
Motivation

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RUNNING HEAD: Motivation

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The ability of humans and animals to survive in a constantly changing environment is a testament to the power of biological processes. At any moment in our lives, we are faced with many sensory stimuli, and we can typically generate a large number of behaviors. How do we learn to ignore irrelevant information and suppress inappropriate behavior so that we may function in a complex environment?

In this chapter we discuss *motivation*, the internal force that produces actions on the basis of the momentary balance between our needs and the demands of our environment. We first give a description of motivation and how it is studied, focusing on behavioral and physiological studies. We then discuss the role of motivation in behavioral theories and neural network modeling.

1. INTRODUCTION

The word *motivation* is common in everyday language, but is not easy to define rigorously in a scientific context. The concept of motivation is related to, but distinct from other concepts, such as *instincts*, *drives*, and *reflexes*. Motivated behavior is usually goal-oriented; the goal may be associated with a drive such as hunger or thirst (called *primary motivation*). However, motivation is also closely tied to sensory stimuli: an animal will not usually exhibit eating behavior unless food is presented. Unlike instinctive behavior, motivation depends on *affect* (emotional state). Finally, motivation can be learned (in which case it is called *secondary motivation*) and typically elicits more complex behaviors than simple reflexes.

An animal is always performing some activity, even when that activity is sleep. At any given time the environment offers the opportunity to carry out many different behaviors,

such as exploratory or consummatory behaviors, but an animal typically carries out a single voluntary activity at a time. The study of motivation is concerned with which activity the animal performs in a given environment, and how the animal maintains a given activity or changes between different activities, as a function of environmental events and internal needs.

Motivation is typically studied using two approaches: psychological studies manipulate environmental events and monitor the resulting patterns of motivated behavior; physiological studies are aimed at clarifying the neural or endocrine origin of motivation. Psychological studies might examine, for instance, how an animal is able to maintain a constant goal-oriented activity as the surrounding stimuli change, or how an animal is able to spontaneously switch between behaviors as its needs change. Physiological studies attempt to identify physiological variables and neural regions that are related to motivated behavior.

2. PSYCHOLOGICAL STUDIES OF MOTIVATION

Motivation figured prominently in the earliest studies of animal psychology around the end of the nineteenth century. The improvements in our knowledge of physiology fostered a significant increase in physiological and psychological studies of motivation around the middle of the twentieth century. A library search on “motivation” will uncover numerous writings published in the forties and fifties. Motivation played a significant role in many theories of behavior, especially Hull’s theory (described below).

Behavioral studies of motivation frequently focus on basic functions related to survival, such as eating, drinking, and avoiding harmful stimuli. Other motivated behaviors that

have been studied, such as sexual behavior or social interactions, do not seem as closely related to immediate survival.

Hunger has been frequently studied in psychological studies of motivation, as the food intake of the animal can be easily controlled. The motivation to eat is not directly controlled by feelings of hunger; when presented with the opportunity to eat, animals eat in anticipation of hunger and continue to eat after satiation to maintain themselves until the next meal. Motivation is also influenced by the subjective value assigned to the rewards arising from motivated behavior, and this subjective value can in turn be influenced by learning. In an elegant experiment Crespi (1942) demonstrated that rats' motivation to obtain food, measured as the speed with which the rats ran down an alley toward food, can be altered not only by changing the absolute "magnitude" of the reward (the amount of food), but also by changing the amount of reward relative to what the rat expects to find at the end of the alley. In Crespi's experiment, three groups of rats were trained to run down an alley to receive 1, 16, or 256 food pellets. Motivation was measured as the running speed with which the rats approached the food. Initially the running speed was proportional to the size of the reward, with the rats receiving 256 pellets showing the greatest speed. In the second part of the experiment, all three groups of rats were provided 16 pellets at the end of the alley. The rats switched from 256 down to 16 pellets exhibited less motivation (ran slower) than those that had remained constant at 16 pellets, while the rats that were switched from 1 to 16 ran significantly faster. We can sympathize with the rat's behavior by imagining how differently we would react if our salary was cut from a high level to some lower level x , as opposed to it being raised to x

from an initially lower level.

3. PHYSIOLOGICAL STUDIES OF MOTIVATION

Research on motivation has focused on the physiological basis for hunger, thirst, and other biological drives (see review by Grossman, 1988). Animals and humans possess complex mechanisms for *homeostasis*, that is, for maintaining an efficient balance between internal needs and environmental affordances to satisfy these needs. Taking for example the need for food, the mechanisms involved in maintaining blood glucose level encompass neural, endocrine, and other physical and chemical mechanisms whose purpose is to monitor continuously the internal need for energy, and whose state affects motivated behavior aimed at finding and consuming food.

A significant amount of motivation-related neural circuitry appears to be located in the hypothalamus (see Ch.48 by Kupferman in Kandel, Schwartz, & Jessell, 1991). In particular, there appear to be discrete hypothalamic areas that play significant roles in the control of homeostatic signals relating to feeding, drinking, and temperature regulation. Most of these areas are organized in *opponent pairs*, that is, areas having opposite effects on the function they regulate. For example, the control of body temperature is jointly regulated by the anterior hypothalamus, responsible for the generation of temperature-lowering behaviors such as dilation of skin blood vessels, and the posterior hypothalamus, responsible for the generation of temperature-increasing behaviors such as shivering. Electrical stimulation of these areas leads to an enhancement of the corresponding behavior, while lesion of each area leads to a suppression of the corresponding behavior. For example, electrical stimulation of the anterior hypothalamus produces panting, while lesions in the

same area lead to chronic hyperthermia.

The control of homeostasis and motivated behavior is not relegated to hypothalamic areas. For one thing, there exist many brain areas that are involved with the control of motivated behavior, so that, for example, feeding behaviors may be disrupted by stimulation or lesion of areas outside of the hypothalamus. In a similar vein, animals subjected to hypothalamic lesions sometimes exhibit gradual but marked recovery of the functions that were disrupted by the lesions, suggesting the existence of other neural centers capable of performing regulatory tasks. These observations are not surprising when one considers the complexity of a seemingly simple behavior such as feeding, which requires the ability to seek out, identify, and consume food, all tasks that involve the coordination of sensory, cognitive, and motor skills.

4. HULL'S BEHAVIORAL THEORY

Hull's theory provides a framework within which motivated behavior can be analyzed. Hull (1943) proposed that "the initiation of learned, or habitual, patterns of movement or behavior is called motivation." In addition, Hull proposed a distinction between *primary motivation*, the evocation of action in relation to primary needs, and *secondary motivation*, the evocation of action in relation to secondary reinforcing stimuli or incentives.

Primary motivation is the cornerstone of Hull's *drive reduction theory*. According to Hull, events that threaten survival give rise to internal drive states, and behaviors that act to reduce drive are thus rewarding. For instance, lack of food causes an increase in the hunger drive, and the consumption of food is rewarding because it leads to a reduction in the hunger drive.

A stimulus repeatedly associated with onset of a drive state can become an *acquired drive*. Once developed, an acquired drive can motivate behavior on subsequent occasions, even in the absence of cues that elicit the original drive state. Stimuli with this property become *incentives*, and their ability to evoke behaviors is known as secondary or incentive motivation. For instance, throughout our lives we learn to associate the sight of food with the impending act of consuming food, so we feel hungry when we see food.

Motivated behavior requires both drives and appropriate stimuli. Hull's theory captures this relationship by proposing that the *behavior potential* for a given action is the product of drive strength and incentive level associated with that action.

$${}_sE_R = D \times V \times K \times {}_sH_R \quad (1)$$

${}_sE_R$ is called the *reaction potential*, the likelihood that a given behavior will be emitted. D represents the drive level, V is proportional to the stimulus intensity, K is the *incentive motivation* associated with stimuli present in the environment, and ${}_sH_R$ is the *habit strength* associated with the behavior. The multiplicative relationship between all the variables suggests that all of these factors must work synergistically in order for a behavior to have a large reaction potential, that is, in order for the behavior to have a high probability of being emitted.

In our daily experiences we are faced with a continuously fluctuating combination of multiple drives and incentives. Somehow we must be able to select the behavior that is most appropriate in a given situation, while suppressing other, less adequate behaviors. Thus, motivated behavior requires a form of *competition*. According to Hull, at any given

time the behavior with the greatest potential to reduce a given drive is released. If the drive persists, that behavior is inhibited, and the second strongest response in the *drive hierarchy* will be released, and so on.

Hull's theory fell out of favor for a number of reasons (e.g., Klein, 1991). For one thing, his theory (Eq. 1) predicts that behaviors should not be emitted in the absence of motivation, because in that case $K = 0$ and the reaction potential is likewise zero. However, a simple experiment by Sheffield and Roby (1950, see discussion in Barker, 1994) showed that rats could learn to perform a behavior to obtain saccharin-flavored water even though they were not hungry, and even though saccharin has no nutritive value. A more significant challenge to Hull's theory came from experiments showing that in some instances drive *induction* can be motivating: In 1954 Olds and Milner (see Barker, 1994) discovered that electrical stimulation of a brain region called the *medial forebrain bundle* is rewarding for rats, and that rats will learn to perform tasks that lead to electrical stimulation as a reward. Later studies have shown that electrical stimulation is not only rewarding but also a direct source of motivation, that is, it can cause the release of behaviors in the absence of appropriate stimuli or homeostatic cues. These findings suggest that brain stimulation is motivating because it *induces* a drive. The concept of reward through drive induction was used by Mowrer (1960), and plays a role in some of the neural network theories described below.

Another reason for the limited success of Hull's theory was that his mathematical approach was different from typical qualitative, descriptive learning theories, and in that sense it was ahead of its time. Today the study of computational Neuroscience and neural networks are promoting an increased role for mathematical models in the study of brain

function.

5. NEURAL NETWORKS OF MOTIVATED BEHAVIOR

As reviewed in various chapters of this *Handbook*, most types of neural networks suppose that learning involves correlation between input and output, or require the presence of an explicit error signal paired with each input. However, these networks learn without reference to the internal state of the network or the external state of the environment. In other words, there is generally no concept in neural network learning that parallels the idea of motivation. The idea of motivation has been used explicitly only by a handful of neural network researchers. The work of Grossberg and his colleagues (see the collections of Grossberg, 1982, 1986, 1989), whose efforts to model animal and human behavior with dynamic neural networks span the past three decades, provides a computational neural framework within which it is possible to give a natural interpretation to the concept of motivation, and to the role of drives and incentives in the generation of purposive behavior.

Grossberg (1971) proposed a neural model of *instrumental* and *classical* conditioning (see CONDITIONING and EMOTION AND COMPUTATIONAL NEUROSCIENCE in this *Handbook*) that embodies many of the concepts discussed in this chapter. Grossberg's model simulates neurons that represent sensory stimuli from the environment, as well as neurons that represent internal drive signals. Reinforcement acts to focus attention on relevant environmental stimuli, and allows the organism to learn what stimuli have value as reinforcers. In his later work, Grossberg expanded the notion of drive neurons to what he termed a *sensory-drive heterarchy*, in which both appetitive and aversive drives

combine with sensory stimuli and compete to determine which behavior will be emitted in response to a given combination of internal needs and environmental stimuli.

The joint action of drives and reinforcers in Grossberg's network embodies Hull's intuition that drives and incentives combine in a multiplicative fashion (Eq. 1). However, Grossberg's model extends Hull's ideas by including both drive induction and drive reduction, and by describing dynamic aspects of behavior and learning, rather than static relationships. A detailed discussion of the relationship between Hull's drive reduction theory and Grossberg's neural theory of conditioning can be found elsewhere (see especially Ch.1 Grossberg, 1986).

We are not aware of other neural network models that explicitly deal with motivation. However, the idea of "drive" neurons that modulate learning is found in several other neural network models. The models of Klopff (ch. 7 of Byrne & Berry, 1989) and Sutton and Barto (1990) explicitly incorporate the idea of a drive neuron. Klopff's *drive-reinforcement theory* suggests that changes in the drive level have reinforcing properties. In this case, however, Klopff suggests that organisms seek stimulation, and that reward comes from *increases* in drive level, as suggested in drive induction theories. Stimuli that occur in contiguity with increases in drive are associated with the behaviors that caused the change in drive level. These stimuli can then energize behavior of the animal. Sutton and Barto (1990) propose the existence of an *eligibility trace* that determines when learning can occur. This level of control is very important when a system must improve its performance on the basis of only general information about its success or failure, which occurs after a potentially long sequence of actions has been carried out. The ability to assign credit or blame to elements of a network for events that took place in the past is known as

the *temporal credit assignment problem*. Aside from making interesting predictions about conditioning phenomena and temporal learning, the work of Sutton, Barto, and their colleagues has led to a number of useful applications in robotics and control.

Strong support for the existence of drive neurons has actually come from experimental and modeling work on both vertebrates and invertebrates. they require convergence of sensory and drive inputs to become active. In vertebrates, some cells in the hypothalamus have been found to respond only when they receive convergent input from internal drive signals and relevant external sensory stimuli (Rolls *et al.*, see ch. 48 of Kandel et al., 1991). Many invertebrates are also capable of sophisticated forms of learning and motivated behavior (Colgan, 1989). Alkon (ch. 1 of Byrne & Berry, 1989), Hawkins (ch. 5 of Byrne & Berry, 1989), and Byrne and his colleagues (Buonomano, Baxter, & Byrne, 1990) have found evidence for *facilitator neurons* in the mollusks *Aplysia* and *Hermisenda*. While the location and specific action of facilitator neurons differ in the different preparations, in all cases the facilitator neuron plays a role similar to that of drive neurons: it is closely linked to fundamental aspects of the animal's life, such as the onset of shock, and it serves to modulate learning at associative synapses.

6. DISCUSSION

We have described motivation as the internal force that energizes behaviors, and that determines which particular behavior will be emitted in response to a given set of environmental stimuli and to the internal needs of an organism. Motivation is a complex topic of research that has been studied from many different approaches. We have briefly summarized some of the psychological and physiological experiments that probe the role

of motivation in the behavior of humans and animals. We reviewed Clark Hull's drive reduction theory, one of the most influential and rigorous behavioral theories from the field of psychology. We have also looked at neural network models that directly or indirectly utilize the concept of motivation, or related concepts such as drives and homeostasis.

Motivation is a concept that is difficult to describe quantitatively. It is perhaps for this reason that motivation is largely unused by neural network modelers. However, we believe that the study of motivation can be useful for students of brain theory in two different ways. First, there are several areas of brain research that are closely related to motivation. This includes for instance the study of conditioning and reinforcement learning (see CEREBELLUM AND CONDITIONING; COGNITIVE MAPS; CONDITIONING; EMOTION AND COMPUTATIONAL NEUROSCIENCE; REINFORCEMENT LEARNING IN MOTOR CONTROL). Second, neural network models that wish to take into account complex goal-oriented behavior may find motivation to be an essential element deserving serious study. In particular, motivation (or the lack thereof) is perhaps the main difference between learning in typical neural networks and learning in humans and animals. Motivation allows the latter to take into account internal needs and external stimuli in order to decide what should and should not be learned in a particular situation. The inclusion of concepts such as drives and motivation will be particularly important in neural network applications that involve interactions between simulated organisms and a realistic environment.

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