The Lakehead University REVIEW

PSYCHOLOGICAL PARALLAXES

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The Organization of Memory by the Brain[1]

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Recent research has shown that the brain is an instrument which receives sensory input and spreads it in a manner which can be described mathematically by a "spread function" such as a Fourier transform. Such a transformation of input allows storage in the frequency domain which is highly efficient in its capacity to handle a great deal of information. However, in order to use that information in the ordinary space-time domain the brain must reorganize this information by processes which result in imaging, verbal behaviour, instrumental behaviour, etc.

The word "remembering" is a good one to keep us alerted as to what is going on. "Remembering" assumes the fact that you "re-member", that is, that there must be something "dismembered" for you to "remember" it. What happens when information is stored in the nervous system is that it becomes dis-membered and then is re-membered, reorganized, or reconstructed when used.

Let us review some of the evidence for this view of brain functioning. Suppose someone has a stroke and half of his visual system is destroyed. He does not come home to the family and recognize his son and say "Hello Johnny", wave at his daughter and say "Hello Julie" and then turn to his wife and his other children and say, "And what are you doing here?" Memory does not work like that. Memory is holistic. In our example, the person will either remember no one, or else he will remember everyone. (Sometimes after a blow on the head there is what is called retrograde amnesia which extends back in *time* for a period depending on how severe that injury is. But the amnesia is for everything that occurred during that period. It is not that one remembers a few people and not other people, a few incidents and not other incidents). After an initial period during which it is subject to destruction a memory store is consolidated that appears to be holistic.

In addition to such clinical observations and similar experimental demonstrations, research results from our laboratory and others have given direct evidence that whatever comes into the brain becomes distributed. For example, recording of event-related electrical activity of the brain shows that in the visual cortex not only input from the retina but motor response and reinforcement evoke very specific brain waves.

Next, let us examine the evidence that the brain process is akin to the *mathematical* spread function we described earlier. What the visual system appears to be doing is analyzing the light and dark aspects of the visual environment over space very much the way the auditory system is analyzing sound over time. The auditory analysis of sound frequency has been known for a hundred years. Now, we are beginning to have evidence that the visual system processes information in a similar way except that it does it on the frequency distribution in space for patterns of luminance (and the wavelength of the light for color). The distribution of luminance over space is called the spatial frequency of light. There is a great deal of visual research currently addressed to showing that the visual system is in fact analyzing any pattern by decomposing it into its basic spatial frequencies. The question being asked is how broadly tuned are the visual channels that make the analysis possible.

Can we then say that this is a basic mode of functioning for all sensory receptor systems and, if so, so what? What if the eye looks like the ear and the ear like the skin? Would this not explain why memory is holistic?

The tuning is being done at synaptic junctions in the networks of the brain. The mathematical description of these processes is in the wave mechanical frequency domain. This description is also the basis of what is called a hologram. A hologram is based on a spread function. One can make a hologram very simply by taking a piece of photographic film and instead of placing it at the image plane in a camera, placing it somewhere near the focal plane. This will blur the picture, but as long as one knows exactly how far forward of the image plane that film was placed, one can retrieve the image by simply deblurring it, i.e., performing the inverse transform of what produced the blur.

There are the two further questions that now must be addressed: Given that inputs are stored in a holographic fashion, how does one re-member this dis-membered holographic store? This was the question we posed initially. The additional question is how does the remembering process become veridical to what is in the environment.

With regard to the first question, let me discuss the frontal lobes and the temporal lobes of the brain. The classical view of these association areas of the cortex has been that they associate sensory inputs. This view holds that what we experience is made up of elements and we associate these elements to produce cognitions (knowledge). In this view the elements are considered to be *sensory* elements. I have just stated that it is true that the memory store in the brain exists in the form of elements. However, the holographic hypothesis denies that these elements are sensory. Rather they are the result of a spread function in which the elementary units represent the whole. Thus, what the "association" cortex must accomplish is a "readout" from this distributed store of holistic "elements" — a constructional process which is *not* necessarily associational.

Our laboratory work with monkeys has shown that the association cortex in the back of the brain — the parietal and temporal lobes — is very largely sensory specific. There is an association area for vision, one for audition, one for tactile sensibility, one for taste, and so on. Each sensory mode has its own separate "association cortex." One would expect that the visual "association cortex" would depend for its functioning on receiving a visual input, but when we destroy all of the known visual input of this cortex, the destruction has no effect. On the other hand, when we destroy the output from this "association" cortex we obtain the same effect as when we destroy the "association" cortex itself. This had led to the idea that the "association cortex" is not dependent on its input, that its function in the brain is dependent on its output. Therefore, we have been spending the last twenty years tracing the output from the "association areas" of the brain. The research is not complete as yet. We have traced the visual pathways as far peripherally as the retina by electrically stimulating the "association cortex" of the temporal lobes.

Stimulating the frontal cortex produces the opposite result. The frontal and posterior (temporal) parts of the brain are antagonistic to each other.

One major finding in all this research has been that the pathways from the association cortex to the periphery have connections in the basal ganglia which up to now have always been thought to be motor structures believed to influence only movement. Thus, the association cortex projects down upon these motor structures and the motor structures influence what is going on in the primary visual system. This sensory function of motor structures appears to be paradoxical — however, it turned out not to be as much of a paradox as it initially seemed to be.

Herein lies another tale: The way the motor cortex is conceived of in most textbooks is as the final common path for all psychological functions. The mind supposedly plays on the motor cortex the way a concert pianist plays on a piano keyboard. John Eccles has even coined the phrase "cognitive caress" to describe this interaction.

We did some experiments on the motor cortex to see whether this really was so. For almost a century an argument had raged as to whether the representation in the motor cortex encoded movements, or whether the muscles were represented. I wanted to check out the pros and cons of this argument for myself. I found out that in fact anatomical data led one to believe that muscles were represented while physiological data showed that electrical stimulation produced movements centered on joints. In addition, I wanted to study the behaviour of the animal. So I took out the motor cortex to see whether muscles were paralyzed or movements were paralyzed. I took movies of the animals climbing cages, eating and grooming each other and I looked at the movies in slow motion. Much to my surprise there was no demonstrable paralysis of any muscle nor was there any deficiency of movements observed. Yet when I quantified the monkeys' behaviour in opening a latch box, I found that these animals *were* deficient. Thus the concept originated that it is neither movement nor muscles that are represented. Rather, *actions* are represented. Action is defined as Tolman and Skinner have defined behaviour, i.e., the environmental consequence of the movement. Take, for instance, my writing on the blackboard with my left hand. The muscles of this hand have never performed this action before. How can my muscles which have never performed these actions, perform them? I puzzled over this for seven years and the answer was finally given to me by the work of a Russian physiologist by the name of Bernstein.

Bernstein had performed a very simple experiment. He dressed people in black leotards and placed them against black backgrounds. He then had them hammer nails or run along a platform which was jiggling up and down. He made movies of these people dressed in black against black backgrounds. However, he had placed white dots on their joints so that the movies showed little white dots moving up and down. What does a white dot look like moving up and down in a movie? A waveform. So Bernstein performed a Fourier analysis on the waveform and was able to predict within two millimeters of where the next blow of the hammer would fall or where the next step would land. From these results I reasoned that if Bernstein could make such a prediction that perhaps his brain could also make it — and if his brain, then my brain and your brain and probably all brains work in this fashion. So once again waveform analysis in the frequency domain has provided answers to what appeared to be an unfathomable mystery.

Thus, the mechanism in the brain that actually performs the analysis of movements as they take place operates like the settings of a thermostat. One simply adjusts a set point, in this case by a mathematical equation, and lets the machinery of the motor system carry out the operations necessary to match the setting. The basal ganglia of the motor system have been known now for years to operate by way of changing set points of muscle receptors rather than by eliciting muscle contractions directly.

We return, therefore, to our finding that the basal ganglia control sensory receptor input. Perhaps this is not so surprising in view of the fact that they exert motor control via the muscle receptors. What is new is that the "association cortex" performs its functions via the basal ganglia and thus operates by computing adjustments on the set points of receptor function.

I want now to finish with the question posed at the outset of this paper. If our brains have encoded memory in a distributed fashion — an orderly blur if you will — how do we construct images of objects and how do we act on the basis of these images? You might rightly ask, "I see an image but is there really an object there?"

The answer to your question lies in understanding the frequency domain. Though in itself spaceless and timeless, space and time can be read out of the frequency representation. Up to now science has been essentially ignoring this frequency domain because we have been looking for and at things through lenses ever since the time of Galileo. When we dispose of lenses and view our universe with gratings (spatial frequencies), paradoxes appear not only in brain physiology but in quantum mechanics. The possibility exists, therefore, that there is an organization in the universe that is similar to that which we are finding in the brain — that indeed there is an isomorphism between brain representation and the universe represented much as the Gestalt psychologists suggested. However, this isomorphism is not at all with the world as we image it — rather it resembles the organized holographic blur we have been describing in this report.

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FOOTNOTES

[1] Adapted from a colloquia presentation sponsored by the Department of Psychology, Lakehead University, on March 16, 1976.