the pain disappears." It was demonstrated that he could vary his eye adaptation by imagining himself to be in rooms of varying levels of illumination.

His strange memory and his synesthetic experience created in this man a critical difficulty in distinguishing between the world of his imagination and the external world. Lacking a clear distinction, such as we know is observed in certain drug states, his fantasies could be as real or more real to him than the external world. "This was a habit I had for quite some time. Perhaps even now I still do it. I look at a clock and for a long while continue to see the hands fixed just as they were and not realize time had passed. That's why I'm often late."

All of which may bear importantly on the major question of how we make this critical distinction between internal and external.

I have gone into detail because this individual provides such a powerful illustration of the interlocking and interdependent character of our various mental and psychological attributes, and thus of the extensive consequences of what are undoubtedly a few strategically placed genetic alterations. Conceivably, they might amount to little more than an altered metabolism leading to the localized endogenous synthesis of an unusual substance with certain LSD-like properties.

I have thus far been principally concerned with the more cerebral and operational aspects of central nervous system function. Another most important field for genetic intervention is our motivational and emotional states.

It seems all too clear to me that we are the victims of a variety of emotional anachronisms, of internal drives no doubt essential to our survival in a primitive past, but quite unnecessary and undesirable in a civilized state.

We have surely more than we need in aggression. Could we not lower aggressiveness, bearing in mind that we must be on guard for possible corollary consequences?

Pessimism and depression are perhaps necessary in a world that merits suspicion, but their exaggeration has little merit. This is illustrated splendidly in the Pooh stories, where Eeyore, the donkey, one of Pooh's friends, is the embodiment of depression. One day

"So much of what we see is in truth what we conceive."

Drawing by W. Steig; © 1968 The *New Yorker Magazine*, Inc.

The Brain Of Pooh . . . *continued*

Eeyore finds his tail is missing.

"You must have left it somewhere," said Winnie-the-Pooh.
"Somebody must have taken it," said Eeyore. "How Like Them," he added.

But in a hopefully more humane world such qualities might be of little use.

We will undoubedly continue to have need of compassion. There is in the Pooh stories another episode in which after a period of intense rain and general flooding of the premises Edward Bear and Christopher Robin are impelled to rescue their close friend Piglet, who is stranded on a tree branch not much above the rising water. But how to accomplish this? After both are stumped for some time, Pooh has an idea which certainly far exceeds his normal cortical limitations. He suggests that they invert Christopher Robin's umbrella and use it as a boat. Christopher is so awed by this unexpectedly brilliant and, I might add, successful invention that he later names this worthy craft *The Brain of Pooh.*

I like to think that driven by necessity or even better by compassion we too will learn to exceed our normal cortical limitations and we too may tap talents yet unseen.

So much of what we see, so much of what we perceive, so much of what we experience is in truth what we conceive. It is contributed by the mind of the beholder and thus must depend in detail upon the innate structures and functions of the mind, upon its accumulated experiences, upon its physiological state, and even in a regenerative manner upon how the mind conceives of itself. And our view of the mind, even the very concept that we may at some future time be able to augment and improve our capacities, may react upon our behavior long before we achieve these visions.

For a number of the most strategic and salient structural elements of the mind there is already evidence of significant genetic determination. These genetic factors, and they may not be so many in number, define our intellectual and conceptual limits. I propose that through phylogenetic studies and through studies of the rare human genetic variants we can learn much concerning their basic cerebral components, in preparation for the day when we wish to begin to move back their limits.

And so perhaps, when we've mutated the genes and integrated the neurons and refined the biochemistry, our descendants will come to see us rather as we see Pooh: frail and slow in logic, weak in memory and pale in abstraction, but usually warm-hearted, generally compassionate, and on occasion possessed of innate common sense and uncommon perception—as when Pooh and Piglet walked home thoughtfully together in the golden evening, and for a long time they were silent.

"When you wake in the morning, Pooh," said Piglet at last, "what's the first thing you say to yourself?"
"What's for breakfast?" said Pooh. "What do *you* say, Piglet?"
"I say, I wonder what's going to happen exciting *today*?" said Piglet.
Pooh nodded thoughtfully.
"It's the same thing," he said.
