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Emotion and the Animal Brain

Emotion, long ignored within the field of neuroscience, has at the end of the twentieth century been experiencing a renaissance. Starting around mid-century, brain researchers began to rely on the LIMBIC SYSTEM concept as an explanation of where emotions come from (MacLean 1949), and subsequently paid scant attention to the adequacy of that account. Riding the wave of the cognitive revolution (Gardner 1987), brain researchers have instead concentrated on the neural basis of perception, MEMORY, ATTENTION, and other cognitive processes. However, starting in the 1980s, studies of a particular model of emotion, classical fear conditioning, began to suggest that the limbic system concept could not provide a meaningful explanation of the emotional brain (LeDoux 1996). The success of these studies in identifying the brain pathways involved in a particular kind of emotion has largely been responsible for the renewed interest in exploring more broadly the brain mechanisms of emotion, including a new wave of studies of EMOTION AND THE HUMAN BRAIN. This article briefly reviews the neural pathways involved in fear conditioning, and then considers how the organization of the fear pathways provides a neuroanatomical framework for understanding emotional processing, including emotional stimulus evaluation (appraisal), emotional response control, and emotional experience (feelings).

The brain circuits involved in fear CONDITIONING have been most thoroughly investigated for situations involving an auditory conditioned stimulus (CS) paired with footshock (see LeDoux 1996; Davis 1992; Kapp et al. 1992; McCabe et al. 1992; Fanselow 1994). In order for conditioning to take place and for learned responses to be evoked by the CS after conditioning, the CS has to be relayed through the auditory system to the amygdala. If the CS is relatively simple (a single tone), it can reach the amygdala either from the auditory thalamus or the auditory cortex. In more complex stimulus conditions that require discrimination or CATEGORIZATION, the auditory cortex becomes involved, though the exact nature of this involvement is poorly understood (see Jarrell et al. 1987; Armony et al. 1997).

CS information coming from either the auditory THALAMUS or the cortex arrives in the lateral nucleus of the amygdala and is then distributed to the central nucleus by way of internal amygdala connections that have been elucidated in some detail (Pitkanen et al. 1997). The central nucleus, in turn, is involved in the control of the expression of conditioned responses through its projections to a variety of areas in the brainstem. These behavioral (e.g., freezing, escape, fighting back), autonomic (e.g. blood pressure, heart rate, sweating), and hormonal (adrenaline and cortisol released from the adrenal gland) responses mediated by the central nucleus are involuntary and occur more or less automatically in the presence of danger (though they are modulated somewhat by the situation).

Other brain areas implicated in fear conditioning are the HIPPOCAMPUS and prefrontal cortex. The hippocampus is important in conditioning to contextual stimuli, such as the situation in which an emotional event occurs. Its role is more of that of a high-level sensory/cognitive structure that integrates the situation into a spatial or conceptual "context" rather than that of an emotional processor per se (Kim and Fanselow 1992; Phillips and LeDoux 1992; LeDoux 1996). The medial area of the prefrontal cortex is important for extinction, the process by which the CS stops eliciting emotional reactions when its association with the shock is weakened (Morgan and LeDoux 1995). Fear/anxiety disorders, where fear persists abnormally, may involve alterations in the function of this region (LeDoux 1996).

The fear pathways can be summarized very succinctly. They involve the transmission of information about external stimuli to the amygdala and the control of emotional responses by way of outputs of the amygdala. The simplicity of this scheme suggests a clear mapping of certain psychological processes (stimulus evaluation and response control) onto brain circuits, and leads to hypotheses about how other aspects of emotion (feeling or experience) come about. However, it is important to point out that the ideas in the discussion that follows mainly pertain to the fear system of the brain, inasmuch as other emotions have not been studied in sufficient detail to allow these kinds of relations to be discussed.

Stimulus evaluation or *appraisal* is a key concept in the psychology of emotion (Lazarus 1991; Scherer 1988; Frijda 1986). Although most psychological work treats appraisal as a high-level cognitive process, often involving conscious access to underlying evaluations, it is clear from studies of animals and people that stimuli are first evaluated at a lower (unconscious) level prior to, and perhaps independent of, higher-level appraisal processes (see LeDoux 1996). In particular, the amygdala, which sits between sensory processes (including low-level sensory processes originating precortically and higher-level cortical processes) and motor control systems, is likely to be the neural substrate of early (unconscious) appraisal in the fear system. Not only do cells in the amygdala respond to conditioned fear stimuli, but they also learn the predictive value of new stimuli associated with danger (Quirk, Repa, and LeDoux 1995; Rogan, Staubli, and LeDoux 1997).

The amygdala receives inputs from a variety of cortical areas involved in higher cognitive functions. These areas project to the basal and accessory basal nuclei of the amygdala (Pitkanen et al. 1997). Thus, the emotional responses controlled by the amygdala can be triggered by low-level physical features of stimuli (intensity, color, form), higher-level semantic properties (objects), situations involving configurations of stimuli, and thoughts or memories about stimuli, and imaginary stimuli or situations. In this way higher-level appraisal processes can be critically involved in the functioning of this system. It is important to note that these hypotheses about the neural substrate of higher-level processes have emerged from a detailed elucidation of the physiology of lower-level processes. A bottom-up approach can be very useful when it comes to figuring out how psychological processes are represented in the brain.

Involuntary emotional responses are EVOLUTION's immediate solution to the presence of danger. Once these responses occur, however, higher-level appraisal mechanisms are often activated. We begin planning what to do, given the circumstances. We then have two kinds of response possibilities. Habits are well-practiced responses that we have learned to use in routine situations. Emotional habits can enable us to avoid danger and escape from it once we are in it. These kinds of responses may involve the amygdala, cortex, and BASAL GANGLIA (see LeDoux 1996; Everitt and Robbins 1992; McDonald and White 1993). Finally, there are emotional actions, such as choosing to run away rather than to stay put in the presence of danger, given our assessment of the possible outcomes of each course of action. These voluntary actions are controlled by cortical decision processes, most likely in the frontal lobe (Damasio 1994; Goldman-Rakic 1992; Georgopolous et al. 1989). Voluntary processes allow us to override the amygdala and become emotional actors rather than simply reactors (LeDoux 1996). The ability to shift from emotional reaction to action is an important feature of primate and especially human evolution.

The problem of feelings is really the problem of CONSCIOUSNESS (LeDoux 1996). Emotion researchers have been particularly plagued by this problem. Although we are nowhere near solving the problem of consciousness (feelings), there have been some interesting ideas in the area of consciousness that may be useful in understanding feelings. In particular, it seems that consciousness is closely tied up with the process we call WORKING MEMORY (Baddeley 1992), a mental workspace where we think, reason, solve problems, and integrate disparate pieces of information from immediate situations and long-term memory (Kosslyn and Koenig 1992; Johnson-Laird 1988; Kihlstrom 1987). In light of this, we might postulate that feelings result when working memory is occupied with the fact that one's brain and body are in a state of emotional arousal. By integrating immediate stimuli with long-term memories about the occurrence of such stimuli in the past, together with the arousal state of the brain and feedback from the bodily expression of emotion, working memory might just be the stuff that feelings are made of.

Ever since William JAMES raised the question of whether we run from the bear because we are afraid or whether we are afraid because we run, the psychology of emotion has been preoccupied with questions about where fear and other conscious feelings come from. Studies of fear conditioning have gone a long way by addressing James's other question —what causes bodily emotional responses (as opposed to feelings)? Although James was correct in concluding that rapid-fire emotional responses are not caused by feelings of fear, he did not say much about how these come about. However, as we now see, by focusing on the responses we have been able to get a handle on how the system works, and even have gotten some ideas about where the feelings come from.

See also CEREBRAL CORTEX; CONDITIONING AND THE BRAIN; CONSCIOUSNESS, NEUROBIOLOGY OF; EMOTIONS; MEMORY, ANIMAL STUDIES; SENSATIONS

—*Joseph LeDoux and Michael Rogan*

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Emotion and the Human Brain

Popular ideas about the mind evolve over time: emotion came to have its contemporary meaning only in the late nineteenth century (Candland 1977). In current usage, the concept of emotion has two aspects. One pertains to a certain kind of subjective experience, "feeling." The other relates to expression, the public manifestation of feeling. These dual aspects of emotion—the subjective and the expressive—were represented a century ago in the writings of William JAMES (1884), who speculated on the neural and somatic basis of feeling, and Charles DARWIN (1872), who examined the evolution of emotional expression in various species. Most workers in this area have also pointed out that feelings and the actions that go with them are an essential part of an organism's relation to its environment. Thus, together with more elaborated cognition, emotions can be said to be the means by which an animal or person appraises the significance of stimuli so as to prepare the body for an appropriate response.

Emotion is traditionally distinguished from cognition, and for most of this century received little research attention in its own right—excepting possibly studies of the brain mechanisms of aggression. Emotion per se has come to be embraced as a legitimate topic only in the last several decades. Its acceptance was probably due in part to Ekman's influential cross-cultural studies of human facial expression (Ekman, Sorenson, and Friesen 1969), which implied an innate, biological basis for emotional experience. Social factors have undoubtedly also facilitated the entry of emotion into the arena of neuroscience research, for current popular culture upholds emotion as a significant feature of human life (McCarthy 1989).

An additional factor in the acceptance of emotion as a neurobiological entity was MacLean's (1952) persuasive account of a brain system specialized for emotion. Building on earlier anatomical theories, MacLean grouped together certain evolutionarily ancient brain structures, primarily regions of medial cortex and interconnected subcortical regions such as the hypothalamus, and called them the "visceral brain." He suggested that activity in this region was responsible for the subjective aspect of emotional experience. Later, following terminology introduced by the anatomist BROCA, he called these structures the LIMBIC SYSTEM.

In the years following MacLean's account, researchers have debated exactly which structures can be said to be "limbic." Most often included are the AMYGDALA, septum, hippocampal formation, orbitofrontal cortex, and cingulate gyrus. However, it is now appreciated that no criteria—be they anatomic, association with visceral function, or association with the behavioral manifestations of emotional experience—bind the regions traditionally called "limbic" unequivocally and uniquely together, leaving the status of this proposal in doubt (LeDoux 1991). Indeed, James had asserted a century ago that there is no special brain system mediating emotional experience. Instead, he held, the bodily changes brought about by a stimulus are themselves experienced in turn through interoceptive pathways that project to sensory cortex; the latter somatic sensations "are" emotional experience. The role of afferent activity from the body in producing states of feeling continues to be emphasized: indeed, the idea that somatic sensations form the critical core of ongoing subjective experience has been repeatedly proposed by philosophers and psychologists. Most neuroscientists accept the idea that the body plays a role, but they also believe that there are particular structures in the human brain that are specialized for emotional experience and behavior.

There are several distinct themes in studies of the neural basis of human emotion. One pertains to the role of neural structures in producing states of feeling. In the 1950s, neurosurgeons demonstrated that subjective emotional experiences, especially fear, could be produced by electrical stimulation in the temporal lobes, particularly in the amygdala and hippocampal formation. The amygdala has come to the fore again in modern imaging studies that suggest that individuals with familial depression have increased metabolic activity in the left amygdala. Depression has been associated with both decreased and increased activity in orbitofrontal cortex. Several decades ago, before the rise of activity-dependent imaging techniques, there was an interest in the relation between mood and hemispheric side of brain lesions, with several researchers concluding that strokes involving the left hemisphere, particularly the frontal regions, produce depression, whereas strokes in the right produce euphoria. Although this interpretation of lesion data has been debated subsequently, stable differences in individual temperament have been attributed to differing patterns of activation of anterior frontal and temporal regions in the two hemispheres.

Links between emotion, memory, and learning have also attracted interest. Normal subjects seem to show a right hemisphere superiority for recall of affective material, and subjects with greater activation of the right amygdala appear to have a greater ability to recall emotional movies. Damasio (1994) has emphasized the role of central representations of relevant somatic states for acquiring appropriate responses to positive and negative situations. In support of his thesis, he has demonstrated that certain patients with orbitofrontal lesions, who seem unable to make appropriate decisions in real life situations, are also deficient in their autonomic responses to arousing stimuli.

A second major theme in emotion research relates to the production and understanding of expressive behavior. The right hemisphere appears to predominate for the production and the perception of expressions, both facial and vocal. Indeed, the temporal cortex of the right hemisphere may have a region specialized for decoding facial expression. Furthermore, some patients with bilateral damage to the amygdala are deficient in understanding facial expressions, especially expressions of fear. One such patient was also found to have difficulty interpreting emotional and nonemotional intonations of voice. These findings are consistent with a number of lesion studies carried out from the 1930s to the 1960s in nonhuman primates, involving structures such as the amygdala, orbital frontal cortex, and cortex of the temporal pole. Researchers had concluded, based on the animals' impaired ability to interpret social signals, that these structures are part of a brain system specialized for social responsiveness in primates (Kling and Steklis 1976). Indeed, case reports have repeatedly shown that humans with lesions in structures such as the hypothalamus, amygdala, cingulate gyrus, and orbitofrontal cortex exhibit altered social behavior and expressiveness. It is at present uncertain whether one should conceptualize the defective performance of patients with amygdala lesions in terms of a primary deficiency of emotional state (e.g., fear) or a primary deficiency of social communication (e.g., ability to interpret expression).

A third theme in emotion research is the neurochemistry of mood. The discovery that the antihypertensive drug reserpine induced depression gave rise to models of depression that invoked catecholamine transmission. Subsequently, the discovery of abnormally low levels of serotonin in the cerebrospinal fluid of suicide victims gave rise to hypotheses invoking serotonin. Both theories are supported by the efficacy of medications that enhance catecholaminergic and serotonergic transmission for the treatment of depression, but empirical confirmation of hypotheses regarding the specific sites and mechanisms of action remains lacking. Other workers have proposed a role for dopamine in disorders of mood. At present, the clear efficacy of antidepressant medications is not matched by an equally clear understanding of their mechanisms. Likewise, roles for GABAergic and serotonergic systems in anxiety have been postulated, based on the clinical effects of agents that interact with these neurotransmitters. Imaging studies show some promise of illuminating the relation between neurotransmitters and mood in the future.

There are some persisting uncertainties in emotion research. For one, workers have long debated the relative contributions of somatic states and cognition to emotional experience. A principled distinction between somatic states that are emotional and those that are not is impossible: as a result, emotion cannot be defined in terms of somatic states alone. Furthermore, there is general agreement that somatic changes cannot be specific enough by themselves to yield the various discriminable emotional experiences. But because somatic elements seem indispensable to emotion, researchers such as Schachter and Singer (1962) have argued that cognitive appraisal of the stimulus must be combined with physiological arousal in order for an emotion to be produced. However, the notion of appraisal itself is complex. Another area of uncertainty concerns which emotions deserve to be called "basic" (Ortony and Turner 1990). Finally, one of the pillars of the emotion concept is the idea of subjective experience—feeling. This raises the thorny problem of QUALIA, a philosophical term for the felt nature of experience (cf. MIND-BODY PROBLEM). Nevertheless, despite—or even because of—these uncertainties, emotion will continue to attract interest as a topic in cognitive science.

See also EMOTIONS; EMOTION AND THE ANIMAL BRAIN; FREUD; INTERSUBJECTIVITY

—Leslie Brothers

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Emotions

An emotion is a psychological state or process that functions in the management of goals. It is typically elicited by evaluating an event as relevant to a goal; it is positive when the goal is advanced, negative when the goal is impeded. The core of an emotion is readiness to act in a certain way (Frijda 1986); it is an urgency, or prioritization, of some goals and plans rather than others. Emotions can interrupt ongoing action; also they prioritize certain kinds of social interaction, prompting, for instance, COOPERATION or conflict.

The term *emotional* is often used synonymously with the term *affective*. Emotions proper usually have a clear relation to whatever elicited them. They are often associated with brief (lasting a few seconds) expressions of face and voice, and with perturbation of the autonomic nervous system. Such manifestations often go unnoticed by the person who has the emotion. A consciously recognized emotion lasts minutes or hours. A *mood* has similar bases to an emotion but lasts longer; whereas an emotion tends to change the course of action, a mood tends to resist disruption. At the longer end of the time spectrum, an emotional disorder, usually defined as a protracted mood plus specific symptoms, lasts from weeks to years. Personality traits, most with an emotional basis, last for years or a lifetime. (Definitions, distinctions, and the philosophical and psychological background of emotions discussed in the next paragraphs, are described in more detail by Oatley and Jenkins 1996.)

Emotions have been analyzed by some of the world's leading philosophers, including Aristotle, DESCARTES, and Spinoza. Following Aristotle, in whose functionalist account emotions were species of cognitive evaluations of events, most philosophical work on emotions has been cognitive. The stoics developed subtle analyses of emotions, arguing that most were deleterious, because people had wrong beliefs and inappropriate goals. Stoic influence has continued. Its modern descendent is cognitive therapy for emotional disorders.

Charles DARWIN (1872) argued that emotional expressions are behavioral equivalents of vestigial anatomical organs like the appendix; they derive from earlier phases of EVOLUTION or of individual development, and in adulthood they occur whether or not they are of any use. According to William JAMES (1884), FOLK PSYCHOLOGY wrongly assumes that an event causes an emotion, which in turn causes a reaction. Instead, he argued that an emotion is a perception of the physiological reactions by the body to the event; emotions give color to experience but, as perceptions of physiological changes, they occur after the real business of producing behavior is over. Following James, there has been a long tradition of regarding emotions as bodily states, and although cognitive approaches now dominate the field, body-based research on emotions continues to be influential (see the third and fourth approaches following). FREUD developed theories of emotional disorder, proposing that severe emotional experiences, whether of trauma or conflict, undermine RATIONAL AGENCY subsequently, and interfere with life.

Cultural distrust of emotions was exacerbated by the work of Darwin, James, and Freud. There seemed to be something wrong with emotions; they were either without useful function in adult life or actively dysfunctional. Starting in the 1950s, however, several influential movements began with cognitive emphases, all stressing function, and all making it clear that emotions typically contribute to rationality instead of being primarily irrational. One result of these movements has been to expand concepts of cognition to include emotion. Among the first cognitive approaches to emotions, in the 1950s, was Bowlby's (see e.g., 1971). Bowlby proposed the idea of emotional attachment of infant to a mother or other caregiver. He was influenced by theories of evolution and of PSYCHOANALYSIS. His compelling analogy was with the ethological idea of imprinting. With attachment—love—in infancy, a child's emotional development is based on the child's building a MENTAL MODEL of its relationship with the caregiver (Bowlby called it a "working model") to organize the child's relational goals and plans.

Mental models are also known as *schemas*. Developmentalists have done much to demonstrate the importance of emotional schemas for structuring close relationships (see SOCIAL COGNITION). Such demonstrations include those of children's models of interaction with violent parents, probably functional in the family where they first occur, but often maladaptive in the outside world where they play a large role in later aggressive delinquency (Dodge, Bates, and Pettit 1990). A parallel, second approach was that of Arnold (e.g., Arnold and Gasson 1954). She proposed that emotions are relational: they relate selves, including physiological substrates, to events in the world. Events are appraised, consciously or unconsciously, for their suitability to the subject's goals, for whether desired objects are available or not, and according to several other features of the event and its context. Appraisal researchers have shown that which emotion is produced by any event depends on which appraisals are made (e.g., Frijda 1986). Work on appraisal was extended by Lazarus (1991) to research on coping and its effects on health. A third approach was also begun in the 1950s, by Tomkins (see, e.g., 1995). He proposed that, based on feedback from bodily processes, particularly from expressions of the face, emotions act as amplifiers to specific motivational systems. Personality is structured by schemas, each with a theme of some emotional issue. Tomkins inspired a surge of research (e.g., Scherer and Ekman 1984) that did much to place the study of emotions on an accepted empirical base. Notable has been the study of facial expressions and their relation to emotions, both developmentally and cross-culturally. Some aspects of such expressions are agreed to be HUMAN UNIVERSALS, although how they are best analyzed remains controversial. A fourth approach occurred with attempts to reconcile the work of James with cognitive ideas: notable were Schachter and Singer (1962), who proposed that emotion was a physiological perturbation, as had also been proposed by James, although not with the distinctive patterning that James had suggested; instead an undifferentiated arousal was made recognizable by cognitive labeling (a kind of appraisal). This work has been extended by Mandler (1984) who, like Simon (see next paragraph) stressed that emotions occur when an ongoing activity is interrupted, and an expectancy is violated.

Prompted by difficulties of COGNITIVE MODELING in capturing what is essential about the organization of human action, Simon (1967) argued that because resources are always finite, any computational system operating in any complex environment needs some system to manage PLANNING, capable of interrupting ongoing processes. The system for handling interruptions can be identified with the emotional system of human beings. An extended idea of Simon's proposal can be put like this: In the ordinary world there are three large problems for orchestrating cognitively based action.

1. Mental models are always incomplete and sometimes incorrect; resources of time and power are always limited.
2. Human beings typically have multiple goals, not all of which can be reconciled.
3. Human beings are those agents who accomplish together what they cannot do alone; hence individual goals and plans are typically parts of distributed cognitive systems.

Although cooperation helps overcome limitations of resources, it exacerbates problems of multiple goals and requires coordination of mental models among distributed agents. These three problems ensure that fully rational solutions to most problems in life are rare. Humans' biologically based solution is the system of emotions. These provide genetically based heuristics for situations that affect ongoing action and that have recurred during evolution (e.g., threats, losses, frustrations), they outline scripts for coordination with others during cooperation, social threat, interpersonal conflict, etc.; and they serve as bases for constructing new parts of the cognitive system when older parts are found wrong or inadequate.

Much recent research is concerned with effects of emotions and moods. Emotions bias cognitive processing during judgment and inference, giving preferential availability to some heuristics rather than others. For instance, happiness allows unusual associations and improves creative PROBLEM SOLVING (Isen, Daubman, and Nowicki 1987); anxiety constrains ATTENTION to features of the environment concerned with safety or danger; sadness prompts recall from MEMORY of incidents from the past that elicited comparable sadness. Such biases provide bases for both normal functions, and for disordered emotional processing (Mathews and MacLeod 1994).

As compared with research on learning or perception, research on emotions has been delayed. With newer cognitive emphases, however, emotions are seen to serve important intracognitive and interpersonal functions. A remarkable convergence is occurring: as well as support from evidence of social and developmental psychology, the largely functionalist account given here is supported by evidence from animal neuroscience (EMOTION AND THE ANIMAL BRAIN) and human neuropsychology (EMOTION AND THE HUMAN BRAIN). There is growing consensus: emotions are managers of mental life, prompting heuristics that relate the flow of daily events to goals and social concerns.

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Empiricism

See INTRODUCTION: PHILOSOPHY; BEHAVIORISM; RATIONALISM VS. EMPIRICISM

Epiphenomenalism

The traditional doctrine of epiphenomenalism is that mental phenomena are caused by physical phenomena but do not themselves cause anything. Thus, according to this doctrine, mental states and events are causally inert, causally impotent; they figure in the web of causal relations only as effects, never as causes. James Ward (1903) coined the term *epiphenomenalism* for this doctrine. However, William JAMES (1890) was the first to use the term *epiphenomena* to mean phenomena that lack causal efficacy. (It is possible that his use of the term was inspired by the medical use of *epiphenomena* to mean symptoms of an underlying condition.) Huxley (1874) and Hodgson (1870) earlier discussed the doctrine of epiphenomenalism under the heading of “Conscious Automatism.” They both held that conscious states are caused by physiological states but have no causal effect on physiological states (see Caston 1997).

According to proponents of epiphenomenalism, mental phenomena seem to be causes only because they figure in regularities. For example, instances of a certain type of mental occurrence *M* (e.g., trying to raise one’s arm) might tend to be followed by instances of a type of physical occurrence *P* (e.g., one’s arm’s rising). But it would be fallacious to infer from that regularity that instances of *M* tend to cause instances of *P*: it would be to commit the fallacy of *post hoc, ergo propter hoc*. According to the epiphenomenalist, when an *M*-type occurrence is followed by a *P*-type occurrence, the occurrences are dual effects of some common physical cause.

Epiphenomenalism is a shocking doctrine. If it is true, then a PAIN could never cause us to wince or flinch, something’s looking red to us could never cause us to think it is red, and a nagging headache could never cause us to be in a bad mood. Indeed, if epiphenomenalism is true, then although one thought may follow another, one thought never results in another. If thinking is a causal process, it follows that we never engage in the activity of thinking.

A central premise in the argument for epiphenomenalism is that for every (caused) event, *e*, there is a causal chain of physical events leading to *e* such that each link in the chain determines (or, if strict determinism is false, determines the objective probability of) its successor. Such physical causal chains are said to leave “no gap” to be filled by mental occurrences, and it is thus claimed that mental occurrences are epiphenomena (McLaughlin 1994).