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The Hebb Legacy*

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Donald Olding Hebb (1904-1985) was, during his lifetime, an extraordinarily influential figure for the discipline of psychology. His principled opposition to radical behaviorism and emphasis on understanding what goes on between stimulus and response (perception, learning, thinking) helped clear the way for the cognitive revolution. His view of psychology as a biological science and his neuropsychological cell-assembly proposal rejuvenated interest in physiological psychology. Since his death, Hebb's seminal ideas exert an ever-growing influence on those interested in mind (cognitive science), brain (neuroscience), and how brains implement mind (cognitive neuroscience).

Raised in Chester, Nova Scotia, Hebb graduated from Dalhousie University in 1925. He aspired to write novels, but chose the more practical field of education and quickly became a school principal in the Province of Quebec. The writings of James, Freud, and Watson stimulated his interest in psychology, and as a part time graduate student at McGill University, Hebb was exposed to Pavlov's program. Unimpressed, Hebb was "softened up for [his] encounter with Kohler's Gestalt Psychology and Lashley's critique of reflexology." Hebb went to work with Lashley, and in 1936 completed his PhD at Harvard on the effects of early visual deprivation upon size and brightness perception in the rat. He accepted Wilder Penfield's offer of a fellowship at the Montreal Neurological Institute where he explored the impact of brain injury and surgery, particularly lesions of the frontal lobes, on human intelligence and behavior. From his observations that removal of large amounts of tissue might have little impact on memory and intelligence, Hebb inferred a widely distributed neural substrate. At Queens University, Hebb developed human and animal intelligence tests, including the "Hebb-Williams" maze, which has subsequently been used to investigate the intelligence of many different species in hundreds of studies (Brown & Stanford, 1997), making it the "Stanford-Binet" of comparative intelligence. Hebb's studies of intelligence led him to the conclusion that experience played a much greater role in determining intelligence than was typically assumed (Hebb, 1942). He would later point out that every bit of behavior is jointly determined by heredity and environment, just as the area of a field is jointly determined by its length and its width (Hebb, 1953).

In 1942 Hebb rejoined Lashley, who had become director of the Yerkes Laboratory of Primate Biology. There Hebb explored fear, anger, and other emotional processes in the chimpanzee. Stimulated by the intellectual climate at the Yerkes Laboratory, Hebb began writing a book synthesizing different lines of research into a "general theory of behavior that attempts to bridge the gap between neurophysiology and psychology (Hebb, 1949, vii)." Hebb returned to McGill as Professor of Psychology and in 1948 was appointed chair. His book, "The Organization of Behavior: A Neuropsychological Theory," wielded a kind of magic in the years after its appearance (Hebb, 1949). It attracted many brilliant scientists into psychology, made McGill University a North American mecca for scientists interested in brain mechanisms of behavior, led to many important discoveries, and steered contemporary psychology onto a more fruitful path.

For Hebb "the problem of understanding behavior is the problem of understanding the total action of the nervous system, and vice versa"(1949, p. xiv) and his advocacy of an interdisciplinary effort to solve this neuropsychological problem was his most general theme. When Hebb's book was published, physiological psychology was in decline, and there was a growing movement in psychology to reject physiological concepts (Skinner, 1938). "The Organization of Behavior" marked a turning point away from this trend. Metaphors, using non-biological devices with well-understood properties, figure prominently in the history of attempts to explain behavior and thought. The mental chemistry of the British Associationists, hydraulics of psychotherapy, magnetic fields of Gestalt Psychology, and the computer metaphor of information processing psychology were all fruitful to a point, but then limited and misleading. Hebb's appealingly simple alternative was to explain human and animal behavior and thought in terms of the actual device which produces them - the brain, and in "The Organization of Behavior", Hebb presented just such a neuropsychological theory.

There were three pivotal postulates:

1) Connections between neurons increase in efficacy in proportion to the degree of correlation between pre- and post-synaptic activity. In Hebb's own words, from the Chapter 4 of the Organization of Behavior: "When an axon of cell A is near enough to excite B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased" (p. 62). In Neuroscience this proposal corresponds to the "Hebb synapse", the first instances of which were later discovered in long term potentiation (Bliss & Lømo, 1973) and kindling (Goddard, McIntyre & Leech, 1969), whereas in Cognitive Science this postulate, often called the "Hebb rule", provides the most basic learning algorithm for adjusting connection weights in artificial

neural network models.

2) Groups of neurons which tend to fire together form a cell-assembly whose activity can persist after the triggering event and serves to represent it. This proposal, illustrated by Hebb in schematic form and shown here in Figure 1, is considered by some to be Hebb's most important conceptual contribution (Milner, 1986).

3) Thinking is the sequential activation of sets of cell-assemblies.

A précis of Hebb's theory is presented in the Introduction to "The Organization of Behavior": "Any frequently repeated, particular stimulation will lead to the slow development of a "cell-assembly," a diffuse structure comprising cells in the cortex and diencephalon (and also, perhaps, in the basal ganglia of the cerebrum), capable of acting briefly as a closed system, delivering facilitation to other such systems and usually having a specific motor facilitation. A series of such events constitutes a "phase sequence" - the thought process. Each assembly action may be aroused by a preceding assembly, by a sensory event, or—normally—by both. The central facilitation from one of these activities on the next is the prototype of "attention." ... The theory is evidently a form of connectionism... though it does not deal in direct connections between afferent and efferent pathways: not an S-R psychology, if R means muscular response... It does not, further, make any single nerve cell or pathway essential to any habit or perception." (p. xix) Hebb knew that his theory was speculative, vague and incomplete. Missing from the model, for example, was neural inhibition (Milner, 1957), a concept Hebb later incorporated (1959; 1980a). But Hebb believed that a class of theory was needed, of which his was merely one specific form - subject to modification or rejection in the face of new evidence; and that the primary role of our fleetingly correct theories was to stimulate scientific discovery. Hebb's ideas certainly were fruitful in generating new evidence, as whole literatures on the role of early experience in perceptual development (Hunt, 1979), sensory deprivation (Zubek, 1969), self-stimulation (Olds & Milner, 1954), the stopped retinal image (Pritchard, Heron, & Hebb, 1960), synaptic modifiability (Goddard, 1980), and learning without awareness (McKelvie, 1987), were provoked or fostered by them.

When philosophy and physiology converged in the 19th century, Psychology emerged with the promise of a science of mental life (Boring, 1950). By providing a neural implementation of the Associationists' mental chemistry, Hebb fulfilled this promise and laid the foundation for neoconnectionism which seeks to explain cognitive processes in terms of connections between assemblies of real or artificial neurons. Let me risk the charge of "hero worship" by predicting that as our relatively young science matures, the stature of Hebb's ideas within psychology and behavioral neuroscience will grow to match the stature of Darwin's ideas within biology.

During his lifetime, Hebb won many honours and awards and held many positions of leadership. Among these, he was named Fellow of the Royal Society of Canada, and of the Royal Society (London), he won the APA Award for Distinguished Scientific Contribution, and he served as President of the Canadian and American Psychological Associations. Hebb's specific contributions as well as his direct and indirect influences have been frequently recognized in many review articles, symposia and books, and in professorships and prizes which bear his name. In Canada, for example, both the Canadian Psychological Association and the Canadian Society for Brain, Behavior and Cognitive Science award prizes for outstanding contributions to psychological science that are named in Hebb's honour.

For the reader interested in learning more about Hebb's life and the evolution of his ideas, his own articles (Hebb, 1959, 1980b) as well as those by Glickman (1996) and Milner (1986) are interesting and informative. Hebb's interest in "The Nature of Thought" was the theme of a lecture series and book (1980a) celebrating his return to Dalhousie in 1977 as an honorary professor. In an introductory chapter to that book I had my first opportunity to provide my own appreciation of Hebb's contributions (Klein, 1980). Late in his life, Hebb became interested in the phenomena of dissociative states and disorders, confident that careful experimental analysis and thoughtful application of a cell-assembly framework would yield a scientifically respectable understanding of this controversial topic. His enthusiasm encouraged Ben Doane (a Dalhousie psychiatrist and one of Hebb's first graduate students at McGill) and I to organize a symposium and edit a book on this topic (Klein & Doane, 1994) that we dedicated to Hebb's memory and contributions.

In the scientific literature references to Hebb, the Hebbian cell-assembly, the Hebb synapse and the Hebb rule, increase each year. These forceful ideas of 1949 are now applied in engineering, robotics, and computer science as well as neurophysiology, neuroscience and psychology, a tribute to Hebb's scientific acumen, foresight and courage to put forth a foundational neuropsychological theory of the organization of behavior.

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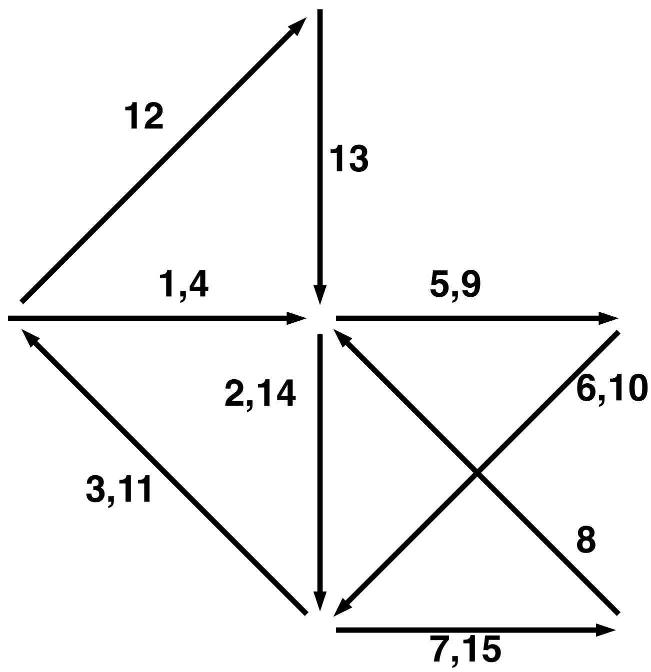

Figure 1. Schematic of Hebb's "cell-assembly" hypothesis. "Arrows represent a simple "assembly" of neural pathways or open multiple chains firing according to the numbers on each (the pathway "1,4" fires first and fourth, and so on), illustrating the possibility of an alternating reverberation which would not extinguish as readily as that in a simple closed circuit." Redrawn from Hebb, 1949, Figure 10, p. 73.