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THE DISTRIBUTED NATURE OF THE MEMORY STORE AND THE LOCALIZATION OF LINGUISTIC COMPETENCIES

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We have heard from Marcel Kinsbourne that there is dichotomania around. If he thought it was bad up until now—I'm going to give two lectures tonight, and even try to give them simultaneously. The problem of brain function as it regards semiotics divides itself (dichotomously) into the problem of non-locality and the problem of localization of function. We've heard mostly about localization of function and I will take up that theme at the end. But first, non-locality.

Non-Locality and Isomorphism

Introduction

I would like to spend some time making clear what is not localized. The work that Lashley did for so many years reflects a condition that is seen frequently in the clinic. If someone has a stroke destroying one-third of his brain he doesn't come home to his family and recognize John and Mary and turn to his wife and say who are you? This is not the way memory works. As Lashley expressed it, no particular engram is ever lost in isolation because of a brain lesion. Classes of engrams, yes; aphasics can't talk very well and with a visual agnosia patients can't recognize things visually and with a tactile agnosia they can't recognize objects tactically. There may be retrograde amnesias, antigrade amnesias, but never amnesia for one single engram. Lashley expressed this so elegantly in 1950 when he said, "after a lifetime of search for the engram the only conclusion that I can reach is that learning is just not possible." Then he added that this may be borne out in the classroom but elsewhere there is evidence that something gets stored.

The problem of non-locality of memory is so important that Boring in his book on the history of experimental psychology pointed out that until physiologists come up with some idea of what the memory trace looks like in the brain, psychologists shouldn't bother with brain physiology.

Skinner has echoed this theme by stating that first we must have a lawful black box psychology before we can relate such laws to physiology. To illustrate the validity of his point, I must tell a story: I gave a course at Harvard one summer and Skinner, George Miller and much of the faculty were sitting in the back row of the classroom. At one point Skinner raised his hand and asked, "Karl, do you believe in isomorphism?" and after a moment of hesitation, I answered, "Sure, I believe in isomorphism." I did think that the brain in some way made a representation of the environment pretty much the way I perceived that environment. Then Skinner said, "All right, imagine some grass growing." And I imagined some grass growing and my cortex was sprouting green. And then he said, "Now, run the lawnmower over it," and I grasped my head in simulated pain and said, "No, it can't work like that." Skinner added, "When you can answer that question, I'll begin to listen to you physiologists."

Now I believe I can begin to provide some answers to Skinner's question. At this point I can do little more than provide a window on a class of models that allow a description of representation processes and their relationship to the problem of isomorphy. I noted at the beginning of the conference that the easiest way to conceptualize representations is in terms of an IBM punch card model. We need now to describe the cards themselves, and the process the computer goes through in reading those cards. Conceive of the brain as being made up of layers of cards with holes that are not perfectly round but have a variety of shapes. Each card is therefore a spatial filter. When the cards are stacked, the commonalities among holes provide a correlation function. In mathematics such a superimposition of shapes, when they are continuous--as when the holes in the cards have overlapping shapes--are called superpositions and these superpositions can be linearly convolved to correlate the information contained on the cards.

The Issue of Isomorphism

I would now like to address this problem of isomorphism. There have been only two answers given to the isomorphism problem. One is the answer we heard this morning from Taylor, which is that there must be some isomorphism if we are to get along in this world. The other answer is that there is no isomorphism. But no one so far has raised the crucial issue as to what is supposed to be isomorphic with what? Neither Taylor nor Köhler, nor anyone else has made a distinction between (1) isomorphism of brain process with phenomenal experience, and (2) isomorphism of brain process with the physical world. This is an important distinction. I will present evidence that there is isomorphism between brain organization and the physical world. Further, a case will be made that isomorphism between brain process and phenomenal experience depends on *sensory* organization.

As usually stated, the theory of isomorphism holds that there is a recognizable correspondence between the organization of our phenomenal perceptions and the organization of our brain states. With regard to the mind-body problems therefore isomorphism is of central concern. No form of identity between mind and brain can be entertained if isomorphism does not hold--if it does, identity is still not mandatory, of course. But to the extent that isomorphy exists, to that extent our intimate existential understanding of the relationship between mind and brain is enhanced.

Isomorphism literally means "of the same form." What needs to be shown is that a brain state measured electrically or chemically has the same form, the same configuration as the mental percept. Recently, Roger Shepard (1979) has extended the concept to include what he calls a close functional relationship between brain representation and percept. Henle rightly criticizes this extension by pointing out that a naming response could be interpreted as "functionally related" yet be far from exhibiting the property of sharing the same form.

What are the pertinent facts. First, Wolfgang Köhler demonstrated that steady state current shifts occur in the appropriate receiving areas of the brain cortex when a visual or auditory stimulus is presented. This shift coterminates with the presentation and in the same and subsequent experiments it was shown that the shift accompanies the desynchronization of the electroencephalogram (see Pribram, 1971, for review).. At the same time a series of experiments undertaken by Lashley (1951) and his students placed gold foil over the cortex in order to short out direct currents and another series performed by Sperry (1955) placed insulated mica strips into grooves cross-hatched into the cortical surface. Neither of these experimental procedures nor another in which electrical epilepsy was produced (Pribram, 1971) resulted in *any* deficiency in discrimination performance of cats and monkeys. This led Köhler to remark that not only his theory but every other brain theory of perception had been jeopardized. In personal discussions and letters it was suggested that perhaps microfields centering on synaptic events might substitute for or underlie the macrofields (see, e.g., Beurle, 1956; Pribram, 1960). Köhler died before any precise conceptual or experimental implementations of these ideas could be accomplished.

Meanwhile, unit recordings of the responses of single cells in the brain cortex had shown that in the visual cortex the response was especially brisk to lines presented in a specific orientation (Hubel & Wiesel, 1959). In view of the finding that below cortex the responsive field of neurons was circular, a Euclidian interpretation of the neural mechanism of perception became popular: below cortex spots, align the spots (by convergence) to make up lines, and from lines any other figure can be constructed by simply extrapolating the process hierarchically. The appeal of the formulation was the appeal of isomorphism--at last the evidence seemed to indicate that brain geometry and mind geometry were the same.

The basis of this cellular isomorphism is, of course, superficially different from that proposed by Köhler. He had suggested that steady state currents were the measure of isomorphism while the unit recordings relied on nerve impulse responses. But closer inspection shows that this difference is not critical: the responsive fields of neurons are made up of their dendrites and are therefore ordinarily referred to as receptive *fields*. Receptive fields receive inputs via synapses. Thus the geometry of the receptive field in fact is the geometry of the steady state microfields (hyper and depolarizations) engendered in the synaptodendritic network of the neuron from which the unit recording is obtained. And, as noted, toward the end of his life Köhler had come to entertain the possibility that it was in fact these synapto-dendritic locations which determined his cortical "fields."

Although the relationship between the data obtained with unit recordings and the proposal of brain-percept isomorphism has not been enunciated heretofore, the overwhelming intuitive appeal of this Euclidian solution to the problem even for Gestalt-oriented perception psychologists such as Teuber, has almost certainly stemmed from a tacit acknowledgment of the relationship.

It would be nice if this is where the discussion of isomorphism could end. But nature and especially biological nature is wayward in dealing with those who wish to broach her secrets. In the mid-1960s it became apparent in several laboratories around the world, e.g., Stanford (Spinelli & Barrett, 1969; Spinelli, Pribram, & Bridgeman, 1970), Harvard (Pollen, Lee, & Taylor, 1971; Pollen & Ronner, 1975), Cambridge (Campbell & Robson, 1968), and Leningrad (Glezer, Ivanoff, & Tscherbach, 1973) that the line-selective neurons in the visual cortex displayed inhibitory and excitatory sidebands in their receptive fields. Their responsivity varied more as a function of the width and spacings of several parallel lines (gratings) presented in a preferred orientation than as a function of any single line. This was conceptualized by the Cambridge group as indicating that the cells were responding to what Fergus Campbell called the spatial frequency of repetition of such parallel lines in a grating rather than to any single line. This view was based on the fact that repeated presentations of a grating of a particular spatial frequency would influence not only the subsequent response to that grating but to gratings with "harmonic" relationships to the initial grating. Campbell therefore proposed that the visual system operates on spatial patterns of light much as the auditory system operates on temporal patterns of sound. Recently the geometric vs. spatial frequency hypotheses have been put to critical test by Russell DeValois at the University of California at Berkeley with a clear quantitative result against the geometric and in favour of the frequency mode of operation (DeValois, Albrecht, & Thorell, 1978 a, b).

More Brain Facts

Evidence has been accumulating for almost a century that such wave-form descriptions of sensory processing are valid. Georg Simon Ohm (of Ohm's Law of the relationship between electrical current, voltage, and resistance) suggested in 1843 that the auditory system operates as a frequency analyzer perhaps according to Fourier principles. The Fourier theorem states that *any* pattern, no matter how complex, can be analyzed into a set of component sine waves, i.e., a set of completely regular wave forms each at a different frequency. Hermann von Helmholtz developed Ohm' suggestion by a series of experiments which provided evidence that such decomposition takes place in the cochlea. Helmholtz proposed that the cochlea operates much like a piano keyboard, a proposal which was subsequently modified by Georg von Bekesy (1960) on the basis of further experimentation which showed the cochlea to resemble more a stringed instrument brought to vibrate at specific frequencies. Nodes of excitation which develop in the vibrating surface (the "strings") account for the piano keyboard-like qualities described by Helmholtz.

Bekesy further developed his model by actually constructing a multiply vibrating surface which he placed on the forearm of a subject. When the phase relationship between the vibrators (there were five in the original model) are appropriately adjusted, a single point of excitation is tactually perceived (Bekesy, 1967). It was then shown that the cortical response evoked by such vibrations is also single: the percept rather than the physical stimulus (Dewson, 1964) is reflected in the cortical response. Somewhere between skin and cortex inhibitory interactions among neural elements had produced a transformation. Bekesy went on to show that by applying two such "artifical cochleas," one to each forearm, and once again making the appropriate adjustments of phase, the subject was made to experience the point source alternately on one arm, then on the other, until after some continued exposure, the source of stimulation was projected outward into space between the two arms. Bekesy noted that we ordinarily "project" our somatosensory experience to the end of writing and surgical instruments; the novelty in his experiments was the lack of solid physical continuity between the experienced source and the actual physical source. In the auditory mode this is, of course, the principle upon which stereophonic high fidelity music systems are based: by appropriate phase adjustment the sound is projected to a location between and forward of the acoustical speakers, away from the physical source of origin.

As noted, over the last decade it has been shown that the visual system operates along similar principles in its processing of spatial patterns. In an elegant series of experiments Fergus Campbell and John Robson (1968, 1974) found that visual processing of gratings (sets of lines or bars) of various widths and spacings produced apparently anomalous results until the experimenters realized that the system adapts not only to a particular grating "frequency" but to its harmonics. The "frequency" of a grating is determined by its spacing--the width of bars and the distance between them--and is thus called a "spatial frequency."

Currently, it has been shown that cells in the visual cortex encode in this "spatial frequency" domain (Schiller, Finlay, & Volman, 1976; Movshon, Thompson, & Tolhurst, 1978; DeValois, Albrecht, & Thorell, 1978 a, b; Pribram, Lassonde, & Ptito, 1981). Most telling are the results of experiments which pitted the neurophysiological "dogma" that the cortical cells were line (bar or edge) detectors against the proposal that they encoded in the waveform (spatial frequency) domain. DeValois showed that the cortical cells were insensitive to bar width and that when crossed with others running perpendicular as in a plaid, the encoding changed dramatically to include the total pattern. Specifically, the cortical cells are selectively sensitive to lines (gratings) presented at particular orientation--a finding (Hubel & Wiesel, 1959) which was instrumental in generating the feature detector proposal. If the cells operate as detectors, additions to the pattern of lines (as in a plaid) should not alter the orientation with which the pattern must be presented; the additional lines in the pattern ought to be processed by additional units selective of that orientation. But if, on the other hand, the total pattern of the plaid is being processed by the cell, the orientation of the stimulus presentation would have to be altered. DeValois performed a Fourier transform by computer on each plaid presented. Such transforms show radii at various angles from the original perpendicular arrangement of the lines of the plaid. DeValois found that *all* stimuli had to be rotated to bring these radii into line with the orientation selectivity of the cells when a grating was changed to a plaid. Furthermore, the rotation was exactly that (to the degree and often to the minute of visual arc) predicted by the proposal that the Fourier transform of the plaid (not its separate lines) is encoded.

The other line of support favouring some sort of wave-form operation of the brain cortex comes from the observation that specific engrams or memory traces are not lost when brain tissue is injured. Whatever the nature of memory traces, they must become distributed over some considerable part of the brain to resist disruption. An effective method of distributing information was invented by Dennis Gabor, a mathematician, who suggested that storing the wave forms generated by energies reaching a recording surface rather than their intensities would provide better resolution in image reproduction (1948). Each electron or photon reaching a film creates ripples much as pebbles thrown into a pond. The ripples form wave fronts which intersect, producing nodes of reinforcement and interference. Mathematically, the point energies composing an image are transformed into a frequency, i.e., a wave-form representation, and by performing the inverse transform the image can be readily reconstructed. Gabor christened the method holography because the entire image becomes distributed, i.e., represented, in each part of the hologram record.

In a hologram each quantum of light acts much as a pebble thrown into a pond. The ripples from such a pebble spread over the entire surface of the pond (the mathematical expression for this is in fact called a spread function of which the Fourier transform is a prime example). If there are several pebbles, the ripples produced by one pebble originate in a different location from those produced by another pebble, thus the ripples intersect and form interference patterns with nodes where the ripples add and sink where they cancel. The nodes can be captured on film as oxidations of silver grains if the ripples are produced by light falling on film instead of pebbles falling into water. Note that the information from the impact of each and every pebble or light ray is spread over the "recording" surface, thus the property that each portion of that surface is encoding the whole. And as noted earlier, performing the inverse transform reconstructs the image of the origin of that information. Thus the whole becomes enfolded in each portion of the hologram since each portion "contains" the spread of information of the entire image.

The holistic principle of the hologram is totally different from earlier views that wholes develop properties different from their parts. The emergence of properties from appropriate combinations was expressed in the Gestalt principle that "the whole is greater than the sum of its parts." The holistic properties of holograms are expressed in the principle that "the whole is contained or enfolded in its parts" and the very notion of "parts" is altered because parts of a hologram have no specifiable boundaries.

The properties of holograms that are important for brain functioning are (1) the distribution of information which can account for the failure of brain lesions to eradicate any specific memory trace (engram), (2) the tremendous readily retrievable storage capacity of the holographic domain--the entire contents of the Library of Congress can currently be stored on holofiche (microfilm recorded in holographic form) taking up no more space than an attache case, (3) the capacity for associative recall which is inherent in holograms because of the coupling of inputs when they become distributed, and (4) this coupling also provides a powerful technique for correlating--cross-correlations and auto-correlations are accomplished almost instantaneously. This is why the Fast Fourier Transform (FFT) is so useful in computer operations when statistical correlations are needed or when image construction, as in X-ray tomography, is required.

The step from showing that cortical cells encode frequencies to viewing the cortical surface as a holographic distributing device for encoding memory is not a completely simple one. The receptive field of each cell may encode holographically, i.e., in the wave-form domain, but such receptive fields are small--e.g., in the visual system they subtend at most some 5° of visual angle. But, as has been shown by engineers using holographic techniques, such patch holograms--also called strip or multiplex holograms--have all the image-reconstructing properties of global holograms. Further, when the patches encode overlapping but not identical patterns, movement can be recorded. Global holograms show the property of translational invariance which allows object constancy to result; but this is at the sacrifice of an explicit encoding of space or time which are enfolded into the "wave number" as physicists term the two-dimensional "spatial frequency" of neurophysiologists.

There are other problems such as the amount of information that can be encoded in wave lengths recorded from neural tissue. But if the wave form is spatially related to dendritic hyper-and depolarizations these can occur angstrom units apart. Furthermore, the wave mechanical treatment of neural holography may not be the most propitious; suggestions have been made to use modified cable theory (Poggio & Torre, 1980); to treat the dendritic net as a manifold in which each polarization point is considered a cell in a lattice of a Lie group (Hoffman, 1970); or to use other mathematical approaches developed in quantum mechanics. Whatever the best quantitative description turns out to be, the current facts are that the dendritic receptive field does encode in such a way that a Fourier transform is appropriate at one level of description (see DeValois, et al., 1978 a, b) and the Fourier transform has the advantage of being readily invertible so that encoding and subsequent image reconstruction is easily achieved.

The reason for looking at quantum mechanics for mathematical treatments of neural holographic processes is that the issues faced at the micro-physical level are in many respects similar to those encountered in current neurophysiology. Thus David Bohm (1971, 1973) has suggested that a holographic-like order which enfolds space and time underlies the observations of quantum physics. Bohm calls this an implicate order to distinguish it from such explicate, explicit orders as those represented by Euclidian geometry and Newtonian physics.

On the basis of these results and formulations the problem of brain-percept isomorphism takes on added complexity. The brain cortex resembles a spatial filter (Movshon, et al., 1978), resonator or interferometer (Barrett, 1969), a musical instrument or hologram constructing percepts. Such an instrument is not a geometric isomorph of the percepts it constructs. Rather, the isomorphism is seen to be between the brain as an instrument and the arrangement of physical energies elsewhere in the universe. The isomorphism is between two "physical" entities, "brain" and "world" rather than between either of them and our percepts!

Were the Gestalt psychologists wrong therefore in their proposal of psychophysical isomorphism? I do not believe so--only the locus of the isomorphism was misplaced. A possible resolution of the complexities introduced by the recent findings of how the brain cortex operates comes from an observation made by David Bohm with regard to current physics. He suggests that all of our conceptualizations in physics (as opposed to experimental manipulations and their formal mathematical treatment) are based on the uses of *lenses*. We have telescopes and microscopes which contain objectives which objectify. Objects are particulate, separated from one another and can thus move with respect to one another to create the appearance of space, time, and causality, i.e., the explicate domain. Take away lenses and one is immersed in the implicate order.

Apply this reasoning to the perceptual isomorphism problem. Our percepts provide us with a Euclidian and Newtonian mechanistic order in which there are objects separated from one another, in which there is space, movement, time, causality. This is the explicate order. Take away our lenses--in this case the lenses and retinal structure of our eyes, the cochlea of the ear and the tactile senses which, as we have seen, Bekesy showed in a carefully conducted series of experiments to be lenslike due to sensory, i.e., lateral inhibition--and we might well be left with an implicate order much as was Helen Keller before she learned to objectify.

How does the brain deal with this lens-produced explicate order? Recall that the holographic transformations are restricted to receptive fields forming a patch or multiplex hologram. The patches, the receptive fields, are, however, spatially arranged to represent the sensory receptor surface--there *is* a topological isomorphism between *receptor* arrangement and receptive field arrangement. Thus a coarse grain/explicate sensory representation and a fine grain/implicate holographic representation characterizes brain organization just as it does physical organization.

Isomorphy according to this analysis is between percept and the coarse grain sensory system mechanism. Contrary to James

Gibson's pronouncements (1979) the lens of the eye does focus an image on the retina which is viewed by most students of comparative neurology when they are given an ox eye to dissect. But then this focused image which objectifies is analyzed into wave forms by the motion of the retina as shown by the "Mexican hat" configuration of the receptive field recorded from the fibers of the optic nerve (Rodieck, 1965). These wave forms are subsequently processed by the brain in two ways: a coarse grain process which maintains the image/object properties and a fine grain process which provides the computational and storage power of the implicate order. In the next section we deal with the problem of how these processes are extended to produce the logicality which emphasizes the subjective/objective isomorphy while others emphasize the invariances produced by wave-form correlations to produce a rational, implicate, enfolded order. In this order, the dualism implied by isomorphism has no role.

Localization and Semiotics

Introduction

In *Languages of the Brain* (Pribram, 1971, chs. 17, 18, 19), I made some preliminary proposals concerning the relationship between human language and the functional organization of the brain. These proposals were based on clinical experience with aphasic patients and on the analysis of the structure of language by Charles Peirce (1934). The proposals were incomplete in many respects and raised problems that have persistently plagued me in trying to understand linguistic processing by the brain. The current conference thus presents an opportunity to enlarge on the earlier views which have been especially enriched by attendance at a conference on the origins of speech and language sponsored by the New York Academy of Sciences (1976), by an interdisciplinary conference on the nature of human language sponsored by the Society for the Interdisciplinary Study of the Mind (1978), and by the participants of this conference.

Perhaps the most important problems concern the relationship between brain organization and Peirce's categories of semantics, pragmatics, and syntactics. The connection between semantics and syntactics appeared to be relatively easy to establish: grammar and meaning mutually imply each other much as partitions on a set determine the organization into subsets (Pribram, 1973 a). Thus, no separate brain locus would be expected to distinguish disturbances of semantics from those of syntax.

Two problems immediately arise from this formulation: one, it is incomplete since it ignores pragmatics; and two, it contradicts the clinical observation that semantic aphasias more often follow parietal lesions while agrammatism is found most often in patients with more anteriorly placed damage in the temporal lobe or adjacently at the foot of the central fissure.

The problems concerning semantics, pragmatics, and syntactics are intimately related to another set of distinctions that Peirce makes, i.e., those that characterize signs and symbols. Signs refer to icons, i.e., images that outline or caricature the sensory input. Signs may also become indices that point to, categorize, or classify that input into groups, i.e., sets and subsets. Symbols, on the other hand, are tokens that bear only an indirect and completely arbitrary relationship to the events or objects symbolized. In *Languages of the Brain* I focused on this distinction between the direct, deictic nature of iconic and indexal signs and the indirect tokens that compose symbols as fundamental. However, the criticism has often been voiced that signs are also tokens, and furthermore, that in *Languages*, Peirce's differentiation between icon and index was not pursued.

These difficulties are compounded by the generally held opinion by philosophers, linguists, and cognitive psychologists that signs and symbols are hierarchically related. Peirce is not altogether clear on this issue, but in *Languages of the Brain*, sign and symbol are conceived to originate from the operation of separate neural systems: signs are processed by the posterior convexity of the brain, symbols by frontolimbic formations. Thus, the neuropsychological formulation has been at variance with accepted linguistic conceptualizations.

Finally, in *Languages of the Brain* I suggested that the ordinary distinction between nouns and verbs in terms of nominalization and predication is in error. Both nouns and verbs are seen as nominalized: verbs refer to nominalized actions while nouns refer to objects, the difference between objects and acts being their relative stability over time and place. Predication is defined neuropsychologically as expressing a relationship, a proposition, a belief about how objects and acts have become momentarily related (see also Eco, 1979, p. 7). Predication, therefore, demands syntax, in English, for example, the use of only a restricted range of verbs such as "is." Linguists, on the other hand, have tended to identify predication with action per se and to consider all verbs as predicates. Verbs are thus instrumental, procedural referents to actions of objects referred to by nouns.

One may be tempted to ignore these differences. After all, differences in disciplinary approach may well produce different analyses. But, if understanding human language is to be of a piece, the different approaches ought to shed light on a commonality of problems, and the discrepancies listed above should be resolvable. The following attempt toward resolution is made in this spirit.

Resolutions of these issues rests on the following proposals: (1) Image processing occurs in the posterior convexity of the brain by virtue of the primary sensory-motor projections systems. (2) Iconic processing results from operations on these images during which one or another aspect of the image is attended and/or deictically signed. Iconic processing is a function of the intrinsic ("association") cortex of the right hemisphere in man. (3) In the left hemisphere this cortex is involved in categorizing aspects of images into informational alternatives. Thus, attention and behaviour toward an aspect (or feature) of an image classifies and indexes that alternative. (4) When arbitrary representations are used in iconic and information processing, communication becomes symbolic. Such arbitrary representations stem from a recurrent regularity (redundancy) in an association between the organism's internal state and an iconic or informative expression. Activity of the frontolimbic forebrain is necessary to the establishment of symbolic processing. (5) Symbolic communication moulds language by reflecting the pragmatic redundancies inherent in social discourse.

Semantic Processing: Image and Information

Note that in this formulation the distinction between image processing (iconicity) and information processing (indexing) rests on hemispheric specialization. The evidence for such specialization has been repeatedly reviewed (e.g., Dimond & Beaumont, 1974) and has become common knowledge. Less well articulated are the relationships between image and information processing and the construction of linguistic symbols. As Peirce makes clear, icons and indicants bear a direct relationship to what is being signified. In today's parlance, images (see, e.g., Paivio, 1971) and information considered as alternatives (see, e.g., Miller, 1953) are also rather directly derived from sensory input. Symbols, on the other hand, are arbitrary and derived from use. This arbitrariness stems from the modification of language by expressions of internal states that give form to the language.

The hierarchical nature of linguistic processing may well have depended initially on the beginnings of hemispheric specialization in the audio-vocal nature of human language. There is considerable evidence that initially primate communication proceeded by establishing a reciprocal relationship between icon and index using bilateral visual-gestural mechanisms. Thus, apes have been taught to indicate their communications by American Sign Language (e.g., Gardner & Gardner, 1969) and the cave paintings of early man suggest considerable skill at iconic symbolization. A plausible scenario of the origins of *speech* might be that frustrations with visual-gestural communication due to darkness in caves, distance, or other awkward circumstances became expressed in vocalizations which then became differentiated into tokens for the unseen gestures.

In this fashion, the expressions became symbols, initially standing in lieu of icons and indexes and then supplanting them because of their overwhelming adaptive advantage. In short, the expressions became words.

It is likely that these first expressions of frustrations were related to actions and were, therefore, verbs. Verbs are words that denote actions (Miller, Galanter & Pribram, 1960, ch. 14). "A hole is to dig" a child will tell you and an aphasic patient will gesture only "to dig." Later in evolution verb words became nominalized and objectified. But as Quine points out (1960), even in their referential functions words are highly sensitive to context. Thus, it does seem more appropriate to identify them as symbolic as is the custom in linguistics and philosophy (e.g., Morris, 1946) and not as signs as in *Languages of the Brain*.

Pragmatic Procedures: Language Formation

But by what mechanism are these higher order arbitrary symbols achieved? The proposal made here is that pragmatic procedures involving the functions of the frontolimbic forebrain continuously modify icon and index once vocal expression becomes involved in the communication. The limbic systems are primarily concerned with monitoring the states of the organism that are expressed as hunger, thirst, sex, etc. (For review see Pribram, 1971, chs. 9, 10.) In addition, the intensive aspects of pain and temperature are regulated by these systems (see Pribram, 1977 a). These basic functions are reflected in higher order processes as establishing the needs and desires, i.e., the bases for the utilities, that determine what reinforces the organism's behaviour (see, e.g., Douglas & Pribram, 1966; Pribram, Douglas & Pribram, 1969; Pribram, 1977 b). In essence, therefore, these systems establish an internally determined pragmatic *context* within which the organism approaches the world about him.

The limbic forebrain shares regulation of context-dependent behaviour with the pole of the frontal cortex which can be considered as the "association" area of the limbic systems (Pribram, 1958). The functions of the frontal cortex make possible the distribution of behavioural responses according to the probability that the behaviour will be reinforced (Pribram, 1961). Thus, frontal cortex participates in determining the utilities which, as noted above, organize the context within which an organism approaches his world. (Utilities are defined in economic theory as derived multiplicatively from desires and probabilities.)

Linguists and psycholinguists have up to now paid little heed to the pragmatics of language. The line of evidence and reasoning pursued here suggests that pragmatic procedures are derived from processes that establish desirabilities and the probabilities of reinforcement given a particular state of desire. The linguistic expression of such pragmatic processes would therefore be episodic, i.e., would be dependent on momentary state. Some mnemonic mechanism must also be involved since state change is monitored and outcome (reinforcement) probability estimates are made. Cognitive psychologists often refer to such mnemonic processes as short term but more recently, and accurately, the process has been identified as "episodic" memory (Tulving, 1970, 1972) to distinguish it from more universally applicable semantic stores.

Forming a Language: The Role of Pausing and Parsing

In non-human primates, lesions of the frontolimbic forebrain, but not of the posterior convexity, interfere with the performance of a task which can be used as a model for relating episodic, context-dependent constructions to linguistic processing. This task is the delayed alternation procedure during which a subject is reinforced for alternating his responses between the two boxes. During the interval between opportunities for response an opaque screen hides the boxes. The screen is kept in place for from five seconds to a minute or longer depending on how difficult one chooses to make the task. When the interval between opportunities is equal, subjects with frontolimbic lesions invariably fail the task: i.e., they seem to forget which box they previously chose, successfully or unsuccessfully. When, however, the intervals between opportunities are made unequal though regular--e.g., five seconds before box one must be chosen and fifteen seconds before box two is the correct choice--then the deficit is quickly overcome (Pribram & Tubbs, 1967; Pribram, Plotkin, Anderson & Leong, 1977).

The reason for performing the above experiment was that it seemed as if a monkey failing the alternation task were in much the same situation as a person hearing or reading a paragraph in which letters and words were separated by equal intervals. Thus, MARESEATOATSANDDOESEATOATSANDLITTLELAMBSEATIVY is unintelligible until parsed into words. In general, chunking (Miller, 1956; Simon, 1974) has been found to be an essential processing mechanism when the limits of competency are involved (Pribram & McGuinness, 1975).

It is remarkable that the same parts of the brain are responsible for the operations that determine context by way of pragmatic procedures and those that determine the *pauses* necessary to parsing utterances, i.e., expressions into words. This identity of neural substrate suggests that *pauses* in speech provide the contextual cues within which the content becomes related to the speaker's state: his mood, his momentary desires and probability estimates of success in meeting those desires. From these contextual cues, therefore, signification and symbolization derive--pragmatic processing *forms* (gives form to) the linguistic production. Pauses, inflections, and the dynamic range of speech form the context in which the content of the communication occurs. This idiosyncratic aspect of language formation may therefore be responsible for the rapid transformation of language into dialect by an intimate group and thus the variety of languages used by man.

Further, this relationship between pragmatics and the *form* of language expression may underlie the process of predication. Making words into sentences would be unnecessary unless a statement about state, about desire and belief (probability), etc. were at stake. Thus, predication stems from pragmatic procedures while nomination, i.e., making words more universally meaningful, results from semantic image and information processing.

Syntactics: The Motor Aspects of Language

What then is the role of syntax? Syntax must reflect both the pragmatic form of language and its semantics. Neurologically, both the frontolimbic forebrain and the posterior convexity of the brain are directly connected to such subcortical motor structures as the basal ganglia which are known to regulate postural and sensory sets (for review, see Pribram, 1977 c). These basal structures are, in turn, intimately connected with the centrally located motor cortex which organizes skills.

Over the past three decades, a great deal has been learned about the hierarchical nature of processing information by the use of symbols (e.g., Miller, Galanter & Pribram, 1960). The construction of programs that make serially operating computers into effective data storage and retrieval mechanisms has shown that such programs must categorize data into items which can be universally retrieved and are thus essentially context-free. Hierarchies of such context-free items (bits → bytes → words) are then compiled into assemblers which in turn are the elements of more complex programming languages.

More recently, cognitive psychologists interested in simulating human experience and behaviour have found that exclusive reliance on such hierarchical organization does not reflect the full nature of human perception, action, and communication. Even the relatively simple process of compiling demands arbitrary decisions that are specific to the "episode" or situation, e.g., the particular computer in *use*. More and more, these investigators have resorted to the construction of "procedures," episode-specific program *clusters* that can be flexibly switched into an ongoing program whenever a situation so demands (see Miller & Johnson-Laird, 1976; Winograd, 1977; Schank & Abelson, 1977). As noted earlier, in primates evidence has accumulated to support the hypothesis that the frontal cortex operates such a context-sensitive noticing mechanism and becomes, in this sense, therefore, the executive organ of the brain (Pribram, 1973 b).

Conclusion

The import of this recent attention to context-sensitive, pragmatic procedures in all cognitive operations does not exclude psycholinguistics or neurolinguistics. In a sense, this paper has summarized a set of conceptualizations that has benefited substantially from recognition of the role of pragmatics, its definition in terms of current issues, and the possibility of constructing a reasonable model of the brain processes involved. Pragmatics has thus proved the key concept in resolving a set of issues and problems that grew from an interest in relating semantics to syntax. Pragmatics provides the context and form within which image and information becomes meaningful. Syntax must thus be accountable to both hierarchical, essentially context-free semantic considerations, and to episode-specific, context-sensitive procedures. Brain mechanisms exist for semantic processing in its posterior convexity and for procedural organization in the frontolimbic systems. Syntactic collation becomes the burden of the motor systems to accomplish for the linguistic act and is little different in this respect from the achievement of other actions (Pribram, 1971, chs. 16, 19).

Semantic and pragmatic routines, i.e., their respective syntactic programs, must operate on a variety of buffer and permanent stores. As described in the previous section, the distributed nature of these stores and the holographic-like process which begets the store, suggest that semantic and pragmatic operations re-member a dis-membered store. Re-membering most likely involves a content-addressable system based on wave-form correlations (Pribram, 1971, pp. 157, 326, 349). Current computers use location-addressable list structure programming but the distributed biological memory has no "address." Whatever the molecular storage mechanism might be, as long as it is distributed, it must be content-addressable. Wave forms, distributed to many locations, could readily be "recognized" by a stored pattern representing prior wave forms initiated by similar receptor processes. This match-mismatch mechanism, a correlation, provides the decision nodes (the holes in the IBM data cards) in the semantic and pragmatic programs. The syntactic structure of the programs, not the decision nodes, differentiates them. Semantic processes are hierarchically organized; pragmatic procedures depend on heterarchical graph structures. Differences in the organization of the systems of the posterior cerebral convexity from that of the frontolimbic forebrain account for these differences in program structure.

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DISCUSSION PERIOD

A Model of the Text Generator, *Michael W. Mair*

A "Model of the Text Generator" purports to be an Organic Basis for Consciousness. The Project thus represents an ultimate in theoretical ambition, and the validity of even attempting such a thing is much challenged. These challenges take two forms.

The first comes from those, usually working in some aspect of brain science, who say that our present state of knowledge is such that we cannot even imagine what such a model would be like. They denigrate all such attempts to the status of a kind of after-dinner entertainment, not for serious consideration. These critics may well be right. But it is the view of this author that we do not know even that which we do *not* believe until we state it, that there are many stages in the evolution of a true theory, as Marcel Kinsbourne has emphasized. This paper is an attempt at a synthesis, certainly not an assertion of "how things are" in the brain and behaviour. It seeks to render visible and explicit some trends in the literature.

The second challenge is more radical, and more ancient. Basically it comes from those who insist that thought and experience *have* to be unamenable to accounting for by any mechanism. It is the ambition of this study to contribute to the emergence of a theory whereby the brain might be rendered "transparent," that is, completely understood in principle if not in detail. There may still remain, when and if this is done, aspects of experience which do not seem to derive from "in there" at all. This point of view will emerge during my paper. I am reminded of a recent conversation I had with a woman psychologist at a conference who, on learning what it was that I considered to be the legitimate goal of the enquiry, said, "Well, I hope you never succeed!" She never stayed to hear the argument. If she had, she might have found the conclusion a little too unphysical.

But this second challenge has been well worked over by philosophers. For example, J. D. Searle (1979) speaking at a recent symposium on Brain and Mind, said of the theory that philosophy is *not* continuous with the empirical disciplines:

> I myself think that this theory is not refuted, but just became irrelevant by the march of events. Philosophy is much more interesting today than it was twenty years ago simply because we no longer want to make a distinction between philosophical questions and other kinds. If this means that the empirical researchers are marching in on our territory, so much the better, because if they look behind them, they will see that we are marching in on their territory too.

But enough of the apologia; Kenneth Craik, writing in the 1940s, well defined the problem, and if in attempting to formulate a stage in the solution I have looked extensively to the work of Karl Pribram, it is not only because I reviewed the work of the latter for this Institute, but because truly his contribution has made of these topics a "Pribram world."

From Craik (1966):

> The adequacy of our examples and explanations of animal mechanisms and behaviour will be largely governed by the general view we take of animal life and its function. There are various theories--such as the stimulus-response theory, the theory of instincts and drives, and the theory of conditioned reflexes and modifiable responses. None of these seems to me to put the emphasis in the right place; the nature of the animal and human mind seems rather to be to copy its environment within itself in an active dynamic model which is capable of realising tendencies and possibilities of that environment which are obstructed in this outer world by the separation of the wrong energy-relations among the parts of that environment; and once these possibilities have been mentally realised they can often be brought to pass physically through the motor mechanisms of man and animal. This notion of life bringing to fruition the possibilities of