N82-13692

FUNCTIONAL STRUCTURE AND DYNAMICS OF THE HUMAN NERVOUS SYSTEM

by: Joseph A Lawrence

This report is an interim report on the status of an effort to define the directions we need to take in extending pilot models. We need these models to perform closed-loop (man-in-the-loop) feedback flight control system designs and to develop cockpit display requirements. The approach we have taken is to first develop a hypothetical working model of the human nervous system by reviewing the current literature in neurology and psychology and second to develop a computer model of this hypothetical working model.

One way of analyzing the nervous system, is to relate the neurons as to their sensory input (Afferent system), processing (Association areas) and output (Efferent system) functions. Konorski, 1965, uses this approach to arrive at some general characteristics of these functional systems.

Konorski organizes the sensory pathways into seven basic functional areas which he calls analyzers: the Visual, Acoustic, Kinesthetic, Somesthetic and Gustatory, Vestibular, Emotional and Olfactory analyzers. These analyzers are so grouped because of similarity in structure and function.

The analyzers have many characteristics in common. Each is built as an n level structure, with each level being an aggregate of neurons performing some signal processing and association tasks. Each level contains cells, "units", that respond maximally to a particular "meaningful" stimulus in the environment. Konorski calls the response a "unitary image response", assuming the nervous system has integrated lower level parts into this meaningful whole. In this manner, the nervous system can operate, for example, from the "ith level on this unitary perception, and/or the unitary perceptio at this level can act as one piece of a more comprehensive unitary image at the next level. This view is supported by the fact that some outputs from this level proceed to the next higher level while others called "exit" neurons leave the analyzer to subserve lower level reflex loops. The unitary images of higher levels tend to be more complex and refined relative to the level of detail of the image.

Exit neurons proceed into areas we will call association areas. In these areas unitary perceptions between analyzers are associated with one another and with meaningful other perceptions formed over time by logic, thought and concept forming transformations. In these areas, internal models of reality are formed which can be thought of as aggregates of expectation on how present sensory inputs will transform as the result of temperal and spacial movements. Perceptions and models are operated on by logic operation at the higher levels, forming more abstract models, principles and rules etc. Basic drives are associated with remembered past outcomes of patterns of movement to form goals or patterns of planned activity matched to expected outcome. Often repeated patterns of thought or behavior become programmed at many levels as schema and subschema. The models, goals and schema thus become a multi-level hierarchical set. This arrangement is consistent with philogenetic and ontogenetic theories of nervous system development and function.

The third area by type of signal flow is the efferent systems or output signal generating systems. I will limit my comments to those efferents pertaining to body movement control. Although still somewhat controversial, many believe that output activity is initiated by the formation of an image of expected and desired movement. The image, however, must be accompanied by a desire to move or we experience only the image. The image is the vehicle through which the nervous system is configured for the action. One way for this to occur naturally is for the efferent systems to use the multi-leveled unitary images already created in the Kinesthetic and Somesthetic analyzers. The many exit neurons at each level of the analyzers can subserve this function. What we therefore have as a final output signal is many signals that are somewhat integrated but with the final integration taking place in the spinal column in the areas surrounding the particular motor neurons that drive the (associated) muscles.

There are four additional aspects of the nervous system that are important to a modeling process. One is the term consciousness. Defining conciousness gets us into the whole Mind-Body issue (Spiritual - Physical). I will not try to solve this problem here. But I think we all have the experience of being aware of what we are doing in different ways. Sometimes we can be concentrating on performing a task and are aware of minute details of our goal, our actions and the result of our actions. At other times we are almost observers of our activity especially in well learned tasks. Finally, there are sometimes when we realize that we've driven home almost automatically while our conscious attention was focused on a work or social problem or event. My point is that some tasks are performed with conscious awareness and/or control while others, or parts of some tasks, are performed automatically.

Observing epileptic patients lead Dr. Penfield (1975), a noted neurosurgeon responsible for mapping the functions of a large part of the human cortex, to propose that there are two somewhat independent integrating systems in the human nervous system. One he calls the "Highest Brain Mechanism" (HBM), which, he contends, supports the process of consciousness. The other he calls the "Automatic Sensory-Motor Mechanism", (ASMM), and claims that this mechanism can carry out very complex learned behavior patterns even after the HBM has been immobilized by a petit-mal epileptic seizure.

Whether we accept Dr. Penfield's proposed concept or our own observation of our behavior, we must deal with the job of allocating task assignment to conscious awareness and control,automatic control with conscious awareness or totally automatic control and awareness. But here we must deal with an additional variable.

Consciousness tends to be serial in nature. The automatic system, however, is structured as a hierarchical multi-leveled control system with feedback and feedforward loops and special function generators. The automatic system can and does perform many functions in parallel.

How then can we properly allocate attention to tasks as we study workload? I don't have the answer to this question yet, but it does allow me to appreciate the confusion that presently exists in workload studies. Multi-task modeling efforts will have to deal with finding a workable solution.

The final element is the general state of arousal that the nervous system is in. The nervous system generates a bias signal on the neurons which conditions them for firing. Many factors affect the arousal level. When at low levels, the neurons can't fire with normal signal inputs from processing units. With high levels, the cells fire easily and the nervous system loses its ability to differentiate between signals, thus causing confusion and errors. This factor is important enough to be included in modeling considerations.

In summary then, we can view the nervous system as a multi-level hierarchical automatic control system with parallel processing, feedback and feedforward loops and with the potential of our being consciously aware of its activity and to have conscious control of many functions. Consciousness can be viewed as a master controller acting through the control of the flow of the complex imagery which drives the automatic system.

Reality consists of internal models, remembered transforms of perception, which give a person a sense of understanding himself and his environment, and the ability to establish a set of expectations on what is going to happen next. Indeed, we tend to operate continuously from this set of expectations and are surprised when something different happens. This set of expectations gives us the feedforward capabilities that we use to plan actions to accomplish goals, instantaneous or future. The particular set of expectations available at any moment depends on the motivational state of the nervous system, a very dynamic and difficult variable to consciously control - as any person attempting meditation has already discovered.

A key point to understand is that the set of expectations in the form of images, act to configure the total nervous system as an operating system - both input and output. Because of sensory filtering, our expectations determine to a large degree what we perceive.

Because of the automatic parallel processing, it is possible for several tasks to be performed simultaneously as long as sensory, processing and output elements are not in conflict in performing these functions. In this way, for example, we can maintain our sense of orientation (model) even though we are focused on giving concentrated effort to identifying a target.

With all these variables and this complexity, the multi-task pilot model will have to also be complex and large. Knowing the structure and functions of the nervous system will allow us to make intellegent decisions on how to limit the model, set up experiments and analyze the results.

REFERENCES

Asanuma, H., et al.(1979) Integration in the Nervous System. Tokyo: Igaku-Shoin.

Bandler, R. and Grinder, J. (1975) The Structure of Magic, Vol. 1. California: Science and Behavior Books.

Griffin, D.R. (1976) The Question of Animal Awareness: Evolutionary Continuity of Mental Experience. New York: Rockefeller University Press.

James, W. (1918) The Principles of Psychology. New York: Henry Holt and Company.

Jerison, H.J. (1973) Evolution of the Brain and Intelligence. New York: Academic Press.

Konorski, J. (1970) Integrative Activity of the Brain: An Interdisciplinary Approach. Chicago and London: The University of Chicago Press.

Oakley, D.A. (1979) Cerebral cortex and adaptive behavior. IN Oakley, D.A. and Plotkin, H.C. (1979) Brain, Behaviour and Evolution. New York: Methuen.

Penfield, W. (1975) The Mystery of the Mind: A Critical Study of Consciousness and the Human Brain. New Jersey: Princeton University Press.

Sommerhoff, G. (1974) Logic of the Living Brain. New York: John Wiley and Sons.

Sperry, R.W. (1970) Consciousness, freewill and personal identity. IN Oakley, D.A. and Plotkin, H.C. (1979) Brain, Behaviour and Evolution. New York: Methuen.

Yho, C.H. (1979) The anatomy of the vertebrate nervous system: an evolutionary and developmental perspective. IN Oakley, D.A. and Plotkin, H.C. (1979) Brain, Behaviour and Evolution. New York: Methuen.