Motivation, Emotion, and Goal Direction in Neural Networks

Edited by

Daniel S. Levine
Samuel J. Leven

LEA

Lawrence Erlbaum Associates, Inc., Publishers
365 Broadway
Hillsdale, New Jersey 07642

Library of Congress Cataloging-in-Publication Data

Motivation, emotion, and goal direction in neural networks / Daniel S. Levine and Samuel J. Leven, editors.
p. cm.
Papers presented at a workshop held in Dallas, 1988, sponsored by the Metroplex Institute for Neural Dynamics.
Includes bibliographical references and index.
ISBN 0-8058-0447-1
1. Motivation (Psychology)—Congresses. 2. Emotions—Congresses. 3. Classical conditioning—Congresses. 4. Neural circuitry--Congresses. 5. Goal (Psychology)—Congresses. I. Levine, Daniel S. II. Leven, Samuel J. III. Metroplex Institute for Neural Dynamics.
BF199.M67 1991
153—dc20 91-12950
CIP

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

Motivation, Emotion, and Goal Direction in Neural Networks

Preface

Emotion used to be a dirty word in science. The late 1800s and the first half of the 1900s were dominated by a profound belief in the ultimate triumph of rationality over ignorance (and, by extension, over emotion). The attempt to rationalize, to quantify, to make things precise spread from the traditional natural sciences to newer disciplines. As academic psychologists strove to be more scientific, they took their cues from the older natural sciences such as physics and chemistry, restricting their attention to phenomena that were easily and cleanly measurable. Hence, the behaviorist, or stimulus–response, school of psychology came to a position of ascendancy. Social scientists in other fields—sociology, political science, management theory, economics—likewise set out to explain the human phenomena they studied by positing rational actors seeking to maximize some measurable quantity. Hence, in all these fields, there has been some tendency to regard emotion as either not worth serious study, or worth serious study because it is undesirable.

The articles gathered in this volume represent examples of a quite different approach to the study of mental phenomena. They represent a blend of theory and experiment, informed not just by easily measurable laboratory data but also by human introspection. Approach and avoidance, desire and fear, novelty and habit are studied as natural events, which may not exactly correspond to but at least correlate with some (known or unknown) electrical and chemical events in the brain.

Whenever there are patterns in nature with any sort of regularity, the temptation arises to look for scientific understanding of the phenomena involved. In the realms of motivation, emotion, and goal direction, the science of brain and behavior is still at any early stage of grappling with problems, but already, from a combination of experimental and theoretical work, some underlying principles are starting to be visible.

Some philosophers of science (e.g., Young, 1951; Stich, 1983; Churchland, 1986) suggested that the precise concepts of neurobiology, as they emerge, will actually replace the more vague concepts of folk psychology. Our belief, rather, is that *some* concepts from folk psychology will be replaced, but others will prove useful in suggesting organizing principles for understanding the brain. In particular we reject the extreme reductionist position that questions of motivation and emotion will be side-stepped as brain science progresses. Further progress in brain science, rather, depends on the courage to use recent technological and theoretical advances to confront these very questions of motivation and emotion.

Obviously part of the problem has been the lack of precise definitions for terms like "emotion." Several recent researchers have made promising attempts at definition. Gray and Baruch (1987) discussed an approach that "treats the emotions as central states elicited by reinforcing events—that is, events, unconditioned or conditioned, that are capable of increasing or decreasing the probability of instrumental responses on which they are made contingent." Similarly Buck (1988, p. 6) viewed motivation as "a potential for the activation and direction of behavior that is inherent in a system of behavior control; then he went on (Buck, 1988, p. 9) to say: "I define emotion as the process by which motivational potential is realized, or 'read out,' when activated by challenging stimuli." Although we are not adhering strictly in this volume to any definition of terms, the articles contained herein all relate to manifestations in natural or artificial neural networks of "motivation" or "emotion" as Gray and Baruch or Buck defined them.

Understanding the roles of emotion in cognition and behavior has an obvious future potential for application to the understanding and treatment of psychiatric disorders. It also has more immediate applications to the industrial uses of neural networks. For, as the previous definitions suggest, the problem of emotion is intimately connected with the problem of goal direction and planning in either a living organism or an intelligent machine. Hence, the subject of study of this volume bears directly on the incorporation of planning and goal direction into artificial neural systems. These capabilities will be particularly important in the use of such systems for control, as in robotics, which is likely to be a major, future growth area for neural network technology. The study of emotion, motivation, and goal direction is also important for the design of better human–computer interfaces, because such design must be based on an accurate portrayal of human decision processes.

The 1970s and 1980s have seen rapid growth in our understanding of brain function and the relations of brain to behavior. Exciting progress in experimental neurobiology has been paralleled by explosive development of computer and mathematical models of neural networks (see, for example, Grossberg, 1982a, 1987, 1988; Levine, 1983; in press; McClelland & Rumelhart, 1987; Rumelhart

& McClelland, 1986). Neural networks are often thought to be mainly of interest to the study of pattern recognition and categorization. The fact is that neural network studies have already begun to address, without yet definitely solving, a wide range of other issues in cognition and behavior. As the chapters in this volume (particularly those of Aparicio and Strong, Grossberg et al., Hestenes, Leven, Levine et al., and Ricart) make clear, this includes issues of motivation, emotion, and goal direction.

Now some rationalists might argue that, sure, emotions are part of functioning, but are they part of *optimal* functioning? Is not the most efficient behavior characterized by the triumph of reason over emotion? Academic psychologists, by and large, supported this notion until the mid-1950s and 1960s, when the explanation of positively reinforcing events as *drive reducing* (Hull, 1943) yielded in part to the alternative explanation of positively reinforcing events as *drive inducing* (Mowrer, 1960).

The drive reduction notion has some intuitive plausibility; after all, eating reduces hunger; drinking reduces thirst; and sexual intercourse reduces lust. Hence, drive reduction has remained popular in some circles despite an apparent telling blow from neurophysiology: the discovery by James Olds (1955) of "pleasure centers" in the hypothalamus of the rat's brain. Olds found that, if rats could press a lever to stimulate certain brain regions, they chose lever pressing over more conventional satisfactions like food and sex. Moreover, the drive for brain stimulation did not satiate in the manner of the hunger or sexual drives; the rats kept pressing the lever on and off for hours.

Further physiological discoveries hinted that strong drive can sometimes be associated with pleasure rather than pain. Although the lateral hypothalamus is one area whose stimulation is pleasurable (Olds, 1977), it has also been found that stimulation of the same area can lead to increased eating (Delgado & Anand, 1953)! From the point of view of understanding brain organization, that a pleasure center is also a hunger center might seem to be a paradox (if it is not the result of sloppy experimentation). Yet the paradox disappears, if we remember, with Maslow (1971) and Grossberg (1982b), the times we have been on the verge of eating a delicious meal or making love with a desirable partner. The experience is one of high drive combined not with pain but with pleasurable anticipation.

The experimental results of Olds, Delgado, Anand, and others suggest that positively reinforcing events are not those events that reduce drive but rather are those events that *induce* drive (i.e., that activate a positive feedback loop in the brain that consummates drive). Hence, stimulation of the lateral hypothalamus does not produce "hunger" in the sense of physiological signs like stomach contractions and low blood sugar. Such stimulation *mimics* the effect of hunger by activating consummatory feedback in the absence of physiological signs that are normally necessary for this feedback to occur. Loops of drive-related neural activity have been studied in neural networks since the early 1970s.

Klopf (1982) attempted to formalize, in neural network terms, the idea that organisms actively seek stimulation. He contrasted the seeking of maximum stimulation with the tendency to seek a balanced or steady-state condition in other respects (such as blood sugar or hormone levels). The seeking of a steady-state condition is called homeostasis (Cannon, 1929); thus, Klopf coined the opposing word *heterostasis* for the seeking of a maximum condition.

In Klopf's theory, all parts of the brain are independently seeking positive stimulation (the analog of "pleasure") and avoiding negative stimulation ("pain"). In other words, brain areas are goal-seeking devices: They respond electrically to stimuli elsewhere in the brain and test the consequences of their own responses. If responding to a given stimulus leads to "pleasure," the given brain area will respond more frequently to that stimulus in the future, just like a miniature version of rats pressing a lever that has previously yielded them food (Skinner, 1938). If responding to that stimulus leads instead to "pain," the brain area will respond less frequently to that stimulus in the future.

Yet Klopf's work also contains an implicit suggestion that there is a single organizing criterion (maximum stimulation of the brain's reticular formation, in this case) by which people and animals make all of our decisions. Levine (1983, p. 64), listed some evidence from experimental psychology that argues against a single decision criterion. Solomon et al. (1953), for example, found an experimental model of learned helplessness. They trained dogs to make a particular motor response to avoid electric shock, then later shocked the animals for making that very same response.. The result was a great deal of confusion and some self-punitive behavior on the part of the dogs. Gray and Smith (1969) and others have found that animals, under many conditions, will perform a response more reliably if it is intermittently reinforced with food than if it is reinforced every time they do it. The comparison with human gambling is obvious.

The controversy over whether there is an all-encompassing human decision criterion rages not only in psychology but also in economics. The orthodox view among economists (e.g., Lancaster, 1966; Weintraub, 1979) is that there is some expected measure of happiness or "utility" that both consumers and producers are maximizing at all times. An opposing view (Heiner, 1983, 1985; Leven, 1988) is that much economic behavior is predictable without being rational. For example, consumers will often stick with the "tried and true" even after a demonstration that a new product is superior in some way—as happened when "new Coke" was rejected and "old Coke" had to be reintroduced, even though the new taste had been preferred by a two-to-one margin over the old one in blind taste tests. Paradoxically, some other products sell just because they are novel and for no other substantive reason.

More pernicious issues may underlie assumptions made about choice processes. Do the ghetto poor, for example, *prefer* their current schedule of leisure and early death to work and education? Implicit suggestions that people are always *optimizing* (and doing so *rationally*) reinforce social agendas that should be viewed with a certain scientific skepticism, and not only conservatives but liberals as well have at times been informed, or rather misinformed, by excessive belief in rationality. Programs for urban renewal in the 1950s and 1960s, for example, tended to emphasize "rational" factors such as space and cleanliness but ignore "affective" factors such as community. Affect and habit are intrinsic in neural function; thus, our models of human behavior must consider them integrally.

Grossberg (1971, 1975, 1982b) addressed some of these decision issues in neural networks designed to explain conditioning data. His networks included some subsystems that coded sensory events, or the memories of those events. The networks also included other subsystems that coded motor actions or the intentions to perform them, but he found that the data could best be explained by the inclusion, in addition to sensory and motor representations, of what he called *drive representations*. That is, there were neural subsystems that simultaneously coded the level of a drive and the possibility of satisfying it. The hunger drive representation, for example, was highly active whenever the organism was hungry *and* there was either available food or some cue that signified future availability of food. Thus, in the classic experiment of Pavlov (1985) where the sound of a bell is repeatedly followed by presentation of meat powder to a dog until the dog salivates to a bell, the association the animal makes is not "bell to meat powder." Rather it is "bell sound representation activation to hunger drive representation activation."

Positive feedback between sensory and drive representations plays many important roles. Such feedback determines which stimuli and which actions a person or animal will find rewarding or punishing. (In addition to representations of "positive" drives like hunger, Grossberg's neural networks also contain representations of "negative" drives like fear.) It also strongly influences which events in a complex environment will be attended to.

In the artificial neural networks developed by Klopf, Grossberg, and many others, reason is in no way "superior" to emotion. Rather, in such networks, reason and emotion perform separate functions, and both are necessary for cognition and memory. Emotion provides the sense of what organisms need and want, whereas reason provides the techniques and strategies for achieving those needs.

The movement in academic psychology toward a more favorable view of human needs and desires has been paralleled by an analogous movement in psychotherapy. Maslow (1968, p. 28) set out to challenge the common notion (shared by a gamut running from theologians to economic theorists) that "good or happiness or pleasure is essentially the consequence of amelioration of this unpleasant state-of-affairs of wanting, of desiring, of needing." Indeed (Maslow, 1968, p. 30) "different basic needs are related to each other in a hierarchical order such that gratification of one need and its consequent removal from the center of the stage brings about not a state of rest or Stoic apathy, but rather the emergence into consciousness of another 'higher' need." In other words, there are *biological* needs not just for survival but for fulfillment, for richness in life, for connectedness. Maslow contrasted this view with a traditional view informed by naive Freudianism, that natural human impulses are almost all toward satisfying base, "animalistic" urges and that a superego of elaborate social codes is required to suppress such destructive urges.

The separate but interacting nature of rational and emotional functions also informs the qualitative notion of the "triune brain" (for example, MacLean, 1970). From extensive behavioral studies of the stimulation or lesion of different brain areas, MacLean developed a theory that the human brain is divided into three "layers" that arrived at different stages of evolution. At the deepest levels is the midbrain reticular formation and other areas forming the "reptilian brain" that has changed little from reptiles to higher mammals to humans. The reptilian brain is responsible for species-specific, almost automatic instinctive behavior. Such behavior is needed for the basic maintenance of the organism but also extends to habitual patterns such as dominance hierarchies. Above the reptilian brain is the limbic system, which is the center of the "old mammalian brain." It is responsible, in this scheme, for emotions such as fear, love, and anger that attend the needs for survival of the individual and survival of the species. Finally, at the top, is the cerebral cortex, which is called the "new mammalian brain" (because it is poorly developed in vertebrates other than mammals, and some of it—the frontal area—is only well developed in primates). The new mammalian brain is the "thinking cap" over the rest of the brain, the part that is responsible for our rational strategies and our extensive verbal and intellectual capacities.

MacLean's scheme is open to, and has received, significant criticism on scientific grounds (e.g., Pribram, 1984). His assignment of functions to specific subregions of the brain is not always correct in detail. Neither is his association of brain regions with species accurate; the hippocampal area of the limbic system, for example, is well developed in reptiles. Yet MacLean made a major contribution to cognitive psychology by adding to the reason–emotion dichotomy a third category for instincts or habits.

The distinction between emotions and habits is also supported by results of recent experiments performed on macaque monkeys (Mishkin & Appenzeller, 1987; Mishkin, Malamut, & Bachevalier, 1984). Mishkin and his co-workers showed that extensive damage to the limbic system prevented monkeys from being able to remember the emotional importance of sensory events, for use in future cognitive tasks. The same limbic damage did not, however, interfere with a more primitive capacity, the learning of an invariant motor response to a previously rewarded stimulus. Seemingly these monkeys remembered the motor response they had developed on the basis of reward while forgetting about the reward itself. These researchers concluded that there are two separate neural systems for encoding memories and habits. The memory system, centered in the hippocampus and amygdala (both parts of the limbic system), stores representations of how rewarding or punishing are specific sensory stimuli or motor actions. The habit system, centered in the basal ganglia, stores representations of the motor actions themselves regardless of their reinforcement value.

In the brain, the interplay of reason, emotion, habit, and novelty is controlled by complex control circuits with extensive feedback. Several of the articles in this volume (those of Banquet et al., Hestenes, Leven, Levine et al., and Pribram) show that the barest beginnings of a system understanding of these control circuits has been achieved. Damage to different regions in this control circuit can lead to various kinds of cognitive defects. Further insights should be obtained from building analogs of these brain regions out of suitable concatenations of artificial networks previously designed to perform simpler functions (such as perception and learning).

The work that is edited here heralds some profound changes in the landscape of our understanding of psychological function. Some of the past and anticipated future intellectual history of our field is discussed by Pribram (1985):

> The transition from behaviorism, especially stimulus-response behaviorism, to cognitive psychology, was characterized by an increasing difficulty to operationalize such concepts as effort and attention. I believe that the next revolutionary turn in psychology will, in a similar way, be characterized by an increasing difficulty in operationalizing concepts we now hold dear, such as information processing, and by an increasing ability to operationalize such concepts as meaning and intuition. (p. 6)

The articles in this volume, while diverse and highly interrelated, fall naturally into three major sections. The first section consists of articles on the theory of Pavlovian (classical) conditioning. This is one of the richest current areas of contact between neurophysiology, psychology, and neural modeling. Further, Pavlovian conditioning studies can illuminate the study of more complex forms of learning that involve motivational influences.

The second section consists of both theoretical and experimental studies on complex brain control circuits and their disruption. Such circuits involve a coordination of cortical areas such as the frontal lobes with subcortical areas such as the limbic system, hypothalamus, and basal ganglia. Computational studies of these brain regions are still in their infancy, but the work discussed herein suggests that encouraging progress may occur in the next several years. Neural network principles are starting to make some order out of the dizzying profusion of regions, connections, and chemical transmitters in these more "central" areas of the brain, areas that are not directly sensory or motor.

The third and last section of this book consists of artificial neural network studies designed with applications in mind. Preliminary efforts to include "plans" or "goals" in industrial systems are apparent here. This is a step toward opening up the promise (or specter, depending on your viewpoint) of building machines with genuine, biological cognitive capabilities.

This book arose from a workshop of the same title, with close to a hundred participants, that was held at the Infomart in Dallas over Memorial Day weekend, 1988. This workshop was sponsored by the Metroplex Institute for Neural Dynamics (M.I.N.D.), a Dallas–Fort Worth area-wide neural networks interest group, with assistance from two local computer companies. Several of the first authors (Aparicio, Leven, Levine, Pribram, Ricart) gave talks at the conference, and others (Cruz and Grossberg) sent material to be presented at the conference in absentia. The remaining first authors (Banquet, Dawes, Hestenes, Kehoe, and Killeen) could not be fit into the conference program but were subsequently invited to submit chapters, because they were working in areas compatible with the theme of the conference.

As coeditors of this volume, and coorganizers of the conference from which it arose, we wish to thank all the contributing authors and many other people who helped make this volume possible. The membership of M.I.N.D. gave the workshop its enthusiastic support, in both time and money. The executive committee of M.I.N.D. and the staff of Martingale Research Corporation (Robert Dawes, its President; David Davis, and others) worked tirelessly to organize the program, invite speakers, put together brochures, and publicize it both locally and nationally. The staff at the Infomart provided unparalleled facilities for the conference. Rockwell International, Defense Communications and Sequent Computer Systems, Incorporated, gave financial assistance to the conference, which enabled us to rent those facilities. Two graduate students active in M.I.N.D., Paul Prueitt (also a co-author on Chapter 9) and Wesley Elsberry, provided invaluable assistance at many stages of the conference and the subsequent organization of the book, including the careful notes that Wesley took at the conference. Harry Klopf and Elliott Ross gave two very stimulating talks at the conference, both of which included videotapes, and unfortunately were not able to contribute to the volume itself because of other time commitments.

We owe a debt of thanks to the staff at Lawrence Erlbaum Associates, Inc.—Julia Hough and Judi Amsel, our editors at different stages; Hollis Heimbouch, our editorial assistant; and Lawrence Erlbaum, president. Julia and Judi in particular realized the importance of the subject at an early stage, and energetically and cheerfully saw the book project through many changes and slow starts.

Finally we would like to thank our wives, Lorraine and Nina. Their support, encouragement, and perspective helped make the project of organizing this book considerably smoother than it would have been otherwise.

Daniel S. Levine
Arlington, TX

Samuel J. Leven
Radford, VA

References for Preface

Buck, R. (1988). *Human motivation and emotion.* New York: Wiley.

Cannon, W. B. (1929). Organization for physiological homeostasis. *Physiological Review, 9,* 399–431.

Churchland, P. S. (1986). *Neurophilosophy.* Cambridge, MA: MIT Press.

Delgado, J. M. R., & Anand, B. K. (1953). Increase of food intake induced by electrical stimulation of the lateral hypothalamus. *American Journal of Physiology, 172,* 162–168.

Gray, J. A., & Baruch, I. (1987). Don't leave the "psych" out of neuropsychology. *The Behavioral and Brain Sciences, 10,* 215–216.

Gray, J. A., & Smith, P. T. (1969). An arousal-decision model for partial reinforcement and discrimination learning. In R. M. Gilbert & N. S. Sutherland (Eds.), *Animal discrimination learning* (pp. 243–272). New York: Academic Press.

Grossberg, S. (1971). On the dynamics of operant conditioning. *Journal of Theoretical Biology, 33,* 225–255.

Grossberg, S. (1975). A neural model of attention, reinforcement, and discrimination learning. *International Review of Neurobiology, 18,* 263–327.

Grossberg, S. (1982a). *Studies in mind and brain: Neural principles of learning, perception, development, and motor control.* Boston: Reidel.

Grossberg, S. (1982b). A psychophysiological theory of reinforcement, drive, motivation, and attention. *Journal of Theoretical Neurobiology, 1,* 286–369.

Grossberg, S. (1987). *The adaptive brain* (Vols. I and II). Amsterdam: Elsevier.

Grossberg, S. (1988). *Neural networks and natural intelligence.* Cambridge, MA: MIT Press.

Heiner, R. (1983). The origin of predictable behavior. *American Economic Review, 73,* 560–585.

Heiner, R. (1985). The origin of predictable behavior: Further modeling and applications. *American Economic Review, 75,* 391–396.

Hull, C. L. (1943). *Principles of behavior.* New York: Appleton.

Klopf, A. H. (1982). *The hedonistic neuron: A theory of memory, learning, and intelligence.* Washington, DC: Hemisphere.

Lancaster, K. (1966). A new approach to consumer theory. *Journal of Political Economy, 74,* 131–157.

Leven, S. J. (1988). *Choice and neural process.* Unpublished doctoral dissertation, Institute of Urban Studies, University of Texas at Arlington.

Levine, D. S. (1983). Neural population modeling and psychology: A review. *Mathematical Biosciences, 66,* 1–86.
Levine, D. S. (in press). *Introduction to neural and cognitive modeling.* Hillsdale, NJ: Lawrence Erlbaum Associates.
MacLean, P. D. (1970). The triune brain, emotion, and scientific bias. In F. Schmitt (Ed.), *The Neurosciences Second Study Program* (pp. 336–349). New York: Rockefeller University Press.
Maslow, A. H. (1968). *Toward a psychology of being.* New York: Van Nostrand.
Maslow, A. H. (1971). *The farther reaches of human nature.* New York: Viking.
Mishkin, M., & Appenzeller, T. (1987, June). The anatomy of memory. *Scientific American,* 80–89.
Mishkin, M., Malamut, B., & Bachevalier, J. (1984). Memories and habits: Two neural systems. In G. Lynch, J. L. McGaugh, & N. M. Weinberger (Eds.), *Neurobiology of learning and memory* (pp. 65–77). New York: Guilford.
Mowrer, O. H. (1960). *Learning theory and behavior.* New York: Wiley.
Olds, J. (1955). Physiological mechanisms of reward. In M. Jones (Ed.), *Nebraska Symposium on Motivation.* Lincoln, NE: University of Nebraska Press.
Olds, J. (1977). *Drives and reinforcements: Behavioral studies of hypothalamic functions.* New York: Raven.
Pavlov, I. P. (1985). *Conditioned reflexes* (V. Anrep, Trans.). London-Oxford University Press.
Pribram, K. (1984). Emotion: A neurobehavioral analysis. In K. Scherer & P. Ekman (Eds.), *Approaches to emotion* (pp. 13–38). Hillsdale, NJ: Lawrence Erlbaum Associates.
Pribram, K. H. (1985). Holism could close the cognition era. *APA Monitor,* Vol. 16, pp. 5–6.
Rumelhart, D. E., & Mc Clelland, J. L. (1986). *Parallel distributed processing.* Cambridge, MA: MIT Press.
Skinner, B. F. (1938). *The behavior of organisms.* New York: Appleton.
Stich, S. (1983). *From folk psychology to cognitive science.* Cambridge, MA: MIT Press.
Weintraub, E. R. (1979). *Microfoundations.*New York: Cambridge University Press.
Young, J. Z. (1951). *Doubt and certainty in science: A biologist's reflections on the brain.* Oxford: Clarendon Press.

List of Contributors

Manuel Aparicio, International Business Machines Corporation, Internal Zip 030440, 5 West Kirkwood Boulevard, Roanoke, TX 76299-0001.

Jean-Paul Banquet, Hôpital de la Salpétrière, Laboratoire d'Électrophysiologie et de Neurophysiologie Appliquée, CNRS, 47 Boulevard de l'Hôpital, 75651 Paris, France and Center for Adaptive Systems, Boston University, 111 Cummington St., Boston, MA 02215.

Claude A. Cruz, Plexus Systems, Inc., 139 Coburn Woods, Nashua, NH 03063.

Robert L. Dawes, Martingale Research Corporation, 100 Allentown Pkwy., Suite 211, Allen, TX 75002.

Stephen Grossberg, Director, Center for Adaptive Systems, Boston University, 111 Cummington Street, Boston, MA 02215.

W. Guenther, Psychiatric Hospital, Munich, Federal Republic of Germany.

David Hestenes, Department of Physics, Arizona State University, Tempe, AZ 85287.

E. James Kehoe, School of Psychology, The University of New South Wales, P. O. Box 1, Kensington, NSW 2033, Australia.

Peter R. Killeen, Department of Psychology, Arizona State University, Tempe, AZ 85287.

Samuel J. Leven, Center for Brain Research and Informational Sciences, Radford University, Radford, VA 24142.

Daniel S. Levine, Department of Mathematics, University of Texas at Arlington, Arlington, TX 76019.

Karl Pribram, Director, Center for Brain Research and Informational Sciences, Radford University, Radford, VA 24142.

Paul S. Prueitt, Department of Physics, Georgetown University, Washington, DC 20057.

Lt. Richard Ricart, 2711 State Route 235, Xenia, OH 45385.

Nestor Schmajuk, Department of Psychology, Northwestern University, Evanston, IL 60201.

Mark Smith, Hôpital de la Salpétrière, Laboratoire d'Électrophysiologie et de Neurophysiologie Appliquée, CNRS, 47 Boulevard de l'Hôpital, 75651 Paris, France.

Paschal N. Strong, Jr., Department of Psychology, University of South Florida, Tampa, FL 33620.

I THEORIES OF PAVLOVIAN CONDITIONING

Contents