BEHAVIORAL AND BRAIN SCIENCES (2005) **28,** 169–245
Printed in the United States of America

Bridging emotion theory and neurobiology through dynamic systems modeling

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Abstract: Efforts to bridge emotion theory with neurobiology can be facilitated by dynamic systems (DS) modeling. DS principles stipulate higher-order wholes emerging from lower-order constituents through bidirectional causal processes – offering a common language for psychological and neurobiological models. After identifying some limitations of mainstream emotion theory, I apply DS principles to emotion–cognition relations. I then present a psychological model based on this reconceptualization, identifying trigger, self-amplification, and self-stabilization phases of emotion-appraisal states, leading to consolidating traits. The article goes on to describe neural structures and functions involved in appraisal and emotion, as well as DS mechanisms of integration by which they interact. These mechanisms include nested feedback interactions, global effects of neuromodulation, vertical integration, action-monitoring, and synaptic plasticity, and they are modeled in terms of both functional integration and temporal synchronization. I end by elaborating the psychological model of emotion–appraisal states with reference to neural processes.

Keywords: appraisal; bidirectional causality; cognition; dynamic systems; emotion; neurobiology; part–whole relations; self-organization

1. Introduction

Both emotion theorists and neuroscientists have studied emotions, and their relation to cognition and behavior, for decades. Yet communication between them has remained relatively constricted. Most emotion theorists continue to ignore neuroscience almost entirely. At a recent international conference on emotions, there were 17 symposia and talks on the psychology of emotion, two on the neurobiology of emotion, and only one that attempted to bridge these perspectives. In partial contrast, neurobiologists adopt basic concepts from emotion theory, but they ignore the larger phenomena that are of greatest interest to psychologists. For example, they map isolated appraisal mechanisms onto specific brain regions, but rarely consider an appraisal as a coherent mental model corresponding with an emotional state. Given emotion theorists' goal of moving toward an integrated "affective science," and given the rapid progress in emotional neurobiology that could expedite this move, why do the psychology and neurobiology of emotion remain largely isolated?

One reason for this isolation may be that emotion theorists and neuroscientists view cause–effect relations and part–whole relations in terms that are nearly incommensurable and, thus, find it difficult to talk to each other. Emotion theory relies on causal assumptions that are simple, linear, and often cognitivist in character, and it emphasizes psychological wholes (e.g., appraisal, attention, "emotion") without explaining how they derive from interacting parts. Neural accounts incorporate far greater complexity, including bidirectional causal assumptions, but they focus almost exclusively on interacting parts (i.e., neural structures and subsystems) while ignoring the properties of the whole. Thus, complex causal processes remain elusive for emotion theorists, psychologically meaningful wholes remain elusive for neuroscientists, and there is little common ground for truly integrative modeling.

In this article I suggest a bridge between emotion theory and neurobiology based on dynamic systems (DS) principles. Nonlinear dynamic systems operate through reciprocal, recursive, and multiple causal processes, offering a language of causality consistent with the flow of activation among neural components. Consequently, psychological accounts informed by DS ideas may be more biologically plausible and better able to integrate neural findings. Dynamic systems are also characterized by the emergence of wholes out of interacting parts, through processes of self-organization and Haken's (1977) circular causality. Such multilevel causal processes can relate coherent wholes such as appraisals, emotions, and traits to the interaction of lower-order constituents, integrating levels of description

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 0140-525X/03 $12.50

both for emotion theory and emotional neurobiology. Thus, DS ideas may provide a foundation for building models that incorporate the rich psychological categories of emotion theory with the biological realism of neuroscience, by addressing causal relations and part–whole relations in a manner relevant for both.

I begin with a brief review of approaches to cognition–emotion relations in emotion theory, followed by a closer look at process models proposed by appraisal theorists. I then show how DS principles can help to reconceptualize appraisal–emotion interactions unfolding in time. Here and elsewhere, DS ideas are presented conceptually, not mathematically. There are many possible approaches to formal modeling that are consistent with this presentation. Next, I outline a model of self-organizing appraisal–emotion amalgams, highlighting reciprocal causation, emergence, and other DS principles. I then turn to emotional neurobiology, introduce some of the structures and functions thought to underpin emotion and appraisal, and propose several mechanisms of integration through which they interact. Finally, I extend the psychological model through reference to neural events and show how this translation helps refine the model while integrating neural processes into psychologically meaningful wholes. By taking two passes at DS modeling, first in psychological terms and then with the addition of neural terms, I attempt to show how DS principles bridge the two disciplines and yield a synthesis enriching to both.

This article does not propose a detailed neurobiological theory of emotion or cognition–emotion relations. Rather, it provides a DS-based framework that can serve as a platform for integrating psychological and neural perspectives, and it develops a model that instantiates this framework feasibly, as a working hypothesis. Predictions based on the model are framed in relation to present and future research directions. Yet, the specifics of both the model and the predictions are secondary to the conceptual framework underlying them. There is simply no overarching framework available, to date, for synchronizing psychological and neural perspectives on emotion and its relation with cognition, behavior, and individual traits; and, although dynamic systems ideas are no longer new, they have never been applied to developing such a framework.

2. Cognition–emotion relations: The view from emotion theory

2.1. Definitional issues

Emotion theory is a large amalgam of approaches to the study of emotion, mostly based on cognitive psychology but with contributions from learning theory, physiological psychology, clinical psychology, and other disciplines including philosophy. The central problem for emotion theory is how emotion interacts with other processes that have been studied more extensively: most notably, cognition. In emotion theory, as in other fields, "cognition" includes perception, attention, evaluation, decision-making, memory, and so on. However, these functions are also lumped under the nomenclature of *appraisal*, defined as the evaluation of significance in a situation that can give rise to an emotional response. Despite its lack of precision, the term "appraisal" is important in most emotion theories, because it denotes an evaluative or interpretive function that is critical for eliciting emotion. Thus, following emotion theorists, I will often use *appraisal* to mean, roughly, cognitive processes that are directed toward what is important for the self. The definition of emotion can be imprecise as well; but many theorists view emotions as response systems that coordinate actions, affective feeling states, and physiological support conditions, while narrowing attention to what is important, relevant, or available to act upon.

As can be seen, working definitions of appraisal and emotion are partially overlapping, especially in terms of evaluating "what is important." This can be problematic for emotion theory. In fact, the central assumption that appraisal and emotion are distinct functions is not as solid as one might like, and several theorists do away with it entirely (e.g., Ortony et al. 1988). However, this solution frames emotion as a class of cognition, leaving emotion theorists without a unique phenomenon to theorize *about*. Despite these definitional conundrums, appraisal and emotion are important and useful psychological categories that are central to a large body of theory and research. I will therefore use these terms throughout the article. When a neurobiological perspective is presented in sections 4–6, however, it will be necessary to revisit definitional issues and examine the overlap between "appraisal" and "emotion" more systematically.

2.2. Three approaches

Among the many approaches to cognition–emotion relations taken by emotion theorists, three stand out as subfields in themselves. The first and most coherent is appraisal theory. As noted, an appraisal is an evaluation of a situation in terms of its relevance for oneself, specifically one's goals or well-being (e.g., Lazarus 1968), and it is the means by which we extract meaning from events and make sense of the world (e.g., Frijda 1993b). Appraisal approaches attempt to determine the specific perceptions, evaluations, interpretations, and so forth, that are necessary and sufficient to elicit a particular emotional state. The classic way to do this has been to define and study a set of appraisal dimensions. Theorists disagree on the exact number and content of appraisal dimensions, but goal-conduciveness, novelty, coping potential, and norm-compatibility figure in most theories (Scherer 1999). Hypothetically, a distinctive pattern or profile on these dimensions stipulates a mental model and elicits a unitary emotion, somewhat like the opening of a lock when all the numbers line up (Lazarus 1991; Ortony et al. 1988; Reisenzein 2001; Roseman 1984). Empirically, subjects report on their thoughts and feelings in response to an emotion-eliciting vignette or the recollection of a significant life event. Their responses are scored on various appraisal dimensions, and the pattern of scores is related to a reported or observed emotional state (e.g., Reisenzein & Hofmann 1993; Roseman 1991; Roseman et al. 1996; Smith & Lazarus 1993).

By producing meaning, an appraisal sets the occasion for an emotional response whose purpose is to organize cognition and action relevant to the situation as appraised (Lazarus 1999; Roseman & Smith 2001). Thus, appraisal theorists generally view appraisal as a temporal and causal antecedent to emotion (Scherer 1993b; 1999; Roseman & Smith 2001). This assumption of the causal and temporal precedence of appraisal has been responsible for considerable controversy, epitomized by the famous Lazarus-Zajonc debate years ago (Lazarus 1984; Zajonc 1984). The debate was eventually put to rest, partly because it reduced to a war of definitions, but also because many appraisal theorists agree that emotions must influence appraisals in some way (Ellsworth 1991; Keltner et al. 1993; Roseman & Smith 2001; Scherer 1999; Smith & Kirby 2001). To finally resolve the temporal sequencing of appraisal and emotion, a (moment-to-moment) process account is necessary, and this appears to be the current challenge facing appraisal theorists (Scherer 2001).

The second approach to cognition–emotion relations is concerned with the cognitive *function* of emotions. Perhaps the main function of emotions is to direct attention to relevant aspects of the environment in the service of action tendencies for altering that environment (e.g., Ekman 1994; Frijda 1986; Izard 1993). From this perspective, attention is always "motivated" (Derryberry & Tucker 1994), and cognition is generally constrained by the type (e.g., sadness, anger, happiness, fear) of emotional state. A good deal of research demonstrates the effects of emotional states on attention and other cognitive processes (e.g., Bower 1992). Sad versus happy emotions differentially affect attentional style and content (Isen 1990). Anxiety biases or narrows attention (Mathews 1990), perhaps through its effects on filtering or inhibition (Wood et al. 2001). Emotion also biases perception (Mathews & MacLeod 1985; Niedenthal et al. 1994), memory retrieval (Eich & Metcalfe 1989; Isen 1985), social judgement (Forgas & Bower 1987; Keltner et al. 1993), and cognitive organization in general (Oatley & Johnson-Laird 1987; see review by Mathews & MacLeod 1994). According to these approaches, the source of the emotion (e.g., "mood induction") is not as important as its effect on subsequent cognitive events. Thus, importantly, the direction of influence, from emotion to cognition, is generally the opposite of that highlighted by appraisal theories.

A third approach is to examine cognition–emotion relations as influenced by personality traits and clinical disorders. Enduring biases, associations, and emotional habits have been well documented in emotion research (e.g., Bradley et al. 2000; Mathews & McLeod 1994). Personality traits such as optimism, pessimism, and anxiety, and clinical disorders including anxiety and depression, have been shown to increase the probability, endurance, and consistency of appraisals that code for specific aspects of the world (Beck et al. 1987; Gallagher 1990; Jerusalem 1993; Teasdale & Barnard 1993). These appraisals also tend to elicit corresponding emotions (Carver & Scheier 1991; Kuiper & Martin 1989). The effects of emotions on attention are often described in terms of trait-specific biases, as when anxious subjects attend selectively (and unconsciously) to anxiety-related words (Mathews & MacLeod 1985; 1986) or faces (Fox et al. 2002), and depressive subjects attend to negative words (Wenzlaff et al. 2001) and recall negative experiences (Clark & Teasdale 1982) more than normal controls. These approaches are generally not concerned with the etiology of the personality or clinical traits that produce these effects, but only with the effects themselves.

All three approaches to cognition–emotion relations take a particular view of causality. They conceptualize phenomena in terms of simple, linear causal processes – cause–effect relations that go in one direction from antecedents to consequents. Appraisal theorists generally view appraisal as the causal antecedent of emotional states; functionalist researchers view emotions as causing cognitive changes; and trait researchers view traits as causes rather than effects of emotional biases. Yet a bird's-eye view of the field suggests more complex causal relations: in particular, bidirectional effects among emotion-related phenomena. If appraisals give rise to emotions and emotions influence cognitive processing, then bidirectional causation would be important for explaining appraisal–emotion interactions (Lewis 1996). Moreover, if different emotions bias attention differentially, and appraisals are consistently constrained by these differences, then individual traits may result from emotional biases as well as cause them. Thus, ignoring bidirectional causal mechanisms yields incomplete models within the branches of emotion theory and impedes integration across these branches.

It should be noted that a few models of cognition–emotion relations do discuss bidirectional or nonlinear causal processes (e.g., Carver & Scheier 1990; Frijda & Zeelenberg 2001; Mathews 1990; Scherer 2000; Teasdale & Barnard 1993), and at least three draw specifically on DS constructs (Lewis 1996; Scherer 2000; Thayer & Friedman 1997). However, some of these models (e.g., Frijda 1993b) treat nonlinear considerations as secondary and do not develop them (see Lewis 1996), others (e.g., Scherer 2000) pursue them as an interesting diversion from more classical modeling, and still others (e.g., Carver & Scheier 1990) focus on negative feedback and error correction but ignore positive feedback and emergence. Despite such limitations, these contributions are important steps toward revamping the core assumptions of emotion theory. They set the stage for further development of bidirectional models, and they will be discussed and integrated further in Section 3.2.

The predominance of simple, linear causality in emotion theory is matched by a tendency to model psychological phenomena as wholes rather than parts. Global constructs such as emotions, appraisals, and traits, and monolithic systems such as attention and memory, figure strongly in the language of emotion theory. When these constructs and systems are dissected into components, they are done so in information-processing terms: resource allocation, propositional networks, knowledge stores, search procedures, value assignment, and so forth (e.g., Mathews & MacLeod 2002; Reisenzein 2001; Teasdale & Barnard 1993; Wells & Matthews 1994; Williams et al. 1997). The causality connecting these information processes can be characterized as cognitivist or computationalist, whereby a sequence of symbol manipulations computes an output for a predesignated problem (Fodor 1975; Putnam 1975). Examples include dimensional approaches to appraisal and information-processing models of attentional bias (e.g., Roseman 1991; Wood et al. 2001). Thus, part–whole relations, when addressed at all, are addressed mechanistically and linearly (with the exception of Teasdale & Barnard 1993, whose model is mechanistic but nonlinear). Such explanations tend to remain at the level of parts rather than wholes and to lack the psychological realism emotion theorists wish to achieve.

Appraisal theorists have become increasingly concerned with the relations between parts and wholes and have begun to develop *process models* capable of connecting them realistically (Frijda & Zeelenberg 2001; Reisenzein 2001; Roseman & Smith 2001; van Reekum & Scherer 1997). However, they have not yet abandoned the language of cognitivist causation. Process models of appraisal are reviewed next, with particular attention to the problems that continue to arise from linear causal assumptions.

2.3. Process models of appraisal

Process models examine the relations between appraisal components and emotional outcomes. But what are the components of appraisal? Dimensional approaches, reviewed earlier, focus on combinations of semantic elements (e.g., novelty, coping potential) to represent appraisals. Process models focus instead on psychological elements. A list of such elements might include perception, evaluation, attention, memory, reflection, and planning – essentially a breakdown of "cognition" broadly defined. By identifying the components of appraisal in this way, theorists can examine their interactions with each other and with emotion as they play out over time.

A key premise of process models is that appraisals are not necessarily slow, deliberate, or even conscious, and they can be perceptual as well as strictly "cognitive" (Lazarus 1984; Scherer 1993b). In fact, rapid, pre-attentive stimulus processing has been an important focus of appraisal theory and research (see Lazarus 1995). Leventhal and Scherer (1987) postulated sensorimotor and schematic processing levels that operate prior to cognitive evaluation. Frijda (1993b) has argued that only the shape of an object need be perceived in order to elicit an emotion. A variety of studies have shown that pre-attentive appraisals are sufficient to elicit emotions such as anxiety, fear (Öhman 1988; Öhman & Soares 1994; Robinson 1998), and possibly anger (Berkowitz 1989). Interestingly, this corresponds well with evidence that coarse perceptual processing by the amygdala is sufficient to activate emotion (LeDoux 1987; see also Lazarus 1999; Scherer 1993b) and that animals without cortical controls have intact emotional responses (LeDoux 1995a; Panksepp 1998a).

However, most theorists are primarily interested in the "higher cognitive" levels of appraisal that seem fundamental to normal human emotions. To incorporate both pre-attentive and higher cognitive processes in their models, many appraisal theorists consider appraisal as a sequence composed of two or more phases. Lazarus's (1966) initial formulation specified a rapid primary appraisal followed by a more reflective secondary appraisal. Öhman (1993) proposes an initial pre-attentive monitoring function followed by more controlled processing once significant events are perceived. Frijda (1993b) views secondary appraisals as necessary for fleshing out rudimentary evaluations that elicit primitive emotional responses. Smith and Kirby (2001) propose a rapid associative process followed by a slower, more controlled, and more focused stage of reasoning. Scherer's (1984; 1999) scheme involves a progression of five increasingly comprehensive evaluative checks operating recursively throughout the duration of an emotion-producing event. The earlier checks are rapid, pre-attentive, and concerned with sensory data, whereas the latter constitute higher-order cognitive evaluations that demand conscious attention.

Thus, sequential accounts of appraisal view some appraisal processes as rapid and some as slow; but they nevertheless maintain an assumption of linear causality. Early appraisal processes lead to later appraisal processes, and later appraisal processes lead to emotions. Or, emotions are partially determined by early appraisal processes and more fully determined by later ones. Yet, it is still appraisal processes that determine emotions, and not the other way around. Frijda (1993b) has been the most prominent critic of "linear" appraisal models, and Frijda and Zeelenberg (2001) make the radical (for emotion theory) claim that appraisal can be viewed as an outcome rather than an antecedent. This idea is also at the root of the few DS treatments undertaken so far (Lewis 1996; Lewis & Granic 1999; Scherer 2000).

The consensus view thus denies emotion a causal role in appraisal processes. Emotions are viewed, instead, as consequents of a one-way sequence of information-processing events. As with any cognitive computation, appraisal events are seen to sort and process information, follow a series of steps, mediate between a condition and an action, and lead to a final answer – an emotional response. However, by keeping emotion out of the causal equation, appraisal theorists ignore the demonstrated effects of emotion on attention, evaluation, judgment, recall, and other cognitive processes. Based on these findings, emotions (or emotion components) generated by pre-attentive processes early in an appraisal sequence should have an impact on what happens next. As sketched in Figure 1, they should immediately begin to influence successive perceptual, attentional, and higher-order cognitive processes, thus contributing to the final appraisal configuration via bidirectional causation. One critical barrier to this kind of modeling is that, even when appraisals are broken down into component events, emotions are still construed as monolithic wholes. This makes it impossible to include emotion "parts" in the causal chaining of appraisal events.

Some theorists represent the effects of emotion on appraisal by proposing appraisal–emotion streams. If appraisals are necessary to specify emotion states, yet emotion states influence subsequent cognitive processes, then there may be a continuous flux or stream of evaluative events in which appraisal and emotion are interspersed (Ellsworth 1991; Lazarus 1999; Parkinson 2001; Scherer 2001). However, this compromise abandons the important idea of an emotional episode (Frijda 1993a). Or, it necessitates two models of appraisal: a classical model of emotion-antecedent appraisal for clearly circumscribed events and a loosely defined appraisal–emotion stream for continuous events. Most critically, this approach tends to construe emotions and appraisals as wholes, not parts. Rather than view appraisals and emotions as alternating wholes in a temporal stream, a process account should demonstrate how constituent processes give rise to a whole appraisal in the first place (see Fig. 1).

2.4. Summary and conclusions

Most emotion theorists apply simple, linear causal models to explain the interactions among psychological entities such as appraisals, emotions, and traits. This brand of causality highlights psychological wholes, or information-processing parts, but it does not relate parts and wholes realistically. Process models have the potential for more realistic explanations; but the linear sequencing of appraisal events, and the general disinclination to see emotions as componential, leave no place for emotional effects on the formation of whole appraisals. Nevertheless, evidence from across the branches of emotion theory indicates that many

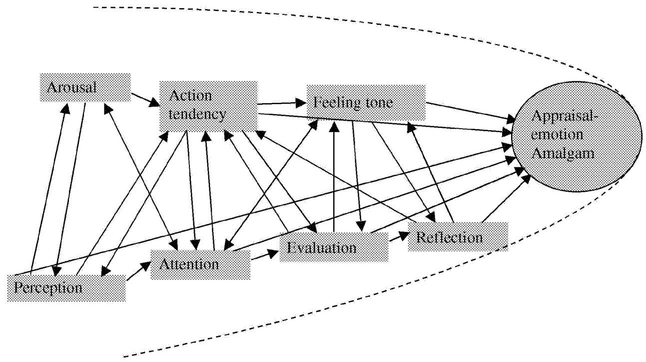

Figure 1. A skeletal model in which bidirectional causal relations between appraisal and emotion constituents lead to a whole appraisal–emotion amalgam. This scheme captures the contribution of emotion components to whole appraisals at the psychological level of description, but the components themselves have to be reconceptualized at the neural level, as discussed later.

cognitive processes influence emotions, emotions influence many cognitive processes, these effects are rapid and spontaneous, and they play out differently for different individuals. These findings suggest complex, bidirectional causal relations that organize parts as well as wholes at both momentary and developmental time scales.

Not only do linear causality and cognitivist assumptions create logical problems for integrating findings from within emotion theory, but they also make it difficult to integrate the burgeoning findings from neurobiology into psychological models. Neurobiology examines processes that are componential, complex, and bidirectional, including reciprocal connections at all levels of neural circuitry from neurons to whole brain systems. In doing so, neurobiology concretely defines constituent parts and subsystems and then relates them via principles of recruitment and synchronization that bear little resemblance to information-processing models. To establish a more comprehensive model of appraisal–emotion relations that can span psychological and neurobiological domains, I next introduce a dynamic systems approach to causality and part–whole relations.

3. Self-organizing appraisal–emotion states

Many characteristics of dynamic systems can be applied to understanding appraisal and emotion. In this section, a basic picture of dynamic cognitive systems is introduced first, with particular emphasis on self-organization, the process by which coherent wholes emerge and consolidate from interacting constituents. Then, a variety of DS principles are applied to appraisal processes and their interactions with emotion, establishing the foundation for a new psychological model.

3.1. Cognition as self-organization

Many cognitive scientists no longer characterize cognition as a linear computational sequence between input and output functions. Rather, they highlight the dynamic, distributed, nonlinear, and emergent aspects of cognition (Clark 1997; Elman et al. 1996; Kelso 1995; Port & Van Gelder 1995; Van Gelder 1998; Varela et al. 1991; Ward 2002). Traditional AI (artificial intelligence) has been overshadowed by connectionist models, and the structure and function of the nervous system have become criteria for plausibility. From this newer perspective, cognition builds on itself, biasing its own outcomes, and moves with only partial predictability from moment to moment. Thus, cognition can be viewed as a process of self-organization in a complex dynamic system. The appeal of viewing cognition as a self-organizing process goes back to the cognitive revolution, when Ashby (1952), McCulloch and Pitts (1943), and von Neumann (1958) explored the surprising properties of processing networks and feedback loops. However, it is not until recent years, with the rapid growth of connectionism, cognitive neuroscience, embodied cognition, and nonlinear dynamic cognitive models, that cognitive self-organization has become recognized as an important alternative.

Self-organization refers to the spontaneous emergence of order from nonlinear interactions among the components of a complex dynamic system. The meaning of "nonlinear" is twofold: (1) cognitive activities are viewed as reciprocal or recursive, as characterized by multiple feedback cycles, such that cause–effect relations are bidirectional or multidirectional; (2) effects in such systems are generally not linear functions of causes. Rather, they may be exponential, subject to threshold effects, and/or sensitive to damping or amplifying effects from other system components. Broadly defined, self-organization refers to the emergence of novel patterns or structures, the appearance of new levels of integration and organization in existing structures, and the spontaneous transition from states of lower order to states of higher order. Examples can be found in ecosystems (Kauffman 1993), social systems (Arrow et al. 2000), cortical systems (Bressler & Kelso 2001; Skarda & Freeman 1987), connectionist networks (Rumelhart et al. 1986a), morphogenesis (Goodwin 1993), and ontogenesis (Lewis 2000b; Thelen & Smith 1994), not to mention tennis, music, and sex. With respect to cognition, self-organization usually refers to the emergence and stabilization of psychological or neural configurations that correspond with (or represent) conditions in the world.

Why emphasize self-organization as a key aspect of dynamic cognitive – and cognitive–emotional – systems? The future states of a dynamic system are a function of its present state, as modified by its own activity (Vallacher & Nowak 1997; Van Gelder & Port 1995). Thus, cognitive systems construed as dynamic systems do not process information transduced from the outside world; they reconfigure themselves in response to an ongoing stream of sensory events (Van Gelder 1998; Varela et al. 1991). Most important, cognitive systems reconfigure themselves by achieving states of higher order through the synchronization of their constituents, both in real time, in response to perturbations, and in development, through experience-dependent change. In real time, coherent, macroscopic unities (e.g., schemas, expectancies, scripts, intentions, beliefs – and, arguably, appraisals) arise through the spontaneous coordination of microscopic constituents (e.g., Kelso 1995; Port & Van Gelder 1995). In development, novel skills and habits emerge, stabilize, and consolidate over months and years (Thelen & Smith 1994). The language of self-organization is well tailored, not only for modeling cognition in general, but also for modeling appraisals, along with the emotions that accompany them. I will now suggest a framework for analyzing appraisals as self-organizing phenomena.

3.2. Principles of self-organization applied to appraisal and emotion

In this section, I outline several principles of self-organizing systems and demonstrate their relevance for the emergence and consolidation of appraisals (along with accompanying emotional states – as detailed in the next section). I indicate where these or related ideas have been explored by other emotion theorists. Emergent appraisals (or appraisal–emotion amalgams) are construed as globally coherent states arising and stabilizing through nonlinear causal transactions among appraisal and emotion *constituents* (see Fig. 1).

3.2.1. Emergent order. Self-organizing systems show the spontaneous emergence of order out of (relative) disorder. Following some perturbation or trigger, novel forms arise without instruction or programming, based on interactions among the system elements themselves. Self-organizing systems start off with many degrees of freedom, but these are "used up" as orderliness emerges, through macroscopic constraints on the activity of individual elements. Self-organizing appraisals should thus become more orderly (i.e., synchronized, coherent) as they progress from initial to subsequent phases. This proposition is consistent with the idea of an evaluative structure consolidating during the latter phase of appraisal (Frijda 1993b), and with the locking in of meaning once appraisal dimensions are computed (Lazarus 1991; Ortony et al. 1988; Roseman 1984).

3.2.2. Positive feedback and self-amplification. Orderliness emerges in complex systems through a combination of self-augmenting (positive) and self-maintaining (negative) feedback processes. In positive feedback, a change in the activity of a subset of system elements feeds back to those elements and amplifies the change. Positive feedback relations thus "grow" new patterns of activation and recruit additional elements to them. Self-amplifying feedback can be modeled by autocatalysis – the tendency for some biochemical reactions to catalyze themselves recursively (Kauffman 1993; Prigogine & Stengers 1984) – producing exponential gradients of change. Although positive feedback is sometimes notorious for its capacity to break down existing structures, it is also a fundamental vehicle for the emergence of novel structures (Juarrero 1999). Consistent with this profile, appraisals and accompanying emotion states have rapid onsets in which many cognitive and emotional factors change together (Frijda 1993a). Positive feedback has been ignored by most emotion theorists, but Teasdale (1983) and Teasdale and Barnard (1993) have modeled the growth of depressive states based on positive feedback between negative appraisals such as self-blame and negative emotions such as sadness. Similarly, Mathews (1990) has suggested that threat-anxiety states may arise from feedback between attention to danger cues and anxious emotions.

3.2.3. Negative feedback, entrainment, and stability. As the elements of the system interact recursively, negative feedback takes over. A negative feedback loop is one in which the effects of one element on another (e.g., excitation) are compensated by reciprocal effects in the opposite direction (e.g., inhibition). Negative feedback loops attain a steady equilibrium or a continuous oscillation. This is because each opposing causal influence counteracts the other, either simultaneously or via ongoing adjustments. In either case, stabilization ensues. Thus, negative feedback stabilizes the growth and change initiated by positive feedback.

Stability anchored in negative feedback circuits can spread out across the whole system through entrainment (or synchronization) with other circuits. Thus, individual elements or groups of elements lose their independence and become embedded in a larger regime. Deviations are dampened and discrepancies resolved, contributing to the consolidation of global orderliness. Such functional synchronization can (but need not) take the form of temporal synchronization or phase synchrony, a theme addressed in some detail later. In general, self-stabilization is a property of many interactive networks, including cellular automata (Nowak et al. 2000) and constraint satisfaction networks (Thagard & Verbeurgt 1998). This tendency may be universal for adaptive systems, because their components must be coordinated to maintain their functionality (Ford 1987; Karoly 1993). Emotion theorists have not had much to say about negative feedback or synchronization, but social-personality psychologists have described discrepancy-reducing feedback processes as determinants of emotion in the short term and of personality styles in the long term (e.g., Carver & Scheier 1990; Higgins 1987). As well, some connectionist theorists have modeled beliefs, attitudes, impressions, and judgments as states of coherence based on interacting constraints (Kunda & Thagard 1996; Shultz & Lepper 1996), and Nerb and Spada (2001) developed a connectionist model of coherence relations among appraisal and emotion elements based on consistency among beliefs and desires.

3.2.4. Circular causality. Feedback is one form of nonlinear causation. A second form, termed *circular causality* (Haken 1977), describes bidirectional causation between different *levels* of a system. A coherent, higher-order form or function *causes* a particular pattern of coupling among lower-order elements, while this pattern simultaneously *causes* the higher-order form. The top-down flow of causation may be considered an emergent constraint (by the system as a whole) on the actions of the parts. Cognitive scientists have begun to model higher-order mental states such as intentionality and consciousness as emergent forms that constrain the activation of the psychological or neural constituents producing them (Freeman 1995; Juarrero 1999; Thompson & Varela 2001). In behavioral systems, functions such as walking or reaching are seen as maintaining the coordination of their perceptual and muscular constituents (Kelso 1995; Thelen & Smith 1994). Appraisals might also be considered higher-order functional or mental organizations that constrain their constituents. Superordinate appraisal themes, such as Lazarus's core relational themes (e.g., irrevocable loss), might hold subordinate, interacting appraisal processes in place, while those processes simultaneously fuel the superordinate. This idea is consistent with Frijda's (1993b) modeling of appraisal as a cumulative gestalt, and it is explicitly captured by Scherer's (2000) view of appraisal as a higher-order parameter "enslaving" its constituents (also based on Haken).

3.2.5. Increasing complexity. In self-organization, coordination among differentiated components of the system permits complexity as well as coherence. Increased organization allows more elaborate configurations of parts and functions, such as coordinated subsystems arranged in sequence or in parallel. An example from neuroscience is the emergence of perceptual binding, arising from the synchronization of neural firing patterns and allowing for complex perceptual processes such as figure–ground segregation and the sequencing of perceptual events (Engel et al. 2001). Several appraisal theorists describe secondary appraisal processes as enriching or supplementing primary appraisals with more elaborate content and meaning (e.g., Frijda 1993b; Smith & Kirby 2001). For example, an appraisal of someone as untrustworthy may start off relatively vague, but once it consolidates, it permits the formation of an intricate interpretation of the other as sneaky, malicious, and dangerous. Thus, the coordination of concepts and associations in orderly ensembles permits the construction of detailed cognitive models.

3.2.6. Multistability and stochasticity. The outcomes of self-organization are fixed or periodic (or chaotic) organizational patterns, called attractors, that endure for some period of time. The principle of multistability holds that many potential attractors coexist on the state space of an adaptive system (Kelso 1995), and systems rapidly move or "evolve" to one or another of them. Moreover, natural systems are usually thought to be influenced by stochastic forces, such that the attractor to which they gravitate is not fully predictable in advance. Appraisals do seem to fall into one of several identifiable attractors. Despite the many potential combinations of values on various appraisal dimensions, appraisal theorists stipulate a limited number of meaningful combinations, leading to a limited number of specific emotions. The core relational themes proposed by Smith and Lazarus (1993) tap these canonical combinations. Moreover, for an individual with a given emotion trait, only a small subset of these combinations occurs regularly (e.g., Horowitz 1998), and only one of these converges at a time.

3.2.7. Phase transitions. Because orderliness is limited to a small number of stable states, self-organizing systems move across thresholds of instability and jump abruptly to new stabilities. These jumps, sometimes called phase transitions or bifurcations, occur when system orderliness breaks down as the result of some perturbation and new patterns of organization rapidly self-amplify. Sudden shifts between incompatible appraisals may be analyzed in this way. Izard (1993) describes a rapid reappraisal that begins when a man is painfully hit from behind. He turns around angrily only to find that the person who hit him is wheelchair-bound, and he immediately reappraises this person as out of control and faultless. In this case, the reappraisal starts with one new element, leading rapidly to a switch in macroscopic organization.

3.2.8. Time scales and learning. Embedded and interacting time scales are typical of self-organizing systems in nature. In psychological systems, time scales typically include the emergence of behavior in *real time* and the emergence of behavioral traits or habits in *developmental time* (Thelen & Smith 1994). Importantly, processes at each scale influence processes at the other scale (Port & Van Gelder 1995). That is, structural changes in system constituents over development both result from and contribute to the emergence of coherent forms in real time. Time scale relations can be seen in the crystallization and automatization of appraisals across occasions (i.e., social learning) and in the constraints of this learning on real-time appraisals. Appraisal theorists avoid this perspective, but psychologists studying emotional and personality development find it crucial for explaining individual differences. For example, Izard and Malatesta (1987) postulate affective-cognitive structures, arising over a series of emotionally loaded situations, as the units of personality development that constrain future interpretations; and Dodge and Somberg (1987) show how several experiences of abuse lead children to develop a "hostile attributional bias" that filters subsequent experience. The vehicle for this learning is another highly general property of self-organizing systems: the tendency for system elements to change in structure as a result of their activity. This principle is built into learning algorithms for connectionist nets and is the basis of Hebbian synaptic strengthening.

3.3. A psychological model of self-organizing emotional interpretations

In this section, a psychological model of appraisal–emotion relations is grounded in the framework just set out. In a subsequent section, this model is revised and elaborated from a neurobiological perspective. As sketched in Figure 1, the model highlights bidirectional interactions among appraisal and emotion components, but it also traces the evolution of an emotion–appraisal state – or *emotional interpretation* (EI) – through several phases. The sequence begins with a trigger event that is defined by a change in the dynamics of the psychological system. Starting with this event, an initial phase of self-amplification represents the growth phase of an EI. This gives way to a phase of self-stabilization, in which global coherence is established and higher levels of complexity appear. Finally, coherent states that endure for some time give rise to learning, extending the influence of the present appraisal to future episodes.

Before going on, it may be useful to present an example of a self-organizing EI. In a number of Western countries there is growing concern with the phenomenon of "road rage" – intense anger coupled with an appraisal of another driver as one's enemy or tormentor, often leading to shouting, swearing, or physical violence. Self-organizing angry appraisals are not unusual in traffic, but road rage, because it is circumscribed, arbitrary, and extreme, provides a paradigm case. Mr. Smart slams on the brakes when noticing the proximity of the car in front. Anger arises initially from frustration, as Mr. Smart wants to keep driving fast, but also from a sense of violated entitlement: he is in the left lane and should not have to slow down. Fear may also be triggered by the close call, eliciting further anger because of an intermediate evaluation of unmanly helplessness. These emotions arise rapidly, but they are paralleled by a co-emerging sense of the other driver as intentionally obstructive (and therefore blameworthy). Mr. Smart's highly focused visual attention, a derivative of anger, takes in the red color of the car ahead, as well as the expensive-looking design, and his anger is amplified by his sense of the unfairness of this show-off blocking his path (based on an implicit memory of some long-forgotten or fantasized rival). A stabilizing angry-anxious state, coupled with ruminative plans for vengeance (perhaps a blast of the horn), anchors attention to the head of the man in front. This lasts for a minute or two while Mr. Smart fashions and modifies plans to pass on the right. However, when the man peers over his shoulder, Mr. Smart evaluates this act as a taunt, generating shame and anger in an elaborated appraisal of humiliation, and calling for extreme action to save his self-image from further subjugation.

3.3.1. Trigger phase. Most appraisal theorists would agree in principle that appraisal–emotion episodes begin with a triggering event. In DS terms, the orderly behavior of the system is interrupted by a perturbation, resulting in a rapid loss of orderliness and an increase in sensitivity to the environment. The perturbing event must have an impact on one or more system elements, or it is invisible to the system. This impact works through a process of nucleation in which the affected element enters into reciprocal, self-enhancing interactions with neighboring elements to create a core proto-organization (Prigogine & Stengers 1984). Thus, a trigger marks a phase transition, characterized by sudden change and temporary disorder as the system switches to a new organization.

Living systems are like taut springs, ready to respond to small perturbations that are biologically meaningful (Kauffman 1995). In the triggering of an EI, the perturbation can be any sensory event, a perceptual or cognitive event (e.g., an image, association, or memory), or a change in arousal or affect (Izard 1993), as long as it induces a self-amplifying interaction among appraisal and emotion elements. It is difficult to predict the conditions for self-amplification, but background psychological and physiological states, both cognitive and emotional, must act as control parameters that adjust sensitivities that determine what is meaningful. A depressive mood makes one insensitive to cheerful events but sensitive to negative events (Teasdale & Barnard 1993), and anxiety biases attention to threat cues (Mathews & MacLeod 1994). Mr. Smart's irritation with traffic served this background function.

A trigger can be used to define the first moment (time-0) of an emotional episode, but it can also occur at any point in an ongoing appraisal–emotion stream. This collapses the distinction between circumscribed emotion episodes and ongoing streams of appraisal–emotion events. Given this assumption, triggers can change existing appraisals by either replacing them or building onto them, depending on the present context and inner state characteristics. For example, an angry EI, in which anger and blame are coupled, can be interrupted by a fear trigger (e.g., cued by awareness of potential retaliation), but it can also be elevated to a state of more intense rage (e.g., if insult is added to injury, as in the case of Mr. Smart). Such cascading triggers can initiate a branching pathway of EI evolution in real time. In fact, the art of fiction writers and movie directors is to deliberately shape the evolution of such pathways.

3.3.2. Self-amplification phase. For an EI to "take over" the psychological system, a phase of self-amplification must follow perturbation and nucleation. Appraisal and emotion constituents may now interact in positive feedback loops, such that the activation of any element leads to the activation of other elements in recursive cycles of increasing magnitude. According to appraisal theorists, appraisal elements (e.g., pre-attentive perceptions of an approaching other) stimulate emotions. As shown by Mathews and others, emotions guide the focus of attention and recall to those features that are emotionally relevant (e.g., facial and postural cues, or the head movements of the driver in front of Mr. Smart). In the present model, this increase in cognitive activities dedicated to emotion-relevant cues strengthens the emergent appraisal and amplifies emotional activation. Thus, perceptual, emotional, and attentional processes amplify one another (positive feedback) but at the same time begin to tune or constrain each other (negative feedback) as the EI grows. Emotional processes may also recruit executive processes in preparation for action (e.g., Mr. Smart's plan to switch lanes), as well as retrieval processes that make sense of the event and guide further emotional activation (e.g., memories of intimidating other drivers). Positive feedback thus "grows" appraisal–emotion processes that capture the psychological system.

While positive feedback predominates, systems are highly sensitive, and small deviations may be rapidly amplified. A raised eyebrow can shift the evolving appraisal from affiliation to humiliation, at least until a coherent interpretation locks into place. During this early phase, appraisals should also be sensitive to the background activation of system elements, including baseline emotion or mood (cf. Frijda 1993a). However, psychological systems, like well-trained neural networks, generally remain in an unstable phase only briefly, then settle to a particular region of the state space and remain there.

The principles of bidirectional and multiple causation in the present model help to resolve some of the problems encountered by mainstream emotion theories. According to the model, appraisal activities and emotional response activities *cause one another*, each activating, propelling, and guiding the other, reciprocally and recursively. Emotional events are granted full causal status, and their effects are felt at or near the beginning of the appraisal sequence. Emotional events are part of the causal chain that contributes to the evolution and consolidation of the appraisal pattern – hence, what evolves is not just an appraisal but an emotion–appraisal amalgam or "emotional interpretation."

3.3.3. Self-stabilization phase. When negative feedback overtakes the system dynamics, change decreases and continuity increases. Appraisal elements become coupled in coherent ensembles or meaningful wholes that are entrained with emotional states. The negative feedback properties responsible for this stabilization can be exemplified by the interaction of anxiety and vigilance. Anxiety initially increases vigilance, but heightened vigilance improves one's grasp of a situation, thus diminishing anxiety. With anxiety decreasing, vigilance also decreases, leading in turn to uncertainty and then increased anxiety once again. This oscillatory pattern may stabilize and endure. However, because such a pattern is ultimately noisy and difficult to measure, one might simply say that a moderate level of vigilance becomes coupled with a moderate level of anxiety. This stabilizing anxious-vigilant mode can now become entrained with other constellations (e.g., a cognitive evaluation of "keeping the lid on"), thus enhancing coherence across multiple subsystems.

Spreading coherence in connectionist networks is modeled by constraint satisfaction solutions involving multiple cognitive elements. To model the coherence of an EI, these constraints must also include emotional elements. The resolution of conceptual discrepancies has been proposed to elicit emotions, but this process is usually modeled as unidirectional. With bidirectional causality, the resolution of discrepancies would not only elicit or stabilize emotions but would also be *caused* by emotions that support particular meanings (see Nerb & Spada 2001). Thus, emotions are necessary to cement emerging interpretations (as when anger fuels Mr. Smart's interpretation of blameworthiness), and emotions are maintained by those same interpretations (as when blame perpetuates Mr. Smart's anger), locking cognition and emotion into an enduring resonance.

Despite the ambiguous nature of the world, and even in the presence of conflicting cues, appraisal–emotion configurations resolve into stable patterns. Indeed, appraisals have been found to resist change in paradigms that use perceptual disengagement in the short run (Fox et al. 2002) and rumination in the long run (Martin & Tesser 1996; Nolen-Hoeksema & Morrow 1991). The possibility of several alternative resolutions is consistent with the principle of multistability in dynamic systems, but the consolidation of a particular "solution" from competing ensembles is rapid and nonlinear (cf. Thagard & Verbeurgt 1998; Tononi & Edelman 1998). Circular causality (Haken 1977) may be a key factor in this consolidation. Through circular causality, top-down and bottom-up causal processes become mutually entrained, and a specific EI coheres and stabilizes. Thus, when a superordinate appraisal (e.g., other driver as deliberate foe) begins to cohere, it may "enslave" its constituents (red car, thinks he owns the road, self as subordinate, shame, anger), while the interactions of the constituents that contribute to that particular appraisal are perpetuated and strengthened. This kind of explanation has proven useful for modeling the emergence of global appraisals (Lewis 1996; Scherer 2000).

The process of cognitive-emotional stabilization may also be guided by functions related to action. Emotion theorists emphasize the role of emotion in propelling and constraining action, and *action tendencies* are often considered aspects of emotion. However, the principle of bidirectional causation suggests that action tendencies may feed back to appraisal and, perhaps, to other aspects of emotion as well. Psychological functions that support action include selective attention, planning, and monitoring one's interaction with the environment.

Finally, DS principles suggest that the consolidation of coherent emotion–appraisal states is necessary for complexification, allowing appraisals to become more elaborate and articulated. Before Mr. Smart can develop a full character sketch of the driver blocking his path, and a plan for confronting him, his cognitive processes must become coordinated and integrated with emotion. Elements in attention, working memory, and planning must cohere to produce a detailed mental model or script. However, complexification can also generate new scenarios or contingencies, potentially triggering a new EI at any point. Rehearsing a plan for retaliation can bring fearful images to mind, sometimes evolving into an appraisal of helplessness and self-doubt. Perhaps the most realistic portrait of a self-stabilizing EI includes several well-worn interpretations that fluctuate intermittently, as familiar images and emotions drive the system between available attractors.

3.3.4. Learning. Enduring biases, beliefs, traits, and emotional habits have been well documented in emotion research, but their relation to real-time appraisal processes has not been fully explored. From a developmental perspective, recurrent episodes of emotion–appraisal contribute to the formation of individual characteristics (Izard 1984; Lewis 1995; Malatesta & Wilson 1988). Thus, each appraisal episode provides the occasion for learning cognition–emotion associations that tend to recur on future occasions. According to the present model, the self-stabilization phase of an EI is the necessary precondition for this learning. Once appraisals have stabilized, interpretations, action plans, and expectancies endure for some period of time, as mediated by coupled cognitive and emotional elements. These enduring couplings seem necessary to strengthen the connections responsible for learning. As noted earlier, self-organizing systems, including brains, show increased connectivity among elements that are reciprocally activated (coupled) in real time.

A good deal of organization already exists in the cognitive-emotional system prior to the emergence of a new EI, and much of this organization derives from learning across past emotional episodes. Mr. Smart's road rage must have grown from a lineage of episodes of frustration and anger, although he may well have a low frustration tolerance by temperament. Associative learning is often considered the principal mechanism for laying down this organization over time. According to the present model, learning is a long-term organization produced by enduring EIs, and the consolidation of order within an individual EI is a short-term organization based in part on learning. As is typical of self-organizing systems, the accumulation of order at two very different time scales is considered interdependent.

3.4. Summary and conclusions

In this section, a framework was established using principles of self-organizing dynamic systems applied to appraisal and emotion. Then a model was developed with specific emphasis on emotion–appraisal states, or emotional interpretations (EIs), as emergent forms, and on the self-amplifying and self-stabilizing causal processes that give rise to them. Rather than sequences of appraisal steps producing emotions, appraisal–emotion processes were viewed as bidirectional interactions among cognitive and emotional constituents, giving rise to new organizational regimes, shifting from growth to coherence in real time, and setting the occasion for complexification, action, and learning.

However, this modeling exercise leaves many questions unanswered. When and how do perturbations trigger new appraisals? How does self-amplification and sensitivity give way to self-stabilization and coherence? How does the superordinate EI constrain the component interactions that give rise to it? What mechanisms relate action and learning to appraisal and emotion? These and other questions point to a major gap, or core ambiguity, in the model presented thus far: What exactly are appraisal elements or constituents, what are the "elements" of emotion, and how can one define these parts in relation to the wholes emerging from their interaction? At the level of psychological modeling, one must describe constituents of appraisals with terms such as "perception," "evaluation," and "attention," whereas emotion constituents, when discussed at all, are defined in terms such as "arousal" or "action tendencies." These terms hardly describe constituents, however. They describe whole, global functions or processes in themselves. This problem reflects a general tendency for psychological theory to gravitate to a level of description that is superordinate, global, and functional. This tendency makes it difficult to concretize causal relations between parts and wholes, and thus to fashion true explanations.

The principles of self-organizing systems have been useful for modeling the evolution of global states on the basis of interacting cognitive and emotional constituents. However, much of the detail has yet to be filled in, and the psychological level of description has little more to offer. I now turn to emotional neurobiology to reconceptualize appraisal and emotion "parts," identify their mechanisms of interaction, put flesh on the bones of the model developed thus far, and demonstrate a conceptual bridge between emotion theory and neurobiology more generally.

4. The neurobiology of emotion and appraisal

To link emotion theory with emotional neurobiology through the application of DS principles, it seems necessary to identify the anatomy and function of brain regions (or structures) that mediate the various constituents of appraisal and emotion, and then to identify the processes that connect these regions in global activities that correspond with psychologically meaningful wholes. Neurobiology provides specific and detailed accounts of what goes on within circumscribed regions and between closely related regions, but it has a more difficult time specifying part–whole relations that integrate activities over the entire brain. In this section and the next, these part–whole relations are highlighted by visualizing neural processes through a DS lens.

It should be emphasized that much theoretical and empirical work in neuroscience has utilized DS principles. For example, cortical activities have been modeled as self-organizing processes of synchronization that yield coherence and/or complexity (Bressler & Kelso 2001; Érdi & Barna 1984; Meyer-Lindenberg et al. 1998; 2002; Nunez 2000; Skarda & Freeman 1987; Skinner & Molnar 1999; Varela et al. 2001), transitions have been studied as instabilities or phase transitions triggered by perturbations (Freeman 1995; Thatcher 1998), individual development has been modeled as emergent patterning of synaptic networks (Edelman 1987; Edelman & Tononi 1997; Harkness & Tucker 2000; Post & Weiss 1997; Schore 2000), and circular causality has been identified between superordinate mental states (e.g., attention, expectancy) and subordinate neural events (Engel et al. 2001; Freeman 1995; Szentagothai 1993; Thompson & Varela 2001). These and other applications suggest many avenues for exploring what is surely the ultimate complex system.

Most of these accounts model phase synchrony or time-based correlations among neural populations in the cortex, and they provide electrophysiologial data in support of this modeling. However, emotional processes necessarily involve subcortical systems, and there has been much less work demonstrating synchronization across multiple levels of the neuroaxis. Therefore, the present analysis of interacting cortical and subcortical systems is grounded more in anatomical and functional data than electrophysiological data; and neural integration is defined and discussed in functional terms before exploring the intriguing possibilities of temporal synchronization.

4.1. Working definitions

The main argument that has been advanced so far, and that will now be extended through a neurobiological analysis, is that reciprocal and recursive relations among appraisal and emotion components lead to the emergence of appraisal–emotion wholes, and that neither whole (i.e., fully articulated) emotions nor whole appraisals can exist in isolation from each other. In Section 2, I suggested that appraisal components include (1) perception, (2) evaluation, (3) attention, (4) memory, and (5) higher-order executive functions such as planning and reflection. I also noted that these terms are inadequate for any real explanation relating parts to wholes, because they denote global functions or processes themselves. Defining emotion parts meets with the same difficulties, and many emotion theorists avoid this conundrum by considering emotions as monolithic wholes. However, it seems unreasonable to treat emotions as wholes when so much attention is given to appraisal components. There are several features that are usually considered indispensable to emotion, and these are useful designators for emotion components. They include (1) arousal, (2) action tendencies, (3) attentional orientation, and (4) affective feeling. It is also generally agreed that these functions rely on physiological changes throughout the brain and body.

This parsing of appraisal and emotion components, though not without its problems, provides a segue to a neural analysis. The next step is to map these terms onto neural systems whose interactions can be described in detail. However, an additional difficulty proves to be the anatomical and functional overlap among systems that subserve appraisal and emotion constituents. In fact, many brain systems up and down the neuroaxis can be included under definitions of both (Lane et al. 2000; Panksepp 1991). This ambiguity may be responsible for ongoing debates over which functions to assign to which systems. For example, the rapid amygdala (AM) response to information from the thalamus can be viewed as an affective computation (LeDoux 1989), but it can also be viewed as a preliminary appraisal (Lazarus 1999; Scherer 1993b; see Parrott & Schulkin 1993, and LeDoux 1993, for a discussion of this issue). The purpose of this article is not to further this debate, but to show how a variety of neural subsystems interact to produce appraisal and emotion processes that become coupled in a macroscopic emotion–appraisal state. Nevertheless, the distinction between appraisal and emotion, both at the level of parts and the level of wholes, continues to be problematic, and I will address it in more detail later.

The appraisal components listed earlier – perception, evaluation, attention, memory, and planning/reflection – are mediated by a variety of neural systems from the brain stem to the cerebral cortex. Primitive sensory and evaluative processes are rooted in the midbrain, whereas higher cognitive functions of attention, memory, and planning correspond chiefly with limbic and cortical systems (though they require the participation of diencephalic and brainstem structures as well). With respect to emotion, arousal and action tendencies, as well as the control of physiological response systems, are generally assigned to brainstem and hypothalamic structures, attentional orientation involves links between these structures and corticolimbic systems, and affective feeling probably involves brainstem, paralimbic (e.g., cingulate), and prefrontal cortical structures (Damasio 1999; Panksepp 1998a). Thus, both appraisal and emotion components are mediated by systems splayed out along the neuroaxis, tracing an evolutionary path from more primitive to more recent acquisitions. Nevertheless, we sometimes associate appraisal with higher (e.g., corticolimbic) systems. Although there is no adequate justification for this, appraisal processes in real time quickly become elaborated through corticolimbic activities that override or control more primitive structures (e.g., the superior and inferior colliculi; Rafal 2002). In contrast, our construals of emotional processes, even as they extend cortically, continue to highlight hypothalamic, brainstem, and bodily activities that mediate feelings and action impulses. This rough parsing of appraisal and emotion by brain region says more about our definitional habits than about fundamental neuroanatomical divisions; but it does agree with the thrust of models proposed by many investigators in affective neuroscience (e.g., Buck 1999; Damasio 1999; Davidson & Irwin 1999; Panksepp 1998a; 2003). It also corresponds with Panksepp's (1998a) metaphor of emotion systems as branching trees, with their roots in the brain stem and their branches extending upward to the cortex. According to this analogy, higher cognitive aspects of appraisal may refine core emotional meanings, extending both spatially (toward the cortex) and temporally (as emotion episodes unfold in time).

I now describe the location, structure, and function of various neural systems that are likely to mediate appraisal and emotion components (see Fig. 2). These are meant to be summary descriptions, providing just enough detail to flesh out the DS-inspired framework and model developed in the previous sections. The selection of systems is also meant to be provisional, supplying a reasonable but not exhaustive list of candidates for each psychological function. A number of neural systems are described in this section, and their bidirectional and emergent interactions are modeled in the next section. Rather than a detailed neurobiological theory, these sections present a framework for thinking differently about neural processes underpinning appraisal and emotion.

4.2. Anatomy and function of systems mediating appraisal

4.2.1. Perception. Sensory information is mediated by the thalamus (among other structures) and then proceeds to various cortical and subcortical systems. Primitive perceptual processes such as motion detection and object direction are mediated by midbrain structures such as the superior and inferior colliculi. More advanced perceptual processes take place in the primary sensory and association areas of the posterior cortex. Unimodal perceptual streams are integrated in temporal and parietal association areas, and higher-order perception, requiring orienting, anticipation, and integration with motor systems, involves bidirectional links between these areas and the prefrontal cortex (PFC). For example, the frontal eye fields control gaze direction, whereas other prefrontal systems mediate the anticipation and organization of information over time. While sensory information is being projected forward to these frontal systems, back-projections control the sensory pickup of significant aspects of the environment (see Fuster 2002, for a review).

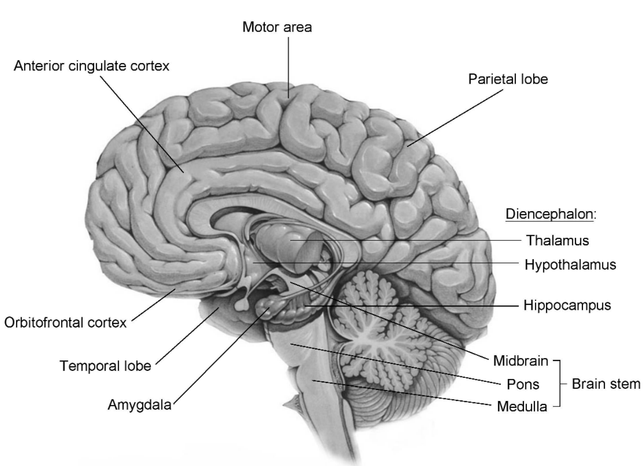

Figure 2. Some of the brain regions and structures mediating emotion and appraisal. The brain image is used with permission of Andrews & Associates/Custom Medical Stock Photo.

4.2.2. Evaluation. Evaluation is a slippery concept covering functions that extend from higher-level attentional systems such as the orbitofrontal cortex (OFC) and anterior cingulate cortex (ACC), to more basic pattern-matching functions of the amygdala (AM) and ventral striatum, to brainstem systems (e.g., the colliculi) that register innately defined events such as motion and rapid approach. The amygdala is a group of nuclei embedded within the temporal lobe of each hemisphere. It is a central limbic structure connected with many other limbic, diencephalic, and cortical areas, and it has long been known to form and maintain associations between neutral stimuli and motivationally tagged stimuli (i.e., emotional conditioning), especially in fear, but in other emotions (including positive ones) as well (LeDoux 1995a; Öhman 1993; Rolls 1999). The striatum, nested around the diencephalon and midbrain, includes various structures that are necessary for switching or selecting motor plans and for incentive motivation necessary for carrying out those plans. The ventral striatum (especially the nucleus accumbens [NAS]) evaluates and responds to conditioned and unconditioned stimuli (Cardinal et al. 2002) and is centrally involved in incentive motivation (Depue & Collins 1999).

4.2.3. Attention. While some evaluative processes are preattentive (Öhman 1988), others rely on attention. Higher-order attentional processes are mediated by prefrontal "executive" cortical systems, including the ventromedial PFC, dorsolateral prefrontal cortex (DLPFC), orbitofrontal cortex (OFC), and anterior cingulate cortex (ACC). More basic attentional processes such as orienting and monitoring are mediated by more posterior (posterior cingulate, parietal, and temporal) orienting systems (e.g., Posner et al. 1988). Most important for now are two "paralimbic" prefrontal systems (adjacent to limbic systems and containing more primitive cell types) considered to be critical for motivated attention (Barbas & Pandya 1989). The first is the OFC on the ventral surface of the PFC. The OFC encodes and holds attention to context-specific, motivationally relevant contingencies, both learned and unlearned (Rolls 1999). The OFC is thought to extend or build onto the more basic conditioning functions of the AM, through reciprocal interactions between them (Cardinal et al. 2002). Specifically, it is far more flexible than the AM, it "attends to" changes in the hedonic valence of anticipated events (Hikosaka & Watanabe 2000; Rolls 1999), and it can be seen as holding and recording "implicit appraisals" of motivationally relevant situations (Schore 1994). Its downstream connections are also integral to emotional states, and it has been shown to "regulate" emotion by inhibiting AM activation (Davidson 1998; Davidson et al. 2000). The second attentional system critical for appraisal is the ACC, which is found on the medial surfaces of the PFC. Its functions include monitoring and evaluating potential actions, monitoring and resolving conflicts, error detection, and so forth (Carter et al. 2000; Gehring et al. 1993; van Veen et al. 2001). The executive system mediated by the (dorsal) ACC is characterized by voluntary choice and is central for directed attention and for learning (Frith et al. 1991; Gemba et al. 1986). However, the more ventral regions of this complex system are also involved in emotion, as discussed later. The OFC and ACC are highly interconnected. Both belong to a "paralimbic ring" (including temporal regions connected to the hippocampus) – an ensemble of primary importance for emotion, motivation, and memory (Mesulam 2002). In fact, both the OFC and ACC have been shown to be central loci for the interaction of attention and emotion (Barbas 1995; Lane et al. 1998). These systems also interact with dorsolateral prefrontal regions responsible for planning and working memory (Mesulam 2002).

4.2.4. Memory. There are a number of diverse memory systems in the brain, and their functions and interactions are not fully understood. Explicit, semantic, or episodic memories are mediated by the hippocampus (HPC), nearby regions of temporal cortex, and related diencephalic structures (Aggleton & Brown 1999). However, the coding, retrieval, and organization of this information relies on prefrontal cortical systems (see Shimamura 2002, for a review). Of particular importance is the lateral PFC, which is implicated in working memory. Working memory probably involves bidirectional interactions between lateral PFC and HPC systems, by which cues are retrieved, sorted, and organized temporally (Moscovitch 1992), while associations are activated in other cortical and subcortical regions. Other structures mediate different kinds of memory. These include (1) the OFC, which encodes and maintains changes in reinforcement contingencies (Rolls 1999) and which may function as an independent working memory system in the presence of emotion (Luu et al. 1998); (2) the ACC, involved in learning the demands of novel tasks (Gemba et al. 1986); (3) the amygdala (AM), responsible for emotional conditioning; and connections between the AM and ventral striatum that sensitize responding relative to that conditioning (see Cardinal et al. 2002). The functions of some of these systems (e.g., OFC, AM) are characterized as implicit or associative memory, in contrast to the conscious and explicit memory functions mediated by the lateral PFC and HPC.

4.2.5. Planning. The appraisal functions of planning, strategy formation, and reflection probably involve all or most prefrontal executive systems, but particularly the dorsolateral, ventrolateral, ventromedial, anterior prefrontal, and ACC systems (Shallice 2002). These systems are capable of organizing information temporally in working memory, monitoring and checking this information, relating the information to present goals and motivational concerns, comparing and contrasting alternative action sequences, and consciously selecting among available choices. The ACC is particularly important for intentional monitoring and choosing among potential actions (Luu & Tucker 2002; van Veen & Carter 2002), partly through its connections to the DLPFC and HPC. Planning also requires activation of the supplementary motor area, closely connected to the ACC, where action plans are volitionally executed (Goldberg 1985). Planning and strategizing also make use of striatal structures, such as the nucleus accumbens (NAS), that narrow attention to incentive events and organize action sequences for behaving accordingly (Depue & Collins 1999). Some theorists emphasize left-hemisphere involvement in action planning, because its analytical/sequential processing style facilitates the organization of discrete steps in a complex motor sequence (e.g., Tucker & Williamson 1984).

4.3. Anatomy and function of systems mediating emotion

4.3.1. Arousal. Emotions are sometimes defined as action tendencies, and any form of action requires the selective arousal of various brain and body systems. In fact, differences in arousal have been used to classify emotions and explore their biological underpinnings (Bradley & Lang 2000). Arousal at the brain level is generally construed as activation of neural systems. Where does this activation come from? Neurotransmitters that modulate synaptic processes extrinsic to their site of origin, sometimes called neuromodulators, are released from cell bodies in the brain stem (BS) and basal forebrain (BFB), along "ascending" pathways. Some of these cell bodies are organized in nuclei (e.g., nucleus basalis of Meynert, locus coeruleus) that have been collectively referred to as the reticular activating system, and whose primary function is indeed to activate neural processes. These cells release dopamine, norepinephrine, acetylcholine, and serotonin to terminal sites in all limbic, striatal, and cortical areas, including the AM and HPC (Izquierdo 1997) and prefrontal cortical systems (Fuster 1996). Their action can thus be construed as global or holistic (Panksepp 1998a). However, that does not mean that they act uniformly throughout the brain, or that neuromodulators as a group simply arouse. Rather, they have specific effects differentiated by the type of neurochemical, the nature of the task or situation, the region of brain in question, and the particular receptor type receiving the input (Arnsten & Robbins 2002). Most important for the present argument, these chemicals are released from BS/BFB areas in response to signals from the AM, OFC, ACC, and other structures involved in the appraisal of emotion-relevant events. Thus, while their activity may not be viewed as "emotional" per se, their participation in the activation of emotional responses is unquestionable.

Arousal of bodily systems is also a critical component of emotions, as it is necessary to prepare for and support the behaviors they induce. States of bodily arousal are tapped by psychophysiological measures such as heart rate and skin conductance, and comparisons of such measures with PET and fMRI data suggest that physiological arousal is correlated with increases in brain activity induced by emotional stimuli (see Bradley & Lang 2000, for a review). Bodily arousal systems are controlled in large part through the autonomic nervous system (ANS), with arousal functions mediated by the sympathetic system and compensatory energy-preserving functions mediated by the parasympathetic system. More specific forms of bodily arousal are mediated by the endocrine system, through which hormones circulate in the bloodstream. Brainstem and hypothalamic structures serve as controls of the ANS, via direct nerve pathways to organs, muscles, and skin. Hypothalamic nuclei also control – through chemicals released by the pituitary – the action of circulating hormones that act on specific glands as well as many other tissues. Taken together, these systems regulate blood flow, muscle contraction, digestion, temperature, respiration, perspiration, and behavioral tendencies related to sex, nurturance, and fight or flight, partly through direct effects and partly through the coordinated release of hormones by endocrine systems throughout the body. Conversely, many bodily sensations resulting from these changes are fed back to brainstem and hypothalamic systems (Thayer & Lane 2000), resulting in rudimentary emotional feelings, and to higher paralimbic and cortical systems that subserve emotional consciousness, as reviewed later.

4.3.2. Action tendencies. Emotion theorists ascribe specific action tendencies to each emotion. The activation of an action tendency (e.g., escape, approach, nurture, explore) and the urge to act accordingly can be mapped onto brainstem motor control systems as well as chemical support processes mediated by various brain regions. Phylogenetically old systems that control primitive, packaged response patterns (e.g., defensive and attack behavior, sexual behavior, vigilance, facial expressions, freezing) are located in the brain stem and in the basal forebrain (BFB). These systems are linked through the hypothalamus to limbic, striatal, and cortical systems; but they orchestrate emotional behavior even in the absence of higher brain systems, as demonstrated by the "sham rage" seen in decorticate animals. They have therefore been referred to as basic emotion circuits (Panksepp 1998a). For example, different regions of the periaqueductal grey are associated with freezing responses related to fear and aggressive responses related to rage (e.g., Fanselow 1994). These response tendencies are then modified and elaborated by higher brain systems in normal emotional behavior (Panksepp 1998a).

Limbic structures have traditionally been associated with emotion, especially the amygdala (AM), which is critical for emotional conditioning (LeDoux 1995a), as reviewed earlier. Connections from the AM to lower (hypothalamic and BS) structures are credited with activating motivational response systems that trigger action modes as well as neurochemical support, given current stimulus events. Other limbic structures, including the septal and hippocampal systems and the "paralimbic" cingulate gyrus, may be necessary to support emotional behaviors (e.g., play, sex, nurturance) and memories (e.g., Gray 1982; MacLean 1993). The motivational and behavioral tendencies mediated by limbic structures may be qualitatively distinct and fall into basic emotion categories (Buck 1999), or they may be more globally categorized as general-purpose response systems (Gray 1982). However, limbic structures require the participation of lower structures to activate emotional behavior, whereas the converse is not true (Panksepp 1998a). Perhaps most important, limbic structures integrate emotionally relevant perceptual and action orientations through their connections to other structures, thus regulating emotional responses in a coherent fashion.

BS nuclei that control action tendencies are closely related to neuromodulator release, discussed previously. However, much more specialized neurochemicals, called neuropeptides, are released from the hypothalamus and other brain areas in correspondence with these tendencies. Neuropeptides support specific mammalian agendas (e.g., nurturance, predation, defense, play) and suppress others, and their action is global, as to the diversity of regions affected, but specific in the behavioral and physiological states they induce (Panksepp 1998a). The reception of neuropeptides by brain and bodily systems may serve both the urge to act according to these action agendas and the dedication of resources to see them through effectively. Some neuropeptides are released by secretion and diffusion (into the blood and ventricular circulation). Their action tends to be less immediate but enduring (Kandel et al. 2000). Such effects are thought to support lasting states of behavioral regulation that are key aspects of mood (Panksepp 1993; 1998a). Other neuropeptides act rapidly, and may contribute very differently to emotional processes. While there is enormous variety in the types and action modes of neuropeptides, some of the most important peptides, acting either singly or in coordination with others, recruit multiple areas to a unitary action tendency corresponding with a particular emotion, and maintain that tendency at the expense of others.

4.3.3. Attentional orientation. Attentional systems were described in some detail earlier. Although the characteristics of these systems support appraisal processes in diverse ways, the global orientation of attention to particular features of the world, cutting across all these systems, is considered a fundamental constituent of emotion. The term "motivated attention" expresses the idea that the beam of attention is focused on whatever is emotionally compelling (Derryberry & Tucker 1994), often interrupting or replacing existing attentional frames (Oatley & Johnson-Laird 1987). Neural systems that participate in motivated attention are widespread. First, the superior and inferior colliculi of the midbrain are essentially fixated on changes in the location or proximity of objects or animals with emotional relevance. At the limbic level, the AM responds rapidly to the emotional valence of stimuli and accordingly controls attentional processes, such as those required for continuous-performance tasks (Holland et al. 2000). Neurons in the nucleus accumbens (NAS) are selectively activated in response to contextually relevant targets, entraining other systems such as the OFC to attend to emotionally relevant events (Depue & Collins 1999). As discussed later, these attentional control mechanisms require communication with other brain regions to carry out their functions.

Higher structures such as prefrontal and paralimbic executive systems contribute to attentional orientation and action readiness simultaneously. These systems are recruited by the emotional responses mediated by lower systems, and they regulate these responses in part by directing attention toward viable behavioral options (Barbas 1995; Bechara et al. 2000; Davidson & Irwin 1999). The OFC, insular cortex, and ACC are key structures that maintain motivated attention while modulating emotionally relevant responses (Barbas 2000; Hariri et al. 2000; Lane et al. 1998). For example, the ACC can shift attention rapidly to emotional stimuli in preparation for an immediate motor response (Carreti et al. 2001). Finally, switches in the relative activation of prefrontal systems suggest direct emotional control of attention. For example, contrasting changes in the activation of dorsal and ventral prefrontal regions indicate that the dorsal ACC and ventral

ACC (including nearby regions of the ventral PFC) compete for the regulation of attention, based on the presence or intensity of negative emotion (Bush et al. 2000) – especially anxiety (Drevets & Raichle 1998) and sadness (Mayberg et al. 1999).

4.3.4. Feeling and consciousness. The final component of emotion is the feeling, phenomenological, or conscious apprehension of emotional states and processes. Many investigators believe that the affective feeling of emotion is a critical aspect of its motivational and adaptive properties (Damasio 1999; Izard 1984; Lane 2000; Panksepp 1998a), and Panksepp argues convincingly that this pertains to nonhuman mammals as well. Lane (2000) provides a scheme for mapping increasingly inclusive levels of feeling/consciousness onto brain regions of increasing sophistication. Visceral processes, such as the contraction of muscles in the gut, are apprehended directly by brainstem mechanisms, constituting a feedback circuit that couples the production and perception of autonomic changes (Thayer & Lane 2000). Panksepp (1998a) views this level of integration as being fundamental to a core sense of self, or primary process consciousness, specifically mediated by the colliculi, periaqueductal grey, and nearby areas, and involving motor maps of the body as much as sensory maps. Visceral processes and perception of action tendencies may also be apprehended by diencephalic and limbic structures (Lane 2000).

Higher-order consciousness of emotional processes is attributed to various cortical and paralimbic structures. The ACC is especially implicated in emotional awareness, possibly as an extension of its more general role in executive attention and response selection (Lane et al. 1998). The ACC also registers the emotional quality of physical pain and, according to recent work, of psychic pain as well (Eisenberger et al. 2003). However, the ventral (i.e., rostral, subgenual) ACC and ventromedial PFC may be focal points for conscious representations of emotional state (Lane 2000). This possibility is consistent with Mayberg et al.'s (1999) findings that ventral ACC activation corresponds with sadness and depressed mood, as well as Drevets and Raichle's (1998) findings of increased ventral activation during anxiety. Closely related regions, the OFC and insula, are also thought to process viscerosensory information as well as other physiological signals from the body, and a number of imaging studies have associated these regions with subjective emotional feelings (see Craig 2002, for a review and synthesis). As discussed by Craig, Schore (1994), and others, the right hemisphere seems particularly important for apprehending these feeling states.

4.4. Conclusions

This analysis of neural systems underlying appraisal and emotion components leads to two conclusions. First, as noted earlier, many systems mediate functions that can be assigned either to emotion or to appraisal. Or, to put it differently, many neural systems that become activated in appraisal also take part in emotional functions, and systems that generate emotional responses may also serve appraisal functions. For example, the AM's dual role in appraisal and emotional response has been described, and the ACC's involvement in attention and planning is difficult to differentiate from its role in attentional *orientation* and emotional consciousness. This consideration makes it tempting to put aside the distinction between appraisal and emotion categories, at least for some important neural systems. Second, each appraisal and emotion "component," defined at a psychological level, becomes a distributed system in itself, or even a collection of fairly distinct systems, when analyzed at the neural level. Thus, there are many brain "parts" that mediate emotional feeling, many brain systems that subserve different kinds of attention, and so forth. This consideration makes it even more tempting to abandon psychological definitions, this time of the components themselves, and focus instead on neural entities as the "parts" that interact in self-organizing states. As suggested earlier, neurobiology seems much better than psychology at specifying interacting parts. Nevertheless, neural parts are only interesting insofar as they perform functions that cross the line into psychological description – even if, or especially if, such description is necessarily more global. The coordination of neural parts in the service of global appraisal and emotion functions is examined next.

5. DS mechanisms of neural integration

Earlier I proposed that, at the psychological level of analysis, appraisal and emotion constituents interact in the consolidation of an emotional interpretation (EI). However, at the neural level, emotion and appraisal constituents are more difficult to differentiate and classify. In this section, I will argue that, even if some neural structures are assigned to appraisal versus emotion categories, the interaction of these structures rapidly gives rise to processes that span both categories. Neural structures perform no function at all until they interact with each other, and even interactions among closely related structures, far below the whole-brain level, bind emotion and appraisal processes tightly together. Thus, brain function prohibits any real independence between appraisal and emotion, even at the level of subordinate processes. Why might this be so? In psychological terms, interacting emotion components tend toward coherence in service of an integrated *response* to the world, whereas appraisal components tend toward coherence in service of an integrated *interpretation* of the world. However, each of these functions is groundless without the other. An integrated response must be informed by the features and properties of a situation, provided by appraisal. An integrated interpretation must be constrained by the relevance provided by emotion. The biology of the nervous system seems to have evolved to unite these functions at many system levels, from part-system interactions to whole-system configurations. It also seems to have united these functions at every level of the neuroaxis, from the phylogenetically primitive brain stem (BS) to the recently evolved prefrontal cortex (PFC).

Thus, interactions between appraisal and emotion processes, within and across each level of the neuroaxis, bind together the "what" of appraisal with the "what to do about it" of emotion, in a functional unity. This binding is proposed to rely on several specific mechanisms of integration, without which global brain-behavior states could not cohere. I now propose five mechanisms of integration among neural systems subserving appraisal and emotion processes – mechanisms that yield the self-organization of global neural configurations mediating whole EIs. At the end of each subsection, broad predictions are proposed as a guide to future research.

5.1. Nested feedback loops and self-synchronization

The first mechanism of integration is feedback among neural structures. Various sets of loops can serve as vehicles for positive and negative feedback interactions among the brain structures underlying appraisal and emotion processes. Neural systems of every size and function are characterized by feedback relations (e.g., Hebb 1949). Reentrant processes at the level of cells and cell assemblies exemplify feedback on a small scale, but I will focus only on large-scale loops, exemplified by reciprocal projections among limbic, cortical, and striatal structures. I first describe these loops as the biological apparatus by which appraisal and emotion processes become integrated. I then connect this framework to research on the functional integration and temporal synchronization of brain systems related to emotion.

Three points need clarification before describing large-scale loops. First, a great many circuits or loops have been proposed by different theorists to subserve emotional processes. Rolls (1999) and Depue and Collins (1999) emphasize loops involving the OFC, striatum, and AM. Thayer and Lane (2000) add to these the ACC, insula, hypothalamus, and BS. Gray (1987) highlights a dopaminergic system underlying behavioral activation and serotonergic and noradrenergic systems underlying behavioral inhibition. The original Papez circuit included the thalamus, hypothalamus, cingulate cortex, and hippocampus, and MacLean (1949) inserted the amygdala in an expanded version that he dubbed the limbic system. All of these proposed circuits are characterized by feedback relations, so any might suffice for DS modeling. However, I focus my modeling on loops among the neural systems I have already identified with appraisal and emotion constituents. This modeling pulls in contributions from many investigators, but it remains independent of any particular theory. Second, as shown in Figure 3, I nest these loops within three higher-order loops subserving evaluation, monitoring, and action functions. This nesting helps one to visualize levels of integration midway between lower-order components and whole-brain systems. Moreover, it demonstrates that intermediate levels of integration mediate both emotion and appraisal processes, not one or the other. Third, I highlight positive and negative feedback relations among neural structures. This is a highly simplified analysis. When a large number of components are connected through a multiplicity of channels, and these channels vary in type of transmission (e.g., type of neurochemical mediators), then positive and negative feedback interact in very complex ways. For example, the flow of excitation and inhibition between any two structures is mediated by the activity of all the other structures to which they are connected. However, as is often the case, a simplified analysis helps one to see the big picture.

This depiction of neural circuitry has another feature. It defines positive and negative feedback relations as causal processes, bridging neural and psychological explanations of self-amplification and self-stabilization. In general, the reciprocal activation of structures with other structures through parallel excitatory connections contributes to the positive feedback dynamics of self-amplification. When activation in one direction is countered by inhibition in the reciprocal direction, negative feedback yields self-stabilization. Because of the ubiquity of reciprocal connections and the complexity of nested loops, large-scale loops will generally include smaller loops showing both positive and negative feedback. This means that higher-order loops will show some characteristics of change and some of stability at the same time. However, the activation of higher-order loops, in which local loops are nested, contributes to self-stabilization and coherence through multiple constraints.

All three categories of loops presented in Figure 3 include the OFC and AM, both key structures in attentional,

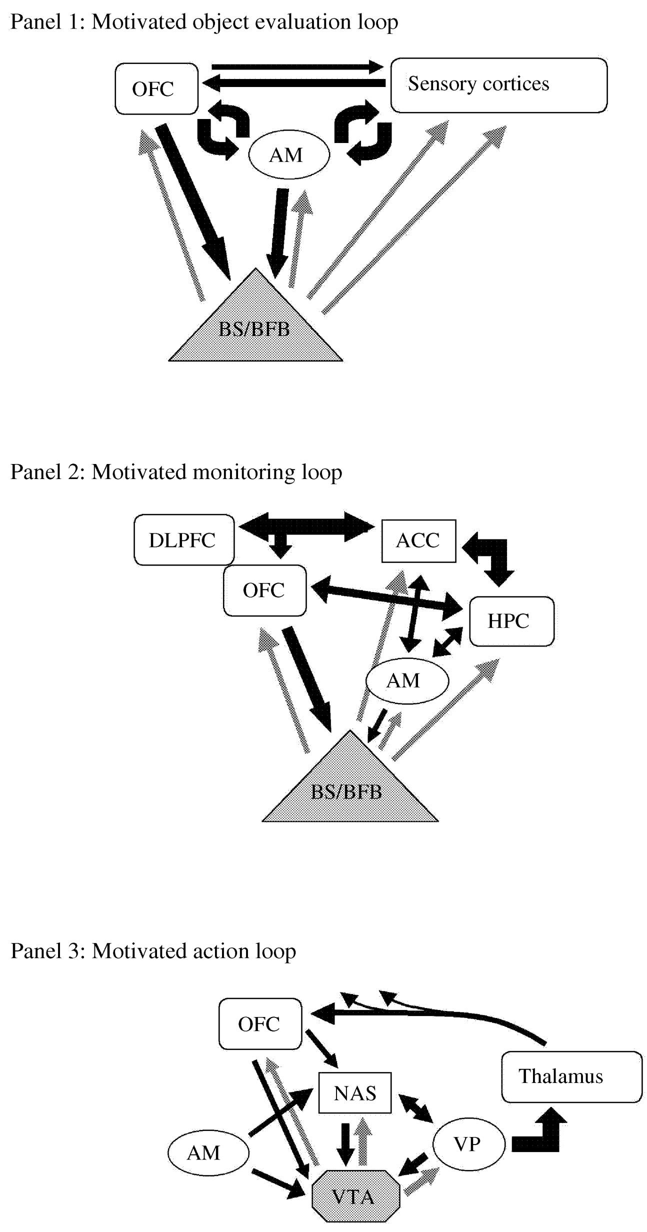

Figure 3. Three higher-order loops comprised of nested feedback circuits, each integrating particular emotion and appraisal processes. Black arrows represent glutamatergic and GABAergic (intrinsic) synaptic pathways. Grey arrows represent neuromodulator (extrinsic) pathways. ACC, anterior cingulate cortex; AM, amygdala; BS/BFB, brain stem/basal forebrain; DLPFC, dorsolateral prefrontal cortex; HPC, hippocampus; NAS, nucleus accumbens; OFC, orbitofrontal cortex; VP, ventral pallidum; VTA, ventral tegmental area.

motivational, and evaluative processes. They also include a representation of either the brain stem/basal forebrain (BS/BFB), denoting a cluster of what are in fact many discrete neuromodulator systems, or else the ventral tegmental area (VTA), a specific neuromodulator system that projects dopamine to the OFC, NAS, and other areas. I include these neuromodulator systems within the depiction of each loop for parsimony, even though their modes of communication (both chemistry and wiring) are different from those of cortical, limbic, and striatal structures, as discussed later.

The loops shown in the first panel of Figure 3 are centered on the amygdala (AM): (1) reciprocal connections between AM and BS/BFB structures that output neuromodulators back up to the AM and to all other limbic and cortical regions (e.g., Wallace et al. 1992); (2) reciprocal connections between the AM and OFC, and thus between two structures that coordinate evaluation and motivated attention (Rolls 1999); (3) reciprocal connections between the AM and integrative sensory areas such as the inferior temporal lobe, by which emotional associations focus perception (Barbas 2000; LeDoux 1995b); and (4) connections from higher-order sensory areas to the OFC (Barbas 2000; Ongur & Price 2000), permitting prefrontal assessment and regulation of sensory input. All three systems receive neuromodulator projections from BS/BFB nuclei, triggered by AM and OFC descending projections. Taken together, these loops constitute a higher-order "motivated object evaluation" loop, within which particular emotion and appraisal processes become integrated. The *motivational* aspect refers to OFC/AM initiation of ascending BS/BFB connections that enhance and orient evaluative/attentional activity; *object evaluation* refers to the specific stimulus-evaluation functions of the AM and OFC, both of which tune perceptual processing in the sensory cortices.

The next category of loops, shown in the second panel, highlights the ACC and HPC, with the latter including parahippocampal areas through which its connections flow: (1) direct bidirectional pathways between the HPC and OFC/DLPFC (Ongur & Price 2000), which may support the value-related modulation of retrieval and working memory (Petrides & Pandya 2002); (2) bidirectional pathways between the HPC and ACC, extending to the DLPFC, necessary for selective attention and monitoring (Petrides & Pandya 2002); (3) bidirectional pathways between the ACC and AM, through which ACC processes control and are tuned by AM associations (Poremba & Gabriel 1997); (4) bidirectional pathways between the HPC and AM, allowing emotional enhancement of episodic memory (Hamann et al. 1999); and (5) primarily one-way connections from the ACC to the OFC (Barbas 1995), possibly synchronizing voluntary attention with motivational set. Again, all four structures receive neuromodulator projections from BS/BFB nuclei, triggered by the OFC and AM. These loops can be described as nested in a higher-order "motivated monitoring" loop, integrating additional emotion and appraisal processes. The *motivational* aspect refers chiefly to BS/BFB and ACC mediation of emotional feeling and attentional orientation, whereas *monitoring* denotes the modulation of prefrontal and HPC activities by the ACC, permitting voluntary attention to challenging circumstances.

A third category of loops involves the ventral striatum: (1) OFC projections to the NAS, reciprocal connections between the OFC and VTA, and reciprocal connections between the VTA and NAS (Haber et al. 1995; Oades & Halliday 1987), collectively underpinning the motivational control of action selection and initiation; (2) reciprocal connections between the NAS and ventral pallidum (VP, an output structure of the striatum), with both structures reciprocally connected to the VTA, constituting a resonating motivational circuit (Depue & Collins 1999); (3) connections from the ventral pallidum to a nucleus of the thalamus, and thence to the OFC (as well as premotor systems, denoted by upward arrows), completing a larger feedback circuit that continuously moderates motivated behavior; and (4) pathways from the AM to the NAS and VTA, enhancing activation of both systems based on emotional associations (Cardinal et al. 2002). These interconnected loops may be said to constitute a higher-order "motivated action" loop, integrating additional emotion and appraisal processes. Specifically, *motivation* refers to arousal and action tendencies mediated by AM/OFC-initiated dopaminergic innervation of orbitostriatal circuits; and *action* is selected and focused on by the NAS, then sequenced by striatal outputs to the thalamus and motor system (Rolls 1999).

As these neural structures interact in positive feedback relations, each of the three higher-order loops becomes activated. As these interactions settle into negative feedback relations, their activity becomes stabilized. However, because these loops are deeply interconnected with each other, through anatomical structures common to all three (e.g., OFC, AM, BS/BFB), their joint activity can be described in terms of a global macrosystem. Sensory data and motivationally relevant associations are integrated with action tendencies through connections between the object evaluation and action loops. This integration affords an ongoing state of engagement with the world, whereby everything we see and hear with emotional significance engages an urge to act. At the same time, connections between the object evaluation and monitoring loops integrate sensory data and motivationally relevant associations with conscious monitoring and explicit memory. This integration affords an ongoing appreciation of the meaning of events in the world – an emotional context that shapes our attention. Finally, connections between the monitoring and action loops permits us to fashion a continuously updated plan, guiding the leading edge of conscious behavior according to what is most compelling. Through this integration (visited in more detail later), we sense ourselves moving through space and time according to a deliberate agenda. Thus, connections within each loop integrate particular emotion and appraisal processes, but these processes become synchronized with each other in a global macrosystem subserving a unified emotion–appraisal gestalt. The specific configuration of activated circuitry (at the macrosystem level) dictates the unique character of this gestalt as it emerges on each occasion.

What evidence is there to suggest that the co-activation of neural structures within loops mediates emotion and appraisal? A number of neuroimaging studies have looked at the role of emotion in functional integration, revealed by changing activation patterns across some subset of regions. First, several studies have specifically examined functional connectivity between the amygdala and cortical regions in relation to emotion (see Dolan 2002; Dolan & Morris 2000, for reviews). For example, functional connectivity between the AM, visual cortex, and BS is enhanced when subjects are exposed to fearful faces, but reduced in the presence of happy faces (Morris et al. 1998). Dolan and Morris (2000) suggest that AM potentiation of sensory processing can be viewed as "effective connectivity" resulting in increased coherence. In the present approach, these findings would suggest self-amplifying feedback and stabilization within the object evaluation loop. Second, various brain regions become activated simultaneously, whereas others may become deactivated, in the presence of emotion. For example, negative emotions such as sadness, anxiety, and guilt are associated with increased activation in the AM, ACC, and OFC and with decreased activation in the dorsolateral PFC and HPC (Liotti et al. 2000; Shin et al. 2000). As well, Dolan and Morris (2000) review evidence that aversive (fear) conditioning produces positive covariation between activation of the hypothalamus and activation of the AM, BFB, OFC, ACC, and HPC. Both sets of findings imply synchronized changes in the object evaluation and monitoring loops, but the specific pattern of changes may vary with the type of emotion. A third kind of functional integration is discussed by Cardinal et al. (2002) as the "upregulation of associability," involving AM activation of BS systems that transmit acetylcholine to cortical sensory association areas following aversive conditioning. Here the motivational effects of fear appear to enhance the receptivity of cortical regions to associations among stimuli. I return to this issue later, but for now it serves as an example of emerging perceptual couplings induced by emotional processes. It also highlights the important point that each "structure" or "system" contains a vast number of synaptic networks, any combination of which can become activated through connections with other structures. Discrete appraisals are discrete because they activate these networks selectively.

These studies provide evidence of *functional* integration among systems subserving appraisal and emotion processes. However, a DS approach might also imply *temporal* synchronization underlying these functional links. As noted earlier, neuroscientists with a dynamical perspective have studied temporal synchronization, mostly across cortical and thalamic sites (e.g., Bressler & Kelso 2001; Engel et al. 2001; Nunez 2000; Skinner & Molnar 1999; Thompson & Varela 2001). These approaches rely on various methods for measuring temporal correlations, such as phase locking or phase synchrony (a fixed temporal relation between the oscillations of independent regions) and coherence analysis (integrating amplitude and phase in one measure), as applied to data from scalp EEG, local field potentials, and single-cell recordings. These techniques are often used to examine synchronization in the gamma band (about 30–80 Hz), sometimes across distal cortical regions, corresponding to attentional states of expectancy or focused perception. A number of studies demonstrate that the degree of synchrony corresponds with the degree of attentional engagement or motor readiness (Lutz et al. 2002; see review by Engel et al. 2001). Thompson and Varela (2001) argue that such synchronization reflects the integration of many dimensions in a unified "cognitive act," rather than the clustering of component perceptual processes. Using dynamical equations, Thelen et al. (2001) demonstrate the emergence of a coherent cognitive act from the coupling of neural components underlying perception, planning, and memory. Such cognitive acts may be analogous to whole appraisals in the present treatment. In any case, this body of research has linked coherent psychological processes to intrinsically generated synchrony, thus demonstrating a key inroad to the study of neural self-organization.

However, the thalamocortical systems studied with this paradigm are concerned with cognition, not emotion, and gamma-band oscillations may not last long enough to tap extended motivational states (see Kopell et al. 2000). The few studies that have investigated temporal synchronization in relation to emotion concentrate instead on the theta band (about 4–8 Hz). Theta waves are thought to signify hippocampal involvement in brain activity, notably in cortico-hippocampal interactions. A "pacemaker" in the septum can generate hippocampal theta, though hippocampal cells fall into theta-frequency oscillations on their own, and other regions including the PFC, ACC, thalamus, hypothalamus, and AM also show theta frequencies (e.g., Vertes & Kocsis 1997). Importantly, theta-band activity corresponds with attentional monitoring, action monitoring, learning, retention, and shifting behavior in situations that demand action (Klimesch 1999; Luu & Tucker 2002). Thus, oscillations in the theta range could be critical for synchronizing appraisals corresponding with emotional demands. Theta-band activity has been found to underpin large-scale synchronization across distant cortical regions (Buzsaki 1996; von Stein & Sarnthein 2000), and possibly throughout the Papez circuit (including the thalamus and hypothalamus) (Vertes et al. 2001). Theta waves have also been described as "carrier waves," in which gamma oscillations representing perceptual details are embedded (van Rullen & Koch 2003), and theta has been proposed as the fundamental rhythm of corticolimbic self-organization (Miller 1991). Thus, self-organizing emotion–appraisal states could potentially be realized by the global synchronizing properties attributed to theta-band oscillations.

Studies of emotion-related theta-band activity are few but revealing. Phase-synchronized theta oscillations were recorded in the AM of animals anticipating a shock, corresponding with blood pressure increases suggesting fear (Paré & Collins 2000). Arousal has also been reported to increase the coherence of theta oscillations between the AM and PFC (see review by Paré et al. 2002). Because theta-band oscillations are recorded in the AM only during emotional states, Paré et al. propose that AM and HPC activities become coupled at theta frequencies in emotion-inducing circumstances, and this coupling harnesses cortical activation related to emotional memories. These ideas find support in recent evidence that HPC-AM synchronization at theta frequencies follows fear conditioning and peaks when animals confront the fear-inducing stimulus (Seidenbecher et al. 2003).

5.1.1. Novel predictions. Theta-band synchronization may mediate emergent couplings among additional neural subsystems when appraisal and emotion processes cohere in a unified gestalt. Specifically, it might be predicted that phase synchrony at theta across the AM, HPC, ACC, OFC, and sensory association areas would emerge when situations or tasks become emotionally relevant, and that this phase synchrony would indeed index their relevance. Thus, theta-band synchrony might correspond with emotional relevance, just as gamma-band synchrony corresponds with perceptual closure. This hypothesis extends Miller's (1991) claim that theta-band synchrony underpins cortico-hippocampal self-organization necessary for processing situational context. Emotions may play a critical role in context processing, and they may be needed for cortico-hippocampal loops to cohere in the first place. Specifically, it is predicted that the degree of phase synchrony in the theta range will correlate with measures of emotional relevance and subjective emotional feelings, and that this synchrony will increase as emotional relevance increases over time, just as the degree of gamma- and beta-band synchronization covaries with changing levels of attention and motor readiness (Engel et al. 2001). Suggestions for testing this prediction are advanced in a later section.

5.2. Neuromodulation: Global effects on change and stabilization

A second basic mechanism of neural integration is the action of ascending neuromodulatory pathways from the brain stem (BS) and basal forebrain (BFB) to all regions of the diencephalon, striatum, limbic system, and cortex. As reviewed earlier, these pathways originate in a variety of cell bodies that release dopamine (DA), norepinephrine (NE), acetylcholine (ACh), and serotonin (5-HT). Also, as noted earlier, the function of ascending neuromodulators has often been characterized in terms of arousal or activation, reflecting their role in the motivational enhancement of attention and action readiness. However, these systems can also be differentiated into highly specific effects across diverse brain regions (see review by Gu 2002). Thus, input from a single neuromodulator system can enhance cortical activities in some areas and inhibit them in others. Despite this specificity, ascending neuromodulators must have global effects on the interaction of appraisal- and emotion-mediating systems, something like the global effects of climate change on an ecosystem (see Fig. 4). This is because neuromodulators act diffusely, over a huge variety of neural regions, influencing activity throughout the brain. Consequently, neuromodulator activation may be seen as a mechanism of global change, either augmenting present firing patterns or altering them in favor of competing activities, but also as a mechanism of global stabilization, consolidating particular activities that regulate them in turn.

The feedback among cortical, limbic, and striatal structures, depicted in the last section, relies on transmission from one cell body to the next via neurotransmitters such as glutamate and gamma-aminobutyric acid (GABA). This kind of activation exerts either excitatory or inhibitory effects on the electrical potentials (and ultimately the firing rates) of target cells: glutamate is always excitatory, and GABA is always inhibitory. In contrast, the action of neuromodulators released from BS/BFB structures is partially a function of their type and origin, and partly a function of the properties and locations of their receptors. This complex interaction effect determines whether constellations will be augmented, maintained, or altered. For example, NE can globally enhance alerting, arousal, and vigilance functions, both in higher brainstem regions and in sensory cortex, thus augmenting present perceptual activities. However, it can also switch the control of perception and behavior from frontal to posterior cortical systems, as a result of the interplay of two receptor types (Arnsten & Robbins 2002). Similarly, ACh has often been linked to motivational enhancement of attention through the activation of cortical neurons, thus triggering new appraisals or augmenting existing ones. However, cortical firing can be inhibited by ACh as well (McCormick et al. 1993). DA activates approach and exploratory behavior globally, through its effects on orbitostriatal neurons, yet its prominent role in cortex is to suppress neuronal firing. DA can also have very specific effects on attention and working memory by selectively enhancing and inhibiting the firing rates of different prefrontal neurons (Williams & Goldman-Rakic 1995). The interplay of excitation and inhibition produced by NE and DA may set the OFC into modes of activation that mediate specific appraisals (Schore 1994). Despite their variety of effects, both the diffuse nature of ascending neuromodulators and the persistence of some neuromodulator effects over time work to insure their global influence. Moreover, the structures affected by neuromodulators include neuropeptide systems that activate and maintain particular motivational and behavioral tendencies in brain and body, as previously discussed.

Neuromodulation has often been associated with emotion or motivation, because of its arousal and activation properties, but also because of its participation in circuits that trigger emotional responses. Neuromodulator release can be initiated and regulated by glutamate projections from the AM, OFC, ACC, or NAS (Cardinal et al. 2002; Ongur & Price 2000); it can then enhance activation of these and other structures in turn. Thus, by activating BS/BFB nuclei, the AM and OFC induce neuromodulator release that not only returns to modify their activity but also fans out to many other cortical, limbic, and brainstem regions (Holland & Gallagher 1999; Rolls 1999). For example, the AM activates BS nuclei that release DA, ACh, and NE, which in turn adjust the activation of prefrontal, orbitofrontal, insular, ACC, and other systems involved in various cognitive and emotional functions (Fuster 1996; Kandel et al. 2000; Oades & Halliday 1987). Thus, structures mediating specific appraisal and emotion processes can trigger neuromodulatory release that binds these and other processes together in global configurations. As shown in Figure 4, any system that ignites neuromodulator release triggers a one-to-many, expanding, influence pattern, coupling information-processing activities across diverse sites. Returning to the climate analogy, the activities of one species may induce climate change that reorganizes the entire

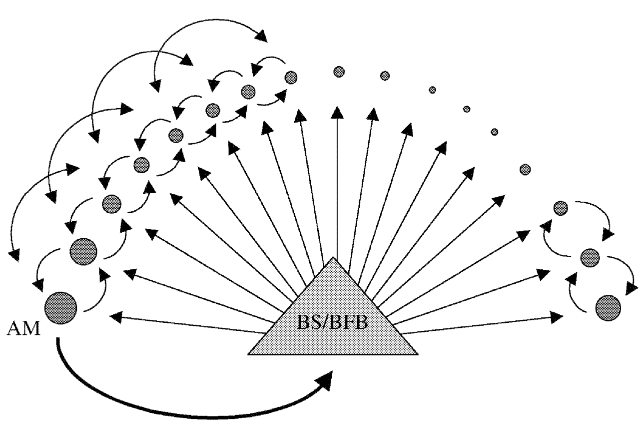

Figure 4. Ascending neuromodulator release from brainstem/basal forebrain (BS/BFB) nuclei visualized as climate change in an ecosystem: some interactions are augmented while others are inhibited. Structures such as the amygdala (AM), which initiate this process, trigger a one-to-many pattern of influence extending to diverse brain regions.

ecosystem, benefiting some organisms while annihilating others.

Panksepp (1998a) reviews evidence that neuromodulators are instrumental in the functional integration of global emotional states as well as the action modes that accompany them. But do neuromodulators play a role in temporal synchronization as well? For many years it has been known that activation of BS reticular systems induces hippocampal theta (e.g., Apostol & Creutzfeldt 1974), and this induced theta is associated with alertness and sensory processing (Bland et al. 1984). More recently, it has been found that various structures within the limbic system, paralimbic cortex (e.g., ACC and parahippocampal areas), and neocortex contain cells that oscillate in the theta band, and that these oscillations are also triggered by ascending neuromodulators (particularly ACh) from BS systems (Bland & Colom 1993). Ascending neuromodulators regulate a variety of electrophysiological rhythms in the cortex as well, corresponding with organized perceptual and motor activities (see review by Vanderwolf 1988). Bland and Oddie (1998) review evidence of a multisynaptic pathway, extending from pontine nuclei in the brainstem, through hypothalamic sites, to the septum, from which inputs are distributed to the HPC, parahippocampal cortex, and cingulate cortex. Both ACh and serotonin (5-HT) stimulate theta activities through this pathway. These authors also report that the amplitude of theta oscillations in these structures corresponds to the intensity of neuromodulator action.

5.2.1. Novel predictions. This literature suggests that ascending neuromodulators (especially ACh) are critical for generating theta-band oscillations in a variety of corticolimbic regions. In the last section, I argued that emerging phase synchrony across corticolimbic structures could underpin global emotion–appraisal states. Integrating these perspectives, it might be predicted that BS-induced corticolimbic synchronization is the vehicle for appraisal–emotion coupling. To test this hypothesis, EEG methods for assessing phase synchrony across diverse cortical areas could be linked with neuroimaging measures of activation in the BS and hypothalamus when emotion-inducing stimuli are being processed. Furthermore, because physiological measures of sympathetic activity (e.g., skin conductance, heart rate) are traditionally used to assess emotional response, and because these measures correspond directly with BS and hypothalamic activation, these measures might also correlate with synchrony coefficients across cortical and paralimbic sites. Measures such as skin conductance are quite sensitive to arousal changes in real time. Therefore, both skin conductance and theta-band synchrony might be expected to increase in tandem during time windows leading up to anticipated anxiety-eliciting events, such as aversive cues, and this effect should be facilitated by state or trait anxiety. To my knowledge, psychophysiological indicators of emotion have never been linked with the study of temporal synchronization across cortical regions, but this may be a fruitful direction for cognition–emotion research.

5.3. Vertical integration

A third mechanism of integration is the superordinate integration of activities across multiple levels of the neuroaxis, termed *vertical integration* by Tucker et al. (2000) and others. Up to this point, I have discussed feedback relations that link structures within nested loops, as well as neuromodulatory activities that exert a global influence on the integration and coupling of these structures. The causal relations described until now include reciprocal and recursive interactions among parts (component systems), or else global influences that flow unidirectionally in an expanding, one-to-many fashion. Although these interactions might indeed yield self-organizing states of coherence, there is as yet no mechanism to relate that coherence back to component interactions. The principle of circular causality fills this gap. As reviewed earlier, Haken's (1977) circular causality describes the relation between a superordinate emergent organization and the subordinate components whose coordination gives rise to it. Specifically, the superordinate maintains the coupling of all the constituents in a top-down fashion, while their coupling maintains the integrity of the whole through bottom-up processes. This perspective is central to neuroscientists with a dynamic orientation. According to one interpretation, neural coherence is manifested globally by the synchronization of a functional whole, but manifested locally by the entrainment of each subsystem to this global pattern (Nunez 2000; Rolls & Treves 1998; Varela et al. 2001). The whole thus grounds the parts, entraining (or "enslaving") them to a particular organizational regime. Importantly, this principle is independent of the negative-feedback relations that couple lower-level components to each other, sometimes in extended networks, through parallel rather than vertical causal interactions.

Vertical integration could instantiate circular causality at the whole-brain level, thus providing an additional mechanism of neural integration. As argued by Tucker et al. (2000), vertical integration joins the levels of the neural hierarchy in a bidirectional stream of influence. These authors characterize upward influences as arousing or recruiting, alerting the cortex to the emotional significance of events, and downward influences as providing detailed information and action plans that regulate lower structures. However, they argue, bidirectional causation, incorporating both recruitment and regulation, coordinates the entire neuroaxis, such that functionally (and phylogenetically) distinctive levels cohere in a unitary mode of action readiness and attentional orientation (see also Freeman 1995; 2000). Vertical integration links the stereotypic functions of the brain stem with the executive, planful, and information-rich character of cortical activity, through the mediation of limbic structures. It is considered necessary for coordinating perception, attention, and planning with primitive action tendencies, so the animal can behave flexibly, skillfully, and intelligently when motivated (Tucker et al. 2000). According to Freeman (2000), the resulting cognitive-emotional orientation to the environment, or the *intentionality* that characterizes this orientation, defines the superordinate in a circular causality.

If vertical integration locks the entire neuroaxis into a coherent mode, it may indeed be the superordinate in a circular causality that entrains the interactions of component subsystems. Yet, the mechanism of this meta-integration is unknown. Phase synchrony has been proposed as the superordinate that entrains cortical neurons through top-down modulation during states of attention or consciousness (e.g., Engel et al. 2001; Thompson & Varela 2001). Is there evidence for an emerging, superordinate phase synchrony across the entire neuroaxis? Kocsis and

Vertes (1992) reported that not only corticolimbic systems but also BS systems (e.g., raphe nucleus) include cells that oscillate in the theta band. Moreover, these oscillations were found to be synchronized with hippocampal theta, leading these authors to conclude that phasic rather than tonic neuromodulator activity induces theta-band oscillations in corticolimbic regions. However, these results still implied a one-way influence from BS to limbic regions. Two years later, Kocsis and Vertes (1994) reported that two nuclei in the hypothalamus, the supramammillary nucleus and the mammillary body (MB), both showed "theta bursting" synchronized with HPC cells. However, because connections from the MB are descending, not ascending to the HPC, they reasoned that theta-band rhythms in the MB might originate from the HPC – the reverse of the direction previously assumed. This work demonstrated the likelihood of two-way synchronizing pathways between the HPC and lower-brain structures, suggesting temporal synchronization as a possible vehicle for vertical integration. However, these reciprocal influences still did not imply an emergent circular causality. Recently, Kocsis et al. (2001) reported findings that crossed this line. They studied a brainstem structure called the tegmental nucleus of Gudden, known to be connected to the MB in a negative feedback loop. They highlighted the importance of spontaneous theta-band activity found in MB neurons (Alonso & Llinus 1992) and hypothesized that it was generated and maintained within this loop, providing a source of theta oscillations independent of the HPC. They then explored the correlation between these two sources of theta-band activity in relation to stimulus events. They found that theta waves recorded in the tegmental nucleus of Gudden (and thus highly correlated with MB activity) became either moderately or highly synchronized with hippocampal theta, depending on sensory stimulation. With no direct stimulation, synchrony was moderate. However, tail-pinch stimulation ramped up the coherence coefficient to an extremely high value. These results suggest that meta-synchronization between two independent self-synchronizing systems (one spanning the hypothalamus and brain stem, and the other in the limbic system) emerges spontaneously as a function of experience. Thus, it may be that the emergence of a superordinate phase synchrony, linking BS and corticolimbic subsystems, is a good candidate for circular causality, constraining the coordination of the subsystems from which it arises.

5.3.1. Novel predictions. By this analysis, vertical integration along the neuroaxis, mediated by meta-synchronization of independent oscillatory subsystems, could be a key mechanism for generating and maintaining a cognitive-emotional orientation to the world. If this is correct, then the spontaneous synchronization of these subsystems should depend not only on sensory stimulation, but also on the emotional relevance of that stimulation. One might assume that having one's tail pinched is motivationally relevant for a rat, but Kocsis et al. (2001) report on only two levels of relevance: absent and high. Further research could investigate whether gradations in the emotional relevance of stimuli are correlated with the degree, consistency, and especially the extent of synchronization along the neuroaxis. Perhaps different emotions tap different subsets of oscillatory systems, and the discovery of additional oscillators in lower-brain regions may be facilitated through emotion-induction paradigms. Thus, extending the hypotheses suggested earlier, theta-band phase synchrony may covary with other measures of emotion continuously, not just dichotomously, and across the entire neuroaxis, not just corticolimbic systems. This finding would support the proposition that emotion is a necessary feature of global self-organizing processes at the whole-brain level.

5.4. Action monitoring: The focus of integration

All the mechanisms of integration discussed so far have a somewhat solipsistic quality: they act within the brain and body, with little concern for the outside world. However, the convergent wholes to which self-organization gives rise should also be identifiable at a functional level – a level at which superordinates of one system (the organism) can interact with those of other systems (the environment). Emotion theorists generally agree that the function of emotion is to cause or propel action by selecting a particular action tendency or creating a state of action readiness (Frijda 1986; Izard 1991). Thus, a fourth mechanism of neural integration might be found in action monitoring – the preparation, execution, and regulation of action. Because the brain has evolved in mammals to delay impulsive actions, appraisal components of attention, planning, and memory normally interact with the primitive action tendencies associated with emotions. This permits the construction and elaboration of an intelligent response, or plan, over an extended time course (Tucker et al. 2000). A continually updated plan, by which behavior is monitored and controlled, may guide the integration of neural systems mediating emotion and appraisal. This idea links vertical integration within the brain to emerging transactions between the brain and the world.

Vertical integration implies emergent synchronization across all levels of the neuroaxis in service of a coherent response to events in the world (e.g., having one's tail pinched). Thus, an action orientation may be critical for the synchronization and coherence of the brain (Freeman 2000). Indeed, the global macrosystem defined by nested feedback loops and the neuromodulatory processes that support its activity are clearly involved with action. Two loops are particularly important. The OFC–striatal–thalamocortical circuits of the motivated action loop initiate and coordinate the steps of a motor sequence, while the hippocampal–ACC–PFC circuits of the motivated monitoring loop monitor and regulate the flow of action consciously and intentionally. These two functions work together in any intelligent behavioral process.

The motivated action loop is specifically dependent on dopamine (DA) released by the VTA. DA facilitates behavior through incentive motivation, but it also constricts behavior by focusing and maintaining attention to specific targets, via a "closed" prefrontal–striatal–thalamocortical loop (Groenewegen 1997). This "dopamine-induced focusing" narrows the activation of NAS neurons to contextually relevant targets highlighted by projections to the NAS from the PFC, AM, and HPC (Depue & Collins 1999). Focusing is also facilitated by the dendritic architecture of the striatum and pallidum, which funnels widespread inputs from the cortex into unitary motor output patterns (Rolls 1999). Thus, integrative feedback processes harness the striatum, where DA and neuronal architecture work together to narrow the focus for action. This implies that vertical integration not only synchronizes brain activity; it also anchors it to a narrow behavioral stream.

The ACC plays a key role in the intentional regulation of action, particularly as influenced by motivational factors (e.g., Holroyd & Coles 2002). Action monitoring by the ACC has been studied using event-related potential (ERP) methods that tap the electrical activity of medial-frontal cortical regions. In particular, the error-related negativity (ERN) and error positivity (Pe) constitute two characteristic ERP deflections, approximately 80 msec and then 200–500 msec following an error response, when the subject is aware of and concerned about an error. These components are thought to index not only attention to errors but action monitoring more generally (Holroyd & Coles 2002; Luu & Tucker 2002; van Veen & Carter 2002). Both components have been localized to the ACC through ERP source analysis techniques as well as fMRI (e.g., Carter et al. 1998; Gehring et al. 2000; van Veen & Carter 2002), though sources in the parietal cortex and rostral ACC appear to contribute to the Pe as well. Frontal ERP deflections following a behavior-relevant cue (e.g., the no-go N2) look similar to those following errors (Luu et al. 2003; van Veen & Carter 2002), suggesting that activation of the ACC mediates the monitoring of behavior even prior to taking action. Finally, in an influential paper, Holroyd and Coles (2002) link DA involvement in ACC activity with its role in reward anticipation (e.g., Schultz 1998). They then propose that the ERN results from a drop in DA innervation from VTA neurons, disinhibiting ACC neurons when errors occur and actions need revision. This mechanism suggests functional coordination between striatal and ACC activities, mediated by DA modulation, when action plans are monitored and updated.

In the preceding sections I developed the argument that phase synchrony in the theta range may underpin the functional integration of systems mediating appraisal–emotion processes. Is there evidence for theta-band synchronization in action monitoring? A number of investigators have proposed that ERPs are produced by the summation of brain waves of the same or related frequencies (e.g., Karakas et al. 2000). This interpretation is particularly congenial with a DS framework in which discrete events are viewed as temporary states of coherence or coupling. Makeig et al. (2002) showed that perceptual ERPs result from the compilation of alpha-band oscillations, synchronized by the triggering effect of a stimulus event. They viewed this synchronization phenomenon as "phase-resetting" across multiple channels. Luu and colleagues have argued that action-monitoring ERPs including the ERN and Pe reflect phase-resetting at the theta band; this hypothesis is particularly interesting in light of evidence for the large-scale synchronizing properties of theta oscillations (Buzsaki 1996; von Stein & Sarnthein 2000). As preliminary evidence, Luu et al. (2003) used an error feedback paradigm and found a rostral ACC source and dorsal-midline source oscillating in phase in the theta range, with their summed deflections constituting the ERN. Luu and Tucker (2002) relate this finding to Asada et al.'s (1999) report of phase-related theta oscillations between generators localized to the ACC and medial PFC during attention-demanding tasks. Luu and Tucker go on to propose a phase-resetting model of action regulation, and they suggest that multiple cortical sources become coupled at theta when ERNs are generated (see Menon et al. 2001, as to where these sources may be located). Thus, medial-frontal ERP components may indeed represent temporary spans of theta-band synchrony subserving action monitoring.

The next question is whether medial-frontal ERPs tap appraisal and emotion processes. Clearly, these ERPs are associated with key ingredients of appraisal: evaluation, attention, and planning. However, a good deal of research indicates that they also tap emotional states or traits. With respect to emotional states, Tucker et al. (1999) found higher-amplitude medial–frontal ERPs when participants received critical feedback on their performance, an effect replicated by Luu et al. (2003) independent of actual recent performance. Tucker et al. (2003) found a similar ERP differentiating between good and bad trait-descriptive words (e.g., "generous" vs. "mean"), potentially tapping appraisals linked to negative emotions such as anxiety. Indeed, ERNs diminish in magnitude when participants are given anxiety-reducing drugs (Johannes et al. 2001). With respect to traits, undersocialized individuals who probably experience little social anxiety show lower-amplitude ERNs (Dikman & Allen 2000). Conversely, obsessive-compulsive individuals show higher-amplitude ERNs than normal individuals (Gehring et al. 2000). Higher-amplitude ERNs have also been associated with lower scores on impulsivity (Pailing et al. 2002). Finally, Luu et al. (2000) found that subjects with higher scores on trait negative affect produced higher-amplitude ERNs. These studies indicate that medial-frontal ERPs correlate with state or trait negative emotionality: Increased negative emotion corresponds to higher mean amplitudes, implying greater theta-band synchrony. In conclusion, the cognitive processes tapped by these ERPs may be recruited to monitor and regulate behavior specifically related to emotion, with greater emotional intensity predicting greater cognitive involvement.

According to this analysis, the evaluative, attentional, and planning aspects of appraisal appear to correspond with action tendencies and emotional feelings, as mediated by functional integration between the ACC and striatum. This integration may be induced by ascending neuromodulator activities, and it may couple the dorsal ACC with other cortical areas, as reflected by the sources of frontal ERPs. Moreover, this integration may be underpinned by the phase-locking of theta-band oscillations that are implicated in large-scale corticolimbic self-organization. In sum, the attentional focus involved in action monitoring may be central for linking the "what" of appraisal with the "what to do about it" of emotion, permitting the modulation of an organized behavioral orientation to a challenging world.

5.4.1. Novel predictions. The relations among action-monitoring ERPs, theta-range synchrony, and neuromodulation suggest a unique approach to the study of appraisal–emotion processes. One implication of this approach is that action-monitoring ERPs actually tap appraisals. While these "mini-appraisals" may not reflect the complexity of everyday cognitive-emotional activities, they nevertheless imply spontaneous synchronization among several discrete systems mediating emotion and appraisal processes. A number of predictions flow from this idea.

First, action-monitoring ERPs suggest a time course for appraisal consolidation, roughly between the appearance of the ERN and the completion of the Pe. Specifically, the Pe, which includes more regions than the ERN, marks the final ERP deflection following an error. The latest stage of the Pe is roughly 400–500 msec postresponse, or 600–800 msec following the awareness of the error, which is thought to precede the response itself by 200–300 msec. Thus, an EI may emerge fully within 800 msec of a challenging event. (Note that Miller [1991] reviews evidence that septohippocampal entrainment grows over six cycles of theta – approximately the same period.) This prediction could be explored through concurrent analysis of ERP wave-forms and profiles of change in psychophysiological measures of emotion. Second, differences in both appraisal contents and emotional feeling states should correspond with the type of ERP (e.g., ERN vs. Pe) and with ERP amplitude. Tucker et al. (2003) found amplitude differences that may reflect positive and negative appraisals induced by positive and negative trait-descriptive words. In this kind of study, where appraisal content is directly manipulated, self-report or physiological measures of emotion should constitute an additional predictor of ERP amplitudes. Third, the degree of cortical synchronization, hypothetically contributing to the shape and magnitude of ERP deflections, should correspond with appraisal coherence and emotional measures. Thus, participants' reports of their appraisal and feeling states, and perhaps their success at focusing on particular appraisals linked with particular emotions, should correspond with synchrony coefficients during the time-frame of the ERP wave-form. New methods for analyzing coherence among cortical sources of ERP activity could be devoted to such an analysis (see Scherg et al. 2002 for a lead-up to cortical source coherence analysis).

5.5. Plasticity and learning

The fifth and final mechanism of integration is one that works not within occasions but across occasions. Earlier in this article, I reviewed the DS principle that the flow of activity among the elements of a system changes the elements themselves, enhancing the probability that the same patterns of activity will recur on future occasions. Hebb (1949) applied a similar principle to explain brain plasticity and learning, whereby the co-activation of neurons produced structural changes at synapses between them, increasing their probability of becoming co-activated in the future. By increasing neuronal connectivity across occasions, mechanisms of learning may be seen as facilitating neural integration in real time. Thus, through the growth of synaptic connections among structures mediating appraisal and emotion, learning establishes and reinforces links among the contents of appraisal as well as links between those contents and emotional response patterns. However, learning also establishes neural integration at the scale of developmental time, by providing continuity between appraisal–emotion patterns from one occasion to the next.

An important class of candidate mechanisms for associative learning includes long-term potentiation (LTP). In LTP, particular frequencies or durations of firing of the pre-synaptic neuron produce long-term chemical changes in the post-synaptic neuron, permanently altering the structure of the synapse. For this to occur, the post-synaptic neuron must be activated, glutamate from pre-synaptic terminals must travel to a specific class of receptors in the post-synaptic neuron, and then protein synthesis must take place for a period of time (up to hours) and/or across occasions. As a result, it takes less activation to produce the same response in the post-synaptic neuron on future occasions.

The state of excitability of the receptive neuron and the time course of its activation are crucial determinants of LTP. For many authors this implies that the neurochemical excitation that accompanies emotional states is essential for synaptic modifiability and learning (Freeman 1995; Post et al. 1998; Tucker 2001). Research demonstrates that neuromodulator arousal facilitates LTP (e.g., Centonze et al. 2001; Izquierdo 1997; Izumi & Zorumski 1999) and that neuropeptide action consolidates synaptic change and enhances memory formation (Adamec et al. 1998; Flood et al. 1990). The amygdala (AM) may be critical to memory consolidation in various systems, because of its facilitation of BS/hypothalamic neurochemical release (Packard & Cahill 2001) and its direct projections to the HPC (Hamann et al. 1999). Action-monitoring ACC activation, previously related to motivation, is also found to enhance learning (Gemba et al. 1986). These and related findings suggest that events that are not emotionally significant may not maintain arousal or attention long enough for learning to take place (Gallagher & Holland 1992; Rolls & Treves 1998; Tucker 2001). Finally, LTP has been observed in limbic, paralimbic, striatal, and cortical structures, but lower brain systems do not show plasticity of this kind. As a result, the information that consolidates through LTP must derive from attentional and evaluative cortical systems and their limbic and striatal underpinnings.

Thus, appraisal elements may be linked over occasions through the formation of associations that depend on emotional activation within occasions. This is exemplified by Cardinal et al.'s (2002) notion of the "upregulation of associability." These authors review findings indicating that the AM influences the associability of stimuli through its projections to BS neuromodulatory systems (e.g., Gallagher & Holland 1994). The AM may trigger ascending ACh projections that terminate in the parietal cortex, permitting the learning of novel associations in the presence of motivationally compelling events. Cardinal et al. (2002) link heightened associability in the cortex with the modulation of "affective" motor response patterns subserved by the BS (e.g., orienting). They conclude by suggesting that the learning of new associations, mediated by AM–BS involvement, is accompanied by autonomic changes, motivational arousal, and attentional orientation – all components of emotion in the present treatment.

This analysis suggests that the functional integration of AM–BS–corticolimbic structures within occasions produces learned associations across occasions. However, in previous sections I suggested a role for temporal synchronization in emotion–appraisal consolidation, induced by neuromodulator activity, participating in vertical integration, and tapped by action-monitoring ERPs. If phase synchrony is necessary for integrated appraisal–emotion processing in real time, then it should mediate learning as well. It has already been suggested that theta-band activity plays a role in learning (e.g., Klimesch 1999) and that ACC activation, hypothetically tapping theta-band synchrony, enhances learning as well (Gemba et al. 1986). Theta-band activity has also been shown to induce or facilitate LTP directly (e.g., Natsume & Kometani 1997; Yaniv et al. 2003). However, theta oscillations may specifically mediate the contribution of emotion to learning. Paré and Collins (2000) report an increase in the responsiveness of theta-synchronized AM cells over learning trials when animals are afraid. Paré et al. (2002) review evidence indicating that theta-band synchronization between HPC and AM neurons is specific to emotional states. Not only does theta synchrony produce recurring time windows that permit synaptic interactions, but it also amplifies the potency of AM neurons that otherwise fire infrequently. These authors conclude that theta-band synchrony promotes learning by facilitating interactions between cortical and limbic regions in the presence of emotion. This suggestion fits well with the present analysis.

5.5.1. Novel predictions. I have suggested that continuity in our responses to emotionally significant events emerges from the integration of appraisal contents and emotional response patterns during coherent EIs. However, attentional and evaluative processes in corticolimbic regions, and the neurochemical patterns that support them, must remain integrated for some period of time for this learning to take place. Only then can the emotional and attentional contents of whole-brain states become available for memory consolidation. A simple prediction based on this idea is that longer-lasting EIs will be more likely to recur than shorter ones, all other things being equal. For example, lasting emotional states in childhood should be good predictors of future appraisal–emotion constellations, compared with emotional states that resolve quickly (Lewis 2000a). If such states are mediated by corticolimbic synchronization at theta frequencies, then the consistency and duration of theta oscillations should mediate these predictions. Moreover, the amplitude and consistency of action-monitoring ERPs, arguably tapping theta synchrony, might make useful predictor variables. Thus, the amplitude and consistency of medial-frontal ERPs, measured in early childhood in an emotion-induction task, should be capable of predicting personality constellations emerging over development. Or, on a shorter scale, emotion-induced medial-frontal ERPs should be predictive of the outcomes of treatment for various behavior problems. My colleagues and I are presently investigating both these hypotheses (see Lewis & Stieben [2004] for an outline of our approach).

6. Putting the pieces together: A neuropsychological model

In this section, I refer to the anatomy and function of brain regions involved in appraisal and emotion, and the mechanisms of integration connecting them, to flesh out the psychological model of self-organizing emotional interpretations (EIs) presented earlier. This is not intended as a detailed theory but as a plausible direction for integrating psychological and neurobiological insights through DS modeling.

6.1. Trigger and self-amplification phases

Triggers were characterized as phase transitions induced by perturbations that disrupt the orderliness of a baseline state (e.g., an existing appraisal), increase sensitivity to environmental circumstances, and result in novel proto-organizations. Perceptual events often trigger emotional episodes, but so do memories or even physiological events such as pain. Thus, the mechanism for triggering an EI should be viewed as highly general. Two mechanisms of neural integration collude to trigger global change: the dynamic properties of feedback loops and the global character of ascending neuromodulatory effects. Because the neural systems mediating appraisal and emotion processes are interconnected in feedback loops, they are poised for sudden shifts to positive feedback dynamics. However, ascending neuromodulator flow, usually initiated by structures within these systems, must activate multiple components to participate in this feedback. For example, the OFC, NAS, and especially the AM induce neuromodulator release in BS/BFB structures. Neuromodulator pathways back up to these and other cortical and subcortical systems increase the activation of some systems while decreasing it in others. Where activation is increased, recursive downward connections further harness BS/BFB nuclei in a cycle of rapid self-amplification. Thus, the OFC, NAS, and AM are candidate structures that can induce positive feedback among multiple systems selectively activated by neurochemical afferents.

When new EIs are triggered through these activities, one's perception shifts, attention begins to orient to new events, affect alters or intensifies, and action tendencies arise. However, changes in the world or the body must be "meaningful" to cause the AM, OFC, or NAS to initiate new neurochemical patterns. Meaning is specified by the evaluative and motivational functions of these systems, according to innate encoding and learned associations (Rolls 1999). But meaning is also constrained by present appraisals and emotions. Thus, already-activated synaptic pathways within and across levels of the neuroaxis constitute a baseline EI to which new activation contributes. Baseline states not only determine thresholds for what is meaningful; they also constrain the character of any novel proto-organizations that emerge. For example, vigilant attention to strangers coupled with anxiety suggests a specific corticolimbic configuration rooted in fear neurochemistry. Sighting a policeman at such a time induces relief, because the OFC is already tuned to possibilities for rescue. At other times, given other preexisting states, sighting a policeman might induce worry instead ("Did I forget to renew my license?"). In keeping with the principles of cognitive self-organization, the present state of the system is the starting point for whatever happens next.

The emergence of an EI is first marked by rapid changes, in one or another higher-order loop, involving reciprocal and recursive augmentation among its constituent structures. For example, within the object evaluation loop, AM activation enhances the sensitivity of sensory cortex, increasing the processing of relevant environmental events, while reciprocal projections enhance AM activation, increasing the salience of learned associations. EIs then grow in strength and scope through the recruitment of additional higher-order loops. Structures such as the OFC, ACC, and AM (mediating evaluation, attention, and emotional memory) may serve as hubs for this expanding activity due to their widely distributed connections. For example, as Mr. Smart scans the road, ACC-mediated action monitoring ("I'm getting too close") and AM-mediated emotional associations ("illegal–police–powerful") together recruit other brain systems mediating feelings (e.g., shame and fear), action tendencies (e.g., urge to escape), and plans (e.g., passing on the right). The integration of appraisal and emotion processes within each loop now extends across loops with complementary functions, such that evaluation, monitoring, and action functions resonate with each other and with an emerging emotional state.

6.2. Self-stabilization phase

The complexity of neural connections entails interactions between positive and negative feedback in all brain activity. In a given EI, brain states begin to cohere and stabilize when negative feedback predominates among activated sets of structures. For example, the orbitofrontal cortex (OFC) appears to inhibit amygdala activation in normal processes of emotion regulation (Davidson et al. 2000), but ongoing emotion regulation implies continual recruitment of orbitofrontal evaluation by amygdala associations, thus stabilizing the activities of both structures. Speaking more broadly, interactions among all loops may stabilize as attentional orientation, perceptual entrainment, and action monitoring narrow the focus of perception, cognition, and behavior to an emotionally relevant stance. Thus, as positive feedback recruits more neural components to an emerging constellation, negative feedback couples them in a stabilizing regime. At the level of the macrosystem, negative feedback is manifested by the satisfaction of multiple constraints, such as neuronal activation and receptivity patterns across multiple systems, as well as parameters of phase synchrony with co-activated neurons. This shift to coherence may underlie the consolidation of recognition, meaning, and "sense" as an EI settles into place. As discussed earlier, ERP data suggest a minimal time course of roughly 600 to 800 msec for this to take place.

The activation of structures at different levels of the neuroaxis drives the brain into vertical integration. Reciprocal influences among BS, hypothalamic, and corticolimbic regions become coupled, perhaps through synchronization of independent oscillators, and this coupling may give rise to an emergent meta-synchronization that coordinates all lower-order couplings. Vertical integration assures that EIs have some degree of psychological momentum or imperturbability. This is a result of downward control by the superordinate pattern on interactions among constitutive structures. However, it also restricts the repertoire of viable EIs. At the subordinate level, connective circuitry, pathways of neuromodulation, and parameters of phase synchrony may constrain which cells enter the dance. At the superordinate level, only particular global constellations are sufficiently coherent to entrain their constituents, partly because of the animal's history of learning. Thus, vertical integration not only maintains but also selects viable EIs.

Emotional states demand action, and vertical integration includes links between striatal structures that narrow the focus of action and ACC-mediated action monitoring. This coupling may extend broadly across corticolimbic systems as potential plans are constructed, rehearsed, or discarded. Thus, action monitoring both broadens the scope of appraisal and narrows its focus, and both may be critical for stabilizing an EI. Anticipation of action and feedback concerning action outcomes are intrinsically motivating. Underlying this motivation, continuous activation of BS/BFB structures maintains particular synaptic configurations. Neuropeptide modulation of brain and body systems may also play an important role in the stabilization of appraisal, by recruiting multiple systems to a unified behavioral tendency. Mr. Smart's angry, blameful state can be seen in terms of an ongoing action plan, and this plan maintains the integrity of his appraisals as well as his physiology. However, the writer choosing her words is equally anchored by action monitoring to an enduring appraisal of her communication with her readers. Thus, parallel anatomical and chemical mechanisms may support the selection and maintenance of a behavioral orientation that coordinates appraisal and emotion processes.

Coordination among the components of a system is necessary for coherence; but it also permits the evolution of intricate and complex activities. I have not done justice to the complexity of real appraisals, focusing instead on basic mechanisms and simple examples. But action plans provide a useful springboard for thinking about complexification. Integration among corticolimbic structures permits focal attention, planning, and memory to work together to elaborate detailed models of one's engagement with the world. New EIs can also be triggered while plans are constructed and revised, as cortically mediated images are reorganized by new patterns of activity in the OFC, ACC, AM, or NAS. For example, planning one's slides for a conference presentation can initiate embarrassing images of criticism or grandiose images of praise. Here, AM-mediated associations to anticipated outcomes recruit explicit memories through connections to the HPC, harness BS/BFB systems that alter arousal and affective feeling, and induce a cascade of new associations mediated by cortical regions. When Mr. Smart thinks about slowing down, he may see himself as a submissive weakling with accompanying feelings of helplessness and shame. Oscillations between coherent appraisals – angry empowerment versus shameful submissiveness – may provide a more realistic account of Mr. Smart's state of mind, with the seeds of each appraisal embedded in ruminations stemming from the other.

In sum, the self-stabilizing phase of an emergent EI may involve the integration of multiple feedback loops and neuromodulatory systems in an emergent synchrony entrained to action. Moreover, new appraisals can emerge from the complexification of existing appraisals, producing a cascade of psychological states or an oscillation between attractors. By this analysis, the component systems underlying appraisal and emotion become synchronized and resynchronized, often rapidly and recursively, perhaps en route to an EI that settles more permanently – such as a lasting mood-like state (Lewis 2000a). Consistent with Frijda and Zeelenberg (2001), appraisal elaboration can be seen as an outcome rather than an antecedent of emotional response.

6.3. Learning and development

Through self-synchronizing processes, the brain may achieve periods of relative stability, when the constellation of neural interactions is constrained by a global EI and accompanying action orientation. Such stable emotional states may be critical for learning. I have reviewed evidence for emotional enhancement of memory formation, exemplified by neuromodulator (and neuropeptide) facilitation of LTP. I have also suggested, on the basis of recent findings, that phase synchrony among corticolimbic systems is enhanced and maintained during emotional states, and that theta-band synchrony contributes directly to LTP. Taken together, these arguments suggest that stable EIs facilitate synaptic plasticity and lasting synaptic change. The associations that get altered and the memories that get laid down during these periods would reflect the synaptic configurations mediating the contents of attention, evaluation, and planning. Hence, what gets learned is the present appraisal, or the tendency to appraise a situation in this particular way and not in some other way, given a particular emotional state. Across several occasions, an accumulation of learning events would then be expected to narrow the degrees of freedom for interpreting any subsequent event of this class (see Tucker 2001, on motivated memory and the stability–plasticity dilemma). This may be the basis for consolidating individual styles of interpretation, feeling, and belief, in a self-organizing process spanning years rather than seconds.

Learning based on appraisal stabilization has unique implications for the relation between emotional episodes and emotional development. On each occasion, the coordination and stabilization of neural interactions forms a gestalt, and this gestalt leaves its trace on some of its component structures. Thus, on subsequent occasions, emerging configurations that include these structures are influenced by their previous history and tend to repeat it. It is only through the synchronization of appraisal–emotion processes within occasions (real-time self-organization) that their influence can be transmitted over longer time scales (developmental self-organization), producing rich and enduring personality patterns on the basis of recurring states. However, this continuity is also mediated by real-time outcomes: in particular, the tendency for vertical integration to consolidate in some configurations and not others. Learning changes tendencies for parts to adjust to each other, but it also changes tendencies for wholes to converge in coherent gestalts. What gets learned gets repeated because the multistability of the brain is not infinite. Only certain constellations work within occasions, and their imprint on synaptic networks makes them all the more likely to work on future occasions.

Accounts that explain personality development on the basis of cognitive-emotional interactions can be made more precise through attention to these neural processes. These accounts include Izard's (1984) model of enduring affective-cognitive structures and Magai and McFadden's (1995) view of emotion traits stemming from recurrent interpretations accompanied by emotions. In addition, clinical syndromes of many kinds (e.g., depression, anxiety disorders) include a learning component. Whereas emotion theorists restrict their analysis to the effects of clinical traits on emotion and appraisal, the present model suggests that causation flows the other way as well, from recurring emotion–appraisal states to enduring clinical patterns. In general, the crystallization of personality or clinical traits is difficult to understand without a principle that allows for real-time sensitivity in brain processes that nevertheless become more entrenched with time. The linked requirements of emotional activation within occasions and synaptic shaping across occasions suggest such a principle.

7. Conclusions

After identifying some of the limitations of conventional approaches in emotion theory, I have emphasized the need for a more comprehensive and realistic account of appraisal–emotion interaction. I have approached this goal by outlining a dynamic systems (DS) framework, developing a psychological model based on that framework, and then shifting the focus from psychological to neurobiological processes. After providing a DS-based analysis of the neural underpinnings of emotion–appraisal states, I revisited the psychological model, integrating constructs and findings from neurobiology with those of psychology. To what extent can this modeling help to enrich and unify approaches within emotion theory, and to what extent can it facilitate further efforts to bridge emotion theory with neurobiology?

In general, appraisal theorists concentrate on the perceptual and cognitive evaluations that give rise to emotion, functionalist approaches concentrate on the cognitive changes produced by emotion, and trait theorists examine individual differences in cognition–emotion interactions with little attention to their origins. The limitations of these approaches and their relative insularity from each other have been shown to derive, in part, from a reliance on simple one-way causal explanations, an emphasis on wholes rather than constituent processes, and a commitment to linear cognitivist assumptions even when process-level analysis is attempted. Exemplifying these issues, process-level accounts within appraisal theory were argued to maintain linear modeling strategies that denied emotion a causal role in the formation of whole appraisals.

Dynamic systems principles highlight reciprocal, multiple, and recursive causality in both the emergence and stabilization of emotion–appraisal states. They also highlight multiple constraints and circular causality in the consolidation and endurance of these states. When the same principles are applied to a neural analysis, it can be demonstrated that neural activities underlying appraisal processes either mediate emotional processes simultaneously or they rapidly interact, evolve, and become integrated with activities mediating emotion processes, even at moderate levels of system architecture, well below the whole-brain scale. Thus, the nonlinear causal interactions and spontaneous synchronization of neural systems that give rise to global emotional states are fundamental to the emergence of whole appraisals evolving in tandem with them.

This reanalysis indicates that coherent appraisals are not antecedents of emotions, but emerging outcomes of interactions among constituent systems underlying appraisal *and* emotion. This conclusion facilitates the integration of appraisal and functionalist approaches in emotion theory: The cognitive consequences of emotions and the cognitive antecedents of emotions are the same, separated only by an arbitrary timeline. In other words, emotional and cognitive processes influence each other continuously during an emotional episode, from the first neural changes induced by a triggering event to the synchronization of the entire nervous system in a coherent mode of thinking, feeling, and acting. Given these considerations, the function of emotion can now be analyzed within appraisal processes themselves. Furthermore, the DS principle relating real-time coherence to structural change provides a means for integrating the third branch of emotion theory, dealing with individual traits, by suggesting how traits might arise from, as well as contribute to, cognition–emotion outcomes. Enduring patterns of synchronization among neural systems mediating emotion and appraisal are necessary for the synaptic changes responsible for learning and development. In all these applications, DS constructs provide a foundation for integrating disparate strands within emotion theory and for achieving compatibility between emotion theory and neurobiology, resulting in greater breadth, realism, and detail.

This analysis can revitalize emotion theory in another way, while contributing to neuroscientific thinking at the same time. Questions posed from the perspective of emotion theory concern the relation between emotional and cognitive systems. A DS analysis of the psychology of emotion frames these questions in terms of part–whole relations and nonlinear causation, bridging psychological and neuroscientific descriptions. A DS analysis of the neurobiology of emotion then demonstrates, in precise and concrete terms, that cognition and emotion were never two distinct systems at all. They are not distinct at the level of interacting parts, nor at the level of the wholes to which these interactions give rise. Neuroscience relies on psychological definitions of functions such as appraisal and emotion, in order to ensure that the forest is not lost through the trees. Some conceptualization of higher-order functions is necessary to identify the elusive wholes emerging from interactions among relatively well-known parts. But the conceptualization of these functions – their definitions and boundaries – may get transformed in the process, and this is what neuroscience offers psychology in return. Although it remains useful to differentiate cognition and emotion for many research agendas, a neuroscientific analysis finds them to be different aspects of a unitary phenomenon in which interpretation and relevance emerge together.

ACKNOWLEDGMENT

I gratefully acknowledge the financial support provided by grant No.1 R21 MH67357-01 from the Developmental Psychopathology and Prevention Research branch of the National Institute of Mental Health (NIMH), as well as ongoing support from the Natural Sciences and Engineering Research Council of Canada (NSERC). I would also like to thank Nico Frijda, E-man Leung, Phan Luu, Jaak Panksepp, Brian Parkinson, Klaus Scherer, Evan Thompson, Don Tucker, and Phil Zelazo for their thoughtful comments on earlier drafts of this article.

Open Peer Commentary

Why not emotions as motivated behaviors?

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Abstract: Lewis's dynamic systems approach is a refreshing change from the reflexology of most neuroscience, but it could go a step further: It could include the expected rewardingness of an emotion in the recursive feedback loop that determines whether the emotion will occur. Two possible objections to such a model are discussed: that emotions are not deliberate, and that negative emotions should lose out as instrumental choices.

We suggest that a key element, motivation *for* emotion, should be included in Lewis's rubric for bridging emotion theory and neurobiology. Despite his admirable departure from reflexology, he follows conventional assumptions that emotions and the neural processes that subtend them are unmotivated occurrences, elicited by specific patterns of stimuli without regard to their hedonic consequences. He proposes a thorough integration of these occurrences, both a horizontal one across "[complementary] evaluation, monitoring, and action functions" (sect. 5.1) and a "vertical integration [that] not only maintains but also selects viable EIs" (sect. 6.2). He does mention motivation at various points, including a "motivated action loop" of dynamic process (cf. Figure 3 in sect. 5.1 of the target article), but he is apparently referring to behaviors motivated by emotions: "Anticipation of action and feedback concerning action outcomes are intrinsically motivating" (sect. 6.2). It is well understood that emotions motivate; the interesting possibility is that they *are motivated*.

Many common experiences suggest that emotions can be both cultivated and nipped in the bud. For instance, you can "swallow" your anger or "nurse" it, you can learn to inhibit your phobic anxiety (Marks & Tobena 1990), panic (Clum et al. 1993; Kilic et al. 1997), or grief (Ramsay 1997), and you can refrain from rejoicing or "give yourself over to it." The road rage in Lewis's example (sect. 3.3) does not attack a passive Mr. Smart, but lures him in competition with other available activities. As Lewis points out, angry empowerment vies with shameful submissiveness (sect. 6.2), and, we could add, with enjoying his radio program or worrying about his impending sales conference. The choice first of all is whether to entertain the emotion or not, before (or in conjunction with) the choice of whether particular actions would go well with it. Techniques to deliberately foster or inhibit emotions in everyday life have been described (Parrott 1991); and most schools of acting teach an ability to summon emotion (e.g., Strasberg 1988) because even in actors actual emotion is more convincing than feigned emotion (Gosselin et al. 1998). The frequent philosophical assertion that emotions have a moral quality – good or bad (e.g., Hume, as presented by Baier 1991) – implies motivated participation; some philosophers have gone so far as to call the passions voluntary (e.g., Sartre 1939/1948). Thus, there have been many suggestions that emotion is a motivated activity. Lewis characterizes the competition of an emotion with alternatives as "oscillations between coherent appraisals," which might mean just between appraisals of whether triggering elements are present; but all affective appraisals include hedonic value, positive or negative, and thus could be capable of motivating choice. Mr. Smart is lured, not forced, into rage.

Psychological theories have been prevented from acknowledging the motivated quality of emotions by two considerations: that deliberately emitted emotions seem inauthentic (Frank 1988) and that a motive to experience "negative" emotions such as panic and grief seems contradictory. Ainslie (2001) has indeed argued that emotional processes which are under deliberate control do not behave in the same way as spontaneous ones – that they deteriorate into daydream status through familiarity and consequent premature satiation, leaving those which are occasioned involuntarily by surprising events as the authentic kind (Ainslie 2001, pp. 48–70). However, this is not to say that the latter kind are independent of reward. The class of reward-shaped behaviors includes many examples that arise too quickly, are too strongly motivated, or are just too trivial to be screened by the will. Direction of attention, withdrawal from painful stimuli, and numerous mannerisms and facial expressions can all be determined by reward without being deliberate. Conscious choice is a special case, the tip of a great iceberg of reward-seeking processes that include even behaviors during sleep (Granda & Hammack 1961).

The greater problem is how individuals could be lured into aversive emotions. Ainslie (2001) has argued also that reward of very short duration can motivate acceptance of experiences that are avoided from a distance and are reported as negative. The highly bowed (hyperbolic) shape of the discount curve for delayed rewards can produce temporary preferences for addictive substances, and, cycling more rapidly, for excoriating itches and biting fingernails; the same shape could lead to an urge to panic that is almost irresistible despite instant regret if it is obeyed (Ainslie 2001, pp. 48–70). The key word here is *almost*. With adequate training and/or motivation people can learn to resist the urge to give in to negative emotions, as noted above, just as they can learn to resist the temporarily preferred reward in itches and addictions. A rewarding component to such emotions is also evident from the fact that, framed properly, they have market value in horror movies and tearjerkers, and indeed from the fact that there is no line between positive and negative emotions: A continuum between them contains "mixed" emotions like anger, nostalgia, and awe, which are not neutral but which may be either cultivated or avoided, depending on the quality of reward from competing sources. This is to suggest that emotions must all pay off quickly to attract participation, but that wide variance in even slightly longer-range payoffs determines how negative they will seem.

We agree that a dynamic systems model is the best way to approach the highly interactive realm of emotions; and if emotions are at least partially selected by their rewardingness, then the apparent reward center in the nucleus accumbens shell belongs not only in Lewis's "motivated action" loop, but also in his "motivated monitoring" and perhaps in his "object evaluation" loops as well (cf. Fig. 3 in the target article). A key component of the relevant dynamic system will be the rehearsal of an emotion leading to some amount of short-term reward and sometimes an increase in the rewardingness (not necessarily pleasure!) of further rehearsal (the "self-augmenting" recruitment phase in which emotional interpretations [EIs] "grow in strength and scope"; sect. 6.1). The same positive feedback process may occur in "conditioned craving" (Ainslie, in press). A person's opportunity to modify this process by intervening in its recursive self-prediction was described by Darwin (and then James and Lange) in the nineteenth century:

> The free expression by outward signs of an emotion intensifies it. On the other hand, the repression, as far as this is possible, of all outward signs softens our emotions. He who gives way to violent gestures will increase his rage; he who does not control the signs of fear will experience fear in greater degree. (Darwin 1872/1979, p. 366)

This process may proceed with such speed as to seem automatic, triggered reflexively rather than shaped by reward; but the frequent observation that clearly motivated processes can override it, implies that it has to bid for dominance in a common marketplace of motivation. Some neurophysiologists have concluded that such a marketplace integrates all behaviors that are selected by reward (Montague & Berns 2002; Shizgal & Conover 1996). Empirical exploration of how emotions interact with this marketplace will not be a simple matter of correlating activity in the known emotional centers with activity in the known reward centers, since these centers overlap; for instance, stimulation of the emotional centers is often rewarding in its own right (e.g., Touzani & Velley 1998). But at the very least, we should not assume that the emotional processes that Lewis models are selected independently of their hedonic consequences.

The concept of circular causality should be discarded

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Abstract: This commentary argues that one specific but central concept in Lewis's theory, circular causality, is fundamentally flawed and should be discarded – first, because it does not make theoretical sense, and, second, because it leads to problems in practice, such as confounding the interaction between different systems with the relationship between different levels of analysis of a single system.

In recent years, the dynamic systems framework has become increasingly popular with cognitive scientists and neuroscientists. Lewis's target article is a valuable contribution to this area, and it extends the reach of the framework to the psychology and neurobiology of emotions. Lewis makes a convincing case for the claim that in emotional interpretations (EIs), the strong interaction between emotions and appraisals may be understood best in terms of the dynamic systems concepts of positive and negative feedback, and the rapid unfolding of an EI may be understood as a phase transition ending in convergence to one of a limited set of attractors. Furthermore, Lewis argues convincingly that such explanations can be plausibly connected to the underlying neural machinery. Even if not all details have been worked out, his comprehensive account of emotions and appraisals provides significant insights as well as valuable guidance to further work.

This commentary focuses on one specific but central element in Lewis's article, the concept of "circular causality." This concept is used in much dynamic systems theorizing and is defined in section 3.2.4 of the target article as follows:

> Feedback is one form of nonlinear causation. A second form, termed *circular causality* (Haken 1977), describes bidirectional causation between different *levels* of a system. A coherent, higher-order form or function *causes* a particular pattern of coupling among lower-order elements, while this pattern simultaneously *causes* the higher-order form. The top-down flow of causation may be considered an emergent constraint (by the system as a whole) on the actions of the parts. (emphasis in original)

One typical example cited by theorists using the term *circular causality* is the phenomenon of emerging orderly patterns in boiling water, called "convection rolls" (e.g., Kelso 1995). In this example, circular causality refers to the relationship between the water molecules and the global convection roll pattern. As is apparent in Lewis's definition, and also in other literature (e.g., Haken 1977; Kelso 1995), circular causality is construed as a kind of "nonlinear" causality, to be contrasted with ordinary, "linear" causation, which is predominant in theorizing about emotions (sects. 1, 2.2–2.4, 3.1, 7). Throughout the target article, Lewis develops the argument that emotion theories based on linear causal processes should be replaced by theories based on nonlinear, circular causality.

This commentary's main argument is that the concept of circular causality is fundamentally flawed and should be discarded. Circular causality, as construed by Lewis and other authors, is about the relationship between different levels of analysis of a single system, between *parts* and *wholes*: the behavior of the parts "causes" the whole form, and the whole form in turn "causes" the behavior of the individual parts. However, since we are considering a single system, the whole form simply *is* the collection of individual parts interacting in a particular way. The word "correspondence" seems more appropriate than "causality" to describe this relationship. The relationship between a *single* constituent part and the whole form is the relationship of being one of multiple components making up the whole; again it is not properly conceived as a causal relationship. In the example of self-organizing convection rolls in boiling water, the convection roll pattern *corresponds* to the combined behavior of all constituent water molecules; and a single water molecule is one *component* of the whole system. In fact, this relationship between different levels of analysis of the same system is not fundamentally different for self-organizing systems than for other types of systems. A car corresponds to the collection of its interacting parts, and a wheel is one component of the whole system.

One of the hallmarks of circular causality (see the definition above) is the "top-down flow of causation" in a self-organizing system, which is considered a special kind of *constraint* by the whole system on the actions of the parts. However, such "constraints" are also there in other kinds of systems. The behavior of a wheel of a car is constrained, in the same sense, by the behavior of the whole car and vice versa: the wheel is moving when the whole car is moving and vice versa. Such a "constraint" is only natural as the wheel is part of the car; but one would not normally refer to it as "circular causality." In other words, these types of constraints are always there between the whole system and its parts, and no special form of causality needs to be invented to enforce them.

Obviously, something special *is* going on in self-organizing systems. Unlike cars, self-organizing systems can "spontaneously" go from unordered regimes to ordered regimes that have surprising complexity, without any obvious, external instruction or programming agency – and this type of behavior may be very relevant for understanding cognition. However, there are already many appropriate concepts to describe what is special about it: self-organization, emergence, phase transitions, attractors, nonlinearities, and so forth. There is no need or justification for invoking a special kind of causality here (circular causality), as distinguished from normal causality.

One might agree with this argument in principle, but not see the relevance beyond a philosophical discussion of fairly arbitrary definitions and semantics. Unfortunately, however, the concept of circular causality leads to identifiable problems in scientific practice, both in Lewis's target article and in other work.

The main problem is that circular causality suggests an interaction between separable entities which does not exist. At worst, this leads to suggestions of Cartesian dualism: "circular causality has been identified between superordinate mental states (e.g., attention, expectancy) and subordinate neural events" (sect. 4, para. 2). At best, it becomes very difficult for the reader (and the author) not to confound circular causality, which according to the definition is about parts and wholes of a *single* system, with "bidirectional" or "reciprocal" causality, which refers to the mutual interaction (feedback) between *different* systems (e.g., sects. 1, 2.4, 3.1–3.3, 4.1, 4.2, 5.1, 5.3, 6.1, 6.2, 7). Not surprisingly, this is particularly apparent when the situation being considered is one of interaction between systems located at different levels of the brain hierarchy or neuroaxis: "Vertical integration could instantiate circular causality at the whole-brain level, thus providing an additional mechanism of neural integration" (sect. 5.3, para. 2). Here it is hard not to interpret this as putting on a par, on the one hand, vertical integration, which refers to connecting systems at different levels of the brain hierarchy through bidirectional feedback loops, and, on the other hand, circular causality, which refers to different levels of analysis of a single system.

All this makes it difficult to determine what exactly are the claims put forward by Lewis, and what scientists should do to verify the claims. Should experimentalists start looking for mechanisms that realize circular causality in the brain? Should theorists start developing mathematical theories that describe formally how circular causality operates in the brain? This commentary argues that circular causality cannot and will not be found in the brain, no matter the amount or the sophistication of experimentation. And mathematical formalization of the proposed self-organizing emotion/appraisal system (or any self-organizing system) should reveal immediately that the relationship between parts and the whole form is not properly understood as causal. For instance, the equations governing the parts of a self-organizing system do not need, as input, variables describing the whole form; instead, they depend only on variables describing other parts. This is why the system is self-organizing in the first place. In general, this highlights the value of providing, together with a conceptual theory, corresponding equations that clarify the concepts and make them precise.

In summary, circular causality is a concept that does not make sense, does not add anything to the theory, and leads to problems in scientific practice. Therefore, it should be discarded. In Lewis's article, the concept of circular causality unfortunately distracts and takes away from his otherwise comprehensive, novel, and important contributions.

Psychological-level systems theory: The missing link in bridging emotion theory and neurobiology through dynamic systems modeling

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Abstract: Bridging between psychological and neurobiological systems requires that the system components are closely specified at *both* the psychological and brain levels of analysis. We argue that in developing his dynamic systems theory framework, Lewis has sidestepped the notion of a psychological level systems model altogether, and has taken a partisan approach to his exposition of a brain-level systems model.

Dynamic systems theory (DST) has produced some elegant modeling solutions in well-constrained contexts and the general concepts and principles involved naturally invite generalisation to emergent "macroscopic unities" such as schemas, expectancies, scripts, or intentions (e.g., Kelso 1995). We therefore have considerable sympathy with Lewis's endeavour to use DST as a tool to explore integration across psychological and neurobiological systems through focusing on the dynamics of discrete emotion episodes.

There appear to be a number of sequential steps in the development of Lewis's argument. First, he adopts a particular model of the psychological processes implicated in emotion with his focus on "emotional interpretations (EIs)." Second, he proposes that EIs emerge as a result of a dynamic interaction between a number of separable "global" appraisal (e.g., perception, attention, evaluation) and emotion (e.g., arousal, action tendency) components (Lewis's Fig. 1). Third, he proposes that psychological levels of explanation cannot move beyond descriptions of the problem space in terms of these global components and, consequently, "the psychological level of description has little more to offer" (sect. 3.4). Finally, he sets out to overcome these purported limitations at the psychological level by endeavouring to reconceptualise these appraisal and emotion components at the level of neurobiology, within a DST framework. As it stands we feel there are significant issues concerning each step of this argument; however, here we focus on the third and the final steps.

Lewis's contention that the psychological level of explanation has reached the end of its shelf life seems premature. The psychological level of description is perfectly capable of "filling in the detail" beyond the level of global components (such as attention or arousal). For example, there exist a range of modeling strategies that can fulfil this role in which properties of processing resources, varieties of mental representation, and/or mental coding attributes are specified in detail. In other words, there are modeling approaches that can provide a *systems account* at the psychological level rather than just a description in terms of global components. Though additional work may be required to extend some of these approaches, such as ACT-R (e.g., Anderson et al. 2004), into the domain of emotion (e.g., see Belavkin 2001; Dalgleish 2004a; Teasdale & Barnard 1993), others already address both cognitive and motivational elements (e.g., Bond 1999). Furthermore, these system-level accounts are open to more formal specification using process algebra (Barnard & Bowman 2003) or even formal logic (Duke et al. 1998).

The essential point here is that if we are to map effectively between comprehensive psychological accounts and neural subsystems, we need to be quite explicit about how to decompose specific processing components, such as those identified by Lewis, at *both* the level of psychological systems analysis and brain-level system analysis. Without the support of explicit system models at a psychological level that endeavour to provide an analysis of what the "elements" of attention, evaluation, memory, or emotion are, DST is stuck with having to map these rather poorly specified global components onto putative brain circuits. This approach leaves substantial scope for ambiguities in relating the behaviour of neural circuits to psychological indices.

Turning now to this mapping exercise, in terms of the neurobiology of emotion, Lewis follows a particular trajectory from perception (sect. 4.2.1) through to feelings and consciousness (sect. 4.3.4). Understandably, this specific treatment of the anatomy and function of neural mechanisms follows the theoretical schema of Lewis's Figure 1. He then concludes (sect. 4.4) that each appraisal and emotion component "defined at a psychological level, becomes a distributed system in itself, or even a collection of fairly distinct systems, when analyzed at the neural level." This, then, is the systems model at the level of the brain. It is the interaction of these neural "parts" that Lewis then seeks to conceptualise in terms of DST. Our problem with this exercise is that Lewis has ended up with a particular brain-level systems account which seems to ignore the numerous other systems accounts in affective neuroscience (see Dalgleish 2004b).

For example, many affective neuroscientists, beginning with Schneirla (1959), have proposed that emotions can be conceptualised in terms of "approach" and "withdrawal," though they often use different terminology and propose different neuroanatomical substrates for each component – for example, behavioural activation and behavioural inhibition systems (Cloninger 1987; Gray 1982); approach and withdrawal systems (Davidson et al. 1990); and appetitive and aversive systems (Lang et al. 1990). Others (e.g., Rolls 1990; 1999) have conceptualised emotions in terms of states elicited by positive (rewarding) and negative (punishing) instrumental reinforcers, within a dimensional space. Yet others have argued for a neo-Darwinian categorical account where a small set of discrete emotions is underpinned by relatively separable neural systems (Calder et al. 2001; Damasio et al. 2000; Izard 1971; Panksepp 1982; Tomkins 1982). In our view, any brain-level systems model needs to demonstrate that it can offer a convincing account of the profiles of data underpinning these other approaches before they can be set aside.

In summary, the likely success of any bridging operation between psychological and neurobiological systems will rest on how well the components of these systems are specified at both the psychological and brain levels of analysis. Lewis has made an important start down this road. However, we suggest that in developing his DST framework, Lewis has sidestepped the notion of a psychological-level systems model altogether and has taken a somewhat partisan approach to his exposition of a brain-level systems model. Further progress, we feel, will depend at least in part on addressing these issues.

Adding ingredients to the self-organizing dynamic system stew: Motivation, communication, and higher-level emotions – and don't forget the genes!

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Abstract: Self-organizing dynamic systems (DS) modeling is appropriate to conceptualizing the relationship between emotion and cognition-appraisal. Indeed, DS modeling can be applied to encompass and integrate additional phenomena at levels lower than emotional interpretations (genes), at the same level (motives), and at higher levels (social, cognitive, and moral emotions). Also, *communication* is a phenomenon involved in dynamic system interactions at all levels.

In his target article, Marc Lewis points out problems inherent in appraisal approaches to emotion that employ linear causality and traditional cognitivist assumptions. Such approaches often ignore the demonstrated influences of emotion upon cognitive processes, even such relatively "primitive" cognitive processes as perception and attention. The application of self-organizing dynamic systems (DS) modeling to the appraisal-emotion interaction draws upon more recent cognitive approaches to conceptualize appraisal itself as a coherent higher-order unity that emerges in real time from the spontaneous coordination and synchronization of constituent elements. Emergent order and coherence, as well as increasing complexity, can arise based upon interactions among system elements involving patterns of nonlinear causation. Nonlinear causative processes include *feedback* – both positive feedback fostering growth and change, and negative feedback fostering stability and equilibration – as well as *circular causality*, which is bidirectional causality between levels of a system. Lewis applies this reasoning to the analysis of emotion-appraisal amalgams, or *emotional interpretations* (EIs), in which the constituent elements of emotion include arousal, attentional orientation, feeling tone, and action tendency, whereas the constituent elements of cognition are perception, evaluation, attention, memory, and reflection. These are aroused by a triggering event, and Lewis provides an example of a road-rage episode where initial anger and frustration are elaborated to involve feelings of helplessness, unfairness, shame, and humiliation, which in turn motivate extreme action. Lewis's DS approach is valuable in that it directs our attention away from traditional issues in the field which have become unproductive, such as the question of the "primacy" of emotion or cognition, to new and important issues: the nature of the constituent elements, how they interact, and at what level they function.

In conceptualizing dynamic interactions between elements, it is often useful to explicitly recognize that such interactions involve *communication*, and communication involves specific components – sender, channel, receiver, message, feedback – that may be usefully distinguished. Communication is a phenomenon at all levels of interaction within and between dynamic systems: from atoms, molecules, genes, to the EI level considered in this target article, to higher-order entities. As it is, Lewis's article is a largely "inside-the-head" account that arguably does not explicitly recognize the expressive and communicative functions of emotion. For example, display is not considered as a constituent element of emotion. This does not deny the value of the DS approach but rather suggests its application to a whole new, interpersonal, social, and communicative realm that is actually implied in Lewis's account. For instance, in his road rage example, some elements of the response involve emotion systems with a relatively clear biological basis (fear, frustration, anger), which may indeed be expected to interact relatively directly at a biological level and to be related to relatively specific neurochemical systems in the brain. Other elements of the response of the angry driver involve higher-level social, cognitive, and moral emotions (feelings of unfairness, shame, and humiliation) that require a relatively long period of socioemotional learning and development to become maturely experienced and expressed (Buck 1999).

An important aspect of Lewis's argument, related to the biological versus higher-level emotion distinction, is his contention that the constituent elements or "parts" that interact in self-organizing EI states should be neural entities. I fully agree in the case of biological emotions, but a consideration of the communicative aspects of emotion suggests complexities. For instance, it is noteworthy that in the road rage example the display of the other driver was presented as a triggering event for shame and humiliation. Specific emotion displays, such as facial expressions, vocal qualities, postures, and even pheromones, may be expected to constitute particularly specialized and effective triggers of specific EIs, resulting in a communicative process where the relevant elements are not only within the sender and/or receiver, but in their personal and social relationship as well. In many respects, this consideration takes the analysis of the elements of EIs outside the brain. Nevertheless, neural entities continue to constitute critical constituent elements in emotional communication: specifically, those neural entities involved in displays of emotion in senders as well as preattunements to those displays in receivers.

Neural entities cannot, however, be the critical constituent "parts" in the case of higher-level social, cognitive, and moral emotions. Biologically based emotions may be constituent elements in higher-level emotions: for example, biologically based prosocial emotions underlying attachment and love may be involved in social emotions, and biologically based emotions underlying exploration and curiosity may be involved in cognitive emotions, and both of these may be involved in moral emotions (Buck 1999). These biological systems may serve to provide the affective "fire" underlying such powerful higher-level emotions as pride, envy, jealousy, guilt, shame, awe, dread, resentment, humiliation, and gratitude (Buck 2004). However, other considerations – comparative gain and loss, fairness and equity, social norms and roles – must arguably be constituent elements in higher-level emotions.

I would like to applaud and expand upon one contention in Lewis's account: that neither fully articulated emotions nor fully articulated cognitions can exist in isolation from one another. I fully agree, and suggest that this is the case with the concept of "motivation" as well. In their fully articulated forms, emotions imply cognitions imply motives imply emotions, and so on (Buck 1985).

Emotion is remarkable in its relevance to phenomena at widely different levels of analysis, literally from atoms, molecules, and genes to social, cultural, and historical phenomena. The DS approach helps us to sort out the ingredients of this self-organizing and dynamic stew in a systematic way, by identifying the constituent elements of ingredients, specifying how they interact with other ingredients, and – critically – assigning the ingredients to the correct level of analysis.

Emotion theory is about more than affect and cognition: Taking triggers and actions into account

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Abstract: Understanding how emotions emerge is difficult without determining what characteristic of the trigger actually triggers them. Knowing whether emotional experiences self-stabilize is difficult without remembering what other processes are set in play as the emotion emerges. It is not clear either that positive feedback is required for the emergence of emotion or that an attractor model captures well what is happening when an emotion arises.

Lewis introduces the target article as an effort to create a bridge between emotion theory and neuroscience. The bridge is narrower than the introduction implies, however. The target article is concerned with the processes by which emotions, once triggered, emerge as full experiences, via emotional influence on cognition and cognitive influence on emotions. The article focuses less on facets of the puzzle that interest me most, however: the intrinsic meaning of emotions and their functional (action-related) properties (Carver 2001; 2004; Carver & Scheier 1998).

I care particularly about two elements the target article downplays. The first is the properties of the trigger – the event evaluated (appraised) as being important to the self. The second is the behavioral function of the emotion. The target article says little about either of these. In my view the analysis thereby loses some of its potency, because the largest share of the functionality of emotions is left out of the discussion.

What triggers emotional experiences? The target article is remarkably abstruse on this key question (sect. 3.3.1). My answer would be that emotional experiences are triggered by events that facilitate or impede either the attainment of a desired condition or the avoidance of an undesired condition. I have characterized facilitating and impeding in terms of rates of progress (Carver & Scheier 1998), though there are other ways to conceptualize them (e.g., moving in the desired direction versus its opposite). A looming object means an approaching impact (undesired). A slow driver willfully obstructing your way means violation of your entitled (desired) place in the world (positive affects are disregarded in this commentary, but see Carver 2003). I believe emotions begin in the (subcortical) registering of such changes.

This is where Lewis picks up the story. Lewis presents a dynamic model of the emotional episode (the rising of emotion from trigger to complete experience), in which positive feedback transforms a minimal reaction into a larger one, and negative feedback then limits the reaction's growth, stabilizing it at a level representing an attractor for that emotional state. I consider the two phases of this depiction in turn.

The idea that initial affect biases subsequent perceptual processing, yielding intensification of the affect (a positive feedback cycle), would creatively account for what brings the affect noticeably off baseline. There is another way to look at this flow of events, however. The event Lewis uses as his example – Mr. Smart's suddenly noticing a slow-moving car in front of him – is sufficiently abrupt in registering that it takes time for the various responses that constitute the emotional reaction to catch up with the perception (it is not just an obstacle but a suddenly appearing one). Further, if affect depends on time (as I believe it does; Carver & Scheier 1998), a 5-second impediment is a smaller provocation to Mr. Smart than a 5-minute impediment. Thus, even without biased information search and confirmation, the mere passing of time creates a steady increase in the trigger's potency, by increasing the extent of the perturbation. Although positive feedback may occur, it is not needed to account for an increase in emotion from baseline.

The second step in Lewis's analysis is that the emotional experience then stabilizes. Does it? Intuition suggests that people whose entitlement was violated can stay in a state of anger for an extended period if nothing changes the situation. Even when put aside, the anger can be re-evoked fairly readily by a reminder of the event. Moreover, the intensity of the anger seems roughly constant (again, absent situational changes), fitting the level of the perceived violation and extent of entitlement. These intuitions are consistent with an attractor model wherein the person bounces quickly to a level of anger and stays there. But this view leaves several disconcerting questions dangling.

Why would stabilizing feedback arise to keep the emotional reaction stable? Further, if the emotion is then in an attractor, why should it change? The target article leaves Mr. Smart stewing in anger. In reality, that is not how such an episode typically ends. It often ends with Mr. Smart acting to reassert his violated sense of entitlement (road rage sometimes leads to violence). Alternatively, he may do something to symbolically reinstate his entitlement (cut someone else off in traffic later, yell at his wife). Another possibility (cognitive, rather than behavioral) is that Mr. Smart can remind himself that he is a particularly saintly person who endures travail with equanimity. Yet another possibility is that he may decide his entitlements are doomed to failure (cf. Carver 2004).

In all except the last denouement, Mr. Smart acts to change the situation so that his goals are being better met. He reinstates his entitled position, or he diminishes its relevance to core values he is embodying. Only in the last case does that not happen. The last case entails giving up, anger changing to depression, disengagement from the goal (Carver & Scheier 1998; Klinger 1975; Nesse 2000). In all the other cases, though, Mr. Smart moves himself toward a desired goal, and in so doing he reduces the negative emotion.

Return, then, to the question of how self-amplification might give way to self-stabilization. I believe the answer lies in the evoking of action aimed at removing the trigger. This point brings me

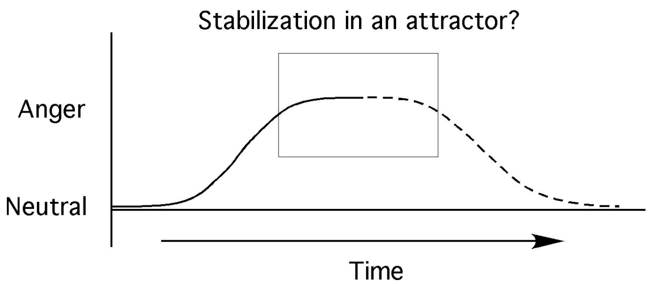

Figure 1 (Carver). Affect across time: Stabilization in an attractor, or gradual countering of a perturbation?

back to my second emotion-theory interest: the behavioral (and eventually affective) consequences of emotion. Behavioral consequences address the emotion's source (removing the obstruction, or reorganizing one's goal system to diminish its importance). When these behaviors are successful, the emotion diminishes (thus, the behavioral consequences have emotional consequences). Toward the end of section 3.3.3, Lewis brings up the possibility that functions pertaining to action play some role in stabilization. That seems far too little too late, however. Functions related to action are critical here.

Indeed, this view leads to skepticism that self-stabilization actually occurs. If affect emerges with registration of the violation, action tendencies emerge simultaneously to counter the violation (a point Lewis makes in the neuroscience part of the article, sect. 5.1). When those action tendencies yield perceived results, the anger diminishes. What appears to be stabilization may actually be the affect-countering effect of the actions (see Figure 1). Because the action often requires time to be fully effective, the emotion may cease to rise, yet fail to display immediate reduction, creating the illusion that stabilizing forces are acting to maintain it at that level. In this case, however, two directional forces are at work (one pushing emotion higher, the other dampening it) rather than a stabilizing force. To interpret this situation as a negative feedback loop maintaining the emotion at that level seems very misleading.

A final note: I am among those inclined to ignore the assumption that appraisal and emotion are distinct functions. How can appraising an event as having adverse implications for the self not imply negative affect? How can negative affect exist apart from registering (at some level, not necessarily conscious) that an event has adverse implications for the self? These seem two sides of the same coin.

I do not think abandoning the distinction renders emotion just another class of cognition, however. Valence, which is intrinsic to emotion, renders this class of experience distinctly different from others. Emotions differ from cognitions in other ways, too. The term emotion connotes physiological changes preparing the body to act. These changes are part of registering that the event has an adverse implication for the self, because adverse implications prompt behavioral responses. Such changes are not part of registering that an event constitutes a tree. This also makes emotions different from other experiences called cognition.

ACKNOWLEDGMENT
The author's work is supported by the National Cancer Institute (CA64710 and CA78995).

An intermediate level between the psychological and the neurobiological levels of descriptions of appraisal-emotion dynamics

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Abstract: Conceptual space is proposed as an intermediate representation level between the psychological and the neurobiological levels of descriptions of appraisal and emotions. The main advantage of the proposed intermediate representation is that the appraisal and emotions dynamics are described by using the terms of geometry.

Lewis proposes two levels of description of appraisal and emotion dynamics. The higher, psychological level is characterized by perception, attention, evaluation, and reflection for the appraisal process, and by arousal, action tendency, and feeling tone for the emotion process (see Fig.1 of the target article). The lower, neurobiological level is characterized by the interaction among several parts and circuits of the brain.

An intermediate "conceptual" level of representation of appraisal and emotion is proposed and discussed, based on conceptual spaces (Gärdenfors 2000). A conceptual space is a geometric level of concept representation which is intermediate, in the sense of Jackendoff (1987), between the lower subsymbolic level characterized by descriptions in terms of dynamics of neural networks, as in the neurobiological level put forth by Lewis, and the higher level characterized by linguistic descriptions of emotion dynamics, as in the psychological level he describes.

As sketched below, the conceptual space level of representation has all the capabilities to describe the perception, attention, planning, and reflection processes discussed by Lewis as the basis of appraisal. Moreover, the conceptual space may be easily generalized in order to represent emotions.

The main advantage of this intermediate description is that the appraisal-emotion dynamics described by Lewis may be expressed in terms of geometry – that is, in terms of vectors, dimensions, geometrics operators, metric functions, and so forth. Geometric descriptions of cognitive processes are easy to model and to manipulate, as discussed in detail in Gärdenfors (2000); moreover, they may be immediately implemented in an artificial agent by standard geometric programming techniques.

A conceptual space is a metric space whose dimensions are related to the quantities processed by the agent sensors. Examples of dimensions could be color, pitch, volume, spatial coordinates. In any case, dimensions do not depend on any specific linguistic description: a generic conceptual space comes before any symbolic-propositional characterization of cognitive phenomena.

A *knoxel* (in analogy with *pixel*) is a point in the conceptual space that represents the epistemologically primitive perceptive element at the considered level of analysis. In an implemented robot vision system (Chella et al. 1997), in the case of static scenes, a knoxel corresponds to a *geon*-like three-dimensional geometric primitive (Biederman 1985). The agent itself is a knoxel in its conceptual space. Therefore, the perceived objects, like the agent itself, other agents, and the surrounding obstacles, are all reconstructed by means of geons and they correspond to suitable sets of knoxels in the agent's conceptual space.

Conceptual spaces may represent moving and interacting entities (Chella et al. 2000). Every knoxel now corresponds to a simple motion of a geon, expressed by adding suitable dimensions in the conceptual space that describe the variation in time of the knoxel. For example, consider the knoxel describing a rolling ball: the robot's dynamic conceptual space takes into account not only the shape and position of the ball, but also its *speed* and *acceleration* as added dimensions (Marr & Vaina 1982).

The example corresponds to a situation in the sense that the motions in the scene occur simultaneously; that is, they correspond to a single configuration of knoxels in the conceptual space. To consider a composition of several motions arranged according to a temporal sequence, we introduce the notion of action: an action corresponds to a "scattering" from one situation to another one in the conceptual space. We assume that the situations within an action are separated by instantaneous events. In the transition between two subsequent configurations, a "scattering" of at least one knoxel occurs. A mechanism of focus of attention may be modeled in the conceptual space by letting the agent suitably scan the current sets of knoxels in order to select the most relevant aspects of a perceived scene.

The dynamic conceptual space lets the agent imagine possible future interactions with the objects in the environment: the interaction between the agent and a generic object is represented as a sequence of sets of *knoxels* that is imagined and *simulated* in the conceptual space before the interaction really happens in the real world. This loop of imagination, simulation, and action is at the basis of the planning capabilities of the agent.

Agent self-consciousness may be generated by a second-order conceptual space, in the sense that each second-order knoxel at time t corresponds to the inner perception of the first-order conceptual space by a time t-1; that is, it corresponds to the perception at a previous time of the configuration of first-order knoxels representing the agent itself and the other current entities.

To summarize, a conceptual space may represent all the processes at the basis of appraisal. The space may be easily generalized towards an "affective" dynamic space in order to represent the emotion components. A suitable number of dimensions may be added that take into account the affective evaluations of the perceived entities. In this new "affective" conceptual space, a knoxel or a group of knoxels is now characterized not only by shape and motion, but also by the associated arousal, action tendency, attentional orientation, and so on.

The appraisal-emotion dynamics described by Lewis in terms of triggers, self-amplifications, and self-stabilizations may be modeled in terms of dynamics in the conceptual space: a trigger corresponds to the scattering of knoxels; self-amplifications and self stabilizations may be represented by suitable geometric operators controlling the scattering sequences of knoxels due to the growing up and decaying down of the corresponding affective evaluations.

Therefore, the DS processes described by Lewis and related with the appraisal-emotion processes and their influences of the cognitive capabilities of the agent, may be fully described in terms of geometric operators in an intermediate conceptual space. In this intermediate level, the dynamics described by Lewis at the basis of appraisal and emotions give rise to a sort of "affective geometry."

Enacting emotional interpretations with feeling

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Abstract: This commentary makes three points: (1) There may be no clear-cut distinction between emotion and appraisal "constituents" at neural and psychological levels. (2) The microdevelopment of an emotional interpretation contains a complex microdevelopment of affect. (3) Neurophenomenology is a promising research program for testing Lewis's hypotheses about the neurodynamics of emotion-appraisal amalgams.

One way to think about Lewis's portrayal of appraisal-emotion interactions is by comparison with dynamic sensorimotor approaches to perception and action (Hurley & Noë 2003; O'Regan & Noë 2001; Varela et al. 1991). According to these approaches, perception is as much a motor process as a sensory one. At the neural level, there is "common coding" of sensory and motor processes (e.g., Prinz 1997; Rizzolatti et al. 1997). At the psychological level, action and perception are not simply instrumentally related, as means-to-end, but are constitutively interdependent (Hurley 1998). These and other findings can be described by saying that perception is *enactive*: it is a kind of action (Noë 2004; Varela et al. 1991).

Lewis's target article can be read as presenting a logically analogous way of thinking about cognition and emotion. At the neural level, brain systems traditionally seen as subserving separate functions of appraisal and emotion are inextricably interconnected. Hence "appraisal" and "emotion" cannot be mapped onto separate brain systems. At the psychological level, appraisal and emotion are constitutively interdependent: one is not a mere means to the other (as in the idea that an appraisal is a means to the having of an emotion, and vice versa); rather, they form an integrated and self-organizing emotion-appraisal state, an "emotional interpretation."

Although the target article ends with this kind of account (see in particular the last two paragraphs), the beginning seems more traditional. Lewis individuates emotion components and appraisal components, and maps them onto distinct brain systems. Emotion and appraisal have some components in common (attentional systems in particular), and their components are highly distributed. Nevertheless, some brain systems and functions are only emotional and do not belong to appraisal (e.g., arousal and feeling), and some belong only to appraisal and not emotion (e.g., planning). Some brain systems constitute either emotion or appraisal (or both), and some merely interact with one or the other.

Lewis presents the emotion/appraisal distinction as an initial heuristic for looking at brain processes. We agree that one must start somewhere. Yet we wonder how much conceptual change Lewis thinks his view of a deeply integrated and dynamic brain implies for the psychological taxonomy with which he began. Consider that his dynamic approach is consistent with other, different views of the relationship between emotion and appraisal. Scherer (2000), for instance, also believes that appraisal and emotion components interact in a way best explained in dynamical terms, but he sees appraisal as a component of emotion. Freeman (2000) thinks that emotion is an endogenously generated (mainly limbic) dynamic activity pattern that mediates sensorimotor loops by providing different degrees of salience to events. According to this view, emotion is a constitutive element of any cognitive process, so that there is no theoretical room for non-emotional appraisals. This neurodynamic account is consistent with phenomenological accounts, according to which perception and evaluation are emotive and valenced (Thompson, forthcoming; Varela & Depraz 2000).

Although we cannot argue the case here, and although we realize this view is outside the mainstream of emotion theory with which Lewis is concerned to communicate, we nevertheless believe that it may ultimately prove unproductive even to try to differentiate distinct "appraisal constituents" and "emotion constituents," which then "interact" in the formation of an emotional interpretation. Rather, we suspect that there may be no appraisal constituent that is not also an emotion constituent, and vice versa. Take feeling, for instance. Lewis describes feeling as a component of emotion, but not appraisal. When an emotional interpretation starts to emerge, feeling plays an important role in modulating appraisals, but it is not itself an appraisal constituent (see what happens to Mr. Smart in the target article). Yet there is a "feeling of appraisal," and appraisal can be seen as constitutive of emotion experience (Frijda 1986). Hence, categorizing feeling as an emotion constituent but not also an appraisal constituent seems limited.

Although feeling plays an important motivational role in Lewis's model, he does not explore the phenomenology of affect (the experiential aspect of emotion) in relation to the emergence of an emotional interpretation. Yet the microdevelopment of an emotional interpretation contains within it a complex microdevelopment of affect. Consider a momentary emotional interpretation, such as seeing a stranger's angry face glaring at you as you walk by. One can point to a number of concurrent components of affect in such an episode (see also Watt 1998):

A precipitating event or trigger, which can be perceptual or imaginary, or both. This component corresponds to the trigger phase in Lewis's model.

An emergence of affective salience, involving a sense of the precipitating event's significance. The emotion/appraisal processes leading to the emergence of this affective salience could reflect the kind of self-amplification and self-stablization processes Lewis describes.

A hedonic tone, along a pleasant/unpleasant polarity.

A motor embodiment, in the form of facial and posture changes, and differential action tendencies or global intentions for acting on the world.

A visceral-interoceptive embodiment, in the form of complex autonomic-physiological changes (to cardiopulmonary parameters, skin conductance, muscle tone, and endocrine and immune system activities).

Neuroscientists have recently emphasized the link between affect and "core consciousness" or the feeling of self (Damasio 1999; Panksepp 1998b), an idea also central to phenomenological philosophy. These two streams of neuroscience and phenomenology intersect in the research program of "neurophenomenology" (Lutz & Thompson 2003; Thompson et al., in press; Varela 1996). Lewis's (2000a) model of emotion-appraisal amalgams at multiple time-scales, together with a richer account of the role of affect in the development of emotional interpretations, can both inform neurophenomenological research on emotion, and also benefit from its rigorous way of linking first-person phenomenological reports and neurodynamical studies of large-scale integration (see Lutz et al. 2002). In particular, neurophenomenology provides a promising research program for exploring and testing Lewis's hypotheses about synchronous/asynchronous interactions across gamma and theta frequency bands in corticolimbic systems (see also Friston 2000; Varela et al. 2001).

Lewis's DS approach is a tool, not a theory

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Abstract: Lewis argues convincingly that a DS approach to emotion theory will be fruitful. He also appears to hold that there are DS principles that constitute a theory or are substantial empirical claims. I argue that this latter move is a mistake.

Dynamics is of course just some mathematics, and a dynamic systems (DS) approach as described by Lewis is the application of such mathematics, inspired also by analogies with other relationships described in other applications of dynamics. As such, a theory adopting the DS approach must ultimately be evaluated on whether it is more fruitful or convenient. The questions we should ask must be something like: If we use these tools to describe these phenomena, will this enable or ease or even just inspire the production of better theories than do some of the alternative tools being used now by other theories? Lewis makes a compelling case that this is so. For example, he rightly observes that we often have been trapped into misleading and simplistic questions about one-directional causal influences from cognition to emotion, or from emotion to cognition. Using tools that allow us to better formulate such relationships as reciprocal is very likely to foster more accurate theories. I conclude that Lewis is offering us valuable suggestions on how we should consider developing future theories in emotion research, and that these future theories are very likely to use the DS approach.

There are theories, or at least substantive claims, that have been made about the mind or brain which we might call DS theories. Van Gelder has described one kind of DS approach as nonrepresentational (1995). He has argued that we can explain much more of our mental phenomena using these nonrepresentational dynamic approaches than we typically assume. This is a substantive, perhaps ultimately falsifiable, albeit very general, claim for a form of DS approach. Lewis is not committed to expunging representations or other semantic kinds, and makes no explicit substantive claim about the DS approach that I could discern.

I have a concern, however, that there are something like substantive claims lurking in Lewis's account, and in much of the pro-DS literature. Lewis argues that DS "principles" will bridge emotion theory and neurobiology. These principles appear to be legion, but include that "Nonlinear dynamic systems operate through reciprocal, recursive, and multiple causal processes" (target article, sect. 1, para. 3). If I understand him correctly, these principles are claims about the kind of empirical relationships that exist. But this list of principles does not distinguish DS from other approaches. Almost every classical, discrete-state, linear AI model, for example, has reciprocal functional modules that can act on each other, and will use recursion. Also, these principles do not seem to describe any systems in a way that is falsifiable. Suppose we find we must admit some nonreciprocal relations and single causal processes into our descriptions of some brain function – is it then no longer dynamic? Also, if we are using the mathematics of dynamics, are not nonreciprocal relations and single-cause processes just particular cases of reciprocal relations and causal processes? Just so, there is nothing in Lewis's novel predictions that specifically contrasts DS principles with non-DS alternatives. His predictions are instead exciting empirical predictions for phenomena that are perhaps best described using the tools of dynamics.

The DS approach as Lewis (and most other defenders) conceive of it is not a theory but a tool and a set of very valuable analogies. We should encourage each other to use these tools and analogies when they are appropriate, but we would be bordering upon a misunderstanding if we ever, for example, argued the merits of a theory in terms of whether it uses a DS approach. To call a theory a DS approach (in Lewis's sense of DS) can at most mean that a certain form of mathematics is in use, or that some of the kinds of relationships described by this mathematics in other theories when applied in other domains are also present in the descriptions of this theory in this domain. That alone does not, and should not, make much of a difference in evaluating our theories.

Keeping this clear can help us avoid potentially distracting confusions as scientists like Lewis develop emotion theory and other theories described using dynamics.

The contribution of cross-cultural study to dynamic systems modeling of emotions

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Abstract: Lewis neglects cross-cultural data in his dynamic systems model of emotion, probably because appraisal theory disregards behavior and because anthropologists have not engaged discussions of neural plasticity in the brain sciences. Considering cultural variation in emotion-related behavior, such as grieving, indigenous descriptions of emotions, and alternative developmental regimens, such as sport, opens up avenues to test dynamic systems models.

Lewis's recasting of emotion theories and neurobiology in dynamic systems theory (DST) is extraordinarily promising. DST offers a vocabulary to understand relations between parts and wholes of complex phenomena, combines radically different scales of study, poses new research questions, and reconciles divergent data in productive ways. A DST-based approach to emotion reorients intractable theoretical debates, suggesting that all monovalent accounts are inadequate to describe a system with feedback loops, dynamic stabilities, and bidirectional causality. Lewis's demand that psychological theories of emotion be "biologically plausible" warrants amplification and would seem to discount virtually all emotion theories currently prevailing in my home discipline: anthropology.

Lewis's discussion of emotion in his target article, however, suffers from the paradigms of the disciplines on which he draws. The author himself highlights this when he notes psychological theory's tendency "to gravitate to a level of description that is superordinate, global, and functional" (target article, sect. 3.4). Lewis points out that psychological theory offers little help with a core ambiguity in his model – what are the constituent parts of emotional wholes? One problem is that Lewis fails to follow up on his own suggestion that action is critical to cognitive-emotional systems (sect. 3.3.3). By failing to return to the effect of behavior on emotion, Lewis neglects a crucial top-down causal relation in affective dynamic systems and allows a creeping cognitivist bias in appraisal theory to reemerge. He passes over here what is probably the most important avenue for cultural variation to affect neural architecture.

Anthropologists might supplement Lewis's promising model, but cognitivist leanings are even more pronounced in their field, and DST-based discussions have made little inroads. The "social construction" of emotion is narrowly construed as linguistic construction, with little consideration of how behavior might affect neurophysiology. The absence of anthropologists from discussions is particularly lamentable considering the contribution that cross-cultural study might make to understanding emotions as dynamic systems. Cross-cultural case studies offer avenues to test hypotheses produced in an integrated affective science. As Esther Thelen (e.g., 1995) has suggested in her studies of motor development, one way to see the workings of a dynamic system, including its constituent parts, is to perturb the system. The kinds of radical manipulation that might reveal the developmental unfolding of emotional systems are forbidden by both basic ethical considerations and the practical demands of laboratory research. Cross-cultural comparison, in contrast, offers abundant naturally occurring experiments.

Take, for example, variation in grief-like emotional dynamics. Even the most cursory survey of mourning practices reveals that emotion-action dynamics surrounding the death of a loved one vary tremendously. Anna Wirzbicka (2003) takes Nussbaum (2001) to task for universalizing even the concept of "grief," when languages like Polish, Russian, and French have no equivalent. The problem is not merely semantic (although excessive semanticism may marginalize anthropological from other affective scientists). Terms for similar emotions in these languages portray subtly different phenomenological dynamics and socially reinforced practices. Whereas contemporary use of the English "grief" singles out a person's death as an extraordinary event, even implying that it demands special treatment, the Russian language offers no unique designation for the emotions surrounding loss of a loved one, suggesting greater contiguity with other experiences, as Wirzbicka describes.

In Bali, where people are renowned for emotional placidity, children are trained very early to fear grief-like emotions as dangerous to their own health (Wikan 1990). One can imagine a stable emotional dynamic employing some of the psychological component processes that constitute what we designate as "grief" shaped by social forces. If, as Hebb (1949) suggests about neurons, those emotional elements of the brain that "fire together, wire together," the Balinese grief-like dynamic system would likely pit subsystems of fear against grief-like subsystems in inhibitory fashion. The ethnographic corpus offers abundant counterexamples. Anthropologist Renato Rosaldo (1984) describes the extraordinary rage that Ilongot men feel when a kinsman dies. Prior to pacification by the state, this rage led them to hunt heads and murder someone from a neighboring group. In contrast, Myers (1986) describes how Australian Aborigine speakers of Pintupi claim a grief-like emotional state leads them to gash their heads or stab their own thighs. The resulting scars become permanent reminders of losses; the longer one lives, the more reminders accumulate. According to Myers, grief-like emotions allegedly pile up steadily over time.

These social patterns of emotional action, following DST logic, likely affect lower-level physiological systems. How profound these changes are is an empirical question that might be addressed with such techniques as neural imaging, tests of autonomic nervous behavior, or endocrine sampling. Anthropologists often shy away from these because of long-standing complaints about "biological reductionism," arising from our field's traumatic experiences with overly simplistic evolutionary, "racial," and genetic explanations of psychological differences among peoples. In contrast, DST is hardly reductionist, and a culturally sensitive dynamic model of how emotional states emerge and consolidate physiologically could take behavioral variety into account. A DST-based explanation of variation also yields a model of culture that is more satisfying and less idealist than many of those dominant in anthropology, yet without neglecting symbolic, social, and cultural influences on development.

Considering cross-cultural data may also increase the recognition of emotion systems' flexibility on a microscopic scale. For example, in ongoing research with athletes involved in extremely demanding martial arts and no-holds-barred fighting, practitioners suggest that very basic emotional responses, like fear when being choked near unconsciousness or the vestibulospinal reflex to the sense that one is falling, can be "unlearned" (Downey, in press). Studies of altered states in meditative practice, possession rituals, and religious ecstasy yield similarly suggestive data. Although the evidence is anecdotal, these accounts are pervasive, suggesting that the phenomenology of emotional changes induced by these practices is relatively consistent. A DST approach to cross-cultural difference in emotional psychology offers the possibility of making physiologically testable hypothesis about emotional responses while recognizing that neural plasticity may be greater than we can imagine. Lewis's exploratory discussion suggests that DST might support greater conversation between brain scientists and anthropologists about both human variation and the nature of stable patterns in emotion.

Generating predictions from a dynamical systems emotion theory

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Abstract: Lewis's dynamical systems emotion theory continues a tradition including Merleau-Ponty, von Bertallanfy, and Aristotle. Understandably for a young theory, Lewis's new predictions do not follow strictly from the theory; thus their failure would not disconfirm the theory, nor their success confirm it – especially given that other self-organizational approaches to emotion (e.g., those of Ellis and of Newton) may not be inconsistent with these same predictions.

As one who has long urged a self-organizational approach to emotion, to the emotional guidance of attention, and to the circular causal relations between emotion and the more cerebral conscious processes such as thoughts, perceptions, and so forth (Ellis 1986; 1995; 2001a; 2001b; 2001c), I applaud the groundbreaking achievements of Marc Lewis in this direction. My reasons for advocating a self-organizational approach were originally derived from Merleau-Ponty's (1942/1963) physiological fleshing-out of phenomenology, combined with a systems conception of entities and processes – a tradition that traces back at least as far as James (1890/1968; consciousness is not an entity but a function), von Bertalanffy (1933/1962; living systems are those that can maintain their pattern across energy and material exchanges), and arguably as far back as Aristotle (*De Anima*; living organisms are those whose parts do not remain the same when disconnected from each other). Merleau-Ponty (1942/1963) also endorsed this process way of thinking; his "psychophysical forms" maintain continuity of the whole across changes in their parts, and can change the pattern of the whole very quickly even when the parts remain the same.

Lewis adds considerable value to this kind of theory by providing neurophysiological specificity, primarily in terms of synchronies of oscillations for gamma and theta wave forms distributed widely through specific brain areas already correlated with emotion, attention, and related psychological processes. By bringing such specificity to the theory, he encourages testing of new predictions involving these distributions of wave patterns. The new predictions are traced to basic principles of self-organization theory: for example, higher and lower level processes mutually influence each other (circular causation); higher level processes maintain stability across perturbations (negative feedback), and can shift abruptly from one global attractor to another (positive feedback) given a fairly discrete perturbation or, in emotion/appraisal terms, a "trigger."

Because of this high degree of specificity in working out the theory and its predictions, one need not wonder "Yes, but isn't this just a reiteration of the common notion that biological feedback systems behave in ways that maintain homeostasis at holistic levels, and that emotion is in the service of these biological needs?" In Lewis's theory, there is no doubt that much more is being asserted. He not only pulls together self-organization theory with a biological underpinning, but suggests specific mechanisms that lend themselves to subserving the proposed self-organizing structure. Most of Lewis's new predictions have to do with synchronies of 30–80 Hz gamma and 4–8 Hz theta oscillations in various widely distributed brain areas. This focus on wave patterns is not merely a reiteration of the old, mostly neglected idea that the brain is a relatively homogeneous soup in which these wave patterns flow around. On the contrary, Lewis makes use of modular divisions of labor among different brain areas known to orchestrate different emotional and appraisal processes.

But the very specificity of these predictions may pose a problem: What if these specific wave patterns are not the only possible mechanisms that could subserve a self-organizational emotion/appraisal system? This possibility would raise two undesirable consequences:

(1) Even if Lewis's predictions do not pan out, this would not falsify his basic theory. But in the scientific method as strictly understood, failure of predictions should falsify a theory. If not, then they are not really a test of the theory. Moreover, the predictions, in order to falsify the theory, must be very strict inferences from the theory, so that the falsity of the predictions would entail the falsity of the theory. That is, from "A → B," we can infer "not-B → not-A," but if A does not strictly entail B, then neither does the failure of B entail the failure of A. The problem, then (not an uncommon one in the recent behavioral sciences), is that Lewis's predictions are not really strict implications from his theory. Instead, they are framed as observable consequences that one "may" or "might" expect, or that "could" be reasonable consequences of the theory.

In my view, this is not a damning problem, because it is highly appropriate at such an early stage in the development of a theory that predictions should be framed in such tentative terms. But the fact that in this case the predictions are not really definitive tests of the theory should also be noted. They are the kinds of predictions whose failure would necessitate further tweaking of the theory, perhaps in terms of some alternative self-organizational framework, and not of abandoning it. This is especially the case when there are actually many alternative stories about brain mechanisms that can subserve a self-organizational emotional system (e.g., see Newton 2000; Ellis 2001a; 2001b; 2001c).

(2) An inverse problem is that, because there are many other versions of self-organizational emotion theories, and even non-self-organizational theories that could predict the same empirical results, it is unclear that the panning out of the predictions would confirm the theory. Instead, it would confirm that some one of these various alternative ways of accounting for the predicted results must be true. Here again, this is the case because the predictions are not strict inferences from the theory. If they were, then it would be much less likely that any alternative account would also be consistent with the same data.

But here again, the reason for this problem has to do with the youth of the theory. We can make very good use of the self-organizational framework proposed by Lewis even if not all of the specific mechanisms he proposes turn out to be the ones that subserve the self-organizational structure he has described. Indeed, it is characteristic of self-organizational structures that they could be subserved in some number of different ways. The very fact that the theory is so heuristic increases the probability of its truth, because in the realm of emotion theory it is difficult to find one coherent theory that can account for the often ill-fitting phenomena at the many different physiological and psychological levels that are involved.

Applications to the social and clinical sciences

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Abstract: Fully interpreted, Lewis's dynamic systems modeling of emotion encompasses psychological-adaptation thinking and individual and group differences in normal and abnormal behavior. It weakens the categorical perspective in evolutionary psychology and the clinical sciences; and suggests continuity between "normal" or "abnormal" behavior in whatever way this is self and culturally constituted, although culture/linguistic factors and selfhood are neglected. Application of a dynamic systems model could improve formulation of clinical problems.

Lewis's dynamic systems model of emotion comprehensively integrates psychological and neural components serving emotional cognition, action tendencies, and motivated behavior, including visceral somatic behavior. Its feedback circuits and mechanisms of neural integration provide a coherent, realistic, and comprehensive formulation of the way a neurocognitive system works in areas basic to virtually all adaptive behavior. I focus on themes not sufficiently elaborated in Lewis's very satisfying formulation.

Lewis's theory of emotion describes a largely monolithic, solipsistic, and universal brain/behavior amalgam. It models how an agent/self appraises, regulates, and operates. When played out in relation to ecology, culture, and historical conditions it produces a complex structure of (cognitive, emotional, visceral/somatic) behavior. Populations of real agents confronting shared environmental conditions would yield more or less distinctive behavior structures. An interesting question is the extent to which such conditions would shape the architecture of Lewis's model. However, there is little mention of factors that introduce individual differences, especially group or cultural differences. Furthermore, when individual differences are referred to, Lewis seems mainly interested in how they affect the model itself,, leaving aside the latter's role in shaping and consolidating human differences (in normal/abnormal, cultural behavior). The role of genes and of temperament in shaping, conditioning, or favoring pathways and centers of Lewis's model is unclear. Potential clinical implications of formulation seem to be not appreciated.

Developmental experiences are conditioned by but also "tune" and "shape" how a dynamic systems model of emotion (DSEI) works. Experiences situated in different attachment/separation milieu, ecological and cultural settings, and adaptive landscapes as per prevalence of hardships and trauma will consolidate as different forms of DSEI. In its operation, DSEI connects working, declarative, and implicit memory systems so as to fashion distinctive modes of appraising, conditioning, learning, experiencing, and motivating, not just emotional, behavior (Freeman 2000). The broad construal of what "emotion" is and does (highly realistic) urges one to see a DSEI as well as its self-representation (a neglected construct in DSEI) as significantly a product of how emotion/cognition have played out in settings governed by distinctive meanings (but focused on universal biological imperatives).

A comprehensive model of emotion has relevance for understanding behavior during transition to and in early communities of Homo sapiens. The way it operates covers approaches to behavior that rely on constructs such as psychological adaptations and modularity of mind (Tooby & Cosmides 1992; Geary & Huffman 2002). Such constructs are analytically very useful but too categorical, and they suggest, if not presuppose, distinct structures of neural organization and function. DSEI formulates adaptive behavior as per evolutionary requirements dynamically and makes evident the complexity of structures and mechanisms that serve it. DSEI's reliance on and explicit link with executive memory, which incorporates temporal integration through working and long-term memory systems (Fuster 2002), presupposes the relevance of social, ecological, and cultural factors in the evaluation, production, and monitoring of behavior. Thus, DSEI's scope supersedes (makes redundant) evolutionary psychologists' cognitive modules, modularity of mind, and especially psychological adaptations (save for perceptions of physics, space, natural kinds; Atran 1998).

Evolutionary psychologists' constructs imply functional design, specialization, and domain specificity. They are still useful descriptive constructs. But, the alleged functions they regulate comprehend highly complex neurobiological and neuropsychological mechanisms that overlap and interconnect across levels and areal divisions of nervous system as suggested by Lewis's model (Mesulam 2000).

Also under-played is the potential significance of a model of emotion for understanding not only the ontology (i.e., essence) but also the production of maladaptive behavior syndromes now formulated as psychiatric disorders. Since self-organization and stabilization of function in short time facilitate and promote longer time regularities of behavior as per associative learning, it suggests that time-bound, context-specific deficiencies or breakdowns of behavior lay the ground work for longer "developmental" time clinical psychological and psychiatric syndromes. A concatenation of adverse development, attachment routines, and experiences, in association with genetic vulnerabilities, can be surmised to create appraisal routines, motivated emotional propensities, action tendencies, feeling regimes, and actual emotionally relevant behaviors easily perturbed (e.g., by negative triggers). The preceding condition causes maladaptive DSEI routines and syndromes of behavior; namely, distinctly configured "disorders" (as per signs and symptoms). However, their current features and interpretation (as compared to their essence) are conditioned by ecological, cultural, and shared historical circumstances affecting behavior and diagnostic practices. Their putative form, in other words, may not be universal and culture free (see below).

Furthermore, when the many "networks" and core areas of DSEI are considered (e.g., visceral somatic), many other contemporary medical problems may be comprehended better (e.g., irritable bowel, fibromyalgia, dissociative ("pseudo") seizures). Work with mild brain injured persons who develop persistent somatic preoccupations and symptoms suggests that a "trigger" of head injury disrupts pre-existing patterns of function in patients' neural organization of emotional networks and centers, producing new, maladaptive patterns of visceral somatic behavior. DSEI provides a satisfying way of understanding circumstances involving confrontation, anger, and the threat of violence as triggers that may lead to a fugue-like state of serial killing (Fabrega 2004).

Given the potential vulnerabilities and sheer imperfections or defects in function of any comprehensive structure governing emotion, a suitable model of it constitutes an obvious device with which to formulate points of weakness or vulnerability of agent and how its behavior is likely to breakdown. Constructs in psychiatry and clinical psychology and their sovereignty over psychophamacology are, like the psychology of emotion, dependent on a "language of wholes." Constructs that sharpen the way emotional behavior disrupts function in the short run provide a language for improving "diagnosis" that could be more useful to clinicians. The latter are likely to want to key in on the power of DSEI through two of its portals: neuro-modulation (i.e., psychopharmacology agents in current use) and self-integration (i.e., acquired characteristics, conceptions, and action tendencies of self). However, as currently formulated, DSEI is too unwieldy for clinicians. The latter need a more streamlined or schematic version of the anatomy and physiology of DSEI, especially its neuro-modulation parameter, and also a more articulated linkage with aspects of self-organization, self-conception and, via these connections, to aspects of environment that pose hardships and potential dangers to self (Fabrega 2003; Strumwasser 2003).

Two domains that Lewis is also cautious about are level of consciousness (Tononi & Edelman 1998) and cultural/linguistic dimension, as per feelings, behavior (D'Andrade 1995; LeVine 1990; Shweder 1991; Wierzbicka 1999). Consciousness fluctuates significantly during "normal" real-time behavior (e.g., literature on flow is relevant here; Czikszentmihalyi 1990) and during some clinical syndromes (e.g., dissociative amnesia and seizures); but it is never dealt with in its own right (except mainly indirectly as a function of arousal, attention). Language and culture involve the agent's representational system of internal states, selfhood, and emotion, which can vary (Lillard 1998; Lutz 1985). A realistic model or theory of emotion for social and clinical sciences would have to have its architecture linked to real-world conventions, traditions, and real-world areas of social and psychological strains.

Emotion is from preparatory brain chaos; irrational action is from premature closure

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Abstract: EEG evidence supports the view that each cerebral hemisphere maintains a scale-free network that generates and maintains a global state of chaos. By its own evolution, and under environmental impacts, this hemispheric chaos can rise to heights that may either escape containment and engender incontinent action or be constrained by predictive control and yield creative action of great power and beauty.

A prevalent view, stemming from Plato's metaphor of the chariot drawn by two horses, contrasts emotion with reason and extols the brain's powers of logic and deduction while relegating feelings to the baggage we share with animals that cannot reason. Is this valid? Although I share the opinion that mammals have emotions closely resembling our own, I see the apposition of logic and passion as engendering a confusion or conflation of emotion with irrational behavior. Certainly many actions detrimental to long-term welfare are taken in the grip of fear or rage, though probably more often in casual neglect or careless indifference; but great achievements of mankind, by logic or by irrational intuition, have been forged in emotional states of high intensity indeed. Still, this equine metaphor may be valid, and it provides a useful starting point to explore neural mechanisms that underlie both rational and irrational behaviors.

Visualize a businessman whose car has been scratched by an arrogant teenager, or a soldier ordered to cross an open field under enemy fire, or a mystic anticipating communion with an angel, or any emotional situation. We see facial blanching or flushing, widened eyes, rumpled hair, heavy breathing, limbs trembling – all the musculoskeletal, autonomic, and neuroendocrine manifestations (Cannon 1939) of bodily preparation by the brain for action. These accompaniments may well be the medium for awareness of emotional states as postulated in the James-Lange theory (cf. James 1890). Neuropsychologists debate how many kinds of emotion there are; novelists show that emotions are in variety not subject to enumeration, and that commonly in schemata they are alloys: grief, for example, combines pain of loss with survivor guilt, nostalgia, anger at betrayal by abandonment, fleeting joy at being rid of an impediment, guilt about that, and so on.

Despite their infinite range, all emotions have four features in common that relate directly to their neurobiology. First is the capacity for rapid onsets and terminations (sect. 2.3 of the target article, "Process models of appraisal"). A single word can precipitate instant rage; another word can transform rage to shame, fear, or guilt. Intracranial and scalp EEG recordings from animals and humans have shown that neocortex operates by sequential state transitions (sect. 3.2.7, "Phase transitions"). Oliver Sacks (2004) concluded: "The mechanism of our ordinary knowledge is of a cinematographical kind." EEG shows that state transitions occur in sequences at rates in theta and alpha ranges (see discussion of theta in sect. 5.1.1), each state lasting about one-tenth of a second (Freeman et al. 2003a). States are expressed by spatial patterns of phase and amplitude modulation of beta and gamma oscillations (sect. 5.1, "Nested feedback loops and self-synchronization"). Each transition begins with a discontinuity in phase by which the oscillations are re-initialized. Resynchronization follows within a few milliseconds, and a new spatial pattern emerges and stabilizes. Then within 25–35 msec of onset the intensity of the pattern increases dramatically (sect. 3.2.2, "Positive feedback and self-amplification"). These phenomena demonstrate the capacity of neural populations for virtually instant reorganization of spatiotemporal patterns (Freeman 2003b; 2004a).

The second feature in common to all emotions is their globality. The entire musculoskeletal, autonomic, and neuromodulatory systems are orchestrated. These associated signs and movements have obvious secondary survival value in providing for reliable communication of emotional states among individuals in societies (Darwin 1872). Multichannel EEG recording from high-density electrode arrays in rabbits and cats provide evidence (Freeman & Rogers 2003; Freeman et al. 2003b; 2003c) that large areas of neocortex in each cerebral hemisphere generate intermittent spatial patterns of synchronized oscillations that are statistically related to intentional behaviors. The fractal distributions of the parameters of phase measurements (Freeman 2004b), the power-law "1/*f*" distributions of spectral energy, and the rapidity of global changes all indicate (Freeman et al. 2003a) that each hemisphere maintains a scale-free network that resembles major airline routings (Wang & Chen 2003) in which a small number of critical nodes have exceptionally high levels of connectivity at which damage can be catastrophic. These nodes in brains may easily be identified inter alia with the thalamus, amygdaloid, entorhinal cortex, and midbrain reticular formation. The impact of an expected conditioned stimulus induces a local state transition in the pertinent primary sensory area, with formation of a local field of neural activity having a reproducible spatial pattern, which is engulfed 200 msec later by a global field (Freeman 2005) established by a global state transition that integrates by multiple interactions (sect. 3.1, "Cognition as self-organization") the several sensory areas with the limbic system (sect. 5.3, "Vertical integration"; Freeman & Burke 2003).

A third feature common to all emotions is dependence of brain states on expectancy. An off-hand remark or gesture by one person can be perceived by another as a compliment or as an insult, irrespective of intent. This property reflects the fact that the overwhelming input to every cortical neuron comes from other cortical neurons and not from sensory pathways. EEG pattern analysis has shown that the chaotic dynamics manifested in background activity in the waking brain elaborates landscapes of chaotic attractors (Skarda & Freeman 1987), each of which constitutes a hypothesis (sect. 3.2.6, "Multistability and stochasticity") about the environment inside and outside the body (Freeman 2003a). The incoming sensory information selects an attractor by placing the local trajectory of the sensory area into its basin of attraction. In the aftermath of the ensuing state transition, the sensory information, having done its work, is washed away in the processes of abstraction, generalization, and classification. The mechanism is the cortical broadcast by divergent-convergent transmission pathways, which extract the newly constructed activity that provides the meaning of information (Freeman 2003a; 2005), not processed information. The meaning is private and may or may not match others' realities. For this reason the hypothesis-testing model from dynamic systems (DS) is superior to information-processing model from artificial neural networks (ANN) in explaining emotion.

The fourth feature in common is the future-orientation of emotion: "What will I do?" Even nostalgia nests in the necessity for coping with a deteriorating environment contrasting with a perceived golden age. Brains are designed by evolution to form goals, act to achieve them, hypothesize the changes in sensory input that follow test action, and assimilate to the consequences of their test by learning. All that brains can know are their hypotheses and the cumulative results of their tests. Emotion is an integral aspect of the predictive, preparatory phase of the action-perception-assimilation cycle, whereas consciousness (sect. 4.3.4, "Feeling and consciousness") is an aspect of the judgmental phase of evaluation of the consequences of action – and therefore is past-oriented: "What have I done?" Perhaps this disjunction between future- and past-orientation is responsible for much of the obscurity that attends our grasp of the nature of emotion – and consciousness.

My hypothesis is that brain dynamics is governed by an adaptive order parameter that regulates everywhere neocortical mean neural firing rates at the microscopic level, and which finds expression in maintenance of a global state of self-organized criticality (Freeman 2004a). Under perturbation by environmental input (including that from the body), brain dynamics moves away from its basal attractor and generates repeated state transitions in its attempt to regain balance. These local states form chaotic itinerant trajectories (Tsuda 2001) that constitute a search for a course of action that can be predicted to restore balance. Selection of an action constitutes closure (sect. 5, "DS mechanisms of neural integration"). If the intensity of the chaotic background activity overwhelms the search trajectories, then closure is premature, and the action chosen is suboptimal and may appear to be irrational and short-sighted – that is, "emotional" in the colloquial sense of the term (Freeman 1995; 1999). Strong self-control is required to reign in a torrent of chaotic discharge to reach optimal closure; from this point of view, Plato's metaphor is valid still.

Dynamic appraisals: A paper with promises

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Abstract: The proposed dynamic systems model of emotion generation indeed appears considerably more plausible and descriptively adequate than traditional linear models. It also comes much closer to the complex interactions observed in neurobiological research. The proposals regarding self-organization in emerging appraisal-emotion interactions are thought-provoking and attractive. Yet, at this point they are more in the nature of promises than findings, and are clearly in need of corroborating psychological evidence or demonstrated theoretical desirability.

The target article makes several impressive contributions to the study of emotion. First, it corrects the common schema of the emotion process in which events lead to appraisals leading to emotional responses. Instead, it presents an appealing model of emotion generation as a process over time that allows for the many things that can happen during that time, and in which a triggering phase, a self-amplification phase, and a self-stabilization phase can be meaningfully distinguished. Each phase is described as guided by ongoing processes that the triggering event impinged upon, by the effects of those processes on subsequent processes, and by the self-organizing interactions between the various outcomes that augment, counteract, dampen, or stabilize the processes that caused them. The article thus sets the agenda for research on the time course of emotion arousal. In fact, considerable research is emerging that substantiates the hypothesis that many things do happen when an emotion is aroused, and before it obtains its distinct contours. Examples are the evidence produced by varying prime exposure times in priming experiments (e.g., Murphy & Zajonc 1993; Stapel & Koomen 2000), and by changes in responses to emotional stimuli over exposure time, which led to the defensive cascade model (e.g., Bradley & Lang 2000).

Second, the target article beautifully describes the processes of emotion generation as an intimate intertwining of appraisal and response generation sub-processes rather than of appraisals preceding emotions. Feedback from intermediate action components steers appraisal processes, but, in addition, appraisals are steered to support ongoing action components and may well be shaped and augmented by what would be needed to select from among available response options. A primary example comes from the impact of one of the major appraisal components in appraisal theory, that of appraised coping competence, which appears as a result of ongoing interactions rather than of prior appraisal. Also, appraisals often reflect accessed action modules rather than determining such access: many stimuli (e.g., human faces) are appraised as attractive or frightening because they happen to elicit an approach or avoidance tendency. One may well hypothesize (I do) that appraisal patterns are shaped and stabilized by what the action modes happen to be responsive to, which responsiveness thus filters out (and makes demands on) the available information. For this intertwining, too, evidence of various sorts exists, both from self-reports and from experimentally shown effects of ongoing emotional responses upon information pick-up and interpretation. I am of the opinion that both the temporal development and the appraisal-response-reciprocities should become elements of any standard account of emotion generation.

Part of this analysis is the view that "emotions" are not considered as wholes but as more or less integrated sets of components, each of which can be separately influenced by appraisal, and can separately act upon appraisal. I agree with Lewis that this is the only viable viewpoint in any process analysis; it is, I think, shared by most current emotion researchers. Emotion words – fear, joy, anger, and so forth – should be avoided unless it is simultaneously specified which component or combination of components in the given analysis they refer to.

The dynamic systems perspective is obviously a third major aspect of Lewis's treatment. Appraisal components presumably organize into "whole appraisals"; appraisal-emotion amalgams somehow tend to stabilize; and higher-level states or structures emerge that constrain the more elementary processes. Lewis proposes that order in the entire domain of emotional phenomena and appraisal-emotion relationships is much more a function of self-organization than of prewired or even of learned structures. The proposal is enticing. It can accommodate salient structure in the phenomena as well as deviations from such salient structures, and phase transitions from one structure to another. It is a promising perspective, considering its achievements in, for example, shedding light on the variability of facial expressions (Camras 2000) and the emergence of patterns in interactional behaviors (Fogel 1985), and in considering the possibility of self-stabilizing in parallel constraint satisfaction networks. Yet, with regard to appraisal and emotion relationships, the dynamic systems perspective still remains mainly a promise. The notion of "whole appraisals" in Lewis's target article is not defined or substantiated. Whether an appraisal of "threat" is more than a linear combination of its constituent components (except when mediated by the word "threat") remains to be demonstrated, though studies by Lazarus and Smith (1988) and Chwelos and Oatley (1994) represent efforts in that direction. Whether actually occurring appraisal patterns indeed form only a small subset of theoretically possible patterns (as Lewis asserts they do), has, to my knowledge, not yet been examined. Whether appraisals indeed stabilize, and if they do, for what reasons, also awaits evidence. Probably, evidence in these regards is not too difficult to come by. So far, little effort has been devoted to analyzing the variability of appraisal patterns linked to a given emotion class. De Boeck and his colleagues (Kuppens et al. 2003) have recently begun work on that issue.

That these proposals are mostly promises does not detract from their plausibility. Certain appraisal patterns may have more internal coherence than others, or their components may be more related; they do, as patterns, have meaningful relationships to particular action readiness modes because they represent precisely what the action readiness modes aim to modify. Action readiness also may well entrain particular actions and physiological activations, and may even form coordinative structures. Attractors may be shaped on those grounds. The dynamic systems approach thus points to focused research in those directions. But appeal and plausibility are dampened by the question that emerges upon reading the article: What are the phenomena that make analysis in terms of self-organization notions desirable?

The fourth contribution of this target article is its detailed review of neurobiological findings that are relevant to emotion processes. The complex neurobiological interactions parallel the complex interactions described at the psychological level. The analysis arrives at three plausible high-level neurophysiological loops. Surprisingly, considering the author's reservations regarding the appraisal–response distinction (confusingly termed the appraisal–emotion distinction), the loops identify appraisal (here called "object evaluation") and action as distinguishable major functional circuits, together with process monitoring.

Exploring psychological complexity through dynamic systems theory: A complement to reductionism

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Abstract: Dynamic systems theory (DS) provides tools for exploring how simpler elements can interact to produce complex psychological configurations. It may, as Lewis demonstrates, provide means for explicating relationships between two reductionist approaches to overlapping sets of phenomena. The result is a description of psychological phenomena at a level that begins to achieve the richness we would hope to achieve in examining psychological life as it is experienced and explored in psychoanalysis.

It has long been evident that the clarity and testablity reached through the reduction of complex psychological phenomena is achieved at the price of the loss of the richness people hope for from psychological explanations. Whether in terms of emotion theory, neuroscience, psychoanalytic theory, or any number of other efforts to reduce personal experience to underlying mechanisms, it is rare for individuals to feel that the theory has achieved an explanatory power adequate to their own experience. One result has been an ongoing tension between the psychological theories and experiential descriptions. This tension is especially evident in clinical work, where the ever-present search for the bases for complex particular psychological states rapidly comes up against the wall of the limitations of empirically testable theories, to the frustration of patients and therapists alike. As a result many clinicians abandoned reductionist approaches, preferring to catalog the phenomena they have observed and to provide explanations in terms of an expanded commonsense psychology.

For many investigators the study of nonlinear systems suggests a route toward a theory that encompasses more of the richness of experience. Coincident with the first efforts to use feedback controls in the design of any but the simplest mechanical and electronic devices, it became evident that the intrinsic nonlinear properties of feedback-driven systems introduced elements suggestive of the sort of richness of action characteristic of living and thinking beings (Arbib 1972; Wiener 1948; 1950; Wiener & Schadé 1965). Wiener quickly realized, as he worked to develop a general theory of feedback systems, that the complexity and richness of behavior of such systems results from the nonlinear dynamics intrinsic to them. As the richness of the phenomena that could result from nonlinear dynamics became increasingly well understood, several authors suggested that some of the richness apparent in everyday psychology resulted from the operation of nonlinear dynamics (Galatzer-Levy 1978; Langs & Badalamenti 1991; Ruelle 1991; Sashin 1985; Sashin & Callahan 1990; Spruiell 1993). However, while this work promised that answers to the origins of common psychological richness might well lie within the intrinsic qualities of dynamic systems, it yielded no specific models of psychological phenomena, much less models the could be tested. Actual modeling of psychological phenomena began to appear with regularity in the mid- to late 1990s and, as might be expected, has been most successful in such areas as the study of the development of locomotion, in which well-defined parameters can be observed. Lewis cites many examples of such models.

In terms of psychological theories, dynamic systems models of neural networks seemed particularly promising because it is clear that psychological phenomenon must in some sense be an expression of the operation of such networks; and the more specific descriptions of these networks as dynamic systems seemed like good models for some moderately complex psychological phenomena (Rumelhart et al. 1986b; Spitzer1999).

Another approach to the use of DS in psychology has been to suggest that phenomenon that appeared to be mysterious or unreal because no satisfactory explanation for them were available, may seem more unlikely than they are because our common sense has been educated to linear conceptualizations (Galatzer-Levy 2004). For example, emergence and phase transitions are not encompassed well within a linear worldview. The mere appreciation that such phenomena can occur makes it possible to recognize them within the context of psychological investigations.

Lewis's contribution is interesting not only because he provides a plausible bridge between neuroscience and emotion theory, but also because it suggests a method for approaching the integration of seemingly disparate reductionist viewpoints regarding complex phenomena. Freud's efforts to create a discipline based in the neuroscience of his times foundered not only because of the limitations of the field at that time (the neuron had just been discovered), but because he lacked any means to integrate the reduction achieved through neuroscience modeling and that achieved by reference to abstract structures such as the id, the ego, and superego which seemed to have explanatory value as psychological entities. Neuroscience models pertinent to psychoanalysis are in a far better state than they were in Freud's time, and many psychoanalytically relevant phenomena can now be addressed from the point of view of neuroscience (Solms & Turnbull 2002). The discipline of neuropsychoanalysis has emerged complete with its own journal, and interesting correlates between brain and complex psychological function have been suggested. However, models integrating the regularities described in psychoanalytic psychology with brain functioning remain largely to be developed. Lewis's iterative approach would seem to be applicable in this situation as well is in the study of emotion theory.

Although dynamic systems theory clearly shows that surprising configurations can emerge within systems that seem improbable and incomprehensible to our linearly trained "common sense," this rich picture of potential worlds must be carefully distinguished from that which has been systematically demonstrated. The history of the study of nonlinear dynamics is full of instances in which investigators confused plausible similarities between observed phenomena and mathematical models with actual demonstrations that those models encompassed the phenomena. Therefore, it seems prudent to be suspicious of verbal arguments about what are essentially mathematical models. Lewis is careful to point this out. Nevertheless, repeated recognition of this limitation of the methodology, as it is currently used, is essential if investigators are not to fall prey to the trap of believing that they have demonstrated more than they in fact have. However, with this word of caution, it would seem that Lewis has hit upon a method that can be extended to the exploration of complicated psychological phenomena and the several possible reductions that can often be found for those phenomena.

START: A bridge between emotion theory and neurobiology through dynamic system modeling

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Abstract: Lewis proposes a "reconceptualization" of how to link the psychology and neurobiology of emotion and cognitive-emotional interactions. His main proposed themes have actually been actively and quantitatively developed in the neural modeling literature for more than 30 years. This commentary summarizes some of these themes and points to areas of particularly active research in this area.

Lewis's stimulating account of data and concepts concerning emotional and cognitive-emotional processing claims that "there is simply no overarching framework available, to date, for synchronizing psychological and neural perspectives on emotion," and that "dynamic systems ideas . . . have never been applied to developing such a framework" (sect. 1, para. 5), before proposing that dynamic system modeling can offer "a common language for psychological and neurobiological models" (target article, Abstract). Lewis frames his proposal after asking "why do the psychology and neurobiology of emotion remain largely isolated?" (sect. 1, para. 1). His own proposal is, ironically, an example of this isolation, for he has ignored the most developed neural models of emotion and cognitive-emotional behavior, which have been building such a framework for more than 30 years. Lewis provides no quantitative models, but this ignored framework does.

All of Lewis's concepts of "nested feedback interactions, global effects of neuromodulation, vertical integration, action-monitoring, and synaptic plasticity . . . modeled in terms of both functional integration and temporal synchronization" (Abstract) are explicated in these neural models of emotion and cognitive-emotional interactions, and are used to explain and predict many behavioral and brain data. When I published my first articles in this area (Grossberg 1971; 1972a; 1972b; 1974; 1975; 1978), there were, as Lewis notes, divisions in the field that prevented an integration of psychological, neural, and modeling perspectives. Since that time, however, the connectionist and computational neuroscience revolutions have occurred, and renewed interest in behavioral and neural modeling and models of the type that Lewis espouses have been published throughout the mainstream literature (e.g., Brown et al. 1999; 2004; Carpenter & Grossberg 1991; Commons et al. 1991; Fiala et al. 1996; Grossberg 1980; 1982a; 1982b; 1984a; 1984b; 1987; 1988; 2000a; 2000b; Grossberg & Gutowski 1987; Grossberg & Levine 1987; Grossberg & Merrill 1992; 1996;

Grossberg & Schmajuk 1987; 1989). My remaining comments summarize aspects of the models that develop Lewis's goals.

The START (Spectrally Timed Adaptive Resonance Theory) model (Grossberg & Merrill 1996) synthesizes three models: a CogEM model, an ART model, and a Spectral Timing model. The CogEM model describes how cognitive and emotional processes learn through reciprocal interactions to focus attention on motivationally desired goals, and to release appropriate actions to realize them. The ART model describes how sensory and cognitive representations are learned, focus attention on expected events, and drive adaptive memory searches in response to unexpected events. The Spectral Timing model describes how learning can release actions at times that are appropriate to a given behavioral context. The START model embodies many of the properties that Lewis seeks.

"Positive-feedback and self-amplification" combined with "self-maintaining (negative) feedback" (sect. 3.2.2) are key elements in these nonlinear models. The assertion that "a coherent, higher-order form or function *causes* a particular pattern of coupling among lower-order elements, while this pattern simultaneously *causes* the higher-order form" (sect. 3.2.4, emphasis in original) is a key hypothesis of ART since its introduction in 1976 (Grossberg 1976b; 1978; 1980; 1995; 1999a; 1999b). Indeed, ART clarifies how these different levels code complementary types of information (cf. Grossberg 2000a) which, by themselves, are insufficient to control behavior. ART also proposes how resonant feedback states can lead to "temporal synchronization . . . corresponding to attentional states of expectancy or focused perception" (sect. 5.1, para. 10; cf. Grossberg 1976b; Grossberg & Somers 1991) and how "attentional and evaluative processes . . . must remain integrated for some period of time for [. . .] learning to take place" (sect. 5.5.1). Indeed, this is the main idea of ART: that resonance drives learning. ART also introduces a concept of "vigilance" that can explain "vigilant attention to strangers" (sect. 6.1) (cf. Carpenter & Grossberg 1987; 1991). Finally, ART mechanizes concepts of "intentionality and consciousness" (sect. 3.2.4) and predicts that "all conscious states are resonant states" (Grossberg 1995; 1999b).

Cognitive-emotional resonances of the CogEM model preceded the introduction of ART (Grossberg 1975) and give mechanistic meaning to Lewis's assertions about "a self-amplifying interaction among appraisal and emotion elements" (sect. 3.3.1) so that "emotions guide the focus of attention . . . to those features that are emotionally relevant (sect. 3.3.2). Indeed, CogEM models how attentional blocking can filter out emotionally irrelevant cues and focus motivated attention upon motivationally relevant ones (Grossberg 1982a; 1982b; 1984b; Grossberg & Levine 1987; Grossberg & Merrill 1996), clarifying how motivated attention provides a "beam of attention . . . focused on whatever is emotionally compelling" (sect. 4.3.3). Lewis cites Damasio's (1999) book to describe the "affective feeling of emotion" (sect. 4.3.4). The Damasio model is a heuristic version of CogEM (Grossberg 2000b). As in ART's sensory/cognitive resonances, CogEM cognitive/emotional resonances provide the "enduring couplings [that] seem necessary to strengthen the connections responsible for learning" (sect. 3.3), notably connections underlying conditioned reinforcer and incentive motivational learning (e.g., Grossberg, 2000a; 2000b). Orbitofrontal cortex and amygdala (cf. sect. 4.2.2) are highlighted in CogEM learning processes (Grossberg 2000b), which clarify how "ongoing emotion regulation implies continual recruitment of orbitofrontal evaluation by amygdala associations, thus stabilizing the activities of both structures" (sect. 6.2) and settling into "a lasting mood-like state" (sect. 6.2). In both ART and CogEM, several different types of nonspecific arousal and neuromodulatory functions are described that are consistent with Lewis's review. Finally, the claim that "emotion theorists restrict their analysis to the effects of clinical traits on emotion and appraisal" (sect. 6.3) is not correct. The reverse direction has been used to clarify symptoms of mental disorders such as schizophrenia and attention deficit disorder (Grossberg 1984a; 2000b).

These long-standing results contradict Lewis's claim that, concerning "self-organizing states of coherence, there is as yet no mechanism to relate that coherence back to component interactions" (sect. 5.3), or that "the mechanism of this meta-integration is unknown" (sect. 5.3). I would argue, instead, that convergent psychological and neurobiological data are starting to confirm long-standing predictions about how these mechanisms work; see, for example, Raizada and Grossberg (2003).

Lewis also discusses how emotional processing may mediate the learning of plans and actions, including the role of dopamine (e.g., sect. 5.4), but does not note that action processes may obey laws that are complementary to those of perception, cognition, and emotion (Grossberg 2000a). Progress towards quantitatively explaining behavioral and neurobiological data about how animals and humans learn actions under the guidance of reinforcing events has also been made (e.g., Brown et al. 1999, 2004; Fiala et al. 1996).

In summary, Lewis provides an excellent introduction to a useful direction for emotion research to follow. He regrettably misses the most-developed models that realize his stated goals, and therefore the brain design principles and mechanisms that can turn his goals into working science. I hope his article will help readers to better understand such models.

Brain, emotions, and emotion-cognition relations

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Abstract: Lewis makes a strong case for the interdependence and integration of emotion and cognitive processes. Yet, these processes exhibit considerable independence in early life, as well as in certain psychopathological conditions, suggesting that the capacity for their integration emerges as a function of development. In some circumstances, the concept of highly interactive emotion and cognitive systems seems a viable alternative hypothesis to the idea of systems integration.

Lewis's significant target article shows the usefulness of dynamic systems theory (DS), particularly the principle of self-organization, in linking emotion theory to the neurobiology of emotions. His exposition of the processes that link emotion feelings and cognition resembles that described by other theories (Izard 1977; 1993; Magai & McFadden 1995). However, he advances recent research and theory by explicating interactions at the neural, affective, and cognitive levels and by treating the gamut of issues relating to emotion-cognition relations. His analysis of the neural systems of emotions and appraisal helps to explain the coupling and veritable integration of thought/memories, emotions, and actions or action tendencies into personality traits. Yet, significant questions remain.

Contextual restraints on integration. When Lewis asserts that emotion and cognition are "parts" that become integrated through interaction, he implies that they become a whole, a unity. Indeed, it does appear that emotion and cognition act in unison in behavior driven by dispositional emotionality. Dispositional emotionality is exemplified in enduring affective-cognitive structures or emotion traits in which a particular emotion feeling and a particular set of thoughts have become functionally integrated (Izard 1977; Magai & McFadden 1995). Functional integration means that the feeling and the associated pattern of thoughts coexist, operate, and interact harmoniously and in synchrony. It is exemplified in the happiness-prone individual who even in difficult situations typically thinks optimistically, expresses hope, and engages in decisions and actions commensurate with a happy feeling-thought pattern. However, such integration does not produce a gestalt in which emotion has lost its distinctive qualities. The individual still experiences both the feeling of happiness and the positive thinking characterized by optimism and hope, albeit in apparent synchrony. This outcome of the harmonious interaction and reciprocal influences of emotion and cognition appears consistent with the concept of the functional integration of the two types of systems.

However, situations in everyday life often elicit appraisals and emotions which do not cohere and operate synchronously through adaptive emotion traits or other mechanisms. In these situations cognitive appraisal and emotion operate as separate systems that may or may not interact harmoniously to produce desirable outcomes. Lewis seems to have implicitly acknowledged this point when he refers to the end product of emotion-cognition interactions as an amalgam. In an amalgam, the parts retain their separate identities and functions. Moreover, inter-system interactions may prove effective without leading to systems integration. Fear-regulating thoughts (and speech) to help conceal the signs of fear from threatening and dangerous individuals illustrates an effective interaction of emotion and cognition without integration. In such a situation, an integration of emotion and cognition in which fear feelings color speech and other forms of expressive behavior may prove maladaptive.

Emotion-cognition integration as a function of development. Evidence suggests that the emotion system involved in emotion-cognition interactions may in certain situations have privileged communication lines that enable it to exclude or override cognitive input and preempt action systems. Data from studies of developmental changes in emotions and emotion-cognition relations in early development suggest that emotions and cognition operate with considerable independence during early development. For example, infants lack the ability to exercise cognitive control of emotions in stressful situations. Pain or separation activates negative emotions that continue at high levels of intensity, despite parental efforts at comforting (Izard et al. 1987; Shiller et al. 1986).

Nevertheless, infants show individual differences in the amount of negative emotion they display during stress, and 1.5-year-old toddlers' negative emotion expression during stress predicted their scores on the personality trait of Neuroticism at age 3.5 (Abe & Izard 1999). In both children and adults, negative emotions essentially constitute the trait of Neuroticism (Izard et al. 1993; Watson & Clark 1992). Data like these raise the question of whether emotion is dominant in such traits. They also raise the question of whether these traits can drive behavior mainly with emotion motivation and involve little or no cognitive control. In general, the socialization of emotion and the development of self-regulation of emotion, which appear to be deficient in individuals high on trait Neuroticism, are the keys to the child's transition to a greater capacity to exercise cognitive control of mood and behavior.

Psychopathological conditions and the functional dissociation of emotions and cognitive control. Both autism spectrum disorders and psychopathy have empathy-related deficits as primary characteristics, and, therefore, are logical candidates for an investigation of the dissociation of emotion and cognitive systems. In attempting to explain autism spectrum disorders, researchers have proposed a theory in which systemizing is dominant and empathizing is severely underdeveloped (Baron-Cohen 2003). In support of this possibility, a recent brain imaging study shows that autistic patients showed less activation of the amygdala and more activation of temporal lobe structures during an emotion recognition task (Baron-Cohen et al. 1999). This study and other evidence of amygdala processing deficits in autism suggest that emotion processing systems are less well-developed in autistic patients, and higher order cognitive processing is used as a compensatory systemizing strategy.

Amygdala deficits are also primary in psychopathy, and psychopaths appear unable to pair stimuli in the environment that are generally considered distressing with cognitive representations of moral behavior (see Blair 2003). However, unlike people with autistic spectrum disorders, psychopaths do appear able to succeed at theory of mind tasks, likely because they can master the cognitive aspects of empathy (Richell et al. 2003). Thus, the dissociation of cognitive and emotional systems is especially striking in psychopathy because cognitive processing of others' emotions is intact, and this ability is often used for personal gain. However, the cognitive understanding of others' emotions is not integrated with emotion-related autonomic responses and empathic behaviors, and this dissociation is clear in neurological measurements of intact (orbital prefrontal cortex) versus impaired (amygdala) brain regions. Are the separability and relatively independent functioning of emotion and cognitive processes that characterize autism and psychopathy categorically different from those of other psychopathological and normative conditions, or different in degree?

Brain injury and the dissociation of emotion and cognition. Research with brain injured patients reveals with remarkable clarity that emotion and cognitive systems have distinct functions in learning, decision making, and actions, and that emotion does not merely add color or tone to cognitive processes (Bechara et al. 1995). Emotions determine choices and actions on some occasions and no amount of cognition can replace the functions of emotions in decision making. Bechara et al. (1997) compared the performance of patients with lesions in the orbitofrontal cortex and normal controls on a card game that offered options of conservative and risky decisions. Conservative decisions (choosing cards from the "good decks") led eventually to a positive outcome (winning game money) and risky decisions (choosing from the "bad decks") led to negative outcomes (big losses of game money). Even after the orbitofrontal patients fully comprehended the consequences of their actions, they still made disadvantageous choices that resulted in losses, presumably for lack of anticipatory arousal and emotion information. Control participants experienced emotion arousal on a number of trials before they fully ciphered emotion information into the decision-making process, suggesting that the emotion and cognitive systems of the normal controls operated quite independently for a while. Also, normal participants who never acquired an understanding of the game (or reached the "conceptual level") still made advantageous choices. Presumably, they did that on the basis of emotion information that was not integrated with cognition at the conscious level. Results for the patients and controls taken together suggest that on a given occasion, emotion and cognitive systems may first operate independently and then interactively or integrally. The concept of highly interactive systems seems to explain the end result for the normal controls (mainly conservative and advantageous decisions). At the least, this study shows that in the course of acquiring a response strategy for risky situations, the integration of cognitive and emotion systems does not occur immediately or simply as a function of emotion arousal. It takes time. During this time emotion and cognition interact and influence each other reciprocally.

In another experiment, patients with orbitofrontal damage not only failed to anticipate the consequences of disadvantageous choices, they demonstrated the firmness of the separation of cognitive and emotion systems by not reporting regret following feedback about their mistakes or poor choices (Camille et al. 2004). Evidence also suggests that the anterior cingulate cortex makes preconscious decisions about the desirability of outcomes (Gehring & Willoughby 2002). One could argue that emotion drives such decisions. No one has shown how they could result from the influence of cognitive control when the decisions occur at the nonconscious level.

ACKNOWLEDGMENTS
Preparation of this manuscript was supported by NICHD grant number 1-R03-HD43036-01 and NIMH grant number-21-MH68443.

Where's the example?

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Abstract: Lewis has missed an excellent opportunity to concisely demonstrate that a dynamical system can provide a bridge between emotion theory and neurobiology.

Lewis proposes constructing a bridge between emotion theory and neurobiology by using concepts from dynamic systems (DSs). Our major criticism is that the author has missed an excellent opportunity to concisely demonstrate what he has tried to explain with pages of words. First, we observe that nowhere in this target article are there any examples of a DS. Second, the diagrams given are very schematic, usually consisting of several boxes with lines and arrows connecting them in all possible manners and directions, and yet they lack the specificity needed to construct a DS. Thus these diagrams do not clarify, but rather simply say that "anything is possible." Third, there are no quantitative comparisons given anywhere, so the mathematically oriented reader is left without any means for judging the validity of the ideas presented.

This target article would have been much improved by the inclusion of just one example of a DS. Ideally, the exemplary DS would model some simple feature of emotion theory, which could then be bridged to some feature of neurobiology. Nothing close to this is given in the article. Instead of demonstrating with an example, the author has spent his effort, and pages, attempting to convince others of the workability of his idea. This may be convincing to readers with a strong neuropsychological background, but practitioners of DS would be, like us, mathematically oriented and would find a quantitative example much more convincing.

Although we are willing to believe that it may be possible to use DS to bridge emotion theory and neurobiology, until a specific DS is proposed and is validated as at least somewhat workable by comparison with observations in the real world, there is no assurance that the proposed theory is useful. See Perlovsky (2002) for an example of a step in this direction.

Anything can be modeled by the use of mathematics. Mathematics is arguably nothing more than the use and manipulation of symbols to test ideas and hypotheses. This target article proposes a hypothesis. Any hypothesis could be tested or demonstrated by mathematics. What is needed is demonstration and verification of the hypothesis by comparison with observation.

ACKNOWLEDGMENT
Thanks to Randall Shumaker for his support and challenging words.

On the relationship between rhythmic firing in the supramammillary nucleus and limbic theta rhythm

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Abstract: Lewis emphasizes the role of theta oscillations in emergent coupling among neural subsystems during emotionally relevant tasks or situations. Here I present some recent data on the relationship of rhythmic neuronal discharge in the supramammillary nucleus and the large-scale theta oscillations in the limbic system which provide support to many of his ideas regarding vertical integration in dynamic systems.

There are two structures in the posterior hypothalamus which exhibit theta rhythmic neuronal discharge. The mammillary body nuclei, which only receive descending input from the hippocampal formation, have been characterized in detail in Lewis's target article. I will add some recent observations regarding the other, the theta-generating diencephalic structure, which has direct bidirectional connections with the septohippocampal system. As mentioned in the target article, in rats anesthetized with urethane the majority of neurons in the supramammillary nucleus (SUM) fire rhythmically in synchrony with hippocampal theta rhythm (Kirk & McNaughton 1991; Kocsis & Vertes 1994). As these neurons project to the septum and hippocampus it is generally assumed that their role is to mediate ascending activation leading to hippocampal theta rhythm. The connections between SUM and the septohippocampal system are reciprocal, however, and there is strong evidence that both septum and SUM are capable of generating theta rhythmic activity. It has been shown that theta rhythm may persist in the septum-hippocampus after large lesions in the posterior hypothalamus (Thinschmidt et al. 1995), as well as in the SUM after pharmacological suppression of the septal generator (Kirk et al. 1996).

Activation (electrical or pharmacological stimulation) of the SUM always results in hippocampal synchronization, but SUM neurons may also be synchronized with hippocampal theta when the rhythm does not originate from the SUM. Few data exist regarding the natural behaviors in which SUM activation significantly contributes to limbic theta rhythm. Pan and McNaughton (2002) used a variety of experimental paradigms to study the effect of partial lesions of the SUM on different behaviors in defensive and learning tasks, and tested whether these effects can be related to the known role of SUM in frequency modulation of the theta rhythm (Kirk & McNaughton 1993). They found that SUM lesion and the resulting small decrease in theta frequency did not change the performance of rats in a spatial learning task (water maze), as hippocampal damage would, but the pattern of changes in motivated-emotional behavior (hyperactivity in defensive and operant tasks) appeared, in general, to be similar to those after hippocampal lesions (Pan & McNaughton 2002). This indicates that although SUM discharge may be generally synchronized with hippocampal oscillations during all theta states, including, for example, moving around in the water maze, its functional contribution to limbic theta is limited to emotional behaviors.

The dynamics of coupling between rhythmic discharge in the SUM and the "global" theta rhythm represented by hippocampal field potentials was further examined in urethane anesthetized rats by comparing the direction of influence during theta states occurring spontaneously and evoked by sensory stimulation (Kaminski & Kocsis 2003). The direction of the theta drive between the two structures and its temporal dynamics was analyzed using the method of directed transfer function (DTF). This measure is derived from short-time spectral estimates based on an autoregressive model (Kaminski & Blinowska 1991) and it provides information about the direction of propagation of neuronal activity and its spectral content. It makes use of the asymmetry of the transfer matrix which describes connections between channels. A larger DTF between two signals in one direction as compared with that for the opposite direction indicates an influence of one structure on the other. We found that DTF values were consistently higher for the descending than the ascending direction in the majority of SUM neurons. Significant SUM-to-hippocampus DTF at theta frequency only appeared for short periods, on the background of a dominant descending drive. Only in a few experiments was the ascending SUM-to-hippocampus theta drive found to dominate the relationship between the two structures, but the asymmetry in these cases was also limited to episodes of sensory stimulation (i.e., tail pinch).

During theta states the oscillations in the two structures are coupled so that each SUM neuron fires at a certain phase relative to the hippocampal rhythm. The phase is different for different SUM neurons but when single cells are recorded over several theta episodes their phase is always the same (Kocsis & Vertes 1997). Thus, every time the two oscillators get engaged – that is, switch from non-coherent activity to coherent rhythm – they do so at a certain phase even if the frequency of theta shows significant variations (between 3.7 and 5.6 Hz in our experiments). But what happens if a change in frequency occurs when the two structures are already connected? We examined this question using segments of recordings in which theta rhythmic activity was elicited in anesthetized rats by tail pinch but in which the rhythm persisted after cessation of the sensory stimulus (Kocsis 2000). It is important to note that during such episodes the frequency of theta decreased without an intervening non-theta state. We found that the firing of many SUM neurons followed the hippocampal theta waves with a constant delay (rather than a constant phase), suggesting that during deceleration associated with a shift from sensory elicited theta to spontaneous theta, this group of neurons was driven by a descending input, most likely from the medial septum.

These findings indicate that SUM is only driving field oscillations in the hippocampus during epochs of sensory elicited theta rhythm, under urethane anesthesia, whereas spontaneous theta in SUM is controlled by descending input from the septohippocampal system. This suggests that although during certain states the rhythmically firing SUM neurons work to accelerate the septal theta oscillator, thereby adding to "global" synchronization of the limbic system, in other states (such as after cessation of the stimulus in these experiments) they surrender to the driving of the slower rhythm of septal origin and assume positions entrained by the superordinate oscillatory network.

Emotional-cognitive integration, the self, and cortical midline structures

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Abstract: Lewis discusses the dynamic mechanisms of emotional-cognitive integration. I argue that he neglects the self and its neural correlate. The self can be characterized as an emotional-cognitive unity, which may be accounted for by the interplay between anterior and posterior medial cortical regions. I propose that these regions form an anatomical, physiological, and psychological unity, the cortical midline structures (CMSs).

Lewis discusses the dynamic mechanisms of emotional-cognitive integration and relates them nicely to various neural networks. These include the orbitomedial prefrontal cortex (OMPFC), the anterior cingulate (AC), the dorsolateral prefrontal cortex (DLPFC), and various subcortical regions (hippocampus, amygdala, nucleus accumbens, brain stem/basal forebrain, ventral tegmental area, ventral pallidum). Though quite exhaustive, his overview neglects two important points. First, he neglects what results from emotional-cognitive integration. I argue that the self as emotional-cognitive unity results from the integration between emotional and cognitive function. Second, Lewis almost entirely neglects posterior and medial cortical structures. He includes the OMPFC and DLPFC, but he does not consider the posterior cingulate (PC) or the medial parietal cortex (MPC). I argue that the interplay between anterior and posterior medial cortical regions generates a functional unit, the cortical midline structures (CMSs). The CMSs are suggested to account for emotional-cognitive unity, the self.

Lewis focuses on the mechanisms of integration rather than on their result. Based on my own review of various emotional and cognitive imaging studies (Northoff & Bermpohl 2004), I argue that the self is what results from emotional-cognitive integration. What is called the self has been associated with the following functions: The feeling of being causally involved in an action has been referred as to as "agency" (Farrer et al. 2003; Frith 2002). Moreover, the own self and its body can be located in space resulting in spatial perspectivity (Ruby & Decety 2001). Another process related to the self is called "ownership." This concerns the experience that one's own body and environment are perceived as personal and closely related to one's own self (Damasio 1999). A further function of the self concerns recognition of the own person and particularly of one's own face, which is called self-awareness or self-recognition (Keenan et al. 2000; 2001). The self is also closely related to its own memories, that is, to autobiographical memories that can be encoded and retrieved (Northoff & Bermpohl 2004).

What is the emotional-cognitive thread linking these processes associated with the self? Damasio (1999) speaks of a "core self," which he describes by the continuous conjunction of intero- and exteroceptive stimuli leading to the experience of the self as a unit. I argue that this unit of the self is an emotional-cognitive unity.

I believe that this emotional-cognitive unity is the processing of self-referential stimuli as distinguished from non-self-referential stimuli. Self-referential stimuli are stimuli that are experienced as strongly related to one's own person. They have also been described as "self-related" or "self-relevant" (Craik 1999; Kelley et al. 2002; Northoff & Bermpohl 2004). The self-relevance of a stimulus is not intrinsic to the stimulus, but rather is determined by the individual and personal context in which it is perceived. I suppose that this is accounted for by linking the stimulus to emotions. The more emotional involvement, the more relevant that particular stimulus is for the person, that is, for its self. Cognitive function then allows for distinguishing these emotionally loaded stimuli from non-emotional ones. Such emotional-cognitive integration leads to the distinction between self-referential and non-self-referential stimuli and ultimately to a self as being distinct from other selves.

Lewis's second neglect concerns posterior and medial cortical regions, the PC and MPC. I argue that the neural correlate of the self as emotional-cognitive unity consists in the collaboration between anterior and posterior cortical midline regions (see also Northoff & Bermpohl 2004). These regions form an anatomical, physiological, and psychological unit which I call cortical midline structures (CMS). CMS include the OMPFC, the AC, the dorsomedial prefrontal cortex (DMPFC), the medial parietal cortex (MPC), and the PC.

Anatomically, the various regions within the CMS maintain strong and reciprocal projections among each other. Furthermore, they show a similar pattern of connectivity to other cortical and subcortical brain regions. These mostly include the regions Lewis discusses, the DLPFC, hippocampus, amygdala, nucleus accumbens, brain stem/basal forebrain, ventral tegmental area, and ventral pallidum (Ongur & Price 2000). The subcortical connections may account for top-down modulation of subcortical regions by CMS (see, e.g., Nagai et al. 2004; Northoff 2002).

Physiologically, the CMS exhibit a high level of neural activity during so-called resting conditions such as fixation task (Raichle et al. 2001). They show the highest level of neural activity during the resting state among all brain regions; this has been characterized as "physiological baseline" or "default mode" (Gusnard & Raichle 2001; Raichle et al. 2001). The CMS are involved in various emotional and cognitive processes, all involved in the processing of self-referential stimuli (see Northoff & Bermpohl 2004). The high resting level of neural activity in the CMS may thus be reflected in continuous emotional-cognitive integration, reflecting self-referential processing, and ultimately in ongoing experience of a self as "psychological baseline."

Functionally, the question for the mechanisms of how the different CMS regions are integrated into a functional unit remains. Among others, Lewis mentions effective connectivity and pattern of activation and deactivation as potential mechanisms of integration. Interestingly, both mechanisms have been described in CMS. A recent study (Greicius et al. 2003) observed increased effective connectivity between OMPFC and PC only in the resting state, whereas during cognitive processing it decreased. Some studies have demonstrated coactivation of anterior and posterior cortical midline regions in emotion (Heinzel et al. 2004), social interaction (Iacoboni et al. 2004), and autobiographical memory (see Fink et al. 1996). All of the different tasks involved self-referential processing, which may account for involvement of CMS. Another mechanism for distinguishing the CMS as a functional unit from other regions is the pattern of neural activity. The CMS regions show coactivation among themselves. By contrast, they do not show coactivation with other regions, such as lateral prefrontal regions. Instead, opposite patterns of activity – concurrent activation and deactivation – have been described between these regions (see Bush et al. 2000; Drevets & Raichle 1998; Goel & Dolan 2003; Northoff et al. 2004). Future research may reveal further details about dynamic mechanisms for integrating CMS regions into a functional unit and, at the same time, distinguishing them from other regions.

ACKNOWLEDGMENT
I am grateful to Felix Bermpohl who critically commented on an earlier version of this article.

Emotional dynamics of the organism and its parts

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http://caspar.bgsu.edu/%7eneuro/Faculty/Faculty_jpanksepp.shtml

Abstract: Emotion-science without basic brain-science is only superficially satisfying. Dynamic systems approaches to emotions presently provide a compelling metaphor that raises more difficult empirical questions than substantive scientific answers. How might we close the gap between theory and empirical observations? Such theoretical views still need to be guided by linear cross-species experimental approaches more easily implement in the laboratory.

Credibly "docking" psychological states in neural processes remains a great challenge for psychobiology. In conceptualizing affective states, dynamic systems analysis should be more productive than telephone switchboard and computer models of the past (Ciompi & Panksepp 2004). As I have previously noted (Panksepp 1998a, p. 3), we "look forward to a day when" such topics

> can be encompassed within the conceptual schemes of sophisticated dynamic approaches. The basic emotional systems may act as "attractors" within widespread neural networks that exert a type of "neurogravitational force" on many ongoing activities of the brain, from physiological to cognitive. Unfortunately, at present we can utilize such dynamic concepts only in vague and metaphoric ways.

As Lewis recognizes in this seminal vision set forth in the target article, such compelling conceptual metaphors must now be cashed out empirically. To the degree that Lewis's synthesis generates many falsifiable predictions and supportive new findings, it will have served us well.

Despite advances in human brain imaging, the underlying neural details upon which Lewis builds his theorizing remain largely inaccessible in human brain research. In contrast, animal investigations allow sufficiently detailed access to homologous brain mechanisms, concentrated sub-neocortically, which are essential for emotional feelings (Panksepp 1998a; 2000). However, here is the rub: Cognitive-appraisals, so evident in human emotional mentation, are not readily deciphered through animal models. With as little association cortex as most other animals have, we can question whether their sensory-perceptual abilities can lead to cognitive activity that would resemble human thought. Therefore, how might we dock the human-type cognitive appraisals, which motivate Lewis's analysis, with the type of basic neuro-emotional mechanisms that can only be detailed in animal models?

Lewis proposes five lines of research to evaluate his overarching theory. Might he flesh out his "novel predictions" with the eight foundational principles of self-organization he describes in section 3.2 of the target article?

1. Cortical theta band activity seems to be quite sensitive to both cognitive and emotional processing in both adults (e.g., Klimesch 1999; Krause et al. 2000) and infants (Maulsby 1971), but what might the time-locked indicators of "emotional relevance" be in such studies? Can theta discriminate positive and negative affective relevance? Subcortical theta, which is so important in the overall functions of extended, hippocampus-centered, limbic networks that promote emotional information processing (Buzsaki 2002; Vertes & Kocsis 1997), may not be the same theta that is evident on the human cortical surface (Buzaki & Draguhn 2004; Sederberg et al. 2003).

2. A study of correlations among various brain and peripheral physiologies is a valuable empirical pursuit. What aspects of multidimensional scaling might confirm or disconfirm dynamic system viewpoints?

3. "Vertical integration" is probably best studied in animal models. What criteria would one use to identify recording sites, and what types of prototypic emotions would one seek to contrast? Where does Lewis stand on the issue of emotional "primes"? Affective processes are treated rather globally in the target article. What measures, within dynamic systems schemes, might distinguish one type of emotional response from another?

4. How might we validate that event-related potential changes shortly after perceptual events have any causal relations to thoughtful appraisal processes? If an unconsciously initiated "appraisal" response to a briefly presented stimulus does not exhibit certain event-related potential (ERP) components, would Lewis predict that there will be no resulting consciously perceived attributional process? If so, what neural changes might indicate specific psychological changes?

5. The temporal analysis of emotional episodes is much understudied. It would be stupendous if early childhood ERPs could predict trajectories of the multi-dimensional aspects of affective personality development (Davis et al. 2003), but how might we study the temporal dynamics of such diverse emotional tendencies in the EEG laboratory? At present we do not have compelling data about the natural time courses of emotional episodes.

Clearly, the devil dwells in the methodological and empirical details. It is understandable that impressive unifying visions such as this are bound to be short on such critical dimensions initially, but how do we move from a mere correlational toward a causal analysis? Brain correlates and theoretical functional decompositions, important as they are, will not give us much causal satisfaction (Schutter et al. 2004). How might causal experiments capitalize on the conceptual wealth of dynamic systems approaches, or must we still rely on simpler one-way linear models? If so, how can the analytic and synthetic perspectives be fruitfully merged?

Reductionistic-dissective analyses give us the components that need to be dynamically reconstructed into the whole, but, so far, that can only be achieved in our imagination (Panksepp 2000). When we dissect the many "organs" of the brain-mind, we see that cognitions (the partitioning of external differences) are vastly different species of brain activities than emotions (which "energetically" valuate perceptions and actions; Ciompi & Panksepp 2004). Only when we consider the intact organism, working as a whole, can we claim "that cognition and emotion were never two distinct systems at all." In fact, they can be scientifically distinguished (Panksepp 2003). Even though the liver and kidneys rely on each other completely, if we do not conceptualize their parts well, we cannot learn much about their more holistic, emergence-producing interactions. How might a synthetic dynamic view help us to analyze the necessary parts?

Lewis is correct in his view that a deep scientific understanding of human emotions cannot be achieved without neuroscience. However, a great deal of that understanding must still be reached using traditional parametric approaches that have sustained mind-brain science for more than a century. Such approaches have yielded many causal neurochemical manipulations to be evaluated for their efficacy in modifying the human mental apparatus (Panksepp 1999; Panksepp & Harro 2004). Before we can grasp the global dynamics of entire systems in fragile butterfly nets of empirical measurements, a mountain of work remains to be done using more pedestrian linear approaches. I remain fond of Descartes' third rule of science: *to think in an orderly fashion when concerned with the search for truth, beginning with the things which were simplest and easiest to understand, and gradually and by degrees reaching toward more complex knowledge, even treating, as though ordered, materials which were not necessarily so* (see Williams 1972). Lewis shares a well-ordered image of complexity whose time will come. We will know that has transpired when caravans of relevant empirical findings appear on the horizon.

Not a bridge but an organismic (general and causal) neuropsychology should make a difference in emotion theory

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Abstract: Does Lewis imply that brain processes might be used to replace an as-yet-unavailable substantive organismic neuropsychology? To counteract this reductionist idea I argue for distinguishing between affects and emotions, and discuss a real-life example of implicit emotional appraisal. Failure to use organismic units of processing such as schemes or schemas makes the bridging attempt fall under a reductionist "mereological fallacy."

This is a thoughtful target article that makes important points, but there are problems with its perhaps unintended theoretical reductionism. First, a dynamic-systems framework is not a substantive theory. Rather it is a metatheory, or epistemological stand, from which substantive theories must be constructed. For instance, the author, like many others, does not seem to distinguish between affects and emotions. Basic affects, however, may be innate organismic processes that assign organismic values ("good", "bad") and dispositions (conations) to both experience and organismic states. Emotions, in contrast, are acquired and situated feelings, more complex than affects, which usually combine affective and cognitive aspects (Pascual-Leone 1991; Pascual-Leone & Johnson 2004). Emotions cannot be purely innate, because they often involve an implicit reference to past experience. Failure to make this distinction complicates mapping onto brain processes.

Second, the author intends to advance neuropsychology, that is, a psychological "macro" theory interpretable within the brain. Hard neuroscience, a relatively "micro" theory (neurons, brain structures, networks) founded on neurology is less important for him. Lewis is aware of this problem of "macro" versus "micro" epistemological levels (epilevels), because he repeatedly states a need for more analytical psychological constructs and complains that common psychological terms are too global (cf. sect. 3.4 of the target article). Surprisingly, given these misgivings, the author does not adopt a functionalist construct such as schemes or schemas, which in the brain appear as distributed assemblies of neurons that are co-functional and often co-activated. Schemes and schemas (systems of schemes) are suitable macro-level units for expressing neuropsychological processes (Arbib et al. 1998), which also have a clear psychological formulation (Pascual-Leone 1995; 1996; Pascual-Leone & Johnson 1991; 2004; 2005). Schemes/schemas can be used to analyze psychologically acts, such as the affective appraisals, that involve emotional interpretations (sects. 2.1 and 3.3).

Consider an example from real life. A person suffers an accident as a passenger in a car. In the rain, the car leaves the road, skipping out of control onto wet sloping grass, speeding as it moves, and as it reaches the end of the hill at the river bank, becomes airborne 12 meters and falls into the river, where the passenger (A) and the driver (B) risked crashing into a huge rock. Although, surprisingly, they were unharmed, A kept for years a hard-to-control anxiety and fear reaction whenever she was in a car driven by B, and driving circumstances seemed dangerous (e.g., passing or coming close to another car). This real-life learned emotional reaction could be dismissed as an instance of one-trial classical conditioning (a descriptive label). This would, however, obscure the fact that emotionally colored thinking processes are involved, and the single experience has automatically synthesized within A's brain a complex schema (i.e., a superordinate scheme) that coordinates several other simpler schemes into an overpowering anticipation of danger. This schema might be symbolized as follows: WHENEVER [[A is driven in a car] AND [the driver is B] AND [present driving circumstances are actually dangerous]], ANTICIPATE THAT [a life-threatening car accident is about to happen to A and B]. In this symbolization the words in capital letters indicate the semantic-pragmatic framework introduced by the superordinate (overall) schema. This schema states that whenever the three stipulated cognitive schemes (which we demarcate with brackets [. . .] and describe in English, although they represent nonlinguistic pieces of knowledge) are coexisting together within the situation (i.e., are part of a synchronized collection of schemes currently dominant in A), the highly probable expectation is that a major accident is about to happen.

Notice that the state of knowledge "A is being driven in a car" is also a complex schema involving appraisal of the situation. The state of knowledge "the driver is B" involves an equally complex process. The situational emotional appraisal "present driving circumstances are dangerous" is likely to involve some combination of the three circuits that Lewis outlines in diagram panels 1, 2, and 3 of Figure 3 in the target article. The three schemes just described must coexist, distinctly but simultaneously, within a synchronized field of activation in A's brain, to evoke the overpowering emotion of an impending car accident. They must coexist as dynamic conditions analogous to those of the prior accident experience (this experience is a fourth distinct scheme!).

This example illustrates that many mental-emotional processes involve the simultaneous synchronized activation of distinct schemes that are the basis (conditions) for transfer of the original emotional experience to the present. This is a distal transfer of learning because car, circumstances, road conditions, and so forth are all different: Transfer is mediated solely by the three schemes I mentioned, first coordinated by A during the original accident. The superordinate schema (i.e., WHENEVER [. . .] AND[. . .] AND[. . .], ANTICIPATE THAT[. . .]), was also implicitly formed during this original accident and included – functionally nested within it (this is the very important *nesting relation* among schemes) – the three initial schemes, which later serve as cues to elicit the schema.

This example also illustrates the idea that schemes emerge within levels of knowing (epilevels), and their heterarchical position within these levels can be appraised in terms of the functional, internally consistent, nesting relations that may hold among them. From this perspective of a repertoire such that schemes can be nested into context-sensitive heterarchies, we can define *low cognition or emotion* as the sub-repertoire in which schemes exhibit low epilevels and cannot have many other schemes functionally nested under them (e.g., in sensorial perception, simple conditioning learning, etc.). In contrast, *high cognition or emotion* is the sub-repertoire of schemes that exhibit high epilevels and can have many other schemes functionally nested under them (e.g., in intellective or intellectual schemes, affective or emotive feelings, representational processes, etc.). The (relative) distinction between affects and emotions I made before can now be clarified by saying that low states are motivated by affects or simple emotions, but high states are motivated by more elaborate emotions or feelings – when they are not affectively neutral.

Because the author's main interest is neuropsychological (i.e., mapping of affects and emotions onto the brain), he should not attempt (as he envisages at the end of section 4.4) to abandon explicit psychological definitions and replace them, perhaps in a piecemeal manner, with neurological structures and pathways, even if he uses the metatheory of dynamic systems. A piecemeal way of relating psychological to neurological processes is invalid and detrimental. This common error of directly imputing psychological meaning to discrete parts of the brain organization without passing by a theory of the psychological organism has been called a *mereological fallacy*, because it violates the logical relations of parts to wholes (Bennet & Hacker 2003).

What is needed is a neuropsychological substantive theory: an *organismic* (i.e., general, causal, and interpretable in the brain) *theory* defined at the macro-level of performance, which can facilitate process and task analysis. The author unwittingly is reinforcing the tendency of neuroscientists to work only with fragmented (i.e., regional, not organismic) theories, such as discrete theories of emotional appraisal, working memory, declarative memory, perception, learning, and so on. This is problematic because the brain works as an integrated totality constituted by subsystems that dynamically interact in complex ways.

ACKNOWLEDGMENTS
Preparation of this commentary was supported by a grant from the Social Sciences and Humanities Research Council of Canada. I thank Dr. Janice Johnson for her advice.

The role of frontocingulate pathways in the emotion-cognition interface: Emerging clues from depression

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Abstract: By emphasizing nonlinear dynamics between appraisal and emotions, Lewis's model provides a valuable platform for integrating psychological and neural perspectives on the emotion-cognition interface. In this commentary, I discuss the role of neuroscience in shaping new conceptualizations of emotion and the putative role of theta oscillation within frontocingulate pathways in depression, a syndrome in which emotion-cognition relations are dysfunctional.

In the target article, Lewis provides a wide-ranging and timely theoretical formulation of emotion-cognition relations. By emphasizing (a) bidirectional interactions between appraisal and emotion; (b) lower-order psychological and neural constituents underlying the emergence of emotion–appraisal processes; and (c) large-scale functional coupling through oscillatory neurophysiological mechanisms, Lewis offers a multilevel account of appraisal-emotion interactions, fostering a better integration of emotion theory and neurobiology.

In this commentary, I elaborate on two important points raised in the target article. First, I emphasize how a brain-based approach to emotion and appraisal can uniquely inform and constrain theoretical models of these complex constructs. Second, I comment on Lewis's assertion that "phase synchrony in the theta range may underpin the functional integration of systems mediating appraisal–emotion processes" (sect. 5.4). To this end, I review recent event-related potential (ERP) findings of action monitoring (Luu et al. 2004) and electroencephalographic (EEG) findings highlighting disrupted functional connectivity within frontocingulate pathways in depression (Pizzagalli et al. 2003a).

With respect to brain-based approaches to emotion and appraisal, Lewis discusses definitional problems that have hindered the development of comprehensive theories of emotion. Here, I would like to emphasize two points. First, as Lewis argues, definitions of "appraisal" and "emotion" often overlap substantially, causing formidable conundrums to theoretical approaches based on the assumption that these two constructs have distinct functions and are governed by simple, linear, and unidirectional causal processes (e.g., appraisal as a temporal and causal antecedent of emotion; Roseman & Smith 2001). Second, and more important, the definitional overlap between emotion and appraisal mirrors substantial anatomical and functional overlap among brain regions subserving affective and cognitive processes (see Davidson 2003b, for an extended discussion). That is, many brain regions subserving appraisal processes also participate in emotional functions, and vice versa. This evidence forcefully contradicts assertions that affect and cognition are subserved by separate and independent neural circuits, and speaks against the notion that affect and appraisal are subcortically and cortically mediated, respectively (e.g., Panksepp 2003). As suggested by Lewis and others (e.g., Davidson 2003b; Pizzagalli et al. 2003b), emotion is not a monolithic process but comprises different subcomponents encompassing a distributed network of cortical and subcortical systems. Acknowledging empirical data consistent with this assertion (Phan et al. 2002) has important theoretical consequences, because, as appropriately stated by Lewis, "brain function prohibits any real independence between appraisal and emotion" (sect. 5). In sum, although Lewis's overview of neural substrates underlying appraisal and emotional processes is neither comprehensive nor new, a reconceptualization of these substrates in terms of dynamic systems is indeed useful for stressing that the brain's anatomy places important constraints upon psychological theories of emotion and its relations to cognition. Emerging brain-based approaches to the study of depression have similarly underscored not only the synergy between emotional and appraisal processes, but also the utility of a neurobiological framework to parsing the clinical heterogeneity of the disorder (Davidson et al. 2002; Pizzagalli et al. 2004).

My second set of comments pertains to the hypothesis that phase synchrony in the theta range may play a critical role in the functional integration of appraisal–emotion processes. Specifically, Lewis predicts that theta synchronization across the amygdala, hippocampus, anterior cingulate (ACC), orbitofrontal (OFC), and prefrontal (PFC) cortices may "underpin the functional integration of systems mediating appraisal–emotion processes" (sect. 5.4). In humans, empirical evidence for this hypothesis is very limited, but recent findings provide promising support. First, a recent ERP study has shown that the error-related negativity (ERN) – an ERP peak occurring 50–100 msec after the commission of an error – was largely explained by transient phase-locking of midline theta activity to the error responses within distinct frontocingulate regions (Luu et al. 2004). This finding replicated and extended a prior report that error monitoring and evaluative feedback engaged dorsal and rostral ACC sources oscillating within the theta range (Luu et al. 2003). As Luu et al. (2003) proposed, these findings indicate that action regulation mediated by the ACC is associated with entrainment of frontocingulate pathways, consistent with the general framework of Lewis's model.

A second, albeit more indirect, line of evidence suggesting that large-scale corticolimbic synchronization is crucially involved in the emergence of emotion-appraisal processes can be derived from recent findings in major depression, a clinical condition in which coordination of these states is dysfunctional (Mineka et al. 2003). In a recent study, Pizzagalli et al. (2003a) found that baseline theta activity within ACC and PFC/OFC regions was functionally coupled for control, but not depressed, subjects. In healthy controls, this functional connectivity within frontocingulate pathways is in line with anatomical data suggesting that the ACC has reciprocal connections with the dorsolateral PFC and OFC (Barbas 1992; Petrides & Pandya 1999). Disrupted functional connectivity within frontocingulate networks in depression is intriguing, particularly in light of evidence reviewed in the target article and elsewhere (Bush et al. 2000) indicating that the ACC is critically implicated in monitoring conflicting response demands, detecting errors, and evaluating the emotional significance of events, and may thus be a site of convergence and integration between affective and cognitive processes. The fact that functional connectivity within frontocingulate pathways emerged for the theta band (6.5–8 Hz) is consistent with the hypothesis that theta may serve a gating function for the information processing flow in corticolimbic limbic regions (Vinogradova 1995; Luu et al. 2003; 2004), thereby providing the necessary neurophysiological substrates for the emergence of adaptive emotion-appraisal processes, as Lewis discusses.

In sum, using a theoretical framework inspired by emerging neurobiological concepts and findings, Lewis proposes a reconceptualization of emotion-cognition relations that emphasizes nonlinear interactions between their psychological and neural constituents, ultimately giving rise to a unitary phenomenon. Large-scale corticolimbic theta synchronization is proposed as a putative neurophysiological substrate giving rise to a coordinated integration of emotion and cognition. Because the strength of any theoretical account lies mainly in its predictive validity, empirical work is now needed to test hypotheses derivable from this model, including its extension to psychopathology.

ACKNOWLEDGMENT

Preparation of this article was supported by NIH Research Grant R01MH68376 funded by the National Institute of Mental Health.

Characteristics of anger: Notes for a systems theory of emotion

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Abstract: Although emotion may subserve social function, as with anger-maintaining dominance, emotions are more than variant cognitions. Anger promotes risk-taking, attention-narrowing, and cognitive impairment. The proposition that appraised "blameworthiness" is necessary for anger excludes young children's anger as well as adults' pain-induced anger. To be complete, any systems model of anger must account for its temporal characteristics, including escalation and persistence.

Lewis's ambitious and thought-provoking overview interweaves the psychology and affective neuroscience of emotion. This commentary advances the discourse by focusing specifically on the emotion of anger.

1. Emotion is not cognition. Emotional processes are not just another cognitive problem-solving option. The term "emotion" stems from the same medieval French root as "motion" and connotes the experience of movement; emotion can move someone to incur risk that would not otherwise be tolerated and to ignore pain that might not otherwise be endured. Although anger can function to maintain social dominance, this is not the same as, for example, a coolly plotted political strategy. Anger provides the motivation for the "commitment to aggression" (in Bronstein's [1981] felicitous phrase), that is, for the ability to sustain the costs, but it does so at the price of reducing self-control, restricting attention, and degrading cognition (cf. Zillman 1994). Cross-culturally, men see anger as a way to seize control of a situation whereas women experience anger as a loss of control (e.g., Astin et al. 2003; Campbell & Muncer 1994; Ramirez et al. 2001). The danger in viewing emotion as just another cognitive process lies not in the potential unemployment of some emotion theorists, but in obscuring emotion's special nature.

2. Appraising appraisal. Lewis's account of appraisal in generating Mr. Smart's road rage is so persuasive that it might convince Mr. Smart himself. However, such accounts may be "just so" afterthoughts. Some evidence suggests that anger can arise first and the angry individual then looks for someone or something to blame (Keltner et al. 1993; Quigley & Tedeschi 1996). The proposition that true anger occurs only in response to a provocation that has been appraised as "blameworthy" (Ortony et al. 1988) can be challenged through reductio ad absurdum because it would exclude anger that, for example, arises from acute or chronic pain (e.g., Bruehl et al. 2002; Gelkopf 1997).

The claim that attribution of blame is a necessary aspect of anger is particularly troublesome in throwing out the angry baby with the bathwater. The expression (and presumably experience) of anger begins in the first year of life. Mothers perceive "hard" or "forceful" cries, red face, arching and undirected kicking as indicating anger in infants by 3 months of age (Klinnert et al. 1984). Similarly, naïve judges reliably identify infants' anger expressions in the absence of contextual information (Stenberg & Campos 1990; cf. Oster et al. 1992). There is general agreement that facial expressions of anger are distinguishable from more generalized distress between 4 and 6 months of age (e.g., Stenberg et.al.1983). Izard and Malatesta's (1987) claim that anger can be distinguished as early as age 2 to 3 months is supported by observations that infants as young as 2 months who learned to pull a lever for pleasant stimulation significantly increased their angry facial expressions in the extinction phase of the task (Lewis et al. 1990).

3. Autonomic activation and subjective experience in anger. Autonomic activation also differentiates primary emotions from cognitive processes. Anger is associated with rises in heart rate and diastolic blood pressure (the latter distinguishes anger from fear; e.g., Levenson 1992). Earlier claims of anger also being signaled by a rise in finger temperature have not been consistently replicated (e.g., Sinha & Parsons 1996), but more recent evidence suggests a strong association with increased forehead temperature (Drummond & Quah 2001; Stemmler et al. 2001). This association is entirely consistent with the recognition, dating to antiquity, that facial flushing can signal anger (Potegal 2000). Many people experience anger as rising heat, often in the face, which may help explain the consistent reference to a hot liquid under pressure as a metaphor for the subjective experience of anger (Lakoff & Koevecses 1987). Autonomic activation also actively augments the experience of anger and increases the probability of aggression (Zillman 1994). Because hypothalamically controlled autonomic activation is so integral a part of emotion, the hypothalamus should be included in the motivated action loop of the target article's Figure 3.

4. Anger intensity and time course: Escalation and persistence. The anger induced by sudden pain can be almost reflexively rapid. In the domain of social provocation, conflicts between strangers may escalate slowly, but anger between parties known to each other flares quickly (Cairns et al. 1994). Anger's rapid rise is just one aspect of its general tendency to escalate. Even when provocation remains at the same level, anger frequently escalates (e.g., Pruitt et al. 1997). Moreover, once anger has been provoked, it often persists for some time after the provocation has stopped (consult any parent who has unsuccessfully tried to mollify a child throwing a tantrum by offering him whatever it was he initially craved). The term "aggressive arousal" (AA) denotes provocation-induced, centrally mediated increases in attack probability in other animals (Potegal 1994). AA can be induced quickly (e.g., by briefly presenting a same-sex conspecific) and persists well beyond the withdrawal of the provoking stimulus. Like anger, AA has a cost in a maladaptive reduction in anti-predator vigilance. AA may be the anlagen of the action tendency associated with anger in humans.

Any thorough model of emotion must account for time course. Temporal persistence is a motif of amygdala function, even at the neuronal level (Potegal et al. 1996). However, the rapid rise and slower fall of anger may be shaped by processes beyond the usual neuronal interactions; for example, yet-to-be-investigated forms of potentiation may underlie the escalation and persistence of AA (Potegal et al. 1996). The amygdala regulates and prolongs motivated behavior through the hypothalamus, which controls not only autonomic concomitants of aggression, but some of its motor patterns and motivational aspects in humans, as well (e.g., Weissenberger et al. 2001). These are additional reasons for including the hypothalamus in the motivated action loop of Figure 3 in the target article. According to Lewis, temporal characteristics might also arise from the "self-amplifying" positive feedback among amygdala, anterior temporal, and orbitofrontal cortices. If so, the reciprocal inhibition between amygdala and dorsolateral frontal cortex (Drevets & Raichle 1998) may explain the decline in dorsolateral frontal cortex-mediated cognition during high levels of anger. To explore these ideas, a reliable, moment-to-moment measure of anger intensity is required (cf. sect. 2.2 of the target article).

5. Quantifying anger. Although the intensity of angry facial expressions can be estimated reliably (Hess et al. 1997), their dynamic range is unknown and they are methodologically difficult to capture. Even here in the 21st century, psychologists still estimate anger from subjective self-reports (e.g., Hoeksma et al. 2004). Peihua Qiu and I have been able to model the overall trajectory of anger based on the time courses of the individual angry behaviors objectively observed in tantrums (Potegal & Davidson 2003). The single latent variable, Momentary Anger, which drives all the individual angry behaviors, would be a suitable output variable in a dynamic systems model (Qiu et al., submitted).

Amalgams and the power of analytical chemistry: Affective science needs to decompose the appraisal-emotion interaction

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Abstract: The issues addressed in this commentary include: (1) the appropriate conceptualization of "appraisal"; (2) the nature and unfolding of emotional episodes over time; (3) the interrelationships between the dynamic elements of the appraisal process and their effects on other emotion components, as well as repercussions on ongoing appraisal in a recursive process; and (4) the use of brain research to constrain and inform models of emotion.

In this BBS target article, an admirable tour de force of scholarship, Lewis presents a formal model of appraisal-emotion relationships and reviews relevant evidence from neurobiology. We found many points in this article with which we agree wholeheartedly, but there are a few major issues on which we beg to disagree. For example, we feel that Lewis unduly equates the psychology of emotion with narrow conceptions of appraisal theory published more than a decade ago and fails to recognize the contribution of cognitive neuroscience to emotion theory (see Davidson et al. 2003; Kosslyn & Koenig 1995; Lane & Nadel 2000; Scherer 1993a; Scherer & Peper 2001). Although Lewis acknowledges that several emotion theorists have proposed appraisal-emotion interactions based on nonlinear dynamics and bidirectional causality, he suspects that the protagonists treat this as "an interesting diversion from more classical modeling" (sect. 2.2 of the target article). It is true that attempts to describe emotions as episodes of subsystem synchronization driven by nonlinear appraisal processes (Scherer 2000), and to specify hysteresis functions in integration models (Scherer 2004), have not progressed beyond a preliminary stage of modeling. Unfortunately, much of nonlinear dynamics theorizing, including the current target article, does not lend itself readily to designing appraisal experiments and analyzing multimodal data. Here we focus on four major issues:

1. The conceptualization of the appraisal process. Google finds 6,700,000 entries for the word "appraisal." Undoubtedly, Lewis's components of appraisal (perception, attention, evaluation, and reflection; see his Fig. 1) are involved in many of these instances. In contrast, appraisal theorists use the term in a more restricted fashion, specifying the *criteria or dimensions* which are constitutive for emotion elicitation and differentiation through event appraisal. These essential elements of appraisal theory are lacking from Lewis's account and readers unfamiliar with the appraisal literature are unlikely to fully comprehend what the discussion is all about. Evidently, the appraisal of these criteria involves *cognitive structures and mechanisms* such as attention, memory, problem solving, and self-representation (Scherer 2001), including multiple levels of processing (Leventhal & Scherer 1987). Appraisal theorists will need to pay greater attention to these cognitive mechanisms – in particular to the executive functions (see Fig. 5.3 in Scherer 2001) – but Lewis's rather general discussion of such "appraisal components" as "evaluation" adds little to our understanding.

2. The definition of emotion. Lewis adopts the componential view of emotion as advocated by appraisal theorists (Frijda 1986; Scherer 1984). However, the components he identifies in his "skeletal model" in Figure 1 and in the text – such as, "arousal," "feeling tone," or "attentional orientation" – are hardly consensual as representative emotion components. The component of *motor expression* is conspicuously absent. The most serious problem of Lewis's account is the lack of a specification on when an emotion begins and when it ends, as well as of the difference between an emotion episode and the non-emotional background of an individual's experience. Lewis (at the end of sect. 2.3) claims that "a process account should demonstrate how constituent processes give rise to a whole appraisal in the first place," and suggests that such an account is presented in his Figure 1. We have trouble understanding how his Figure 1 explains the unfolding of an emotional episode. If appraisal-emotion relationships are to be explored with respect to their circular causality, there must be a way of delimiting the respective episodes in order to avoid the rather unsatisfactory statement that everything interacts with everything else all the time. One solution is Scherer's (1984; 2000; 2001) suggestion to define the onset of an emotion episode as a certain degree of synchronization of emotion components driven by specific appraisal outcomes.

3. The nature of the appraisal-emotion relationship. Appraisal theorists have never denied that motivation and affect have a strong influence on appraisal. Most theories explicitly integrate the motivational state of the individual as one of the major determinants of appraisal outcomes. Obviously this includes emotion components such as action tendencies that have been produced by prior appraisal. A process-oriented account (see Scherer 2000; 2001), assuming constantly changing appraisal due to new information, would seem to cover bidirectional causality over time. Lewis's "skeletal model," lacking concrete mechanisms and predictions, does not provide a viable alternative to existing models. His terminology, with vague concepts such as appraisal-emotion "amalgam" or "whole," and the absence of suggestions for operationalization or experimental designs for empirical study, raises concerns about the epistemological status of the proposal. One senses an underlying reticence to engage in analytical procedures designed to take the amalgam apart in order to understand its nature. Yet, we need to decompose the appraisal-emotion interaction to understand its nature (just as we require analytical chemistry to study metal amalgams). As an alternative model of the dynamic elements of the appraisal process and their effects on other emotion components, as well as repercussions on ongoing appraisal in a recursive process, we suggest the Component Process Model proposed by Scherer (1984; 2000; 2001; 2004). Our Figure 1 presents a combination of Figures 5.1 and 5.2 in Scherer (2001). We feel that this model is sufficiently well specified to allow posing concrete questions about bidirectional appraisal-emotion interactions.

Contrary to Lewis's model, this model allows a detailed consideration of the effects of emotional processes on attention, memory, and other cognitive processes. In particular, it suggests a distinction between (i) an effect of particular *appraisal criteria* on

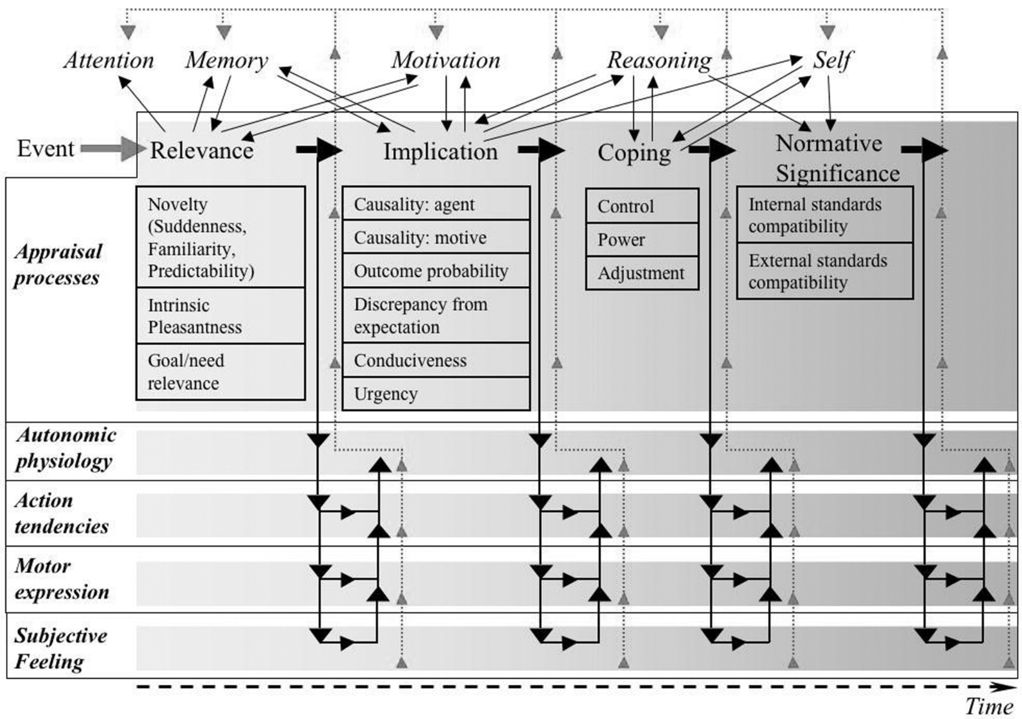

Figure 1 (Sander & Scherer). Comprehensive illustration of the Component Process Model of Emotion (adapted from Scherer 2001).

other cognitive processes and (ii) an effect of particular *emotion components* on these cognitive processes. Moreover, *direct versus indirect* types of emotional effects on appraisal criteria can be distinguished. Direct effects would consist in the modulation of appraisal criteria by other emotion components. Indirect effects would consist in an effect of these components on particular cognitive processes that, in turn, can influence appraisal criteria (see Figure 1). It can be expected that most effects are indirect – in the sense of individual emotion components affecting attention, memory, and other cognitive processes or representations.

4. The role of the underlying neural architecture. Identifying the neural mechanisms subserving emotional processes serves to constrain and inform models of emotion (see Davidson 2000; Sander & Koenig 2002). Unfortunately, Lewis's extensive review of the vast literature concerning the cerebral basis of major cognitive functions and other psychological processes is of limited use for this purpose because the information is often too general to allow inferences concerning specific functional architectures. The treatment of the amygdala is a good example: According to Lewis, the role of the amygdala in the evaluative component of appraisal consists of a "basic pattern-matching function" (sect. 4.2.2). However, a more specific account of the function of the amygdala, as based on recent research, is required to constrain and inform models of emotion. Contrary to the assumption that the amygdala is central to a "fear module" (Öhman & Mineka 2001), presumably supporting a discrete emotion model, patient data and brain imaging studies clearly demonstrate that this structure contributes to the processing of a much wider range of negative affective stimuli (for a review, see Sander et al. 2003). As the amygdala seems also involved in the processing of positive events, it was suggested that it modulates arousal, independently of the valence of the elicitor (e.g., Anderson et al. 2003) – potentially supporting dimensional theories of emotion. However, it has been shown that equally intense stimuli differentially activate the dorsal amygdala (e.g., Whalen et al. 2001), and that arousal ratings in a patient with an amygdala lesion are impaired for negative, but not positive, emotions (Adolphs et al. 1999). These results seem to contradict the view that the amygdala codes arousal irrespective of valence. Converging evidence supports the view that the computational profile of the human amygdala meets the core appraisal concept of *relevance detection* (for a detailed analysis, see Sander et al. 2003), a view which integrates established findings on the amygdala and suggests that it may be central in processing self-relevant information. Although this type of neural architecture can be directly integrated into appraisal models like the one shown in our Figure 1, it is difficult to see how it informs very general models like the one presented by Lewis.

Developmental affective neuroscience describes mechanisms at the core of dynamic systems theory

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Abstract: Lewis describes the developmental core of dynamic systems theory. I offer recent data from developmental neuroscience on the sequential experience-dependent maturation of components of the limbic system over the stages of infancy. Increasing interconnectivity within the vertically integrated limbic system allows for more complex appraisals of emotional value. The earliest organization of limbic structures has an enduring impact on all later emotional processing.

In this target article, as in all of his writings, Marc Lewis describes the essential developmental core of self-organization theory, a theory that fundamentally models the emergence of novel patterns or structures, and the appearance of new levels of integration and organization in existing structures. In light of his contributions and research in developmental psychology, it is curious that he offers little in the way of data from developmental psychology or developmental affective neuroscience that may bear directly upon his model of self-organizing emotional appraisals. In his neurobiology he emphasizes the roles of the amygdala, anterior cingulate, and orbitofrontal cortex. These same structures are also central to Adolphs' (2001) neurobiology of social cognition and Schore's (1997; 2000; 2001) and Davidson et al.'s (2000) circuits of emotion regulation. In two recent books (Schore 2003a; 2003b), I have documented a growing body of research on the experience-dependent maturation of these three limbic structures over early stages of development, which ontogenetically evolve in a subcortical to cortical sequence over discrete critical periods of postnatal brain development. These studies demonstrate that increasingly complex emotional communications embedded in attachment experiences imprint a fixed ontogenetic sequence of early maturing amygdala, then ventral anterior cingulate, and finally orbitofrontal levels of the limbic system (Helmeke et al. 2001; Nair et al. 2001; Neddens et al. 2001; Poeggel et al. 2003; Ziabreva et al. 2003). The organization and increasing interconnectivity of these limbic structures over the stages of postnatal development (the first 2 years in humans) allows for the appearance of more complex systems for appraising emotional value and regulating psychobiological states.

Lewis's fertile model brings the following questions to mind. Could this developmental information about the sequential-stage, experience-dependent maturation of a three-tiered limbic system offer clues about the sequence of psychoneurobiological operations of the trigger phase, self-amplification phase, and self-stabilization phases of self-organizing emotional appraisals in the adult human brain? Could these three amygdala, cingulate, and orbitofrontal limbic levels produce separate subcortical-cortical implicit appraisals (and visceral responses), and would their vertical integration across multiple levels of the vertical limbic neuraxis be involved in what Lewis calls "emergent wholes"? Could "flows of activation" among these subcortical and cortical systems be linking energetic (excitatory and inhibitory synaptic) pathways that are originally sequentially imprinted in critical periods of development of these corticolimbic structures? Would these patterns of energy flow follow the rostral-to-caudal development of expanded arousal-energy systems in the maturing brain? Could each component level process a trigger, self-amplification, and self-stabilization phase, with information reciprocally moving bottom-up and top-down between and within levels of the neuraxis, with such synchronized dynamic adjustments allowing for what Lewis calls "an ongoing state of engagement with the world." Does this mechanism describe Lewis's "vertical integration," and could this more complex interconnectivity of higher and lower components of the limbic system optimally adapt on a moment-to-moment basis to a rapidly changing environment?

Although Lewis makes an important contribution emphasizing lower subcortical mechanisms that regulate the arousal (and energy metabolism) of the higher cortex, I suggest the current appraisal literature has largely overlooked a key contributor to bottom-up emotion processes, the energy-expending sympathetic and energy-conserving parasympathetic components of the autonomic nervous system, and thereby the body. In other words, vertical circuits also include "limbic-autonomic circuits" (Schore 2001). Craig (2002) provides evidence that the right orbitofrontal cortex, the hierarchical apex of the right limbic system, processes information from the ANS and generates the most complex subjective evaluation of interoceptive state, the highest representation of the sense of the physiological condition of the body. This line of research suggests that the higher corticolimbic centers appraise not just exteroceptive information, but also interoceptive information that is critical to adaptive function (see Schore 2003a; 2003b). Furthermore, studies indicate that this same right frontal area is dominant for the appraisal of biologically meaningful exteroceptive and interoceptive self-related information in contexts of threat (Sullivan & Gratton 2002). These data clearly suggest that appraisal mechanisms need to be studied in more than the non-stressed or artificially stressed state, and in states of low and high arousal.

In the target article Lewis also offers some brief thoughts on the roles of the right and left hemispheres in appraisal processes. There is now compelling evidence that the right hemisphere develops in early infancy, before the left, and that the rapid emotional communications and appraisals embedded in attachment transactions imprint the right limbic system (Schore 2003b). I agree with Lewis's conclusion that right hemisphere processing of somatic-affective information precedes left hemisphere semantic processing. In recent work (Schore 2003a; 2003b) I suggest this may reflect early implicit appraisals of the ventral processing stream dominant in the right hemisphere, antecedent to the explicit appraisals of the dorsal stream dominant in the left. This left lateralized (dorsolateral prefrontal cortex) processed explicit information may then be callosally fed back to right orbitofrontal implicit systems. The right orbitofrontal cortex, centrally involved in affect regulation, may then top-down relay this information to lower levels of the right limbic-autonomic neuraxis to cingulate and amygdalar limbic structures and to monoaminergic arousal and hypothalamic motivational centers, which in turn alter CNS arousal and ANS autonomic arousal. This bottom-up adjusted arousal state and somatic-affective information can then be fed back up the neuraxis, altering higher cortical processing. Resonance between the higher and lower levels of the right brain may then allow it to self-organize to an optimal level of complexity and act as "an emergent whole." The right brain has been suggested to be dominant for the ability to maintain a coherent, continuous, and unified sense of self (Devinsky 2000; Schore 1994).

The dynamic systems perspective of emotional processes presented by Lewis also suggests that longitudinal studies of a single system dynamically moving through state spaces may be of more value than averaging group measures. This experimental approach may offer a deeper understanding of emotion psychopathogenesis. Self-organization concepts can also be applied to the field of emotion communication and brain-to-brain intersubjectivity. This integration can lead to an emotion theory that can shift between a one-person and a two-person psychology.

The importance of inhibition in dynamical systems models of emotion and neurobiology

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Abstract: Lewis makes a compelling case for a dynamical systems approach to emotion and neurobiology. These models involve both excitatory and inhibitory processes. It appears that a critical role for inhibitory processes is implied but not emphasized in Lewis's model. We suggest that a greater understanding of inhibitory processes both at the psychological and neurobiological levels might further enhance Lewis's model.

Lewis has made a very important contribution by arguing that antecedent and consequent processes are one and the same. For too long appraisal processes and cognitive consequences of emotional arousal have been considered separate academic domains. It is refreshing to reevaluate this long-held assumption in light of modern neurobiology and to consider the implications of this insight for future research. Lewis's framework also incorporates individual differences within a single model that addresses antecedent and consequent processes. This unifying vision has great potential for expanding our understanding of emotional processes.

A major conclusion of this target article is that traditional distinctions between cognition and emotion break down and no longer appear valid when one considers the neural substrates and the dynamic interactions of the processes in question. This was in fact the fundamental thesis of the volume *Cognitive Neuroscience of Emotion* (Lane & Nadel 2000). It is refreshing to see this fundamental thesis, which breaks from centuries of academic tradition, taken seriously.

In our neurovisceral integration model we too have proposed dynamical systems as a unifying framework in which the boundaries between emotion and cognition are brought down (Thayer & Lane 2000). Lewis certainly has incorporated many aspects of our model into his work. Thus, our models share many similarities including the integration of emotion theory with neurobiology, and the use of a dynamical systems framework. However, there are some important differences as well. One important difference is our emphasis on the role of inhibitory processes. Whereas we share the idea that emotions may be viewed as attractors or points of stability in an emotional state-space, we argue that inhibitory neural processes are critical for the phase transitions that allow a system to move adaptively from one attractor or emotion to another in the state-space. In fact, we would propose that inhibitory processes are crucial for all of the phases that Lewis states make up an emotional interpretation. As noted above, inhibitory processes are associated with phase transitions and are therefore involved in Lewis's trigger phase. We have noted previously that what Lewis calls the self-amplification phase is a result of disinhibition, that is, a release or sensitization of excitatory processes as a result of decreased inhibition. Lewis clearly notes the importance of inhibition for his self-stabilization phase and we have noted elsewhere the importance of inhibition for learning (Thayer & Friedman 2002). Therefore, to complete the connection between emotion theory and neurobiology we feel that an understanding of the role of inhibitory processes is essential. Inhibitory processes provide for the sculpting of neural action at all levels of the neuraxis. The features that make inhibitory processes critical have been progressively explored in neurobiology.

Constantinidis et al. (2002) have recently detailed the role of inhibition in the temporal flow of information in the prefrontal cortex. Using simultaneous single cell recordings in monkeys, they demonstrated inhibitory interactions between neurons active at different time points during the course of a complex working memory task. They noted that the influence of inhibition was particularly evident at transition points in the action sequence, thus supporting the idea that inhibitory neurons are critical for behavioral state changes. Similarly, it has recently been demonstrated in humans that enhancement of GABA-related inhibition may be a very efficient mechanism for synchronizing larger neuronal populations (Fingelkurts et al. 2004). These findings and others (Waldvogel et al. 2000) suggest that a little inhibition at the right time can have a large influence on the behavior of the organism, highlighting the nonlinear nature of the inhibitory control.

At the psychological level, we have also argued for the importance of inhibitory processes. We have noted that perseverative behavior, including worry and rumination, may represent the breakdown of inhibitory processes (Thayer & Lane 2002). Again, neurobiology supports such an idea. For example, in a murine model of anxiety, decreased GABAA-receptor clustering was associated with harm-avoidance behavior and an explicit memory bias for threat cues (Crestani et al. 1999). Mice with reduced GABAA-receptor clustering showed enhanced reactivity to threat stimuli (an effect that was reversed by diazepam), a facilitation of trace conditioning in a fear conditioning paradigm, and a deficit in ambiguous cue discrimination. These findings are remarkably similar to the HR acceleration to and explicit memory bias for threat words, and failure to habituate to neutral words, found in generalized anxiety disorder patients in a conditioning paradigm (Friedman et al. 2000; Thayer et al. 2000).

It should also be noted that whereas GABA is usually an inhibitory neurotransmitter and Lewis states that "GABA is always inhibitory" (sect. 5.2, para. 2), GABA like many neurotransmitters is functionally complex and hence can have excitatory actions (Köhling 2002). Therefore, recognition of the complexity of the neurobiology is also needed and is in fact called for in dynamical systems models.

Taken together, however, it appears that an understanding of the role of inhibition is critical if one is to fully integrate emotion theory, or behavior in general, with neurobiology. In the end we feel that Lewis has made an important contribution by outlining this general framework. It will definitely serve as a catalyst for additional theoretical and empirical work.

Mechanisms of the occasional self

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Abstract: Considered in relation to the component brain systems of appraisal-emotion interactions, dynamical systems theory blurs the divisions that seem obvious in a psychological analysis, such as between arousal, emotion, and appraisal. At the same time, the component brain mechanisms can themselves be seen to be incomplete as units of analysis, making sense only in the context of the whole organism.

In a time when powerful new methodologies are applied to studying human brain activity, the growing evidence base calls for more complex theoretical models. It is time to begin training theoreticians, generalists who forego methodological or empirical specialization to acquire the scholarship, intellectual discipline, and conceptual flexibility necessary for understanding both psychological and neural mechanisms. In this target article, Lewis explores the form that a comprehensive theoretical analysis might take when it is applied to cognition-emotion interactions in the brain.

Perhaps the major point of the article is that the evidence points to complexity in causal relations among the psychological functions of emotion and cognition, and a corresponding complexity in the causal relations among the brain mechanisms underlying those functions. Dynamic systems theory provides metaphors for complex cybernetics, including positive and negative feedback, self-stabilization, and emergent properties. Perhaps more important is that, through Haken's (1977) insights, this line of reasoning shows that the causality in part-whole relations is not always best understood through reductionism, toward mechanistic parts from superordinate wholes. Rather, the functional role that a mechanism plays within an integrated system becomes the embedding context that is also a kind of explanation. Certainly there are proximal causes that can only be understood as originating from the body's physico-chemical substrate. Yet, in a systems explanation, this functional role of a mechanism's operation is as important an explanation as the more elementary physiological and physicochemical processes from which it emerges. In the psychological analysis of appraisal and emotion, Lewis provides important examples of the causal complexity that makes one-sided accounts (emphasizing linear cognitive or emotive causality) unsatisfying.

In the application to neural systems, the theoretical analysis faces a more daunting challenge. The brain systems currently understood to be integral to motivation, emotion, and cognition are not only complex but multiple. With patient scholarship, Lewis surveys the relevant landscape of brainstem, diencephalic, striatal, and corticolimbic circuits, and even here the review is illustrative rather than comprehensive. Nonetheless, it soon becomes apparent that, in every circuit or system surveyed, we find no separation, causal or otherwise, between emotional and motivational functions and cognitive functions. Apparently, psychological function and physiological function are not aligned in any simple harmony, at least not in the way we approach them in psychological theory. The conclusion, then, must be unsettling for psychologists. Whereas the separation of emotion and cognition seems to be obvious to a functional analysis, the complexity of interactions among multiple systems, for arousal, for specific action tendencies, or for more general attentional and memory biases, leads to great difficulty in saying what is cognition and how it differs from emotion. Is this what we expect from a theoretical analysis of complexity, that we begin to lose the meaning of the functional questions that seemed so clear in the beginning?

Maybe it is. Maybe it could even become a necessary step toward sophistication in neuropsychological theory.

More than the loss of familiar functional distinctions, neurophysiology shows us the scope of constituent mechanisms. Lewis's review of neural circuits and processes leads us to confront a scope of phenomena – arousal, drives, memory organization, attentional control – that is much broader than the mental functions that were considered relevant in psychological appraisal theory. Even in his selective illustration of the brain's control systems, each system seems to cross multiple functional levels, leading to the remarkable conclusion that functions such as motives or emotions that we would isolate so clearly in a psychological analysis turn out to be embedded within a larger neurophysiological landscape.

What if we take this embeddedness of mechanisms back to the psychological theory? We would have to conclude that our isolation of emotions as separable functions, or of cognitions as distinct causal entities, may be psychological fictions – fictions that may be useful for academic psychological theory, but are of limited use for a neuropsychological theory that attempts to span both brain and mind of actual people. Rather, we need to fit any mechanism within the appropriate part-whole relations, where the organism-in-environment is the context, the whole that explains the mechanisms. Neither cognitions nor emotions are discrete causal agents that can be separated from the whole of the biological context. This context is formed both by the immediate physiological exigencies, such as environmental threats or visceral need states, and by the enduring residuals of the person's developmental history. In neural terms, the whole of the organism's cognitive-emotive matrix is achieved by vertical integration of multiple systems of the neuraxis. In psychological terms, the embedding whole represents the superordinate construct of the personality, the self.

On the other hand, when we instantiate an organismic construct, like the self, within neurophysiological terms, this construct becomes more tentative than when expressed only in psychological terms. Both cognitive and emotional components of the self are dependent upon their constituent physico-chemical substrates. As a result, the self cannot be assumed as an organizing principle for all mental or neural processes. Rather, it forms a context for only those processes that operate when the constituent self mechanisms are activated. Again, the discipline of thinking in both psychological and neurophysiological terms raises new challenges for the theorist. Not only does it complicate familiar functional distinctions, but it makes clear that dynamical psychophysiological systems are indeed dynamic, such that the embedding context of the ongoing self is an occasional state, emerging only to the extent that the constituent mechanisms are recreated in the continual flux of psychophysiological processes.

Dynamic brain systems in quest for emotional homeostasis

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Abstract: Lewis proposes a solution for bridging the gap between cognitive-psychological and neurobiological theories of emotion in terms of dynamic systems modeling. However, an important brain network is absent in his account: the neuroendocrine system. In this commentary, the dynamic features of the cross-talk between the hypothalamic-pituitary-adrenal (HPA) and gonadal (HPG) axes are discussed within a triple-balance model of emotion.

Lewis's dynamic systems approach on the interaction between brain, emotion, and cognition provides a timely contribution to heuristic reasoning in the field of affective neuroscience. However, his notion that psychologists and biologists cannot communicate on the issue of emotion misses ground. Admittedly, theories are still in their infancy but the first steps towards psychobiological theories of emotion have been set (e.g., Damasio 1998; Davidson 2003a; Panksepp 1998a).

This commentary mainly concentrates on a pivotal emotional network underexposed in Lewis's framework: the endocrine system. Attention is given in particular to the dynamic cross-talk between the hypothalamic-pituitary-adrenal (HPA) and the hypothalamic-pituitary-gonadal (HPG) axes (Viau 2002) and the antagonistic effects of their end-products, cortisol and testosterone, on motivation and emotion (e.g., Van Honk et al. 2003; 2004). Our discussion is framed in a triple balance model (TBM) of emotion, a heuristic which suggests that reverberating neurodynamic affective maps, created on different anatomical levels of the brain, depend in their continuous quest for emotional homeostasis on the fine-tuned action of the steroids cortisol and testosterone (Van Honk & Schutter, in press).

Emotional homeostasis is crucial for survival and a prerequisite for balanced reactions to reward and punishment (Ressler 2004). This homeostasis depends on (1) *Subcortical balance*: The primordial responses of reward and punishment are approach or withdrawal, and in simple animals they are classically illustrated by fight or flight, which is initiated in subcortical affective circuits and controlled by endocrine-autonomic nervous system interactions (Decatanzaro 1999). Millions of years of evolution have sculptured these primordial flight or fight machines into primates with highly complex social emotional brains. (2) *Cortical balance*: In humans, approach and withdrawal provided the rudimentary building blocks for the development of the emotions anger and anxiety. These occur in the behavioral hiatus when actions are delayed and provide for more flexible behavioral tendencies in which the neocortex is heavily implicated. In particular, the left and right prefrontal cortices are subsequently involved in these sophisticated forms of behavioral approach and withdrawal (Davidson 2003a). (3) *Subcortical-cortical balance*: Finally, to secure complete homeostatic emotion regulation, this layered subcortical-cortical system necessarily needed integration, therefore the expansion of the neocortex was accompanied by the emergence of one of evolution's finest yet most vulnerable adaptations, a loosely-coupled brain communication pathway (MacLean 1990). This TBM of emotion is an evolutionary inspired psychobiological heuristic that not only aims to scrutinize the neurobiological mechanisms behind adaptive homeostasis in human social-emotional functioning, but also sets out to predict the maladaptive, pathological consequences of particular imbalances in emotion (Van Honk & Schutter, in press). A crucial hypothesis in the model is that the end-products of the HPA and the HPG axes, the steroid hormones cortisol and testosterone, are pivotally involved in homeostatic emotion regulation through their *antagonistic* action on the balance between the sensitivity for punishment and reward.

This antagonism begins with the mutually inhibitory functional connection between the HPA and HPG axes (Viau 2002). Cortisol suppresses the activity of the HPG axis at all its levels, diminishes the production of testosterone, and inhibits the action of testosterone at the target tissues (Johnson et al, 1992). Testosterone in turn inhibits the stress-induced activation of the HPA axis at the level of both the hypothalamus and the pituitary gland (Viau 2002). The same steroids are also suggested to act by binding to amygdaloid-centered steroid-responsive neuronal networks (Wood 1996) where they regulate and facilitate neuropeptide gene-expression, which changes the likelihood of approach (testosterone) or withdrawal (cortisol) when confronted with particular emotional stimuli (Schulkin 2003).

The antagonistic involvement of cortisol and testosterone in the sensitivity for punishment and reward can be traced on the three balances of our psychobiological model of emotion. (1) *Subcortically*, animal evidence demonstrates that at the amygdala, cortisol-facilitated CRH-gene expression versus testosterone-potentiated amygdalar vasopressin gene-expression results in the expected reversed shift in the balance between the sensitivity for punishment and reward (DeVries et al. 1995; Schulkin 2003). Concurring antagonistic effects of cortisol and testosterone have been observed in humans during implicit or unconscious measures of approach- and withdrawal-related emotions that predominantly depend on subcortical processing (Van Honk et al. 1998; 1999; 2003; 2004). (2) Although the steroids primarily target subcortical affective regions, there is evidence for a relationship between cortisol and dominant right-sided *cortical* asymmetry in young children and nonhuman primates, which accompanies punishment-sensitive characteristics of behavioral inhibition (Buss et al. 2003; Kalin et al. 1998). Contrariwise, recently we found that testosterone administration induces reward-associated left prefrontal cortex activation during the display of erotic movies (unpublished observation). (3) Our *subcortical-cortical* evidence builds on a theory wherein the phylogenetically different brain systems relate to the subcortically generated delta (1–3 Hz) and cortically generated beta (13–30 Hz) oscillations in the electroencephalogram (EEG). Relative increases or decreases in subcortical-cortical cross-talk are computed by correlating the change in power between these bands, and it has repeatedly been demonstrated that elevated subcortical-cortical cross-talk as indexed by EEG is accompanied by elevated punishment sensitivity (Knyazev & Slobodskaya 2003; Knyazev et al. 2004). On the endocrinological level, increased levels of cortisol have been associated with enhanced punishment relative to reward sensitivity and are evidently accompanied by increased subcortical-cortical cross-talk (Schutter & Van Honk 2005). In an opposite fashion, reductions in subcortical-cortical cross-talk after administration of testosterone have been observed in healthy volunteers (Schutter & Van Honk 2004). This *decoupling* of subcortical and cortical processing is argued to indicate a shift in motivational balance from punishment towards reward sensitivity (Schutter & Van Honk 2004).

In sum, an increasing body of evidence suggests that the steroid hormones cortisol and testosterone are antagonistically involved in the modulation of emotional homeostasis on the different phylogenetic levels of the brain. Importantly, this emotional homeostasis is not only subcortically controlled by bottom-up inter- and intra-axes negative feedback mechanisms, but also cortically through top-down psychological regulatory processes (Mazur & Booth 1998). This dynamic steroid hormone regulation of social emotional behavior provides a bridging principle between the psychological and biological domains, and might well prove to be an important neurobiological mechanism in motivation and emotion.

ACKNOWLEDGMENT
This work was sponsored by an Innovational Research Grant (# 016-005-060) from the Netherlands Organization for Scientific Research (NWO).

A dynamic duo: Emotion and development

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Abstract: A dynamic systems (DS) approach uncovers important connections between emotion and neurophysiology. It is critical, however, to include a developmental perspective. Strides in the understanding of emotional development, as well as the present use of DS in developmental science, add significantly to the study of emotion. Examples include stranger fear during infancy, intermodal perception of emotion, and development of individual emotional systems.

Lewis presents a dynamic systems approach to emotion with an emphasis on self-organization of small neurological units and larger social wholes. As is typical of self-organizing systems, he proposes that large complex emotion systems arise from oscillating interactions among smaller and often simpler forms that may have emotional potential. We also have argued that the study of emotion must not veer into a barren, reductionist landscape in which a set of boxes fixed in a linearly organized fashion sit waiting to be opened. We wish only to add some examples from our work that expand Lewis's call and also reintroduce the critical need to include development in any study of emotion, and especially in a dynamic systems (DS) approach to emotion (see also Lewis 2000b). Some of the most outstanding research on emotion is developmental (Izard et al. 1995; Malatesta & Izard 1984; Nwokah and Fogel 1993; Witherington et al. 2001), as is some of the best work using DS principles (Magai & Haviland-Jones 2002; Thelen & Smith 1994). This is no accident: During particular age periods of rapid change (e.g., infancy), one can observe the coaction of a number of systems in real time within a reasonable research time frame. However, across a life span the DS principles are applicable.

A decade ago, we proposed a multicomponent systems approach for understanding the origins and development of emotion (Haviland & Walker-Andrews 1992). Our primary focus was on the socialization of emotion, and our primary example was the emergence of fear of strangers. We argued that stranger fear was not an additive growth function built with "more" cognition, but, in DS terminology, a phase. Further, stranger fear is expressed (or not) due to a number of initial conditions, including the typical infant-caregiver communication patterns that have emerged over time. Since that first article we have added other examples that could both benefit from a DS perspective and contribute support to DS principles.

One example arises from research on infants and their self-organizing patterns of emotion perception. The environment is replete with multimodal and co-occurring information for objects, events, and personal experience. An observer moving through the world sees occluding surfaces, hears transient sounds, may touch rigid objects, and smell and taste various substances concurrently. Information for emotion is available multimodally as well. An angry person may scowl, raise his voice, gesture abruptly, and tense his muscles. The perception of the emotional expression is not merely the sum of each of these components. Rather, the observer perceives a unified multimodal pattern that has unique communicative affordances. Moreover, the presence of multimodal information may facilitate the perception of an event (Bahrick & Lickliter 2000; Walker-Andrews & Lennon 1991). The detection of meaning in an expression develops as the observer's perceptual skills develop, as she gains experience, as she becomes more familiar with a particular person and eliciting situations. Consequently, an adult may recognize that someone is angry by observing gestures alone or attending to the situation, but the young infant appears to need the redundant, extended information. Similarly, the experience of emotion is multifaceted, including kinesthetic, somatosensory, and other modality-specific information. According to Stern (1985), such experience may provide for infants a feeling of deja vue that allows the infant to develop a sense of self as an extended emotional agent. The perception of multimodal information for emotions of the self and of others is an example of how "individual elements or groups of elements lose their independence and become embedded in a larger regime" (sect. 3.2.3 of the target article).

In a second example, fractal patterns have emerged in studies of life-span emotional development (Magai & Haviland-Jones 2002). The social-cognitive emotion system at a point in time shows features of fractal geometry or self-similarity of emotion pattern replicated at lower and higher orders of magnification. Individuals reproduce their unique emotion organizations psychologically. Without examining long-term development of individual change, as is required by DS, such fractal structures would not become apparent. Once established, the fractal patterns tend to organize new sensory information to form a "growing" system that is subject to phase shifts. This newer work on individual development of emotion systems is related to the model described above (Haviland & Walker-Andrews 1992) and a more mathematical visualization of emotion patterns emerging from small and potentially chaotic events – dependent also on initial neurological conditions (Haviland-Jones et al. 2001).

Given our work and that of many others, Lewis may have overstated the case for social emotions systems to be linear rather than self-organizing or dynamic. It is certainly true that, historically, approaches to research on emotion are linear and normative, but developmental theory even in its own infancy dating from Vygotsky or Piaget has been built upon the emerging principles of individual change and self-organization.

Dynamics of cognition-emotion interface: Coherence breeds familiarity and liking, and does it fast

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Abstract: We present a dynamical model of interaction between recognition memory and affect, focusing on the phenomenon of "warm glow of familiarity." In our model, both familiarity and affect reflect quick monitoring of coherence in an attractor neural network. This model parsimoniously explains a variety of empirical phenomena, including mere-exposure and beauty-in-averages effects, and the speed of familiarity and affect judgments.

In the target article, Lewis argues for conceptualizing the interplay between cognition and emotion in dynamical terms. His proposed framework highlights bidirectional links and multiple feedback loops between cognitive and emotional processes. The framework's focus on comprehensiveness and abstract principles spanning different levels of analysis is valuable. However, as a result of this focus, the framework specifies few concrete mechanisms that perform the postulated integration of cognition and emotion. In our commentary, we illustrate the value of the dynamical systems approach by discussing specific mechanisms linking recognition memory and affect.

Titchener (1910) noticed that familiar stimuli elicit a "warm glow." Nearly a century later, a host of studies show that variables that enhance familiarity also enhance positive affect (Reber et al. 1998; Winkielman & Cacioppo 2001; Winkielman et al. 2002). Thus, both familiarity and liking are enhanced by (1) repeated exposure to a stimulus (mere-exposure effect), (2) exposure to category exemplars that converge on a prototype (beauty-in-averages effect), (3) presenting the target with higher clarity or at longer durations, or (4) preceding the target with perceptual or semantic primes. In addition to these commonalities, familiarity and affect are both fast processes. Familiarity judgments are often faster than recognition judgments (Mandler 1980) and liking judgments are often faster than judgments about descriptive attributes (Zajonc 1980).

On the surface, there are no obvious reasons for these commonalities between familiarity and liking. However, things become clearer when memory and affect are conceptualized in dynamical terms as processes occurring in a neural network. In such a network, representations (learned patterns) correspond to attractors, that is, states to which the network dynamics converges (Hopfield 1982; O'Reilly & Munakata 2000). During the stimulus recognition process, each neuron of the network adjusts to the signal coming from other neurons until the network gradually approaches a stable state, an attractor. Typically, the behavior of a network is characterized by a degree of match between the input and output pattern. However, the network can also be characterized by its "volatility" – a number of neurons changing state and the coherence of signals arriving at each neuron. Simulations show that such volatility is different when the network is recognizing known versus novel patterns. When the network is close to its attractor, relatively few neurons change their state because most neurons already match the attractor. When the incoming pattern is novel, however, a large number of neurons change their state. Based on this observation, Lewenstein and Nowak (1989) proposed that the network uses its volatility signal to determine a global familiarity of the incoming pattern. Remarkably, such estimation of whether a pattern is generally "new" or "old" (i.e., proximity to its closest attractor) can occur within the first moments of processing, long before the pattern is actually recognized (sometimes in as little as 3% of the time needed for full recognition). Now, what about affect? Note that the volatility signal also allows the network to quickly estimate the potential valence of the pattern. This is because novelty is a cue to a potential danger whereas familiarity is a cue to positivity – after all, familiar objects have not eaten us yet. It is also important that this rough valence estimate is obtained fast, before the network fully knows what it is dealing with, as it helps prepare immediate avoidance-approach actions.

The proposed conceptualization nicely accommodates the empirical phenomena listed earlier. In the mere-exposure effect, many prior encounters establish a strong memory for a pattern, whereas few prior exposures establish a relatively weak memory. Later, a test pattern with a relatively stronger memory (i.e., stronger attractor) elicits little volatility, and thus is more familiar and liked (Drogosz & Nowak, in press). In the beauty-in-averages effect, converging exemplars create a strong attractor for a prototype, which is recognized with less volatility. Patterns presented with longer duration or with higher clarity are represented by more extreme values of activation, and result in less volatility. Finally, priming pre-activates neurons that encode the pattern, which add up to the activation from the actual target, resulting in more extreme values of activation and less volatility. In sum, according to the proposed computational model, repetition, prototypicality, duration, contrast, clarity, and priming enhance familiarity and liking because all these manipulations reduce the network's volatility and increase its coherence. These changes in volatility manifest early, long before the full completion of the recognition process, thereby accounting for the fast nature of familiarity and affect.

In addition to quick feedback about the valence of the incoming stimulus, the early pre-recognition of familiarity may be used to control the recognition process, so that known stimuli are processed differently than new ones. This may be achieved by linking the outcome of pre-recognition based on monitoring the system dynamics to a control parameter (e.g., network's overall noise level) that influences the later stages of the recognition process. A number of specific models that involve a feedback loop between pre-recognition and the noise level have been proposed. For example, in the original model by Lewenstein and Nowak (1989), unknown patterns raised the noise level, preventing false "recognition" of unfamiliar patterns – a common problem for neural networks. In another example, by monitoring its own early dynamics a network can switch between recognizing known patterns and learning novel patterns (Zochowski et al. 1995). Yet another implementation of this control mechanism allows a network to recognize the emotional quality of the stimulus in the pre-recognition process and use this emotional pre-recognition to facilitate the recognition of stimuli that are relevant to this emotion (Zochowski et al. 1993). This is a concrete exemplification of one of the main feedback loops proposed in Lewis's model: that the early cognitive processes elicit emotion that control further cognitive processing. For an extensive model of how such loops are used in self-regulation, see Nowak and Vallacher (1998) and also Vallacher and Nowak (1999).

In closing, we hope our short discussion of dynamical mechanisms linking affect and recognition memory illustrates the potential of the dynamical approach for providing parsimonious explanations for specific empirical phenomena in the domain of emotion-cognition interaction.

ACKNOWLEDGMENTS
Work on this paper was facilitated by National Science Foundation grant BCS-0217294 to Piotr Winkielman. We thank Marek Drogosz, Tedra Fazendeiro, Poonam Hooda, Yuko Munakata, and Randy O'Reilly for discussion of these ideas.

Author's Response

An emerging dialogue among social scientists and neuroscientists on the causal bases of emotion

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Abstract: The target article developed a dynamic systems framework that viewed the causal basis of emotion as a self-organizing process giving rise to cognitive appraisal concurrently. Commentators on the article evaluated this framework and the principles and mechanisms it incorporated. They also suggested additional principles, mechanisms, modeling strategies, and phenomena related to emotion and appraisal, in place of or extending from those already proposed. There was general agreement that nonlinear causal processes are fundamental to the psychology and neurobiology of emotion.

My response to the commentaries is organized in several sections. The themes of these sections progress from general agreement on the value of a dynamic systems (DS) reformulation of emotion science, to modeling strategies and mechanisms of emotion I did not employ in the target article, to arguments specific to a DS conceptualization, to fundamental questions about the nature of emotion in relation to cognition, and finally to developmental, clinical, and empirical considerations. The arguments of the commentators, with each other and with me, can be seen as bidirectional transactions that give rise to an emergent form – a dialogue that is still consolidating into a new scientific perspective on emotion.

R1. A new way to think about emotion

To take a scientific interest in emotion is a little like acquiring a giant squid for one's aquarium: it would be so much easier to kill it first. Emotion is unruly, powerful, strange, and complicated. It is intrinsically difficult to study. More than any other psychological phenomenon, it resists categorization, its function is not at all obvious, it does not correspond neatly to any subset of the nervous system, and it can be reproduced in the laboratory only in watered-down form. Yet emotion is at the core of being human, and to give up studying it would be to give up understanding human thought, experience, and behavior.

Unfortunately, the solutions arrived at by emotion theory have come quite close to killing it. Emotion has been hitched like a trailer to cognitive appraisal in a one-way causal sequence. How would we know what emotion to have unless cognitive appraisal preceded and directed it? In fact we wouldn't, and keeping emotion alive requires allowing its irrationality. Emotional effects on cognition have also been portrayed in a narrow, artificial way, as biases or distortions in an independent stream of thought, again in a one-way causal direction. The failure to link these two causal arrows, in a bidirectional process that shapes momentary experience as well as development, makes it difficult to capture emotion without killing it. And the failure to see emotion as complex and iterative robs it of its vitality, leaving an inert shell in its place.

In the target article, I highlighted these deficits in mainstream emotion theory and outlined DS principles that frame causality and part-whole relations in more realistic terms. I argued that the causality of emotion does not reside in cognitive appraisal; it resides in self-organizing processes that give rise to appraisal concomitantly. With DS modeling, it appeared that emotion would not have to be killed in order to be studied, and this provided new possibilities for a bridge with neurobiology. The intricate and recursive flow of current and chemicals in the brain, and the convergent synchronization of its rhythms, could instantiate the causality of emotion only if it too were seen to be intricate, recursive, and inherently dynamical. I went on to demonstrate that self-organizing neural processes, mediated by bidirectional and circular causal relations, give rise to emotion and cognitive appraisal at the same time – each a different aspect of an emergent unity.

R1.1. DS constructs and psychological realism

Most of the emotion theorists who wrote commentaries agree that we need to think about emotion in new ways, and most are enthusiastic about the utility of a DS framework and its facilitation of neural modeling. **Frijda** calls the approach taken in the target article "considerably more plausible" than traditional models, and sees it as a template for modeling appraisal processes in relation to emotion. He states that "both the temporal development and the appraisal-response-reciprocities should become elements of any standard account of emotion generation." Frijda has long argued against the conventional "linear model" of appraisal (e.g., Frijda 1993b). Although he has never fully developed a nonlinear alternative, his commentary outlines several points of agreement with my model: (1) appraisals evolve through feedback with emotional response processes, and trigger, self-amplification, and self-stabilization phases can be meaningfully distinguished; (2) appraisals stabilize through feedback with response options, action plans, and action-monitoring; and (3) dynamic systems approaches are useful for retooling emotion theory along these lines.

Izard, **Trentacosta**, **& King** (**Izard et al.**) also find the principles of self-organization useful for understanding the coupling of cognitive and emotional processes, and in recent theorizing Izard and colleagues have considered similar principles (Izard et al. 2000). **Buck** agrees that emotions and accompanying cognitions arise simultaneously and interdependently, and he endorses the notions of self-organization, complexification, and emerging coherence for describing and explaining this process. For Buck, it is time to move away from traditional debates within emotion theory and concentrate instead on the nature of the constituents and their means of interaction. **Ellis** also advocates principles of self-organization and applies them in his own model of emotion and consciousness. If, as he suggests, some predictions in the target article are consistent with both models, their confirmation would support a self-organizational approach that spans multiple perspectives. **Potegal** emphasizes that emotion should not be considered an outcome of appraisal, and **Fabrega** finds my treatment of emotion "highly realistic" relative to conventional psychological theory.

R1.2. DS constructs and neural realism

Pizzagalli and **Thayer & Lane** think that the study of emotion can be much improved by compliance with the constraints imposed by the brain. They eschew the linear causality of conventional models of emotion, and they argue that the traditional compartmentalization of emotional and cognitive systems is untenable from a neural perspective. Pizzagalli and I agree that the definitional overlap between emotion and appraisal reflects functional and anatomical overlap among brain systems, and that this overlap befuddles cause-and-effect models. He likes my use of bidirectional causation, functional coupling or synchronization, and distributed emotional subcomponents that become assembled on-line. Thayer & Lane endorse my efforts to unify the cognitive antecedents and cognitive consequents of emotion, again as demanded by neural realism. They are also very explicit about the benefits of a DS analysis for linking emotion theory and neuroscience, and have pursued a similar course in their own modeling. **Tucker** thinks that contemporary scholarship should pursue general models that span psychological and neural processes of emotion. He reviews the explicit advantage of DS principles for elaborating reciprocal, iterative causal mechanisms as well as Haken's (1977) circular causality. He agrees that this approach to modeling gets at the complexity that is ignored by unidirectional (cognitive or emotional) causal accounts in psychology, resulting in the disconcerting (but revitalizing!) loss of one's definitional starting point.

R1.3. Richness and complexity

Realism is not the only thing sacrificed by linear models. As nicely captured by **Galatzer-Levy**, "the clarity and testability reached through the reduction of complex psychological phenomena is achieved at the price of the loss of the richness people hope for from psychological explanations." He notes that DS modeling allows for richness and innovation in the behavior of all kinds of systems and thus makes plausible what seemed inexplicable on the basis of linear assumptions. With these assumptions discarded, the infusion of richness back into theories of emotion can make them compatible, finally, with our actual experience of emotional life as revealed in psychoanalysis. Galatzer-Levy notes that this direction of theory development and its integration with neuroscience follow an agenda set out by Freud, but with conceptual and methodological tools that were unavailable in his lifetime. I agree with him that a more satisfying interface between emotion theory and neuroscience invites psychoanalytic considerations that have been avoided by mainstream psychology.

R2. Other models and mechanisms of emotion

Although many commentators saw the target article as moving in the right direction, just as many felt I had ignored or underplayed key mechanisms of emotion, and a few argued that I had missed important considerations for modeling these mechanisms. In response, this section moves from general criticisms of the modeling strategy, to alternative mechanisms of emotion, to psychological, neural, and social extensions compatible with the target article.

R2.1. Modeling issues

Barnard & Dalgleish make a case for systemic models of appraisal-emotion at the psychological level of description. They say that my mapping out of global appraisal components such as perception, evaluation, and attention, and my conclusion that the psychological level has little more to offer, ignore the existence of much more sophisticated psychological models that specify interacting parts. These models would presumably provide a more detailed platform for bridging psychology with neurobiology. Although this argument seems persuasive at first, it misses a substantive consideration and a logical step. I do refer to component-system models of emotion-appraisal in section 2.2, but I designate them as information-processing approaches and emphasize their disadvantages, perhaps too glibly. Indeed, the terms suggested by these commentators – "properties of processing resources, varieties of mental representation, and/or mental coding attributes" – fit the rubric of information processing. I argue that these models are mechanistic, hence lacking in realism, and that they remain at the level of interacting parts without explication of part-whole relations. I go on to review process models of appraisal, as a step toward greater realism from within emotion theory, and propose my own process-level account in section 3.3, based on an alternative set of (DS) principles. I can therefore be accused of giving information-processing models short shrift, but not of ignoring them. It would be helpful for these commentators to demonstrate the advantages of such models. Do they really provide a better basis for bridging the psychology and neurobiology of emotion? Are processing resources and mental coding attributes really translatable to types or locations of neural activities? On the logical side, my conclusion that the psychological level of description has little more to offer does not follow my discussion of these models. It follows the presentation of a detailed *systemic* model of my own. My point was that psychological detail can take us only so far, no matter what principles guide the modeling.

According to **Pascual-Leone**, my "failure to use organismic units of processing such as schemes or schemas makes the bridging attempt fall under a reductionist 'mereological fallacy.'" He claims that schemas are the macro units of choice for both psychology and neuroscience, and that they can be used successfully to analyze appraisals. There are two parts to this criticism. What Pascual-Leone calls a mereological fallacy is the blithe mapping of psychological functions onto brain parts. I do use appraisal and emotional "constituents" to fashion a map of neural systems on the basis of function. However, I go to great pains to demonstrate that each constituent/function corresponds with many different structures distributed across the brain (sects. 4.2 and 4.3), and I conclude (sect. 4.4) that the definition of these constituents is challenged by a neural analysis. Although Pascual-Leone is a masterful theoretician, he seems to confuse parts and wholes more than I do. Schemas are parts of several "organismic" theories, but importing this term does not make a theory organismic. In fact, Pascual-Leone's use of schemas seems rather mechanistic to me (or else organismic in too strong a sense). The fear reactions of the passenger in his example are explained by an "automatically" synthesized meta-scheme. According to my model, there is indeed a juxtaposition of events which together with emotion (arousal, action tendencies, and attentional orientation) yield a powerful and coherent appraisal. But it is the self-organizing stability of this appraisal that permits the learning (by synaptic shaping) of associations *over time*. Nothing is "automatic." Pascual-Leone is right that several subassemblies must be co-activated synchronously when emotional interpretations (EIs) complexify (i.e., contain more information), either in real time or development. However, this too must be enabled through synaptic shaping *over time*. Few theorists are interested in models that are organismic in the strongest sense, and DS models are often located somewhere in the border region of contextualist and organismic metaphors, or they can be said to rely instead on the fundamental concept of emergence (Lewis 2000b). In such models, outcomes are never completely specified in advance, and coherence must emerge through recursive system activity.

Sander & Scherer begin their commentary by claiming that I equate the psychology of emotion with narrow conceptions of appraisal theory more than a decade old and that I fail to recognize the contribution of cognitive neuroscience to emotion theory. This makes little sense to me. Appraisal theory hasn't really changed that much in ten years. A thorough reading of Scherer et al.'s (2001) handbook on appraisal processes (to which I contributed a chapter) shows that most of the traditional positions are alive and well. However, relatively recent process models of appraisal have garnered more attention, as thoroughly reviewed in section 2.3 of the target article. As for the cognitive neuroscience of emotion, **Thayer & Lane**, chief proponents of this approach, praise the thoroughness and relevance of my treatment. Indeed, I cite and incorporate the work of cognitive neuroscientists throughout the article. But Sander & Scherer's hollow criticism is the tip of an unfortunate iceberg. What is most disappointing is that these theorists, who hold a compatible view of dynamic emotional processes (see Scherer 2000), choose to inflate discrepancies rather than highlight our common vision and shared goals.

Let me address their four substantive complaints in sequence. First, **Sander & Scherer** state that I ignore appraisal dimensions and focus instead on cognitive structures and mechanisms. I do not ignore appraisal dimensions: I review this classical approach in the first paragraph of section 2.2. My emphasis on cognitive mechanisms is similar to Scherer's process orientation. I don't see the problem. Second, these authors say that my Figure 1 does not explain the unfolding of an emotion episode and want a more specific delimiting of its beginning and end. In fact, Figure 1 does not deal with the time course of emotional episodes. Rather, it sketches a feedback reconceptualization of appraisal-emotion processes. This sketch is soon followed by section 3.3, which is given to the explicit modeling of the phases of an emotion episode. Behind these misapprehended details, Scherer's model and mine share an emphasis on synchronization in emotion episodes. This should be the basis for congeniality, not dispute. The third criticism is that my model relies on constructs that are vague and lacking in concreteness, and it therefore provides no analytical advantage over, say, Scherer's (1984) model. I am chastised for appearing unwilling to "take the [appraisal-emotion] amalgam apart in order to understand its nature." One hopes that these commentators read beyond Figure 1, because that is exactly what the remainder of the article set out to do. A high degree of specificity in psychological modeling was provided in sections 3.2 and 3.3, and concrete neural structures and processes were presented in great detail in sections 4 and 5. Finally, Sander & Scherer discuss theory and findings concerning the amygdala to highlight a perceived lack of detail in my own account. Although the amygdala is referred to frequently throughout the target article, I don't disagree with any of their discussion, and I am happy with the notion of relevance detection (see sect. 4.2.2). More functional detail is always welcome in a discussion of multiple neural systems and their mechanisms of interaction. But the overarching goal of such efforts should be an integrated perspective in which neural details adhere to a coherent set of principles derived from the work of like-minded theorists.

R2.2. Alternative mechanisms

According to **Carver**, the meaning of emotion can't be gleaned without elaborating the nature of triggers. He sees triggers as events evaluated (i.e., appraised) according to their relevance for attaining or avoiding desired or undesired conditions. For Carver, dynamic mechanisms such as positive and negative feedback are unnecessary to explain the amplification and stabilization of emotion. Rather than positive feedback, "the mere passing of time creates a steady increase in the trigger's potency," resulting in the rise of emotion from baseline. Similarly, he claims that stabilization (to an attractor) happens sometimes, but usually action reduces emotion back to baseline, by changing the eliciting conditions. In Carver's account, rather than stewing in anger, "Mr. Smart acts to change the situation so his goals are being better met." But importantly, this can take time, *giving the appearance of stabilization* until the cognitive or behavioral response succeeds at reducing the emotion. Carver's account might be compelling in a world of robots busily reducing discrepancies between conditions and goals. But in such a world, emotions are unnecessary. In fact, Carver's account of what I call *triggers* misses the point entirely. A trigger is an event in which a discrete cause produces a disproportionately large (nonlinear) effect: the effect grows based on the properties of the system, not the properties of the trigger. Carver's linear model epitomizes the cognitivism that I am trying to get away from, so it is no wonder that his proposed mechanisms differ from my own. I will tackle his claims in order.

Do emotions rise from baseline simply by virtue of the passage of time? Assuming that one can define an emotional baseline (which I doubt), and that this baseline is somehow equivalent to numerical zero (which is even more troublesome), this would be like saying that a car accelerates because the engine speed catches up with the amount of fuel released into the carburetor. For cars this is roughly true in theory, although there are of course many nonlinearities where the rubber meets the road. But **Carver** seems to believe that emotion accelerates because a passive cognitive system appraises more and more of what's going on. On the contrary, organisms function in the world through changes in multiple internal systems that interact with each other and with the environment. These changes are constantly informed by environmental input resulting from *active* perceptual and motor processes. A DS approach highlights active adjustments on the part of the organism and characterizes this set of interactions as recursive and self-organizing. This is what explains the nonlinear profile of change.

Is emotional stabilization really a result of successful action whose impact is, again, delayed in time? Stepping on the brake stabilizes acceleration, and brings the vehicle to a stop eventually. But this simple system is a poor model for complex animate processes. In fact, **Carver** seems to misunderstand the requirements for successful action. He believes that action tendencies, which I agree are generated with emotion, are the same as coherent actions. But raw action tendencies are useless for effective behavior. Instead, the evolutionary advantage of emotion for a sophisticated brain is to constrain and guide cognition until it coheres around a plan. Frijda (e.g., 1993a) and others have made this clear at the psychological level. At the neural level, the prefrontal cortex transcends the "default mode" leading directly from stimulus to response, so that foresight and reflection can guide behavior (Mesulam 2002). According to my model, this sophisticated system achieves stabilization through vertical integration with limbic and brainstem systems, allowing intelligent action to be synchronized with attention and emotion.

Finally, how far-fetched is my portrayal of Mr. Smart stewing in anger? According to **Carver**, "In reality, that is not how such an episode typically ends." Would that it were so. In his commentary, **Potegal** describes the phenomenon of aggressive arousal, a centrally mediated and enduring state of low-level aggression commonly observed in animals. Like children's tantrums (or just a grumpy mood), it "persists well beyond the withdrawal of the provoking stimulus." This cross-species phenomenon is consistent with the kind of attractor state model proposed by the target article and antithetical to Carver's explanation.

In my view, there are some situations in which actions terminate emotional states quickly, when goals can easily be achieved or discarded. But on most occasions we are unable to fully achieve or fully discard our goals. Situations are usually not so accommodating. This results in enduring mood-like states in which emotions and interpretations continue for some time, and action plans are assembled, rehearsed, and discarded, as was the case for Mr. Smart. Elsewhere (Lewis 2000a) I have suggested that these enduring states contribute the most to developmental outcomes, because they foster ongoing synaptic shaping through LTP and related mechanisms. Consequently, the EIs that become entrenched in personality development are precisely those that maintain engagement with situations in which goals are not quickly satisfied.

Northoff identifies two major "neglects" in my treatment. The first is my neglect of his theory, which I actually find intriguing. It seems reasonable that the processing of self-referential stimuli, as opposed to non-self-referential stimuli, should contribute to an emergent self, and that emotional intensity helps to foster this distinction. But then to say that emotion is only present for self-referential events seems circular. I also object to the idea that cognition-emotion integration or unity is a special case of some kind. This implies that cognition-emotion disunities also abound. **Izard et al.** describe cognition-emotion disunities in various pathological conditions. But for me, emotion always fosters integration, because emotional "constituents" include the arousal and attentional focus necessary for cognitive activity to cohere and consolidate. My second neglect, according to Northoff, is my inattention to the role of the medial parietal cortex and posterior cingulate cortex. However, the high level of activity in these and associated regions during resting states (Northoff refers to them as a "physiological baseline") implies that they have less to do with immediate emotional responding than do other regions. In fact, activation is thought to switch from posterior to anterior cingulate cortex when animals are challenged, expectancies are violated, and new learning must take place (see review by Luu & Tucker 2002). This shifting of activation to the ACC appears to mediate action-monitoring in emotionally compelling circumstance (e.g., Luu et al. 2003), as I discuss in section 5.4 of the target article.

Barnard & Dalgleish say that I neglect other important neurobiological systems, including approach-avoidance systems, behavioral activation versus inhibition systems, reward-punishment systems, and appetitive and aversive systems. Many such parsings are possible, but the intent of the target article was not to elaborate every alternative for slicing the neural pie. It was to describe representative structures, believed to mediate key psychological functions, in order to demonstrate the mechanisms of integration most relevant to a DS analysis.

Van Honk & Schutter rightly claim that I do not go into very much detail on the neuroendocrine system. Indeed, endocrine processes constitute a critical mechanism for the stabilization of emotional states. This is not "absent" from my account, but is dealt with in summary form in my discussion of mechanisms of arousal and neuropeptide activity (sects. 4.3.1 and 4.3.2). These commentators propose that various kinds of balance between brain systems, and critically between competing endocrine systems, are necessary to arrive at "emotional homeostasis." But I question whether the term *homeostasis* works as well for lasting emotional states as for endocrine balance. Cannon's homeostasis means maintenance of a steady state, and this is achieved in biological systems by self-regulation following a perturbation. Stable emotional states may be better characterized as *dynamic equilibria*, a term used by dynamic systems thinkers such as Jantsch (1980) to describe the stability of systems that actively maintain their self-organization, or by the term *homeorhesis* as proposed by Waddington (1962). Stable emotional states are not necessarily resting states, as is evident in the commonplace phenomenon of low-intensity moods.

Potegal describes states of aggressive arousal that persist without the help of cognitive appraisal. Most interestingly, he identifies an amygdala-hypothalamic circuit that maintains aggressive states, through control of autonomic and motor functions. This mechanism is important and fits well enough in my overall treatment. Then why does Potegal imagine that our positions are diametrically opposed? I don't claim that Mr. Smart must first assign blameworthiness and then experience anger. The whole point of the target article was to move beyond this cognitivist idea. I do claim that, very often, a blame appraisal consolidates *with* anger, as it did for Mr. Smart. Anger generally focuses attention on obstacles, including features of other people. Focusing on those features of the other that obstruct one's goals is fundamental to the appraisal of blame. Potegal's account of the rapid rise and stabilization of anger corresponds neatly with my self-amplification and self-stabilization phases, as he acknowledges, and it argues against **Carver**'s assertions. But I would challenge Potegal to find a lasting state of high aggressive arousal in humans without the assignment of blame. To ignore the role of appraisal in the temporal extension of emotional states throws the baby out with the bathwater.

R2.3. Extensions

R2.3.1. Psychological mechanisms. The commentary by **Ainslie & Monterosso** develops the idea that emotions are motivated, not just motivating. They claim that evaluation of the rewardingness of an emotion helps to select it. If they are right, then, as they suggest, the self-augmenting phase of an EI should include this mechanism of emotion generation, and the nucleus accumbens should be featured in the motivated monitoring loop as well as the action loop. This is an elegant argument and I agree with parts of it. Indeed, if cognitive appraisal is concerned with what is most salient, the anticipation of an emergent or soon-to-emerge emotional state ought to occupy appraisal as much as any feature of the external world. Viscerosensory feedback could channel information about emergent emotions without conscious attention. But I would say that the anticipation of a certain emotion, as a phase of appraisal, must have its own emotional concomitant: anxiety or excitement. I am anxious about the likelihood of becoming angry, or excited about the onset of pleasure or vengeful satisfaction. I would further argue that anticipatory anxiety, and not just anticipated reward, can facilitate the *generation* of emotions (not just their minimization). Anxiety about imminent shame increases attention to the self, thereby accelerating shame, and anxiety about anxiety is clearly self- amplifying. Thus, anticipation could be considered a cognitive feature of many EIs, adding to the mix of other features in a self-organizing process already underway. The result, either enhancement or minimization of emotional states, is what many theorists refer to as *emotion regulation*.

R2.3.2. Neural mechanisms. Other extensions to the model are suggested by **Thayer & Lane**. They highlight the importance of inhibitory processes at both the psychological and neural levels of analysis. They argue that inhibitory neural processes are critical for all stages of an EI, not just the self-stabilization and learning phases, as I emphasize. They cite evidence that inhibitory processes among neurons facilitate phase transitions, and that states of psychological entrenchment, such as rumination, indicate a breakdown of inhibitory processes at the psychological level. The link between inhibition and sensitivity proposed by these commentators is fascinating. We agree on one mechanism of sensitivity and change: positive feedback, which implies a loss of inhibition. However, they propose an additional mechanism: the presence of inhibition, which, as I understand it, tunes the system and makes it more responsive. There is room for convergence here. I claim that inhibitory processes (in negative feedback) allow EIs to become focused, coherent, and organized. This consolidation process could be the condition for rapid transitions to alternate states, but only when these transitions are directed by intention or focused thought. Coherent EIs enable directed action, and switching one's focus from one state to another is directed action in the form of planned cognition (e.g., shifting out of rumination). I do not elaborate these ideas in the target article, and Thayer & Lane's modeling suggests that this is a gap that needs filling.

Schore asks many intriguing questions concerning core mechanisms of emotion. Does the developmental sequence of maturation of the amygdala (AM), anterior cingulate cortex (ACC), and orbitofrontal cortex (OFC), respectively, parallel the sequence of activation of these neural systems in an EI in real time? In the target article, I cite evidence linking trigger phenomena (at the start of the sequence) with AM activation, as well as later processes of consolidation and stabilization with the ACC and OFC. The order of activation of these latter two structures may depend on whether the appraisal sequence is initiated through the object-evaluation or monitoring loop, but I know of no evidence that bears on this question directly. Schore also suggests that distinct *representations* at the level of each of these structures may link up to form emergent wholes. In the target article, I claimed that vertical integration links *functions* at different levels of the neuroaxis and suggested a superordinate phase synchrony as a likely mechanism for this phenomenon. But I am not sure how one would identify distinct "representations" at different levels, given the assumption by most theorists that representations depend on cross-level integration. Finally, Schore proposes another sequence for systems involved in emotion regulation. Consistent with my discussion, but articulated beyond it, he suggests that early implicit appraisals mediated by the right OFC precede explicit appraisals mediated by (more dorsal aspects of) the left prefrontal cortex, with the latter feeding back to the right OFC. If these transmissions then modulate vertical integration within the right brain, as Schore suggests, they would provide an ideal mechanism for the consolidation of emotion regulation in the presence of explicit (dorsally mediated) self-monitoring. I like this modeling. My only complaint is that Schore describes an "emergent whole" within the right brain. This seems to ignore his own assertion that modulation by the left brain is necessary to regulate right-brain appraisals. The left hemisphere plays too important a role to be left out of Schore's emergent whole.

Freeman summarizes his highly innovative theory of self-organizing brain states that are both intentional and emotional. I take it as inspirational that a neuroscientist who has been in the fray for so long uses principles of self-organization to model emotion. I have been greatly influenced by Freeman's work, so it is not surprising to find a good match with many of his arguments: (1) Freeman and I agree that the rapid onset of emotional states is trigger-like, constituting, in his words, a "virtually instant reorganization" of brain states. (2) These changes can be modeled neurally as phase transitions leading to self-amplification. However, Freeman's *local* phase transitions occur many times a second, indicating discrepant time scales for the reinitialization of neural patterns and perceptible changes in emotional states. (3) According to Freeman, local state transitions are swallowed up by a *global* state transition about 200 msec after stimulus onset, integrating several sensory systems with the limbic system in a vertical integration. Here the time scale is more in line with my modeling of EIs: the completion of the self-amplification phase of an EI (the "swallowing") could feasibly take up one-quarter to one-third of the minimum time course I estimated for its stabilization (600–800 msec, based on error-related ERPs). (4) Freeman claims that large areas of cortex enter into synchronized oscillations corresponding to intentional behavior on the part of the animal. If all intentional behavior is indeed emotional, this suggests another plank of broad compatibility. (5) We both see self-organizing appraisal states in terms of the selection of one of a number of attractors (multistability). Freeman calls neural attractors hypotheses about the world, and he shows that trajectories of sensory activation select among competing attractors. This phase is followed by abstraction and generalization, consistent with the cognitive elaboration I impute to the complexification of an EI.

Freeman's neural mechanisms of emotion are highly detailed and quantitatively explicit, but they need to be integrated with constructs available to other neuroscientists and psychologists. One of my goals in the target article was to set out a comprehensive but global framework anchored by mainstream research findings in neuroanatomy and neurophysiology, and use it to make sense of emotional processes observable to psychologists. An important next step would be to forge connections between this broad-based framework and Freeman's unique theoretical and empirical contributions.

R2.3.3. Social mechanisms. **Buck** agrees that emotions are self-organizing and that cognition and emotion arise interdependently. His commentary goes on to emphasize the role of communication at all levels of a dynamic system. However, according to Buck, my modeling of emotional processes remains "inside-the-head," and he recommends moving beyond neural constituents to social constituents such as roles and norms for the analysis of higher-order social emotions. One could indeed say that emotions self-organize among individuals as well as within individuals, and various forms of interpersonal signaling become critical at this level of analysis. The emotions involved in riots or sports events appear to require interpersonal coordination, and Fogel (1993) identified emotions in infant-mother transactions as belonging to the dyad, not to either partner. However, this kind of argument can also muddy the waters. Buck refers to Mr. Smart's shame as a social emotion, even though the other driver may have been completely oblivious to Mr. Smart's presence. Emotions, after all, do occur within individuals, whether or not communication is going on between them. The motivational thrust of an emotion is felt by the individual, as mediated by neural and endocrine processes within the individual's body. This thrust may *also* express itself interpersonally and may couple with that emerging in another individual, in a self-organizing process at a higher level of analysis. Studies of interpersonally correlated brain activities (e.g., Hasson et al. 2004) may eventually concretize relations between these levels.

Fabrega has many positive things to say about the target article, but like **Buck** he worries that EIs are modeled within the (individual's) head. As he demonstrates, many heads acting in a shared environment (culture) produce individual differences. Thus, a system of emotional interpretations develops uniquely for each individual, though still culturally constrained, with the extreme being psychopathology and other syndromes. I agree wholeheartedly with this emphasis. Like Fabrega, I see short-term stabilization as tuning long-term appraisal habits through associative learning. Fabrega's clinical and societal emphasis complements my own interest in how the emotion/appraisal system shapes and consolidates individual differences. I regret that I could not devote more time to these issues in the target article.

I am guilty, as charged by **Downey**, of underplaying one of the most important influences on the shaping of emotional patterns. I demonstrate how action shapes and stabilizes EIs, but I neglect the impact of an important class of actions – learned forms of emotional behavior. Habits of emotional behavior (e.g., grief behavior, anger displays) should indeed exert a critical top-down influence on the self-organization of EIs, helping to crystallize interpretation and emotion. Downey's most interesting claim is that this top-down factor "is probably the most important avenue for cultural variation to affect neural architecture." What an excellent point! If culture constrains habits of emotional behavior, emotional behavior helps stabilize EIs, and stabilization sculpts the synaptic circuitry that provides developmental continuity, then cultural forms of action will select and stabilize highly distinct EIs entrenched in the neural architecture of members of that culture. I particularly like Downey's conclusion: "A DST approach to cross-cultural difference in emotional psychology offers the possibility of making physiologically testable hypothesis about emotional responses while recognizing that neural plasticity may be greater than we can imagine." I would only add that constraints on emotional behavior supplied by family members or temperamental proclivities should affect developmental outcomes as profoundly.

R3. Do's and don't's for dynamic systems modeling

R3.1. Matters of principles

The commentaries I have dealt with so far address substantive arguments in the target article. However, a few commentators raise formal issues regarding the conceptualization or presentation of a DS framework. According to **DeLancey**, I may have slipped into thinking that DS principles, in and of themselves, provide a theory or a set of testable claims. He goes on to caution that "there are something like substantive claims lurking in Lewis's account." I certainly hope there are substantive claims in my account. But I do not imagine that these derive directly from DS principles. As suggested by the title, the modeling is where the substantive claims lie, and the DS nomenclature indicates, as DeLancey agrees, a set of conceptual tools for analyzing relations of a particular sort (reciprocal, recursive, etc.). **Pascual-Leone** also asserts that dynamic systems theory is a metatheory, not a substantive theory of its own. I completely agree, and I have spelled this out elsewhere (Lewis 2000b). DeLancey is correct that it does not praise or damn a theory to say that it is a DS theory, as DS has no substantive value added on its own. And he's correct that the predictions themselves don't explicitly contrast DS with non-DS principles, though the early sections of the article should make it obvious that non-DS (conventional) principles lead to very different predictions.

Bakker claims that the notion of circular causality is meaningless and should be discarded. The behavior of wholes doesn't *cause* the behavior of parts; it simply corresponds to it. And the fact that wholes constrain parts is obvious for any system. With respect to my neural modeling, he suggests that vertical integration should not be seen as a within-system (levels) issue but rather as reciprocal causation (e.g., feedback) across neural systems, in which case circular causality need not be invoked. Bakker's argument is very clear, and it would apply to any model of self-organization. But is he right? Causality between wholes and parts is a novel construct introduced by Haken (1977) to help explain processes that had never been adequately explained. So the fact that circular causality defies conventional notions should not be surprising. Juarrero (1999) contrasts circular causality with conventional types of causality and argues for its appropriateness when self-organization gives rise to a "new 'type' of entity" (p. 129). She concludes that "self-cause" is necessary for explaining the continuity of complex adaptive systems.

Yet **Bakker** is not the only scholar to express dissatisfaction or at least confusion concerning circular causality. What exactly does it add? As I understand it, synchronization between two oscillating units (whether cuckoo clocks or cicadas) involves bidirectional signals that entrain their oscillations. Add another clock or cicada, and we have signals from each unit to two other units, making the job of entrainment a little more complicated. But with dozens or thousands of units, unit-to-unit signals would not be capable of establishing a single frequency to which the oscillations of all units correspond. Phasing would drift as the sequence of signals fans out from unit to unit. This is not what happens. A vast number of oscillating units remain tightly coupled in lasers as well as brains. Circular causality, in the form of a unitary frequency, provides a top-down influence that simultaneously entrains (or "enslaves") all units, while they simultaneously produce the global oscillation that embodies that frequency. The need for circular causality is perhaps most obvious in brains. Interneuronal transmissions involve large numbers of cell bodies, firing independently, and influencing each other through synapses that vary structurally and chemically. Hence, phase locking across neural assemblies requires something more than lateral forces. It may be for this reason that many scientists who model brain processes dynamically find circular causality indispensable, including **Freeman**, **Tucker**, and **Grossberg** among the commentators and others cited in the target article (e.g., Engel et al. 2001; Szentagothai 1993; Thompson & Varela 2001). If circular causality is a ghost in the machine, it is an *emerging* ghost, and that might be exactly right.

R3.2. Math chauvinism and neural network modeling

Other commentators had very little to say about the target article except that it missed the point entirely – not for reasons of inadequate substance or misplaced principles, but because it did not pay homage to mathematics or neural network modeling. According to **Kaup & Clarke**, all my verbiage means nothing without equations to construct a sample dynamical system. They admit that my modeling might be convincing to those with backgrounds in neuropsychology, but dynamicists require equations. They suggest that a sample dynamic system (a set of equations corresponding to the relations proposed between components of the model) should "model some simple feature of emotion theory, which could then be bridged to some feature of neurobiology." But that's the problem. A simple feature of emotion theory mapped onto a highly idealized neural system would do little to account for the complex processes that interest me. I am aware of mathematical and neural network models of emotion induction and cognition-emotion interaction, but their simplicity and idealization make them less convincing to me than a detailed model corresponding to biological data. Math modelers have an important role to play, but it is only one among many, and problems of realism don't go away just because you supply some numbers.

Grossberg's principal complaint is that I ignored 30 years of work bridging emotion theory and neuroscience – namely, his neural modeling of cognitive and emotional processes. Grossberg's theory and modeling have indeed been important, and I probably should have referred to them in the target article, but I am hardly reinventing the wheel that he has been constructing for many years. Grossberg has been a key figure in developing quantitative models that are strongly self-organizing. Indeed they contain many of the DS mechanisms that I mention. Some of these models (CogEM) also contain modules that have motivational functions (in terms of proximity to goals, etc.), and this makes the modeling slightly more realistic. However, Grossberg is not an emotion theorist, and emotion theory has paid little heed to his work. The converse is true as well: Grossberg is not concerned with arguments and findings in the province of emotion theory. Why this mutual disinterest? In part, because this kind of modeling simplifies "emotion" so much as to make it untranslatable to the variety and color of human emotional behavior. In Grossberg's model, actions are "released" and memory searches are "driven" in a major simplification of psychological and neural function. In turn, emotion is seen as a parameter, not a process, not even a psychological state, in a set of relations that are highly mechanistic despite being dynamical. This is not a fault intrinsic to the modeling; quantitative models require this simplicity. But neither does it provide a bridge that everyone wants to cross.

Winkielman & Nowak claim that my framework "specifies few concrete mechanisms that perform the postulated integration of cognition and emotion." In fact a great number of pages are given over to specifying exactly those mechanisms. The largest section in the target article, section 5, details five neural mechanisms of integration, each referring to data on the functional integration as well as temporal synchronization of brain systems. Winkielman & Nowak's neural network simulations seem useful for modeling cognitive phenomena and speculating as to their emotional concomitants. But they are, after all, simulations of neural processes. If these commentators are interested in real neural processes, they might reread section 5 to see how brains actually work. A handful of dynamically oriented theorists have arrived at the notion that simulations and mathematical models are the main road, if not the only road, to concreteness. Such models are useful, *as* models, for understanding various computational mechanisms.

However, these models are not concrete; they are abstract. They are metaphorical representations of flesh-and-blood systems. Let's not confuse specificity with concreteness.

R3.3. Moving too fast?

A few commentators appear queasy about a DS makeover of emotion science. **Carver** rejects the need for any dynamical mechanisms for explaining emotional processes. For him, positive and negative feedback mechanisms are "creative" solutions to problems that could be more easily solved with cognitivist formulas. This position is relatively extreme, however. **Frijda** expresses a great deal of enthusiasm for DS principles of feedback, emergent order, and self-stabilization, which indeed support his stand against linear appraisal models. But he goes on to ask what phenomena make a self-organization analysis "desirable." Frijda seems happy with the intellectual parsimony of DS modeling, but like other emotion theorists he may lose track of the strain imposed on emotional phenomena by the Procrustean bed of traditional models. Features of emotions that don't fit the bed, but do fit with a self-organizational perspective, include their rapid emergence on the basis of minimal triggers, their initial sensitivity to context, their globality and coherence once formed, and their resistance to change for prolonged periods, giving way to global reorganizations in response to a subset of perturbations. These features simply cannot be modeled in linear causal terms.

Panksepp calls the DS approach to emotion "a compelling metaphor that raises more difficult empirical questions than substantive scientific answers. . . . Such theoretical views still need to be guided by linear cross-species experimental approaches . . ." He concludes that DS methods cannot hope to tackle the analytical chores of neuroscience. I don't agree. Linear methods, such as correlating single events in one system with single events in another system, have tremendous value for compiling a foundational corpus of data in neuroscience and other fields. But in a system of complex causal interactions, the synthesis of these observations into an overarching explanatory framework requires nonlinear modeling. It is important to study the relations among discrete parts, but we also want to understand the whole. Not only are DS ideas critical for theoretical integration, but they have also proved highly productive for neuroscientific experimentation. The second paragraph in section 4 of the target article lists more than a dozen empirical papers based on dynamical approaches to the brain. This is a representative sampling of an exponential trend facilitated by new methods for time-based analysis of scalp EEG, local field potentials, single-cell recordings, and so forth. Most of these studies rely on methods for assessing synchrony or coherence in the behavior of interacting neural systems, as advocated in the target article. Also, studies of phase synchrony not specifically informed by DS ideas (see **Pizzagalli** and **Kocsis** among the commentators) provide data consistent with these approaches and with models such as my own. Surely these empirical directions complement more traditional analytical approaches and lead to insights not otherwise available.

R4. Cognition and emotion: Two systems or one?

For a number of commentators, the arguments raised by the target article highlight a conceptual fault line running through the psychology and neurobiology of emotion. Should we construe emotion and cognition as two interacting systems or as a single integrated system?

To introduce the debate, let me contrast the views of two commentators. **Potegal** hammers home the point that emotion is not cognition. He cites physiological, developmental, and evolutionary arguments that pitch emotion as a phenomenon distinct from and independent of cognition. Then he goes on to dismiss an obvious role for cognitive appraisal in the temporal extension of angry states. This zealous segregation of emotion and cognition becomes extreme. At the other extreme, **Chella** argues that conceptual space modeling can already map out the cognitive mechanisms of appraisal. By extending the features (to include arousal, action tendencies, etc.) represented by elements in this space, he says it may also be able to map emotional processes. But I don't think that adding to the list of features represented by a point (knoxel) in conceptual space takes us from cognitive appraisal to emotion. This could work for a description of emotional events, but not for the emotion process itself. Even higher-order spaces merely re-describe lower-order interactions. There is something about emotion (the "what to do about it," not just the "what") that is fundamentally not a description. Potegal and Chella place themselves at opposite fringes of the unity debate, viewing emotion either as highly independent of cognition or as a category of cognition. But for many theorists, issues of independence, integration, and unity are more complicated, and a DS analysis brings these issues to a head.

R4.1. Parts and wholes

For years Izard and Ekman, both well-known figures in the field, have been champions of an independent emotion system. In their commentary, **Izard et al.** argue that "the concept of highly interactive emotion and cognitive systems seems a viable alternative hypothesis to the idea of systems integration." They recognize that cognition and emotion are designed by evolution to interact seamlessly in normal circumstances, but they reject the idea that this constitutes a single integrated system. The only integration they allow for is the "functional integration" between particular emotional and cognitive constellations for individuals with a given personality style. The idea that certain appraisals evolve and consolidate with particular emotions over development is the basis of Izard's theory of personality development, and it is a theory I have borrowed from liberally for many years (e.g., Lewis 1995). In fact, in the target article, my modeling of the fourth phase in the evolution of an EI specifies this very process (sect. 3.3.4) along with its likely neural underpinnings (sect. 6.3). However, "integration" means different things at the scales of real time and development. As I see it, integration in development means a *predominant tendency to couple* in real time. This difference in scales is central to a DS analysis, but it is conflated by the semantics used by these commentators.

The crux of the argument put forth by **Izard et al.** is that instances of cognition-emotion nonintegration or dissociation provide evidence that the cognitive and emotional systems are generally independent. They construe infants' inability to regulate emotions cognitively, autistics' and psychopaths' lack of emotional involvement, the disadvantageous decisions made by orbitofrontal patients, and even the responses of normal subjects early in the gambling task, as indicators of cognition-emotion independence. This independence is then replaced by interactive integration for normal adults as situations unfold. But I take issue with some of these arguments. Infants, autistics, and other individuals may not show disintegration between emotion and cognition as much as inadequate functioning (by normal adult standards) in the system as a whole. Emotional infants integrate whatever cognitive controls they have at their disposal, as is evident by their efforts to avert gaze or self-soothe when distressed. The inadequacies of autistic functioning are as much cognitive – particularly in the domain of social cognition – as they are emotional. These authors point to amygdala processing deficits in autistics and orbitofrontal deficits in brain-damaged patients as evidence for a stunted emotional system, compensated by cognition. But as I argue in section 4.4 of the target article, these structures are as much involved in appraisal as they are in emotion, and in fact the two roles are impossible to differentiate satisfactorily. Thus, orbitofrontal patients could as easily be described as incapable of certain kinds of appraisals – those based on previous or anticipated rewards or punishments.

My sense is that **Izard et al.** have built their position as a bastion against excessive cognitivism in developmental theory and emotion theory, and it has served its purpose well. But with the advent of new models, especially those that discard cognitivist assumptions at the outset, it may no longer be necessary to take so hard a line. Izard et al. want to see emotion as independent of cognition, because the alternative has always been to see it as a subordinate component of cognition. My emphasis on integration (yes, functional integration – it happens in real time, even though its contents are shaped over development) is far from cognitivist and it grants emotion and all its constituent processes their full status. Integration doesn't have to demean emotion; on the contrary, it makes emotion fundamental to all processing.

Echoing **Izard et al.**'s concerns at the level of neurobiology, **Panksepp** questions my synthetic modeling of emotion and cognition. "When we dissect the many 'organs' of the brain-mind, we see that cognitions . . . are vastly different species of brain activities than emotions." Panksepp, like Izard, goes to considerable pains to draw such distinctions. He has done a great deal of research on brainstem circuits and neuropeptides that point to emotional primes. This body of research and the vision of the brain it imparts have had a bracing effect on the field. But despite the importance of isolating circuits that mediate basic emotional response systems, we should not ignore the interaction of these circuits with other brain systems. Panksepp comes around reluctantly, by saying: "Only when we consider the intact organism, working as a whole, can we claim 'that cognition and emotion were never two distinct systems at all.'" Then let us consider the intact organism! Psychologists think best in terms of wholes, and quite a few neuroscientists care about wholes as well as parts. For **Tucker** and **Pizzagalli**, contextualizing part relations within meaningful wholes is the chief agenda for current theorizing.

Moreover, I doubt that cognition and emotion are distinct in the same sense as liver and kidney (**Panksepp**'s analogy). Brainstem response systems fundamental to emotion receive sensory modulation directly from hypothalamic and nearby brainstem circuits, as well as from higher up the neuroaxis, and they act directly and indirectly on these circuits simultaneously. In other words, they form integrated systems at a relatively local level. These sensory circuits would seem to be involved in mapping out the world in terms of primary appraisals. I am a believer in emotional primes, but without appraisal primes I don't see how they could operate (cf. Ekman 1994). Each of Panksepp's primes implies a basic interpretation: seeking implies resources to discover; panic implies the loss of an attachment figure. Thus, even in the neurobiology of simpler animals, we can say that emotion and appraisal are integrated in any coherent activity.

R4.2. The argument for unity

Other commentators worry about too much segregation. **Colombetti & Thompson** say that it is unproductive to differentiate appraisal constituents and emotional constituents at any level of the argument, for either neural or psychological systems. Feeling is no less part of appraisal than of emotion, so why classify it as an emotional component per se? We are in agreement on the importance of looking at parts in relation to wholes, but for these authors there is only one whole – the unitary brain, whereas I continue to use the language of two systems. For example, I describe appraisal and emotion as being bound in a "functional unity." But *binding* still implies duality. Yet even these commentators have to use phrases such as "constitutively interdependent" to describe the relation between perception and action. The use of "interdependent" must provide them with some leverage by thinking in terms of two as well as one. Similarly, if we do away with "cognition" and "emotion" at all levels, we may be left with a kind of soup. We can only characterize wholes by understanding their parts. And if the wholes are no longer classifiable by traditional functional terms (i.e., if a functional unity is really a unity), then we lose the benefit of these designators all the way down the hierarchy. The danger here is that the wholes will become opaque and unidimensional because the parts can't be adequately characterized. I am arguing now in a similar vein to **Panksepp**. Let's allow cognitive parts and emotional parts for the heuristic purposes of designation and mapping, and then let's notice at what levels of analysis it no longer makes sense to do so. In fact, the target article is intended as a bridge, and it wouldn't be a very good bridge if it did away with the categories psychologists (and some neuroscientists) find necessary and useful. Philosophers of science like Colombetti & Thompson are in a good position to guide the semantics of neuropsychology toward more radical ground, but certain heuristics are hard to abandon in the mean time.

Tucker is not surprised that, when examining neural circuits at all levels, we find no separation of cognitive functions from emotional functions, thus losing the functional categories with which the analysis began. In fact, much like **Colombetti & Thompson**, he suggests that these isolated functions are "psychological fictions," and losing them may be a necessary step in the development of more sophisticated neuropsychological models. Tucker goes on to suggest that the embedding whole in psychological terms is the self, and that this corresponds to the vertical integration of neural activities reflecting both past and present needs and demands. However, once again, by bridging psychology and neuroscience, we end up with a transformed psychological construct: the self as an occasional state "emerging only to the extent that the constituent mechanisms are recreated in the continual flux of psychophysiological processes." I address Tucker's thoughts about the occasional self in the next section. But his notion of embedding might help resolve ambiguities about the cognition–emotion nomenclature. For Tucker, these functions remain isolated in one context – psychological analysis – but become unified once they are embedded within a second context – a neurophysiological landscape. Thus, there is no right answer for the dualism issue. The embedding context in which phenomena are examined, whether psychological experiments, discretized neural experiments, or whole-brain approaches, will determine the most appropriate semantics.

R5. Developmental considerations

Walker-Andrews & Haviland-Jones as well as **Schore** scold me for not making development a central theme of the modeling and for not presenting more developmental data. As I often consider myself a developmental psychologist, this possibility certainly crossed my mind. However, it seemed necessary to pin down real-time, moment-to-moment processes fundamental to the psychology and neurobiology of emotion, before I could hope to analyze developmental processes at a satisfying level of detail. Despite this concern, I did not want to ignore development completely, and the target article deals with associative learning and synaptic shaping, both as a key mechanism of integration (sect. 5.5) and as the final phase in the consolidation of an EI (sects. 3.3.4 and 6.3). This discussion allowed me to analyze experience-dependent pathways of individual development in a manner consistent with Schore.

Schore and I concur that emotionally compelling experiences in early development lay down lasting patterns of interpretation at the scale of developmental self-organization, and **Fabrega** takes a similar view. I state in section 6.3: "Across several occasions, an accumulation of learning events would then be expected to narrow the degrees of freedom for interpreting any subsequent event of this class . . . consolidating individual styles of interpretation, feeling, and belief." From my perspective, what gets learned *is* the present appraisal (and action orientation), and the stabilization of an EI is necessary so that the contents of this appraisal can be consolidated through processes such as LTP. Schore emphasizes the role of emotion in individual development, and I also suggest "that events that are not emotionally significant may not maintain arousal or attention long enough for learning to take place" (sect. 5.5, para. 3). Both Schore and Fabrega propose continuity between personality outcomes and psychiatric disorders based on this kind of learning, as influenced by early attachment conditions. But what I am most interested in is the interplay between real-time and developmental processes, and the role of phase synchrony in facilitating synaptic change that leads to consolidating developmental forms. Although I do not cite a great deal of developmental literature, I do emphasize research that has some bearing on this interplay. I would like to hear Schore address these processes and mechanisms as well as those he has written about so extensively.

Walker-Andrews & Haviland-Jones point out that DS approaches in psychology have been particularly fertile in the area of development, and they model several normative acquisitions in early child development in terms of emergence, consolidation of wholes out of interacting parts, and even fractal-like patterns of self-similarity. I am very sympathetic to developmental DS approaches, particularly in the domain of emotional development, and these authors have indeed contributed to this area. However, one of the problems facing authors in this tradition is how to concretize their models, particularly with respect to temporal measurement, and thereby achieve a level of specificity that advances communication with other scientists. Phenomena in the domain of emotional development are so complex as to make this a major challenge. Mathematical approaches (van Geert & van Dijk 2002) and advanced statistical methods (Hsu & Fogel 2003) have just begun to be applied, and my colleagues and I have introduced our own temporal-statistical methodology (Granic & Hollenstein 2003; Lewis et al. 1999). These methods are suitable for behavioral data, but my approach in the target article was to concretize emotional processes with reference to neural events, such that spatiotemporal processes at the neural level can be related to descriptive phenomena at the psychological level.

A final developmental consideration relates to **Tucker**'s provocative thoughts on the self. If, indeed, psychological causation is emergent rather than unidirectional, and based in brain processes that are complex and self-organizing in the moment, then, as Tucker argues, we might view the self as an emergent form, corresponding to the vertical integration of neurophysiological events. Tucker views the self as an occasional state arising whenever the necessary neurophysiological conditions are recreated (cf. **Northoff**). I agree, but I would even go a step further. Because vertical integration emerges out of neural activities reflecting immediate environmental demands as well as the residue of past appraisals selected by present circumstance, there should be a variety of selves, any of which might emerge on a given occasion. The view that the self is multiple or polyphonic has cropped up in psychological theory (e.g., Hermans 1996) and it has attracted developmentalists with a DS perspective (e.g., Kunnen et al. 2001). I suggest that there are several highly familiar selves (e.g., a strong, confident self; a childish self; a critical self), each constituted by an anticipated, actual, or imagined dialogue with a predictable other, and this cluster of selves fosters a family of attractors for self-referential appraisals. I recently speculated about the neural underpinnings of some of these self-like "positions" based in part on their emotion-regulation and cognitive style characteristics (Lewis 2002). But, unlike Tucker, I think these forms do have a special organizing status. Their frequent re-emergence produces strong continuities over development and their emotional relevance provides consistent constraints on interpretive activities within occasions, each property feeding back to the other recursively. The result, as **Schore** might agree, would be selves that are highly robust despite their limited time on stage – selves that do provide an organizing principle for development, even though they are always instantiated in momentary neuropsychological processes.

R6. Clinical considerations

Galatzer-Levy reminds us that the emotional phenomena of conventional psychological theories are pale reflections of the difficult, irrational, and conflicting emotions of interest to psychoanalysis. Therefore, emotion theory has less to contribute to the understanding of character patterns and clinical syndromes than one might like. Galatzer-Levy recommends a kind of parallax perspective in which DS modeling and neuroscience can recapture this richness. I agree that the rapid switching of behavior in clinical syndromes, emergent phenomena such as generalized anxiety and depression, and the multistability of competing character organizations are now within the purview of scientific modeling. Beyond supplying the details for such models, neurobiology provides new methods for getting at self-organizing brain processes of particular clinical relevance. For example, **Pizzagalli**'s research concretizes the notion that depressed patients experience some kind of disconnect in self-monitoring – a disconnect that prevents adaptive appraisals from making sense of current emotional states (cf. **Izard et al.**). His findings reveal that depressed patients do not show the theta-band synchrony along frontocingulate pathways typical of normal controls (see also **Northoff**). Here, a DS-related prediction about the role of synchrony in functional integration appears useful for helping to explain the symptomatology of major depression.

Schore and **Fabrega** want to distill developmental aspects of DS-inspired neural modeling to explain continuities from difficult temperament and poor attachment patterns to problematic outcomes. These authors agree with me on the importance of habitual appraisals consolidating across emotionally compelling occasions en route to the consolidation of normal and pathological traits. Points of disagreement are confined to the details, and even there I see nothing significant to argue about. Fabrega concludes that "constructs in psychiatry and clinical psychology . . . are, like the psychology of emotion, dependent on a 'language of wholes.' Constructs that sharpen the way emotional behavior disrupts function in the short run provide a language for improving 'diagnosis' that could be more useful to clinicians." He says that my modeling moves in the right direction, but the neural account needs more streamlining and depictions of the self need more articulation in order to maximize the effectiveness of this communication.

The challenge of making this approach accessible and useful for clinicians is onerous, but it is certainly worth pursuing. The research reported by **Pizzagalli** provides a nice example of how the identification of a "disconnect" in neural synchrony can translate directly to clinical intuitions and observations. But perhaps the greatest value of a DS-based neuropsychological approach will be in providing constructs and methods for analyzing individual trajectories of problematic development, as emphasized by **Schore**. Clinicians are always concerned with individual variation, but their models, based on traditional approaches in psychology and psychiatry, highlight categorical syndromes divorced from developmental processes. The field of developmental psychopathology recognizes this constraint and offers developmental-systems accounts to correct it. These accounts are now beginning to include DS-informed models of neuropsychological development (e.g., Derryberry & Rothbart 1997; Post & Weiss 1997), making them far more precise and ultimately more powerful than would otherwise be possible.

R7. Empirical considerations

As noted earlier, **Panksepp** has little confidence in DS-inspired modeling and methods for neuroscience. But he also takes aim with some very specific challenges. These take the form of a list of questions that attempt to squeeze more juice from my admittedly global predictions. He asks: How do I know that cortical theta (measured at the scalp) is the same as the subcortical theta recorded from single cells in animals? Does my modeling of vertical integration suggest particular recording sites or other parameters that could differentiate predictions according to emotional primes? What neural changes measurable through scalp EEG differentiate conscious appraisal from precursor processes? I don't have complete answers to these questions at present. And I agree that they are the kind of questions that need to be articulated and then applied systematically in neurophysiological research.

Although I agree with the appropriateness of **Panksepp**'s questions, I challenge his suggestion that DS approaches are unequal to the task of answering them. In fact, we need not look very far to see answers beginning to appear. In his commentary, **Kocsis** presents "recent data on the relationship of rhythmic neuronal discharge in the supramammillary nucleus and the large-scale theta oscillations in the limbic system which provide support to many of [Lewis's] ideas regarding vertical integration in dynamic systems." Kocsis shows that oscillations of nuclei in the brain stem can drive septohippocampal oscillations on some occasions (induced by the potent stimulus of tail pinch) and be driven by them on others. He also shows that each can drive the other over the same time span, one showing up in the "background" of the other. Here we have not only the phenomenon of emergent phase synchrony across levels of the neuroaxis, but also two triggers of this synchronization, one of which is correlated with negative emotion (probably anxiety) induced by tail-pinch. In this research as well as that cited in the target article, Kocsis has gone a long way toward sorting out the source nodes of emotion-related phase synchrony across the brain stem and limbic system. This approaches Panksepp's ideal of selecting recording sites to match specific categories of emotional response.

As far as differentiating conscious appraisal processes through scalp EEG, it is encouraging that this too is underway, as exemplified by the neurophenomenology research program advocated by **Colombetti & Thompson**. Following principles laid out by Thompson and Varela (2001), Lutz et al. (2002) trained participants to report on subjective states of experience when anticipating and attending to challenging visual displays during EEG recordings. They found a correspondence between states of conscious attention and gamma-band synchrony across frontal cortical regions. As in other studies, gamma-band synchrony appears to tap featural consciousness related to perceptual focusing. Other investigators have looked for synchrony in the theta range corresponding to self-monitoring in emotionally loaded circumstances. **Pizzagalli** summarizes recent work by Luu et al. (2003) indicating theta-band synchrony across anterior cingulate and other cortical sites when subjects are engaged in a difficult process of action monitoring. Luu et al. (2004) extend this paradigm by decomposing action-monitoring ERPs into synchronous and nonsynchronous waveforms tapped at the single-trial level. It seems that guided self-report coupled with single-trial analysis of frontal theta could provide highly sensitive measures of conscious appraisal processes as requested by **Panksepp**.

These research findings are preliminary, and they represent new conceptual and methodological approaches that are just now gaining serious attention. One hopes they will lead to increasing convergence among investigators studying the properties of neuronal synchronization and those developing hypotheses and research strategies for analyzing self-organizing processes underlying emotion and appraisal. As pointed out by **Ellis**, evidence for neural self-organization as the basis of emotion would not necessarily authenticate my particular model. He is correct in noting that the predictions I propose are general enough to be shared by other models of self-organizing emotional states. Indeed, the validation of these and related predictions, and the convergence of findings from scalp EEG, consciously reported cognitive activities, psychophysiological measures, and detailed neural hypotheses, can lend credence to a family of models, all of which depict neural mechanisms of self-organization fundamental to emotional processes.

Organizing a response to 30 energetic and creative thinkers has not been easy. There were pools of converging opinion, but just as many diverging views. Yet it has been greatly informative, and very often fun, to join in a debate on so many fronts. My thinking has been challenged and hopefully advanced by revisiting old problems such as duality versus unity in cognition-emotion. Challenges concerning the use and abuse of dynamic systems constructs have refined arguments that I have left simmering for some time. Extending the discussion into developmental, clinical, psychoanalytic, social, and anthropological domains has provided a good deal of intellectual richness for me, and hopefully for the reader. And debating the significance of additional psychological and neural mechanisms has furthered the tension that generally leads to theoretical improvement. I am thankful to the commentators for their converging and diverging views, as both will move the dialogue forward.

References

Letters "a" and "r" appearing before authors' initials refer to target article and response, respectively.

Abe, J. A. & Izard, C. E. (1999) A longitudinal study of emotion expression and personality relations in early development. *Journal of Personality and Social Psychology* 77:556–77. [CEI]

Adamec, R., Kent, P., Anisman, H., Shallow T. & Merali, Z. (1998) Neural plasticity, neuropeptides and anxiety in animals: Implications for understanding and treating affective disorder following traumatic stress in humans. *Neuroscience and Biobehavioral Reviews* 23:301–18. [aMDL]

Adolphs, R. (2001) The neurobiology of social cognition. *Current Opinion in Neurobiology* 11:231–39. [ANS]

Adolphs, R., Russell, J. A. & Tranel, D. (1999) A role for the human amygdala in recognizing emotional arousal from unpleasant stimuli. *Psychological Science* 10(2):167–71. [DS]

Aggleton, A. P. & Brown, M. W. (1999) Episodic memory, amnesia, and the hippocampal-anterior thalamic axis. *Behavioral and Brain Sciences* 22:425–89. [aMDL]

Ainslie, G. (2001) *Breakdown of will*. Cambridge University Press. [GA]

(in press) A selectionist model of the ego: Implications for self-control. In: *Disorders of volition*, ed. N. Sebanz & W. Prinz. MIT Press. [GA]

Alonso, A. & Llinus, R. R. (1992) Electrophysiology of the mammillary complex in vitro. II. Medial mammillary neurons. *Journal of Neurophysiology* 68:1321–31. [aMDL]

Anderson, A. K., Christoff, K., Stappen, I., Panitz, D., Ghahremani, D. G., Glover, G., Gabrieli, J. D. & Sobel, N. (2003) Dissociated neural representations of intensity and valence in human olfaction. *Nature Neuroscience* 6(2):196–202. [DS]

Anderson, J. R., Bothell, D., Byrne, M. D., Douglas, S., Lebiere, C. & Qin, Y. (2004) An integrated theory of the mind. *Psychological Review* 111:1036–60. [PB]

Apostol, G. & Creutzfeldt, O. D. (1974) Crosscorrelation between the activity of septal units and hippocampal EEG during arousal. *Brain Research* 67:65–75. [aMDL]

Arbib, M. A. (1972) *The metaphorical brain: An introduction to cybernetics as artificial intelligence and brain theory*. Wiley-Interscience. [RMG-L]

Arbib, M. A., Erdi, P. & Szentagothai, J. (1998) *Neural organization: Structure, function and dynamics*. MIT Press. [JP-L]

Aristotle (1993) *De anima*, trans. D. W. Hamlyn. Clarendon Press. [RDE]

Arnsten, A. F. T. & Robbins, T. W. (2002) Neurochemical modulation of prefrontal cortical function in humans and animals. In: *Principles of frontal lobe function*, ed. D. T. Stuss & R. T. Knight, pp. 51–84. Oxford University Press. [aMDL]

Arrow, H., McGrath, J. E. & Berdahl, J. L. (2000) *Small groups as complex system: Formation, coordination, development, and adaptation*. Sage. [aMDL]

Asada, H., Fukuda, Y., Tsunoda, S., Yamaguchi, M. & Tonoike, M. (1999) Frontal midline theta rhythms reflect alternative activation of prefrontal cortex and anterior cingulate cortex in humans. *Neuroscience Letters* 274:29–32. [aMDL]

Ashby, W. R. (1952) *Design for a brain*. Wiley. [aMDL]

Astin, S., Redston, P. & Campbell, A. (2003) Sex differences in social representations of aggression: Men justify, women excuse? *Aggressive Behavior* 29:128–33. [MP]

Atran, S. (1998) Folkbiology and the anthropology of science. *Behavioral and Brain Sciences* 21:547–609. [HF]

Bahrick, L. E. & Lickliter, R. (2000) Intersensory redundancy guides attentional selectivity and perceptual learning in infancy. *Developmental Psychology* 36:190–201. [ASW-A]

Baier, A. (1991) *A progress of sentiments: Reflections on Hume's Treatise*. Harvard University Press. [GA]

Barbas, H. (1992) Architecture and cortical connections of the prefrontal cortex in the rhesus monkey. *Advances in Neurology* 57:91–115. [DAP]

(1995) Anatomic basis of cognitive-emotional interactions in the primate prefrontal cortex. *Neuroscience and Biobehavioral Reviews* 19:449–510. [aMDL]

(2000) Connections underlying the synthesis of cognition, memory, and emotion in primate prefrontal cortices. *Brain Research Bulletin* 52:319–330. [aMDL]

Barbas H. & Pandya, D. N. (1989) Architecture and intrinsic connections of the prefrontal cortex in the Rhesus monkey. *Journal of Comparative Neurology* 286:353–75. [aMDL]

Barnard, P. J. & Bowman, H. (2003) Rendering information processing models of cognition and affect computationally explicit: Distributed executive control and the deployment of attention. *Cognitive Science Quarterly* 3:297–328. [PB]

Baron-Cohen, S. (2003) *The essential difference: The truth about the male and female brain*. Basic Books. [CEI]

Baron-Cohen, S., Ring, H. A., Wheelwright, S., Bullmore, E. T., Brammer, M. J., Simmons, A. & Williams, S. C. R. (1999) Social intelligence in the normal and autistic brain: An fMRI study. *European Journal of Neuroscience* 11:1891–98. [CEI]

Bechara, A., Damasio, H. & Damasio, A. R. (2000) Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex* 10:295–307. [aMDL]

Bechara, A., Damasio, H., Tranel, D. & Damasio, A. R. (1997) Deciding advantageously before knowing the advantageous strategy. *Science* 275:1293–94. [CEI]

Bechara, A., Tranel, D., Damasio, H., Adolphs, R., Rockland, C. & Damasio, A. R. (1995) Double dissociation of conditioning and declarative knowledge relative to the amygdala and hippocampus in humans. *Science* 269:1115–18. [CEI]

Beck, A. T., Brown, G., Steer, R. A., Eidelson, J. I. & Riskind, J. H. (1987) Differentiating anxiety and depression: A test of the cognitive content specificity hypothesis. *Journal of Abnormal Psychology* 96:179–183. [aMDL]

Belavkin, R. V. (2001) The role of emotion in problem-solving. In: *Proceedings of the AISB'01 Symposium on emotion, cognition and affective computing, Heslington, York, England*, ed. C. G. Johnson, pp. 49–57. AISB Press. [PB]

Bennett, M. R. & Hacker, P. M. S. (2003) *Philosophical foundations of neuroscience*. Blackwell. [JP-L]

Berkowitz, L. (1989) On the formation and regulation of anger and aggression: A cognitive-neoassociationistic analysis. In: *Advances in experimental social psychology, vol. 22*, ed. L. Berkowitz. Academic Press. [aMDL]

Biederman, I. (1985) Human image understanding: Recent research and a theory. *Computer Vision, Graphics and Image Processing* 32:29–73. [AC]

Blair, R. J. R. (2003) Neurobiological basis of psychopathy. *British Journal of Psychiatry* 182:5–7. [CEI]

Bland, B. H. & Colom, L. V. (1993) Extrinsic and intrinsic properties underlying

oscillation and synchrony in limbic cortex. *Progress in Neurobiology* 41:157–208. [aMDL]
Bland, B. H. & Oddie, S. D. (1998) Anatomical, electrophysiological and pharmacological studies of ascending brainstem hippocampal synchronizing pathways. *Neuroscience and Biobehavioral Reviews* 22:259–73. [aMDL]
Bland, B. H., Seto, M., Sinclair, B. R. & Fraser, S. M. (1984) The pharmacology of hippocampal theta cells: Evidence that the sensory processing correlate is cholinergic. *Brain Research* 299:121–31. [aMDL]
Bond, A. H. (1999) Describing behavioural states using a system model of the primate brain. *American Journal of Primatology* 49:315–38. [PB]
Bower, G. H. (1992) How might emotions affect learning? In: *The handbook of emotion and memory: Research and theory*, ed. S.-Å. Christianson, pp. 3–31. Erlbaum. [aMDL]
Bradley, B. P., Mogg, K. & Millar, N. H. (2000) Covert and overt orienting of attention to emotional faces in anxiety. *Cognition and Emotion* 14:789–808. [aMDL]
Bradley, M. M. & Lang, P. J. (2000) Measuring emotion: Behavior, feeling, and physiology. In: *Cognitive neuroscience of emotion*, ed. R. D. Lane & L. Nadel, pp. 242–76. Oxford University Press. [NHF, aMDL]
Bressler, S. L. & Kelso, J. A. S. (2001) Cortical coordination dynamics and cognition. *Trends in Cognitive Sciences* 5:26–36. [aMDL]
Bronstein, P. (1981) Commitments to aggression and nest sites in male *Betta splendens*. *Journal of Comparative and Physiological Psychology* 95:436–49. [MP]
Brown, J. W, Bullock, D. & Grossberg, S. (1999) How the basal ganglia use parallel excitatory and inhibitory learning pathways to selectively respond to unexpected rewarding cues. *Journal of Neuroscience* 19:10502–11. [SG]
(2004) How laminar frontal cortex and basal ganglia circuits interact to control planned and reactive saccades. *Neural Networks* 17:471–510. [SG]
Bruehl, S., Burns, J. W., Chung, O. Y., Ward, P. & Johnson, B. (2002) Anger and pain sensitivity in chronic low back pain patients and pain-free controls: The role of endogenous opioids. *Pain* 99:223–33. [MP]
Buck, R. (1985) PRIME theory: An integrated approach to motivation and emotion. *Psychological Review* 92:389–413. [RB]
(1999) The biological affects: A typology. *Psychological Review* 106:301–36. [RB, aMDL]
(2004) The gratitude of exchange and the gratitude of caring: A developmental-interactionist perspective of moral emotion. In: *The psychology of gratitude*, ed. R. A. Emmons & M. McCullough, pp. 100–22. Oxford University Press. [RB]
Bush, G., Luu, P. & Posner, M. I. (2000) Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences* 4(6):215–22. [aMDL, GN, DAP]
Buss, K. A., Schumacher, J. R., Dolski, I., Kalin, N. H., Goldsmith, H. H. & Davidson, R. J. (2003) Right frontal brain activity, cortisol, and withdrawal behavior in 6-month-old infants. *Behavioral Neuroscience* 117:11–20. [JvH]
Buzsaki, G. (1996) The hippocampal-neorcortical dialogue. *Cerebral Cortex* 6:81–92. [aMDL]
(2002) Theta oscillations in the hippocampus. *Neuron* 33:325–40. [JP]
Buzsaki, G. & Draguhn, A. (2004) Neuronal oscillations in cortical networks. *Science* 304:1926–29. [JP]
Cairns, R. B., Santoyo, C. & Holly, K. A. (1994) Aggressive escalation: Toward a developmental analysis. In: *The dynamics of aggression: Biological and social processes in dyads and groups*, ed. M. Potegal & J. F. Knutson, pp. 227–53. Erlbaum. [MP]
Calder, A. J., Lawrence, A. D. & Young, A. W. (2001) Neuropsychology of fear and loathing. *Nature Reviews Neuroscience* 2:352–63. [PB]
Camille, N., Coricelli, G., Sallet, J., Pradat, P., Duhamel, J. R. & Sirigu, A. (2004) The involvement of the orbitofrontal cortex in the experience of regret. *Science* 304:1167–70. [CEI]
Campbell, A. & Muncer, S. (1994) Sex differences in aggression: Social representation and social roles. *British Journal of Social Psychology* 33:233–40. [MP]
Camras, L. A. (2000) Surprise! Facial expressions can be coordinative motor structures. In: *Emotion, development, and self-organisation*, ed. M. D. Lewis & I. Granic, pp. 100–24. Cambridge University Press. [NHF]
Cannon, W. B. (1939) *The wisdom of the body*. Norton. [WJF]
Cardinal, R. N., Parkinson, J. A., Hall, J. & Everitt, B. J. (2002) Emotion and motivation: The role of the amygdala, ventral striatum, and prefrontal cortex. *Neuroscience and Biobehavioral Reviews* 26:321–352. [aMDL]
Carpenter, G. A. & Grossberg, S. (1987) A massively parallel architecture for a self-organizing neural pattern recognition machine. *Computer Vision, Graphics, and Image Processing* 37:54–115. [SG]
(1991) *Pattern recognition by self-organizing neural networks*. MIT Press. [SG]
Carreti, L., Mart'n-Loeches, M., Hinojosa, J. A. & Mercado, F. (2001) Emotion and attention interaction studied through event-related potentials. *Journal of Cognitive Neuroscience* 13:1109–1128. [aMDL]
Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D. & Cohen, J. D. (1998) Anterior cingulate cortex, error detection, and the online monitoring of performance. *Science* 280:747–49. [aMDL]
Carter, C. S., MacDonald, A. M., III, Botvinick, M. M., Ross, L. L., Stenger, V. A., Noll, D. & Cohen, J. D. (2000) Parsing executive processes: Strategic vs. evaluative functions of the anterior cingulate cortex. *Proceedings of the National Academy of Sciences USA* 97:1944–48. [aMDL]
Carver, C. S. (2001) Affect and the functional bases of behavior: On the dimensional structure of affective experience. *Personality and Social Psychology Review* 5:345–56. [CSC]
(2003) Pleasure as a sign you can attend to something else: Placing positive feelings within a general model of affect. *Cognition and Emotion* 17:241–61. [CSC]
(2004) Negative affects deriving from the behavioral approach system. *Emotion* 4:3–22. [CSC]
Carver, C. S. & Scheier, M. F. (1990) Origins and functions of positive and negative affect: A control-process view. *Psychological Review* 97:19–35. [aMDL]
(1991) A control-process perspective on anxiety. In: *Anxiety and self-focused attention*, ed. R. Schwarzer & R. A. Wicklund, pp. 3–8. Harwood. [aMDL]
(1998) *On the self-regulation of behavior*. Cambridge University Press. [CSC]
Centonze, D., Picconi, B., Gubellini, P., Bernardi, G. & Calabresi, P. (2001) Dopaminergic control of synaptic plasticity in the dorsal striatum. *European Journal of Neuroscience* 13:1071–77. [aMDL]
Chella, A., Frixione, M. & Gaglio, S. (1997) A cognitive architecture for artificial vision. *Artificial Intelligence* 89:73–111. [AC]
(2000) Understanding dynamic scenes. *Artificial Intelligence* 123:89–132. [AC]
Chwelos, G. & Oatley, K. (1994) Appraisal, computational models, and Scherer's expert system. *Cognition and Emotion* 8:245–58. [NHF]
Ciompi, L. & Panksepp, J. (2004) Energetic effects of emotions on cognitions – Complementary psychobiological and psychosocial findings. *Consciousness and Emotion* 1:23–56. [JP]
Clark, A. (1997) *Being there: Putting brain, body, and world together again*. MIT Press. [aMDL]
Clark, D. M. & Teasdale, J. D. (1982) Diurnal variation in clinical depression and accessibility of memories of positive and negative experiences. *Journal of Abnormal Psychology* 91:87–95. [aMDL]
Cloninger, C. (1987) A systematic method for clinical description and classification of personality variants. *Archives of Geneal Psychiatry* 44:573–88. [PB]
Clum, G. A., Clum, G. A. & Surls, R. (1993) A meta-analysis of treatments for panic disorder. *Journal of Consulting and Clinical Psychology* 61:317–26. [GA]
Commons, M. L. Grossberg, S. & Staddon, J. E. R., eds. (1991) *Neural network models of conditioning and action*. Erlbaum. [SG]
Constantinidis, C., Williams, G. V. & Goldman-Rakic, P. S. (2002) A role for inhibition in shaping the temporal flow of information in the prefrontal cortex. *Nature Neuroscience* 5:175–80. [JFT]
Craig, A. D. (2002) How do you feel? Interoception: The sense of the physiological condition of the body. *Nature Reviews Neuroscience* 3:655–666. [aMDL, ANS]
Craik, I. M. (1999) In search of the self. A PET study. *Psychological Science* 10:26–34. [GN]
Crestani, F., Lorez, M., Baer, K., Essrich, C., Benke, D., Laurent, J. P., Belzung, C., Fritschy, J. M., Luscher, B. & Mohler, H. (1999) Decreased GABAA-receptor clustering results in enhanced anxiety and a bias for threat cues. *Nature Neuroscience* 2:833–39. [JFT]
Csikszentmihalyi, M. (1990) *Flow: The psychology of optimal experience*. Harper & Row. [HF]
Dalgleish, T. (2004a) Cognitive approaches to posttraumatic stress disorder (PTSD): The evolution of multi-representational theorizing. *Psychological Bulletin* 130:228–60. [PB]
(2004b) The emotional brain. *Nature Reviews Neuroscience* 5:582–89. [PB]
Damasio, A. R. (1998) Emotion in the perspective of an integrated nervous system. *Brain Research Reviews* 26:83–86. [JvH]
(1999) *The feeling of what happens: Body and emotion in the making of consciousness*. Harcourt Brace. [GC, SG, aMDL, GN]
Damasio, A. R., Grabowski, T. J., Bechara, A., Damasio, H., Ponto, L. L. B., Parvizi, J. & Hichwa, R. D. (2000) Subcortical and cortical brain activity during the feeling of self-generated emotions. *Nature Neuroscience* 3(10):1049–56. [PB]
D'Andrade, R. (1995) *The development of cognitive anthropology*. Cambridge University Press. [HF]
Darwin, C. (1872/1979) *The expressions of emotions in man and animals*. Julian Friedman/Murray. [GA, WJF]
Davidson, R. J. (1998) Affective style and affective disorders: Perspectives from affective neuroscience. *Cognition and Emotion* 12:307–30. [aMDL]
(2000) Affective style, psychopathology, and resilience: Brain mechanisms and plasticity. *American Psychologist* 55:1196–214. [DS]

(2003a) Affective neuroscience and psychophysiology: Toward a synthesis. *Psychophysiology* 40:655–65. [JvH]

(2003b) Seven sins in the study of emotion: Correctives from affective neuroscience. *Brain and Cognition* 52:129–32. [DAP]

Davidson, R. J., Ekman, P., Saron, C., Senulis, J. & Friesen, W. V. (1990) Approach-withdrawal and cerebral asymmetry: Emotional expression and brain physiology I. *Journal of Personality and Social Psychology* 58:330–41. [PB]

Davidson, R. J. & Irwin, W. (1999) The functional neuroanatomy of emotion and affective style. *Trends in Cognitive Sciences* 3:11–21. [aMDL]

Davidson, R. J., Pizzagalli, D., Nitschke, J. B. & Putnam, K. (2002) Depression: Perspectives from affective neuroscience. *Annual Review of Psychology* 53:545–74. [DAP]

Davidson, R. J., Putnam, K. M. & Larson, C. L. (2000) Dysfunction in the neural circuitry of emotion regulation: A possible prelude to violence. *Science* 289:591–94. [aMDL, ANS]

Davidson, R. J., Scherer, K. R. & Goldsmith, H., eds. (2003) *Handbook of affective sciences*. Oxford University Press. [DS]

Davis, K. L., Panksepp, J. & Normansell, L. (2003) The affective neuroscience personality scales: Normative data and implications. *Neuro-Psychoanalysis* 5:21–29. [JP]

Decatanzaro, D. A. (1999) *Motivation and emotion: Evolutionary, physiological, developmental, and social perspectives*. Prentice Hall. [JvH]

Depue, R. A. & Collins, P. F. (1999) Neurobiology of the structure of personality: Dopamine, facilitation of incentive motivation, and extraversion. *Behavioral and Brain Sciences* 22:491–569. [aMDL]

Derryberry, D. & Rothbart, M. K. (1997) Reactive and effortful processes in the organization of temperament. *Development and Psychopathology* 9:633–52. [rMDL]

Derryberry, D. & Tucker, D. M. (1994) Motivating the focus of attention. In: *The heart's eye: Emotional influences in perception and attention*, ed. P. M. Niedenthal & S. Kitayama, pp. 167–96. Academic Press. [aMDL]

Devinsky, O. (2000) Right cerebral hemisphere dominance for a sense of corporeal and emotional self. *Epilepsy and Behavior* 1:260–73. [ANS]

DeVries, A. C., DeVries, M. B., Taymans, S. & Carer, C. S. (1995) Modulation of pair binding in female voles by corticosterone. *Proceedings of the National Academy of Sciences USA* 92:7744–48. [JvH]

Dikman, Z. V. & Allen, J. J. B. (2000) Error monitoring during reward and avoidance learning in high- and low-socialized individuals. *Psychophysiology* 37:43–54. [aMDL]

Dodge, K. A. & Somberg, D. R. (1987) Hostile attributional biases among aggressive boys are exacerbated under conditions of threats to the self. *Child Development* 58:213–24. [aMDL]

Dolan, R. J. (2002) Emotion, cognition, and behavior. *Science* 298:1191–94. [aMDL]

Dolan, R. J. & Morris, J. S. (2000) The functional anatomy of innate and acquired fear: Perspectives from neuroimaging. In: *Cognitive neuroscience of emotion*, ed. R. D. Lane & L. Nadel, pp. 225–41. Oxford University Press. [aMDL]

Downey, G. (in press) *Learning Capoeira: Lessons in cunning from an Afro-Brazilian art*. Oxford University Press. [GD]

Drevets, W. C. & Raichle, M. E. (1998) Reciprocal suppression of regional blood flow during emotional versus higher cognitive processes: Implications for interactions between emotion and cognition. *Cognition and Emotion* 12(3):353–85. [aMDL, GN, MP]

Drogosz, M. & Nowak, A (in press) A neural model of mere exposure: The EXAC mechanism. *Polish Psychological Bulletin*. [PW]

Drummond, P. Q. & Quah, S. H. (2001) The effect of expressing anger on cardiovascular reactivity and facial blood flow in Chinese and Caucasians. *Psychophysiology* 38:190–96. [MP]

Duke, D. J., Barnard, P. J., Duce, D. A. & May, J. (1998) Syndetic modelling. *Human-Computer Interaction* 13:337–93. [PB]

Edelman, G. M. (1987) *Neural Darwinism*. Basic Books. [aMDL]

Edelman, G. M & Tononi, G. (1997) Commentary: Selection and development: The brain as a complex system. In: *The lifespan development of individuals: Behavioral, neurobiological, and psychosocial perspectives: A synthesis*, ed. D. Magnusson, pp. 179–204. Cambridge University Press. [aMDL]

Eich, E. & Metcalfe, J. (1989) Mood dependent memory for internal versus external events. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 15:443–56. [aMDL]

Eisenberger, N. I., Lieberman, M. D. & Williams, K. D. (2003) Does rejection hurt? An fMRI study of social exclusion. *Science* 302:290–92. [aMDL]

Ekman, P. (1994) All emotions are basic. In: *The nature of emotion: Fundamental questions*, ed. P. Ekman & R. Davidson, pp. 15–19. Oxford University Press. [arMDL]

Ellis, R. D. (1986) *An ontology of consciousness*. Kluwer/Martinus Nijhoff. [RDE]

(1995) *Questioning consciousness: The interplay of imagery, cognition and emotion in the human brain*. John Benjamins. [RDE]

(2001a) Implications of inattentional blindness for "enactive" theories of consciousness. *Brain and Mind* 2:297–322. [RDE]

(2001b) A theoretical model of the role of the cerebellum in cognition, attention and consciousness. *Consciousness and Emotion* 2:300–09. [RDE]

(2001c) Can dynamical systems explain mental causation? *Journal of Mind and Behavior* 22:311–34. [RDE]

Ellsworth, P. C. (1991) Some implications of cognitive appraisal theories of emotion. In: *International review of studies on emotion*, ed. K. T. Strongman. Wiley. [aMDL]

Elman, J. L., Bates, E. A., Johnson, M. H., Karmiloff-Smith, A., Parisi, D. & Plunkett, K. (1996) *Rethinking innateness: A connectionist perspective on development*. MIT Press. [aMDL]

Engel, A. K., Fries, P. & Singer, W. (2001) Dynamic predictions: Oscillations and synchrony in top-down processing. *Nature Reviews Neuroscience* 2:704–16. [arMDL]

Érdi, P. & Barna, G. (1984) Self-organizing mechanism for the formation of ordered neural mappings. *Biological Cybernetics* 51:93–101. [aMDL]

Fabrega, H. (2003) Commentary: On building a clinical cognitive neuroscience. *Psychiatry* 66:32–41. [HF]

(2004) Cultural formulations of homicide: Two case studies. *Psychiatry* 67(2):178–96. [HF]

Fanselow, M. S. (1994) Neural organization of the defensive behavior system responsible for fear. *Psychonomic Bulletin and Review* 1:429–38. [aMDL]

Farrer, C., Frank, N., Georgieff, N., Frith, C. D., Decety, J. & Jeannerod, M. (2003) Modulating the experience of agency: A positron emission tomography study. *Neuroimage* 18(2):324–33. [GN]

Fiala, J. C., Grossberg, S. & Bullock, D. (1996) Metabotropic glutamate receptor activation in cerebellar Purkinje cells as substrate for adaptive timing of the classically conditioned eye blink response. *Journal of Neuroscience* 16:3760–74. [SG]

Fingelkurts, A. A., Fingelkurts, A. A., Kivisaari, R., Pekkonen, E., Ilmoniemi, R. J. & Kähkönen, S. (2004) Enhancement of GABA-related signaling is associated with increase of functional connectivity in human cortex. *Human Brain Mapping* 22:27–39. [JFT]

Fink, G. R., Markowitsch, H. J., Reinkemeier, M., Bruckbauer, T., Kessler, J. & Heiss, W. D. (1996) Cerebral representation of one's own past: Neural networks involved in autobiographical memory. *Journal of Neuroscience* 16(13):4275–82. [GN]

Flood, J. F., Baker, M. L., Hernandez, E. N. & Morley, J. E. (1990) Modulation of memory retention by neuropeptide K. *Brain Research* 520:284–90. [aMDL]

Fodor, J. (1975) *The language of thought*. Harvester. [aMDL]

Fogel, A. (1985) Coordinative structures in the development of expressive behavior. In: *The development of expressive behavior: Biology-environment interactions*, ed. G. Zivin. Academic Press. [NHF]

(1993) *Developing through relationships: Origins of communication, self, and culture*. University of Chicago Press. [rMDL]

Ford, D. H. (1987) *Humans as self-constructing living systems: A developmental perspective on behavior and personality*. Erlbaum. [aMDL]

Forgas, J. P. & Bower, G. H. (1987) Affect in social and personal judgments. In: *Affect, cognition and social behavior: New evidence and integrative attempts*, ed. K. Fiedler & J. Forgas. Hogrefe. [aMDL]

Fox, E., Russo, R. & Dutton, K. (2002) Attentional bias for threat: Evidence for delayed disengagement from emotional faces. *Cognition and Emotion* 16:355–79. [aMDL]

Frank, R. H. (1988) *Passions within reason*. Norton. [GA]

Freeman, W. J. (1995) *Societies of brains: A neurophysiological study of love and hate*. Erlbaum. [WJF, aMDL]

(1999) *How brains make up their minds*. Weidenfeld & Nicolson. [WJF]

(2000) Emotion is essential to all intentional behaviors. In: *Emotion, development, and self-organization: Dynamic systems approaches to emotional development*, ed. M. D. Lewis & I. Granic, pp. 209–35. Cambridge University Press. [GC, HF, aMDL]

(2003a) A neurobiological theory of meaning in perception. Part 1, Information and meaning in nonconvergent and nonlocal brain dynamics. *International Journal of Bifurcation and Chaos* 13:2493–511. [WJF]

(2003b) A neurobiological theory of meaning in perception. Part 2, Spatial patterns of phase in gamma EEG from primary sensory cortices reveal the properties of mesoscopic wave packets. *International Journal of Bifurcation and Chaos* 13:2513–35. [WJF]

(2004a) Origin, structure and role of background EEG activity. Part 1, Analytic amplitude. *Clinical Neurophysiology* 115:2077–88. [WJF]

(2004b) Origin, structure and role of background EEG activity. Part 2, Analytic phase. *Clinical Neurophysiology* 115:2089–2107. [WJF]

(2005) Origin, structure and role of background EEG activity. Part 3, Pattern classification. *Clinical Neurophysiology*. Available via Science Direct at: http://authors.elsevier.com/sd/article/S1388245705000064. [WJF]

Freeman, W. J. & Burke, B. C. (2003) A neurobiological theory of meaning in perception. Part 4, Multicortical patterns of amplitude modulation in gamma EEG. *International Journal of Bifurcation and Chaos* 13:2857–66. [WJF]

Freeman, W. J., Burke, B. C. & Holmes, M. D. (2003a) Aperiodic phase re-setting in scalp EEG of beta-gamma oscillations by state transitions at alpha-theta rates. *Human Brain Mapping* 19:248–72. [WJF]

Freeman, W. J., Burke, B. C., Holmes, M. D. & Vanhatalo, S. (2003b) Spatial spectra of scalp EEG and EMG from awake humans. *Clinical Neurophysiology* 16:1055–60. [WJF]

Freeman, W. J., Gaál, G. & Jornten, R. (2003c) A neurobiological theory of meaning in perception. Part 3, Multiple cortical areas synchronize without loss of local autonomy. *International Journal of Bifurcation and Chaos* 13:2845–56. [WJF]

Freeman, W. J. & Rogers, L. J. (2003) A neurobiological theory of meaning in perception. Part 5, Multicortical patterns of phase modulation in gamma EEG. *International Journal of Bifurcation and Chaos* 13:2867–87. [WJF]

Friedman, B. H., Thayer, J. T. & Borkovec, T. D. (2000) Explicit memory bias for threat words in generalized anxiety disorder. *Behavior Therapy* 31:745–56. [JFT]

Frijda, N. H. (1986) *The emotions*. Cambridge University Press. [GC, aMDL, DS]

(1993a) Moods, emotion episodes, and emotions. In: *Handbook of emotions*, ed. M. Lewis & J. M. Haviland, pp. 381–403. Guilford. [arMDL]

(1993b) The place of appraisal in emotion. *Cognition and Emotion* 7:357–87. [arMDL]

Frijda, N. H. & Zeelenberg, M. (2001) Appraisal: What is the dependent? In: *Appraisal processes in emotion: Theory, methods, research*, ed. K. R. Scherer, A. Schorr & T. Johnstone, pp. 141–55. Oxford University Press. [aMDL]

Friston, K. J. (2000) The labile brain: II. Transients, complexity, and selection. *Philosophical Transactions of the Royal Society of London B*. 355:237–52. [GC]

Frith, C. (2002) Attention to action and awareness of other minds. *Conscious Cognition* 11(4):481–87. [GN]

Frith, C. D., Friston, K., Liddle, P. F. & Frackowiak, R. S. (1991) Willed action and the prefrontal cortex in man: A study with PET. *Proceedings of the Royal Society of London: Series B: Biological Science* 244(1311):241–46. [aMDL]

Fuster, J. M. (1996) *The prefrontal cortex: Anatomy, physiology and neuropsychology of the frontal lobe*, 3rd edition. Raven Press. [aMDL]

(2002) Physiology of executive functions: The perception-action cycle. In: *Principles of frontal lobe function*, ed. D. T. Stuss & R. T. Knight, pp. 96–108. Oxford University Press. [HF, aMDL]

Galatzer-Levy, R. (1978) Qualitative change from quantitative change: Mathematical catastrophe theory in relation to psychoanalysis. *Journal of the American Psychoanalytic Association* 26:921–35. [RMG-L]

(2004) Chaotic possibilities: Toward a new model of development. *International Journal of Psychoanalysis* 85:419–41. [RMG-L]

Gallagher, D. J. (1990) Extraversion, neuroticism, and appraisal of stressful academic events. *Personality and Individual Differences* 11:1053–57. [aMDL]

Gallagher, M. & Holland, P. C. (1992) Understanding the function of the central nucleus. In: *The amygdala*, ed. J. P. Aggleton, pp. 307–21. Wiley. [aMDL]

(1994) The amygdala complex: Multiple roles in associative learning and attention. *Proceedings of the National Academy of Sciences USA* 91:11771–76. [aMDL]

Gärdenfors, P. (2000) *Conceptual spaces*. MIT Press. [AC]

Geary, D. C. & Huffman, K. J. (2002) Brain and cognitive evolution: Forms of modularity and functions of mind. *Psychological Bulletin* 128(5):667–98. [HF]

Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E. & Donchin, E. (1993) A neural system for error detection and compensation. *Psychological Science* 4:385–90. [aMDL]

Gehring, W. J., Himle, J. & Nisenson, L. G. (2000) Action monitoring dysfunction in obsessive-compulsive disorder. *Psychological Science* 11:1–6. [aMDL]

Gehring, W. J. & Willoughby, A. R. (2002) The medial frontal cortex and the rapid processing of monetary gains and losses. *Science* 295:2279–82. [CEI]

Gelkopf, M. (1997) Laboratory pain and styles of coping with anger. *Journal of Psychology* 131:121–23. [MP]

Gemba, H., Sasaki, K. & Brooks, V. B. (1986) "Error" potentials in limbic cortex (anterior cingulate area 24) of monkeys during motor learning. *Neuroscience Letters* 70:223–27. [aMDL]

Goel, V. & Dolan, R. J. (2003) Explaining modulation of reasoning by belief. *Cognition* 87(1):B11–22. [GN]

Goldberg, G. (1985) Supplementary motor area structure and function: Review and hypotheses. *Behavioral and Brain Sciences* 8:567–616. [aMDL]

Goodwin, B. (1993) Development as a robust natural process. In: *Thinking about biology*, ed. W. Stein & F. J. Varela, pp. 123–48. Addison-Wesley. [aMDL]

Gosselin, P., Kirouac, G. & Dore, F. Y. (1998) Components and recognition of facial expression in the communication of emotion by actors. *Journal of Personality and Social Psychology* 68:83–96. [GA]

Granda, A. M. & Hammack, J. T. (1961) Operant behavior during sleep. *Science* 133:1485–86. [GA]

Granic, I. & Hollenstein, T. (2003) Dynamic systems methods for models of developmental psychopathology. *Development and Psychopathology* 15:641–69. [rMDL]

Gray, J. A. (1982) *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system*. Clarendon Press/Oxford University Press. [PB, aMDL]

(1987) *The psychology of fear and stress*, 2nd edition. Cambridge University Press. [aMDL]

Greicius, M. D., Krasnow, B., Reiss, A. L. & Menon, V. (2003) Functional connectivity in the resting brain: A network analysis of the default mode hypothesis. *Proceedings of the National Academy of Science USA* 100(1):253–58. [GN]

Groenewegen, H. J. (1997) Cortical-subcortical relationships and the limbic forebrain. In: *Contemporary behavioral neurology: Blue books of practical neurology, vol. 16*, ed. M. R. Trimble & J. L. Cummings, pp. 29–48. Butterworth-Heinemann. [aMDL]

Grossberg, S. (1971) On the dynamics of operant conditioning. *Journal of Theoretical Biology* 33:225–55. [SG]

(1972a) A neural theory of punishment and avoidance, I: Qualitative theory. *Mathematical Biosciences* 15:39–67. [SG]

(1972b) A neural theory of punishment and avoidance, II: Quantitative theory. *Mathematical Biosciences* 15:253–85. [SG]

(1974) Classical and instrumental learning by neural networks. In: *Progress in theoretical biology*, ed. R. Rosen & F. Snell, pp. 51–141. Academic Press. [SG]

(1975) A neural model of attention, reinforcement, and discrimination learning. *International Review of Neurobiology* 18:263–327. [SG]

(1976a) Adaptive pattern classification and universal recoding, I: Parallel development and coding of neural feature detectors. *Biological Cybernetics* 23:121–34. [SG]

(1976b) Adaptive pattern classification and universal recoding, II: Feedback, expectation, olfaction, and illusions. *Biological Cybernetics* 23:187–202. [SG]

(1978) A theory of human memory: Self-organization and performance of sensory-motor codes, maps, and plans. In: *Progress in theoretical biology*, ed. R. Rosen & F. Snell, pp. 233–374. Academic Press. [SG]

(1980) How does a brain build a cognitive code? *Psychological Review* 1:1–51. [SG]

(1982a) A psychophysiological theory of reinforcement, drive, motivation, and attention. *Journal of Theoretical Neurobiology* 1:286–369. [SG]

(1982b) Processing of expected and unexpected events during conditioning and attention: A psychophysiological theory. *Psychological Review* 89:529–72. [SG]

(1984a) Some normal and abnormal behavioral syndromes due to transmitter gating of opponent processes. *Biological Psychiatry* 19:1075–118. [SG]

(1984b) Some psychophysiological and pharmacological correlates of a developmental, cognitive, and motivational theory. In: *Brain and information: Event related potentials*, ed. R. Karrer, J. Cohen & P. Tueting, pp. 58–142. New York Academy of Sciences. [SG]

(1987) *The adaptive brain, Volumes I and II*. Elsevier/North-Holland. [SG]

(1988) *Neural networks and natural intelligence*. MIT Press. [SG]

(1995) The attentive brain. *American Scientist* 83:438–49. [SG]

(1999a) How does the cerebral cortex work? Learning, attention, and grouping by the lminar circuits of visual cortex. *Spatial Vision* 12:163–86. [SG]

(1999b) The link between brain learning, attention, and consciousness. *Consciousness and Cognition* 8:1–44. [SG]

(2000a) The complementary brain: Unifying brain dynamics and modularity. *Trends in Cognitive Sciences* 4:233–46. [SG]

(2000b) The imbalanced brain: From normal behavior to schizophrenia. *Biological Psychiatry* 48:81–98. [SG]

Grossberg, S. & Gutowski, S. (1987) Neural dynamics of decision making under risk: Affective balance and cognitive-emotional interactions. *Psychological Review* 94:300–18. [SG]

Grossberg, S. & Levine, D. S. (1987) Neural dynamics of attentionally modulated Pavlovian conditioning: Blocking, inter-stimulus interval, and secondary conditioning. *Applied Optics* 26:5015–30. [SG]

Grossberg, S. & Merrill, J. W. L. (1992) A neural network model of adaptively timed reinforcement learning and hippocampal dynamics. *Cognitive Brain Research* 1:3–38. [SG]

(1996) The hippocampus and cerebellum in adaptively timed learning, recognition, and movement. *Journal of Cognitive Neuroscience* 8:257–77. [SG]

Grossberg, S. & Schmajuk, N. A. (1987) Neural dynamics of attentionally-modulated Pavlovian conditioning: Conditioned reinforcement, inhibition, and opponent processing. *Psychobiology* 15:195–240. [SG]

(1989) Neural dynamics of adaptive timing and temporal discrimination during associative learning. *Neural Networks* 2:79–102. [SG]

Grossberg, S. & Somers, D. (1991) Synchronized oscillations during cooperative feature linking in a cortical model of visual perception. *Neural Networks* 4:453–66. [SG]

Gu, Q. (2002) Neuromodulatory transmitter systems in the cortex and their role in cortical plasticity. *Neuroscience* 111:815–35. [aMDL]

Gusnard, D. A. & Raichle, M. E. (2001) Searching for a baseline: Functional imaging and the resting human brain. *Nature Reviews Neuroscience* 2(10):685–94. [GN]

Haber, S. N., Kunishio, K., Mizobuchi, M. & Lynd-Balta, E. (1995) The orbital and medial prefrontal circuit through the primate basal ganglia. *Journal of Neuroscience* 15:4851–67. [aMDL]

Haken, H. (1977) *Synergetics – An introduction: Nonequilibrium phase transitions and self-organization in physics, chemistry and biology*. Springer Verlag. [BB, arMDL, DMT]

Hamann, S. B., Ely, T. D., Grafton, S. T. & Kilts, C. D. (1999) Amygdala activity related to enhanced memory for pleasant and aversive stimuli. *Nature Neuroscience* 2:289–93. [aMDL]

Hariri, A. R., Bookheimer, S. Y. & Mazziotta, J. C. (2000) Modulating emotional responses: Effects of a neocortical network on the limbic system. *NeuroReport* 11:43–48. [aMDL]

Harkness, K. L. & Tucker, D. M. (2000) Motivation of neural plasticity: Neural mechanisms in the self-organization of depression. In: *Emotion, development, and self-organization: Dynamic systems approaches to emotional development*, ed. M. D. Lewis & I. Granic, pp. 186–208. Cambridge University Press. [aMDL]

Hasson, U., Nir, Y., Levy, I., Fuhrmann, G. & Malach, R. (2004) Intersubject synchronization of cortical activity during natural vision. *Science* 303:1634–40. [rMDL]

Haviland, J. M. & Walker-Andrews, A. S. (1992) Emotion socialization: A view from development and ethology. In: *Handbook of social development: A lifespan perspective*, ed. V. B. V. Hasselt & M. Hersen, pp. 29–49. Plenum Press. [ASW-A]

Haviland-Jones, J., Boulifard, D. & Magai, C. (2001) Old-new answers and new-old questions of personality and emotion; A matter of complexity. In: *Identity and emotions: A self-organisational perspective*, ed. S. Kunnen & H. Bosma. Cambridge University Press. [ASW-A]

Hebb, D. O. (1949) *The organization of behavior: A neuropsychological theory*. Wiley. [GD, aMDL]

Heinzel, A., Bermpohl, F., Schlaug, G., Pascual-Leone, A. & Northoff, G. (2004) How do we modulate our emotions? Parametric fMRI reveals cortical midline structures as regions specifically involved in the processing of emotional valences. *Cognitive Brain Research*. (in revision). [GN]

Helmeke, C., Ovtscharoff, W., Jr., Poeggel, G. & Braun, K. (2001) Juvenile emotional experience alters synaptic inputs on pyramidal neurons in the anterior cingulate cortex. *Cerebral Cortex* 11:717–27. [ANS]

Hermans, H. J. M. (1996) Voicing the self: From information processing to dialogical interchange. *Psychological Bulletin* 119:31–50. [rMDL]

Hess, U., Blairy, S. & Kleck, R. (1997) The intensity of emotional facial expressions and decoding accuracy. *Journal of Nonverbal Behavior* 21:241–57. [MP]

Higgins, E. T. (1987) Self-discrepancy: A theory relating self and affect. *Psychological Review* 94:319–40. [aMDL]

Hikosaka, K. & Watanabe, M. (2000) Delay activity of orbital and lateral prefrontal neurons of the monkey varying with different rewards. *Cerebral Cortex* 10:263–71. [aMDL]

Hoeksma, J. B., Oosterlaan, J. & Schipper, E. (2004) Emotion regulation and the dynamics of feelings: A conceptual and methodological framework. *Child Development* 75:354–60. [MP]

Holland, P. C. & Gallagher, M. (1999) Amygdala circuitry in attentional and representational processes. *Trends in Cognitive Sciences* 3:65–73. [aMDL]

Holland, P. C., Han, J. S. & Gallagher, M. (2000) Lesions of the amygdala central nucleus alter performance on a selective attention task. *Journal of Neuroscience* 20:6701–06. [aMDL]

Holroyd, C. B. & Coles, M. G. H. (2002) The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review* 109:679–709. [aMDL]

Hopfield, J. J. (1982) Neural networks and physical systems with emergent collective computational abilities. *Proceedings of the National Academy of Sciences USA* 79:2554–58. [PW]

Horowitz, M. J. (1998) *Cognitive psychodynamics: From conflict to character*. Wiley. [aMDL]

Hsu, H.-C. & Fogel, A. (2003) Stability and transitions in mother-infant face-to-face communication during the first 6 months: A microhistorical approach. *Developmental Psychology* 39:1061–82. [rMDL]

Hurley, S. L. (1998) *Consciousness in action*. Harvard University Press. [GC]

Hurley, S. L. & Noë, A. (2003) Neural plasticity and consciousness. *Biology and Philosophy* 18:131–68. [GC]

Iacoboni, M., Lieberman, M. D., Knowlton, B. J., Molnar-Szakacs, I., Moritz, M., Throop, C. J. & Fiske, A. P. (2004) Watching social interactions produces dorsomedial prefrontal and medial parietal BOLD fMRI signal increases compared to a resting baseline. *Neuroimage* 21(3):1167–73. [GN]

Isen, A. M. (1985) The asymmetry of happiness and sadness in effects on memory in normal college students. *Journal of Experimental Psychology: General* 114:388–391. [aMDL]

(1990) The influence of positive and negative affect on cognitive organization: Some implications for development. In: *Psychological and biological processes in the development of emotion*, ed. N. Stein, B. Leventhal & T. Trabasso. Erlbaum. [aMDL]

Izard, C. E. (1971) *The face of emotion*. Appleton-Century-Crofts. [PB]

(1977) *Human emotions*. Plenum Press. [CEI]

(1984) Emotion-cognition relationships and human development. In: *Emotions, cognition and behavior*, ed. C. E. Izard, J. Kagan & R. B. Zajonc, pp. 17–37. Cambridge University Press. [aMDL]

(1991) *The psychology of emotion*. Plenum. [aMDL]

(1993) Four systems for emotion activation: Cognitive and noncognitive processes. *Psychological Review* 100:68–90. [CEI, aMDL]

Izard, C. E., Ackerman, B. P., Schoff, K. M. & Fine, S. E. (2000) Self-organization of discrete emotions, emotion patterns, and emotion-cognition relations. In: *Emotion, development, and self-organization: Dynamic systems approaches to emotional development*, ed. M. D. Lewis & I. Granic, pp. 15–36. Cambridge University Press. [rMDL]

Izard, C. E., Fantauzzo, C. A., Castle, J. M., Haynes, O. M., Rayias, M. F., & Putnam, P. H. (1995) The ontogeny and significance of infants' facial expressions in the first 9 months of life. *Developmental Psychology* 31:997–1013. [ASW-A]

Izard, C. E., Hembree, E. A. & Huebner, R. R. (1987) Infants' emotion expressions to acute pain: Developmental change and stability of individual differences. *Developmental Psychology* 23:105–13. [CEI]

Izard, C. E., Libero, D. Z., Putnam, P. & Haynes, O. M. (1993) Stability of emotion experiences and their relation to traits of personality. *Journal of Personality and Social Psychology* 64:847–60. [CEI]

Izard, C. E. & Malatesta, C. (1987) Perspectives on emotional development I: Differential emotions theory of early emotional development. In: *Handbook of infant development*, ed. J. D. Osofsky, pp. 494–554. Wiley. [aMDL, MP]

Izquierdo, I. (1997) The biochemistry of memory formation and its regulation by hormones and neuromodulators. *Psychobiology* 25:1–9. [aMDL]

Izumi, Y. & Zorumski, C. F. (1999) Norepinephrine promotes long-term potentiation in the adult rat hippocampus in vitro. *Synapse* 31:196–202. [aMDL]

Jackendoff, R. (1987) *Consciousness and the computational mind*. MIT Press. [AC]

James, W. (1890/1968) Does "consciousness" exist? In: *The writings of William James*, ed. John McDermott, pp. 169–80. Random House. [RDE]

(1890) *The principles of psychology*. Holt. [WJF]

Jantsch, E. (1980) *The self-organizing universe*. Pergamon. [rMDL]

Jerusalem, M. (1993) Personal resources, environmental constraints, and adaptational processes: The predictive power of a theoretical stress model. *Personality and Individual Differences* 14:15–24. [aMDL]

Johannes, S., Wieringa, B. M., Nager, W., Dengler, R. & Münte, T. F. (2001) Oxazepam alters action monitoring. *Psychopharmacology* 155:100–06. [aMDL]

Johnson, E. O., Kamilaris, T. C., Chrousos, G. P. & Gold, P. W. (1992) Mechanisms of stress: A dynamic overview of hormonal and behavioral homeostasis. *Neuroscience and Biobehavioral Reviews* 16:115–30. [JvH]

Juarrero, A. (1999) *Dynamics in action: Intentional behavior as a complex system*. MIT Press/Bradford. [arMDL]

Kalin, N. H., Larson, C., Shelton, S. E. & Davidson, R. J. (1998) Asymmetric frontal brain activity, cortisol, and behavior associated with fearful temperament in rhesus monkeys. *Behavioral Neuroscience* 112:286–92. [JvH]

Kaminski, M. J. & Blinowska, K. J. (1991) A new method of the description of the information flow in the brain structures. *Biological Cybernetics* 65:203–10. [BK]

Kaminski, M. J. & Kocsis, B. (2003) Direction of the theta rhythmic drive between neurons in the supramammillary nucleus and the septohippocampal system in urethane anesthetized rats. *Neuroscience Abstracts* 29, No.938.13. [Online: *2003 Abstract Viewer/Itinerary Planner*. Society for Neuroscience, Program No. 928.13] [BK]

Kandel, E. R., Schwartz, J. H. & Jessell, T. M. (2000) *Principles of neural science*. McGraw-Hill. [aMDL]

Karakas, S., Erzengin, O. U. & Basar, E. (2000) The genesis of human event-related responses explained through the theory of oscillatory neural assemblies. *Neuroscience Letters* 285:45–48. [aMDL]

Karoly, P. (1993) Mechanisms of self-regulation: A systems view. *Annual Review of Psychology* 44:23–52. [aMDL]

Kauffman, S. A. (1993) *The origins of order: Self-organization and selection in evolution*. Oxford University Press. [aMDL]
(1995) *At home in the universe: The search for the laws of self-organization and complexity*. Oxford University Press. [aMDL]
Keenan, J. P., Nelson, A., O'Connor, M. & Pascual-Leone, A. (2001) Self-recognition and the right hemisphere. *Nature* 409(6818):305. [GN]
Keenan, J. P., Wheeler, M. A., Gallup, G. G. & Pascual-Leone, A. (2000) Self-recognition and the right prefrontal cortex. *Trends in Cognitive Sciences* 4(9):338–44. [GN]
Kelley, W. M., Macrae, C. N., Wyland, C. L., Caglar, S., Inati, S. & Heatherton, T. F. (2002) Finding the self? An event-related fMRI study. *Journal of Cognitive Neuroscience* 14(5):785–94. [GN]
Kelso, J. A. S. (1995) *Dynamic patterns: The self-organization of brain and behavior*. MIT Press/Bradford. [BB, PB, aMDL]
Keltner, D., Ellsworth, P. C. & Edwards, K. (1993) Beyond simple pessimism: Effects of sadness and anger on social perception. *Journal of Personality and Social Psychology* 64:740–52. [aMDL, MP]
Kilic, C., Noshirvani, H., Basoglu, M. & Marks, I. (1997) Agoraphobia and panic disorder: 3.5 years after alprazolam and/or exposure treatment. *Psychotherapy and Psychosomatics* 66:175–78. [GA]
Kirk, I. J. & McNaughton, N. (1991) Supramammillary cell firing and hippocampal rhythmical slow activity. *NeuroReport* 2:723–25. [BK]
(1993) Mapping the differential effects of procaine on frequency and amplitude of reticularly elicited hippocampal rhythmical slow activity. *Hippocampus* 3:517–26. [BK]
Kirk, I. J., Oddie, S. D., Konopacki, J. & Bland, B. H. (1996) Evidence for differential control of posterior-hypothalamic, supramammillary, and medial mammillary theta-related cellular discharge by ascending and descending pathways. *Journal of Neuroscience* 16:5547–54. [BK]
Klimesch, W. (1999) EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews* 29:169–95. [aMDL, JP]
Klinger, E. (1975) Consequences of commitment to and disengagement from incentives. *Psychological Review* 82:1–25. [CSC]
Klinnert, M. D., Sorce, J. F., Emde, R. N., Stenberg, C. & Gaensbauer, T (1984) Continuities and change in early emotional life. In: *Continuities and discontinuities in development*, ed. R. N. Emde & R. J. Harman, pp. 339–54. Plenum Press. [MP]
Knyazev, G. G., Savostyanov, A. N. & Levin E. A. (2004) Alpha oscillations as a correlate of trait anxiety. *International Journal of Psychophysiology* 53:147–60. [JvH]
Knyazev, G. G. & Slobodskaya, H. R. (2003) Personality trait of behavioral inhibition is associated with oscillatory systems reciprocal relationships. *International Journal of Psychophysiology* 48:247–61. [JvH]
Kocsis, B. (2000) Possible descending theta-rhythmic drive to neurons in the supramammillary nucleus. *Neuroscience Abstracts* 26, No.70.8. [Online: *2000 Abstract Viewer/Itinerary Planner*. Society for Neuroscience, Program No. 70.8] [BK]
Kocsis, B. & Vertes, R. P. (1992) Dorsal Raphe neurons: Synchronous discharge with the theta rhythm of the hippocampus in the freely behaving rat. *Journal of Neurophysiology* 68:1463–67. [aMDL]
(1994) Characterization of neurons of the supramammillary nucleus and mammillary body that discharge rhythmically with the hippocampal theta rhythm in the rat. *Journal of Neuroscience* 14:7040–52. [BK, aMDL]
(1997) Phase relations of theta rhythmic firing of neurons in the supramammillary nucleus and mammillary body to the hippocampal theta activity in urethane anesthetized rats. *Hippocampus* 7:204–14. [BK]
Kocsis, B., Viana Di Prisco, G. & Vertes, R. P. (2001) Theta synchronization in the limbic system: The role of Gudden's tegmental nuclei. *European Journal of Neuroscience* 13:381–88. [aMDL]
Köhling, R. (2002) GABA becomes exciting. *Science* 298:1350–51. [JFT]
Kopell, N., Ermentrout, G. B., Whittington, M. A. & Traub, R. D. (2000) Gamma rhythms and beta rhythms have different synchronization properties. *Proceedings of the National Academy of Sciences USA* 97:1867–72. [aMDL]
Kosslyn, S. M. & Koenig, O. (1995) *Wet mind, the new cognitive neuroscience*. Free Press. [DS]
Krause, C. M., Viemerö, V., Rosenqvist, A., Sillanmäki, L. & Åström, T. (2000) Relative electroencephalographic desynchronization and synchronization in humans to emotional film content: An analysis of the 4-6, 6-8, 8-10, and 10-12 Hz frequency bands. *Neuroscience Letters* 286:9–12. [JP]
Kuiper, N. A. & Martin, R. A. (1989) Type A behavior: A social cognition motivational perspective. In: *The psychology of learning and motivation: Advances in research and theory, vol. 24*, ed. G. H. Bower, pp. 311–41. Academic Press. [aMDL]
Kunda, Z. & Thagard, P. (1996) Forming impressions from stereotypes, traits, and behaviors: A parallel-constraint-satisfaction theory. *Psychological Review* 103:284–308. [aMDL]
Kunnen, E. S., Bosma, H. A., van Halen, C. P. M. & van der Meulen, M. (2001) A self-organizational approach to identity and emotions: An overview and implications. In: *Identity and emotion: Development through self-organization*, ed. H. A. Bosma & E. S. Kunnen, pp. 202–30. Cambridge University Press. [rMDL]
Kuppens, P., Van Mechelen, I., Smits, D. J. M. & De Boeck, P. (2003) The appraisal basis of anger: Specificity, necessity, and sufficiency of components. *Emotion* 3:254–69. [NHF]
Lakoff, G. & Koevecses, Z. (1987) The cognitive model of anger inherent in American English. In: *Cultural models in language and thought*, ed. D. Holland & N. Quinn, pp. 195–221. Cambridge University Press. [MP]
Lane, R. D. (2000) Neural correlates of conscious experience. In: *Cognitive neuroscience of emotion*, ed. R. D. Lane & L. Nadel, pp. 345–70. Oxford University Press. [aMDL]
Lane, R. D. & Nadel, L., eds. (2000) *Cognitive neuroscience of emotion*. Series in Affective Science. Oxford University Press. [DS, JFT]
Lane, R. D., Nadel, L., Allen, J. J. B. & Kaszniak, A. W. (2000) The study of emotion from the perspective of cognitive neuroscience. In: *Cognitive neuroscience of emotion*, ed. R. D. Lane & L. Nadel, pp. 3–11. Oxford University Press. [aMDL]
Lane, R. D., Reiman, E. M., Axelrod, B., Yun, L., Holmes, A. & Schwartz, G. E. (1998) Neural correlates of levels of emotional awareness: Evidence of an interaction between emotion and attention in the anterior cingulate cortex. *Journal of Cognitive Neuroscience* 10:525–35. [aMDL]
Lang, P. J., Bradley, M. M. & Cuthbert, B. N. (1990) Emotion, attention, and the startle reflex. *Psychological Review* 97(3):377–95. [PB]
Langs, R. & Badalamenti, J. (1991) Statistics and mathematics in psychotherapy research. *The Society for Psychoanalytic Psychotherapy Bulletin* 6:2–13. [RMG-L]
Lazarus, R. S. (1966) *Psychological stress and the coping process*. McGraw-Hill. [aMDL]
(1968) Emotions and adaptation: Conceptual and empirical relations. In: *Nebraska Symposium on Motivation, vol. 16*, ed. W. J. Arnold, pp. 175–270. University of Nebraska Press. [aMDL]
(1984) On the primacy of cognition. *American Psychologist* 39:124–29. [aMDL]
(1991) *Emotion and adaptation*. Oxford University Press. [aMDL]
(1995) Vexing research problems inherent in cognitive-mediational theories of emotion and some solutions. *Psychological Inquiry* 6:183–96. [aMDL]
(1999) The cognition-emotion debate: A bit of history. In: *Handbook of cognition and emotion*, ed. T. Dalgleish & M. Power, pp. 3–19. Wiley. [aMDL]
Lazarus, R. S. & Smith, C. A. (1988) Knowledge and appraisal in the cognition-emotion relationship. *Cognition and Emotion* 2:281–300. [NHF]
LeDoux, J. E. (1987) Emotion. In: *Handbook of physiology: Vol. 5. Higher functions of the brain*, ed. F. Plum, pp. 419–59. American Psychological Society. [aMDL]
(1989) Cognition-emotion interactions in the brain. *Cognition and Emotion* 3:267–89. [aMDL]
(1993) Emotional networks in the brain. In: *Handbook of emotions*, ed. M. Lewis & J. M. Haviland, pp. 109–18. Guilford. [aMDL]
(1995a) Emotion: Clues from the brain. *Annual Review of Psychology* 46:209–35. [aMDL]
(1995b) In search of an emotional system in the brain: Leaping from fear to emotion and consciousness. In: *The cognitive neurosciences*, ed. M. S. Gazzaniga, pp. 1049–61. MIT Press. [aMDL]
Levenson, R. W. (1992) Autonomic nervous system differences among emotions. *Psychological Science* 3, 23–27. [MP]
Leventhal, H. & Scherer, K. (1987) The relationship of emotion to cognition: A functional approach to a semantic controversy. *Cognition and Emotion* 1:3–28. [aMDL, DS]
LeVine, R. A. (1990) Enculturation: A biosocial perspective on the development of self. In: *The self in transition: Infancy to childhood*, ed. D. Cicchetti & M. Beeghly, pp. 99–117. University of Chicago Press. [HF]
Lewenstein, M. & Nowak, A. (1989) Recognition with self-control in neural networks. *Physical Review* 40:4652–64. [PW]
Lewis, M., Alessandri, S. M. & Sullivan, M. W. (1990) Violation of expectancy, loss of control, and anger expressions in young infants. *Developmental Psychology* 26:745–51. [MP]
Lewis, M. D. (1995) Cognition-emotion feedback and the self-organization of developmental paths. *Human Development* 38:71–102. [arMDL]
(1996) Self-organising cognitive appraisals. *Cognition and Emotion* 10:1–25. [aMDL]
(2000a) Emotional self-organization at three time scales. In: *Emotion, development, and self-organization: Dynamic systems approaches to emotional development*, ed. M. D. Lewis & I. Granic, pp. 37–69. Cambridge University Press. [GC arMDL]
(2000b) The promise of dynamic systems approaches for an integrated account of human development. *Child Development* 71:36–43. [arMDL, ASW-A]
(2002) The dialogical brain: Contributions of emotional neurobiology to

understanding the dialogical self. *Theory and Psychology* 12:175–90. [rMDL]
Lewis, M. D. & Granic, I. (1999) Self-organization of cognition-emotion interactions. In: *Handbook of cognition and emotion*, ed. T. Dalgleish & M. Power, pp. 683–70. Wiley. [aMDL]
Lewis, M. D., Lamey, A. V. & Douglas, L. (1999) A new dynamic systems method for the analysis of early socioemotional development. *Developmental Science* 2:458–76. [rMDL]
Lewis, M. D. & Stieben, J. (2004) Emotion regulation in the brain: Conceptual issues and directions for developmental research. *Child Development* 75:371–76. [aMDL]
Lillard, A. S. (1998) Ethnopsychologies: Cultural variation in theories of mind. *Psychological Bulletin* 123(1):3–32. [HF]
Liotti, M., Mayberg, H. S., Brannan, S. K., McGinnis, S., Jerabek, P. & Fox, P. T. (2000) Differential limbic-cortical correlates of sadness and anxiety in healthy subjects: Implications for affective disorders. *Biological Psychiatry* 48:30–42. [aMDL]
Lutz, A., Lachaux, J.-P., Martinerie, J. & Varela, F. J. (2002) Guiding the study of brain dynamics by using first-person data: Synchrony patterns correlate with ongoing conscious states during a simple visual task. *Proceedings of the National Academy of Science USA* 99(3):1586–91. [GC, arMDL]
Lutz, A & Thompson, E. (2003) Neurophenomenology: Integrating subjective experience and brain dynamics in the neuroscience of consciousness. *Journal of Consciousness Studies* 10:31–52. [GC]
Lutz, C. (1985) Ethnopsychology compared to what? Explaining behavior and consciousness among the Ifaluk. In: *Person, self, and experience*, ed. G. White & J. Kirkpatrick. University of California Press. [HF]
Luu, P., Collins, P. & Tucker, D. M. (2000) Mood, personality, and self-monitoring: Negative affect and emotionality in relation to frontal lobe mechanisms of error monitoring. *Journal of Experimental Psychology: General* 129:43–60. [aMDL]
Luu, P. & Tucker, D. M. (2002) Self-regulation and the executive functions: Electrophysiological clues. In: *The cognitive electrophysiology of mind and brain*, ed. A. Zani & A. M. Preverbio, pp. 199–223. Academic Press. [arMDL]
Luu, P., Tucker, D. M. & Derryberry, D. (1998) Anxiety and the motivational basis of working memory. *Cognitive Therapy and Research* 22:577–94. [aMDL]
Luu, P., Tucker, D. M., Derryberry, D., Reed, M. & Poulsen, C. (2003) Electrophysiological responses to errors and feedback in the process of action regulation. *Psychological Science* 14(1):47–53. [arMDL, DAP]
Luu, P., Tucker, D. M. & Makeig, S. (2004) Frontal midline theta and the error-related negativity: Neurophysiological mechanisms of action regulation. *Clinical Neurophysiology* 115:1821–35. [rMDL, DAP]
MacLean, P. D. (1949) Psychosomatic disease and the "visceral brain": Recent developments bearing on the Papez theory of emotion. *Psychosomatic Medicine* 11:338–53. [aMDL]
(1990) *The triune brain in evolution: Role in paleocerebral functions*. Plenum Press. [JvH]
(1993) Perspectives on cingulate cortex in the limbic system. In: *Neurobiology of cingulate cortex and limbic thalamus: A comprehensive handbook*, ed. B. A. Vogt & M. Gabriel, pp. 1–15. Brikhauser. [aMDL]
Magai, C. & Haviland-Jones, J. (2002) *The hidden genius of emotion: Lifespan transformations of personality*. Cambridge University Press. [ASW-A]
Magai, C. & McFadden, S. H. (1995) *The role of emotions in social and personality development: History, theory, and research*. Plenum Press. [CEI, aMDL]
Makeig, S., Westerfield, M., Jung, T.-P., Enghoff, S., Townsend, J., Courchesne, E. & Sejnowski, T. J. (2002) Dynamic brain sources of visual evoked responses. *Science* 295:690–94. [aMDL]
Malatesta, C. Z. & Izard, C. E. (1984) The facial expression of emotion: Young, middle-aged, and older adult expressions. In: *Emotion in adult development*, ed. C. Z. Malatesta & C. E. Izard, pp. 253–73. Sage. [ASW-A]
Malatesta, C. Z. & Wilson, A. (1988) Emotion/cognition interaction in personality development: A discrete emotions, functionalist analysis. *British Journal of Social Psychology* 27:91–112. [aMDL]
Mandler, G. (1980) Recognizing: The judgment of previous occurrence. *Psychological Review* 87:252–71. [PW]
Marks, I. & Tobena, A. (1990) Learning and unlearning fear: A clinical and evolutionary perspective. *Neuroscience and Biobehavioral Reviews* 14:365–84. [GA]
Marr, D. & Vaina, L. (1982) Representation and recognition of the movements of shapes. *Proceedings of the Royal Society of London, B* 214:501–24. [AC]
Martin, L. L. & Tesser, A. (1996) Some ruminative thoughts. In: *Ruminative thoughts, vol. 9, Advances in social cognition*, ed. R. S. Wyer, pp. 1–47. Erlbaum. [aMDL]
Mathews, A. (1990) Why worry? The cognitive function of anxiety. *Behaviour Research and Therapy* 28:455–68. [aMDL]
Mathews, A. & MacLeod, C. (1985) Selective processing of threat cues in anxiety states. *Behavior Research and Therapy* 23:563–69. [aMDL]
Mathews, A. M. & MacLeod, C. (1986) Discrimination of threat cues without awareness in anxiety states. *Journal of Abnormal Psychology* 95:131–38. [aMDL]
(1994) Cognitive approaches to emotion and emotional disorders. *Annual Review of Psychology* 45:25–50. [aMDL]
(2002) Induced processing biases have causal effects on anxiety. *Cognition and Emotion* 16:331–54. [aMDL]
Maulsby, R. L. (1971) An illustration of emotionally evoked theta rhythm in infancy: Hedonic hypersynchrony. *Electroencephalography and Clinical Neurophysiology* 31:157–65. [JP]
Mayberg, H. S., Liotti, M., Brannan, S. K., McGinnis, S., Mahurin, R. K., Jerabek, P. A., Silva, J. A., Tekell, J. L., Martin, C. C., Lancaster, J. L. & Fox, P. T. (1999) Reciprocal limbic-cortical function and negative mood: Converging PET findings in depression and normal sadness. *American Journal of Psychiatry* 156(5):675–82. [aMDL]
Mazur, A. & Booth, A. (1998) Testosterone and dominance. *Behavioral and Brain Sciences* 21:353–97. [JvH]
McCormick, D. A., Wang, Z. &. Huguenard, J. (1993) Neurotransmitter control of neocortical neuronal activity and excitability. *Cerebral Cortex* 3:387–98. [aMDL]
McCulloch, W. & Pitts, W. (1943) A logical calculus of the ideas immanent in nervous activity. *Bulletin of Mathematical Biophysics* 5:115–33. [aMDL]
Menon, V., Adleman, N. E., White, C. D., Glover, G. H. & Reiss, A. L. (2001) Error-related brain activation during a Go/NoGo response inhibition task. *Human Brain Mapping* 12:131–43. [aMDL]
Merleau-Ponty, M. (1942/1963) *The structure of behavior*. Beacon. [RDE]
Mesulam, M. (2002) The human frontal lobes: Transcending the default mode through contingent encoding. In: *Principals of frontal lobe function*, ed. D. T. Stuss & R. T. Knight, pp. 8–30. Oxford University Press. [arMDL]
Mesulam, M-M. (2000) Behavioral neuroanatomy: Large-scale networks, association cortex, frontal lobe syndromes, the limbic system, and hemispheric specializations. In: *Principles of behavioral and cognitive neurology*, ed. M.-M. Mesulam, pp. 1–120. Oxford University Press. [HF]
Meyer-Lindenberg, A., Bauer, U., Krieger, S., Lis, S., Vehmeyer, K., Schueler, G. & Gallhofer, B. (1998) The topography of non-linear cortical dynamics at rest, in mental calculation and moving shape perception. *Brain Topography* 10:291–99. [aMDL]
Meyer-Lindenberg, A., Ziemann, U., Hajak, G., Cohen, L. & Berman, K. F. (2002) Transitions between dynamical states of differing stability in the human brain. *Proceedings of the National Academy of Sciences USA* 99:10948–53. [aMDL]
Miller, R. (1991) *Cortico-hippocampal interplay and the representation of contexts in the brain*. Springer-Verlag. [aMDL]
Mineka, S., Rafaeli, E. & Yovel, I. (2003) Cognitive biases in emotional disorders: Information processing and social-cognitive perspectives. In: *Handbook of affective science*, ed. R. J. Davidson, K. R. Scherer & H. H. Goldsmith, pp. 976–1009. Oxford University Press. [DAP]
Montague, P. R. & Berns, G. S. (2002) Neuroeconomics and the biological substrates of valuation. *Neuron* 36:265–84. [GA]
Morris, J., Friston, K. J., Buechel, C., Frith, C. D., Young A. W., Calder, A. J. & Dolan, R. J. (1998) A neuromodulatory role for the human amygdala in processing emotional facial expressions. *Brain* 121:47–57. [aMDL]
Moscovitch, M. (1992) Memory and working-with-memory: A component process model based on modules and central systems. *Journal of Cognitive Neuroscience* 4:257–67. [aMDL]
Murphy, S. T. & Zajonc, R. B. (1993) Affect, cognition, and awareness: Affective priming with optimal and suboptimal stimulus exposures. *Journal of Personality and Social Psychology* 64:723–39. [NHF]
Myers, F. (1986) *Pintupi country, Pintupi self: Sentiment, place and politics among Western Desert Aborigines*. Smithsonian Institution. [GD]
Nagai, Y., Critchely, H. D., Featherstone, E., Trimble, M. R. & Dolan, R. J. (2004) Activity in ventromedial prefrontal cortex covaries with a sympathetic skin conductance level: A physiological account of a "default mode" of brain function. *Neuroimage* 22:243–51. [GN]
Nair, H. P., Berndt, J. D., Barrett, D. & Gonzalez-Lima, F. (2001) Maturation of extinction behavior in infant rats: Large-scale regional interactions with medial prefrontal cortex, orbitofrontal cortex, and anterior cingulate. *Journal of Neuroscience* 21:4400–407. [ANS]
Natsume, K. & Kometani, K. (1997) Theta-activity-dependent and -independent muscarinic facilitation of long-term potentiation in guinea pig hippocampal slices. *Neuroscience Research* 27:335–41. [aMDL]
Neddens, J., Brandenburg, K., Teuchert-Noodt, G. & Dawirs, R. R. (2001) Differential environment alters ontogeny of dopamine innervation of the orbital prefrontal cortex in gerbils. *Journal of Neuroscience Research* 63:209–13. [ANS]
Nerb, J. & Spada, H. (2001) Evaluation of environmental problems: A coherence model of cognition and emotion. *Cognition and Emotion* 15:521–51. [aMDL]

Nesse, R. M. (2000) Is depression an adaptation? *Archives of General Psychiatry* 57:14–20. [CSC]

Newton, N. (2000) Conscious emotion in a dynamic system: How I can know how I feel. In: *The caldron of consciousness: Motivation, affect, and self-organization*, ed. R. Ellis & N. Newton, pp. 91–108. John Benjamins. [RDE]

Niedenthal, P. M., Setterlund, M. B. & Jones, D. E. (1994) Emotional organization of perceptual memory. In: *The heart's eye: Emotional influences in perception and attention*, ed. P. M. Niedenthal & S. Kitayama, pp. 87–113. Academic Press. [aMDL]

Noë, A. (2004) *Action in perception*. MIT Press. [GC]

Nolen-Hoeksema, S. & Morrow, J. (1991) A prospective study of depression and distress following a natural disaster: The 1989 Loma Prieta earthquake. *Journal of Personality and Social Psychology* 61:115–21. [aMDL]

Northoff, G. (2002) What catatonia can tell us about "top-down modulation": A neuropsychiatric hypothesis. *Behavioral and Brain Sciences* 25(5):555–77; discussion 578–604. [GN]

Northoff, G. & Bermpohl, F. (2004) Cortical midline structures and the self. *Trends in Cognitive Sciences* 8:102–07. [GN]

Northoff, G., Heinzel, A., Bermpohl, F., Niese, R., Pfennig, A., Pascual-Leone, A. & Schlaug, G. (2004) Reciprocal modulation and attenuation in the prefrontal cortex: An fMRI study on emotional-cognitive interaction. *Human Brain Mapping* 21:202–12. [GN]

Nowak, A. & Vallacher, R. R. (1998) *Dynamical social psychology*. Guilford. [PW]

Nowak, A., Vallacher, R. R., Tesser, A. & Borkowski, W. (2000) Society of self: The emergence of collective properties in self-structure. *Psychological Review* 107:39–61. [aMDL]

Nunez, P. L. (2000) Toward a quantitative description of large-scale neocortical dynamic function and EEG. *Behavioral and Brain Sciences* 23:371–437. [aMDL]

Nusbaum, M. (2001) *Upheavals of thought: The intelligence of emotions*. Cambridge University Press. [GD]

Nwokah, E. & Fogel, A. (1993) Laughter in mother infant emotional communication: Humor. *Journal of Humor Research* 6:137–61. [ASW-A]

Oades, R. D. & Halliday, G. M. (1987) Ventral tegmental (A10) system: Neurobiology. 1. Anatomy and connectivity. *Brain Research Reviews* 12:117–65. [aMDL]

Oatley, K. & Johnson-Laird, P. N. (1987) Towards a cognitive theory of emotions. *Cognition and Emotion* 1:29–50. [aMDL]

Öhman, A. (1988) Preattentive processes in the generation of emotions. In: *Cognitive perspectives on emotion and motivation*, ed. V. Hamilton, G. H. Bower & N. H. Frijda, pp. 127–44. Kluwer Academic Publishers. [aMDL]

(1993) Fear and anxiety as emotional phenomena: Clinical phenomenology, evolutionary perspectives, and information-processing mechanisms. In: *Handbook of emotions*, ed. M. Lewis & J. M. Haviland, pp. 511–36. Guilford. [aMDL]

Öhman, A. & Mineka, S. (2001) Fears, phobias, and preparedness: Toward an evolved module of fear and fear learning. *Psychological Review* 108(3):483–522. [DS]

Öhman, A. & Soares, J. J. F. (1994) "Unconscious anxiety": Phobic responses to masked stimuli. *Journal of Abnormal Psychology* 103:231–40. [aMDL]

Ongur, D. & Price, J. L. (2000) The organization of networks within the orbital and medial prefrontal cortex of rats, monkeys and humans. *Cerebral Cortex* 10(3):206–19. [aMDL, GN]

O'Regan, K. J. & Noë, A. (2001) A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences* 24:883–917. [GC]

O'Reilly, R. C. & Munakata, Y. (2000) *Computational explorations in cognitive neuroscience: Understanding the mind by simulating the brain*. MIT Press. [PW]

Ortony, A., Clore, G. L. & Collins, A. (1988) *The cognitive structure of emotion*. Cambridge University Press. [aMDL, MP]

Oster, H., Hegley, D. & Nagel, L. (1992) Adult judgements and fine-grained analysis of infant facial expressions: Testing the validity of a priori coding formulas. *Developmental Psychology* 28:1115–31. [MP]

Packard M. G. & Cahill, L. (2001) Affective modulation of multiple memory systems. *Current Opinion in Neurobiology* 11:752–56. [aMDL]

Pailing, P. E., Segalowitz, S. J., Dywan, J. & Davies, P. L. (2002) Error negativity and response control. *Psychophysiology* 39:198–206. [aMDL]

Pan, W. X. & McNaughton, N. (2002) The role of the medial supramammillary nucleus in the control of hippocampal theta activity and behaviour in rats. *European Journal of Neuroscience* 16:1797–809. [BK]

Panksepp, J. (1982) Toward a general psychobiological theory of emotions. *Behavioral and Brain Sciences* 5:407–67. [PB]

(1991) Affective neuroscience: A conceptual framework for the neurobiological study of emotions. In: *International reviews of studies in emotions, vol. 1*, ed. K. Strongman, pp. 59–99. Wiley. [aMDL]

(1993) Neurochemical control of moods and emotions: Amino acids to neuropeptides. In: *Handbook of emotions*, ed. M. Lewis & J. Haviland, pp. 57–107. Guilford. [aMDL]

(1998a) *Affective neuroscience: The foundations of human and animal emotions*. Oxford University Press. [JvH, aMDL, JP]

(1998b) The periconscious substrates of consciousness: Affective states and the evolutionary origins of self. *Journal of Consciousness Studies* 5:566–82. [GC]

(1999) Emotions as viewed by psychoanalysis and neuroscience: An exercise in consilience, and accompanying commentaries. *Neuro-Psychoanalysis* 1:15–89. [JP]

(2000) The neurodynamics of emotions: An evolutionary-neurodevelopmental view. In: *Emotion, self-organization, and development*, ed. M. D. Lewis & I. Granic, pp. 236–64. Cambridge University Press. [JP]

(2003) At the interface of affective, behavioral and cognitive neurosciences: Decoding the emotional feelings of the brain. *Brain and Cognition* 52:4–14. [aMDL, DAP, JP]

Panksepp, J. & Harro, J. (2004) Future prospects in psychopharmacology. In: *Textbook of biological psychiatry*, ed. J. Panksepp, pp. 627–60. Wiley. [JP]

Paré, D. & Collins, D. R. (2000) Neuronal correlates of fear in the lateral amygdala: Multiple extracellular recordings in conscious cats. *Journal of Neuroscience* 20:2701–10. [aMDL]

Paré, D., Collins, D. R. & Pelletier, J. G. (2002) Amygdala oscillations and the consolidation of emotional memories. *Trends in Cognitive Sciences* 6:306–14. [aMDL]

Parkinson, B. (2001) Putting appraisal in context. In: *Appraisal processes in emotion: Theory, methods, research*, ed. K. R. Scherer, A. Schorr & T. Johnstone, pp. 173–86. Oxford University Press. [aMDL]

Parrott, W. G. (1991) Mood induction and instructions to sustain moods. A test of the subject compliance hypothesis of mood congruent memory. *Cognition and Emotion* 3:41–52. [GA]

Parrott, W. G. & Schulkin, J. (1993) What sort of system could an affective system be? A reply to LeDoux. *Cognition and Emotion* 7:65–69. [aMDL]

Pascual-Leone, J. (1991) Emotions, development and psychotherapy: A dialectical-constructivist perspective. In: *Emotion, psychotherapy and change*, ed. J. Safran & L. Greenberg, pp. 302–35. Guilford. [JP-L]

(1995) Learning and development as dialectical factors in cognitive growth. *Human Development* 38:338–48. [JP-L]

(1996) Piaget, Vygotsky and the problems of Plato. *Swiss Journal of Psychology* 55: 84–92. [JP-L]

Pascual-Leone, J. & Johnson, J. (1991) The psychological unit and its role in task analysis: A reinterpretation of object permanence. In: *Criteria for competence: Controversies in conceptualization and assessment of children's abilities*, ed. M. Chandler & M. Chapman, pp. 153–87. Erlbaum. [JP-L]

(2004) Affect, self-motivation, and cognitive development: A dialectical constructivist view. In: *Motivation, emotion and cognition: Integrating perspective on intellectual functioning and development*, ed. D. Y. Dai & R. J. Sternberg, pp. 197–235. Erlbaum. [JP-L]

(2005) A dialectical constructivist view of developmental intelligence. In: *Handbook of understanding and measuring intelligence*, ed. O. Wilhelm & R. Engle, pp. 177–201. Sage. [JP-L]

Perlovsky, L. I. (2002) Physical theory of information processing in the mind: Concepts and emotions. *SEED* 2:36–54. [Available at: http://www.library.utoronto.ca/see/SEED/Vol2-2/2-2%20resolved/Perlovsky.pdf]. [DJK]

Petrides, M. & Pandya, D. N. (1999) Dorsolateral prefrontal cortex: comparative cytoarchitectonic analysis in the human and the macaque brain and corticocortical connection patterns. *European Journal of Neuroscience* 11:1011–36. [DAP]

(2002) Association pathways of the prefrontal cortex and functional observations. In: *Principals of frontal lobe function*, ed. D. T. Stuss & R. T. Knight, pp. 31–50. Oxford University Press. [aMDL]

Phan, K. L., Wager, T., Taylor, S. F. & Liberzon, I. (2002) Functional neuroanatomy of emotion: A meta-analysis of emotion activation studies in PET and fMRI. *Neuroimage* 16:331–48. [DAP]

Pizzagalli, D. A., Oakes, T. R. & Davidson, R. J. (2003a) Coupling of theta activity and glucose metabolism in the human rostral anterior cingulate cortex: An EEG/PET study of normal and depressed subjects. *Psychophysiology* 40:939–49. [DAP]

Pizzagalli, D. A., Oakes, T. R., Fox, A. S., Chung, M. K., Larson, C. L., Abercrombie, H. C., Schaefer, S. M., Benca, R. M. & Davidson, R. J. (2004) Functional but not structural subgenual prefrontal cortex abnormalities in melancholia. *Molecular Psychiatry* 9:393–405. [DAP]

Pizzagalli, D. A., Shackman, A. J. & Davidson, R. J. (2003b) The functional neuroimaging of human emotion: Asymmetric contributions of cortical and subcortical circuitry. In: *The asymmetrical brain*, ed. K. Hughdal & R. J. Davidson, pp. 511–32. MIT Press. [DAP]

Poeggel, G., Nowicki, L. & Braun, K. (2003) Early social deprivation alters

monoaminergic afferents in the orbital prefrontal cortex of *Octodon degus*. *Neuroscience* 116:617–20. [ANS]
Poremba, A. & Gabriel, M. (1997) Amygdalar lesions block discriminative avoidance learning and cingulothalamic training-induced neuronal plasticity in rabbits. *Journal of Neuroscience* 17:5237–5244. [aMDL]
Port, R. F. & Van Gelder, T., eds. (1995) *Explorations in the dynamics of cognition: Mind as motion*. MIT Press. [aMDL]
Posner, M. I., Petersen, S. E., Fox, P. T. & Raichle, M. E. (1988) Localization of cognitive functions in the human brain. *Science* 240:1627–31. [aMDL]
Post, R. M. & Weiss, S. R. B. (1997) Emergent properties of neural systems: How focal molecular neurobiological alterations can affect behavior. *Development and Psychopathology* 9:907–29. [arMDL]
Post, R. M., Weiss, S. R. B., Li, H., Smith, M. A., Zhang, L. X., Xing, G., Osuch, E. A. & McCann, U. D. (1998) Neural plasticity and emotional memory. *Development and Psychopathology* 10:829–55. [aMDL]
Potegal, M. (1994) Aggressive arousal: The amygdala connection. In: *The dynamics of aggression: Biological and social processes in dyads and groups*, ed. M. Potegal & J. Knutson, pp. 73–112. Erlbaum. [MP]
(2000) Some characteristics, correlates, and consequences of visible autonomic activity in the temper tantrums of young children. In: *Crying as a sign, a symptom and a signal*, ed. R. G. Barr, B. Hopkins & J. A. Green, pp. 121–36. Mac Keith Press. [MP]
Potegal, M. & Davidson R. J. (2003) Temper tantrums in young children: 1. Behavioral composition. *Journal of Developmental and Behavioral Pediatrics* 24:140–47. [MP]
Potegal, M., Hebert, M., DeCoster, M. & Meyerhoff, J. (1996) Brief, high frequency stimulation of the corticomedial amygdala induces a delayed and prolonged increase of aggressiveness in male Syrian golden hamsters. *Behavioral Neuroscience* 110:1–12. [MP]
Prigogine, I. & Stengers, I. (1984) *Order out of chaos*. Bantam. [aMDL]
Prinz, W. (1997) Perception and action planning. *European Journal of Cognitive Psychology* 9:129–54. [GC]
Pruitt D. G., Parker J. C. & Mikolic J. M.. (1997) Escalation as a reaction to persistent annoyance. *International Journal of Conflict Management* 8:252–70. [MP]
Putnam, H. (1975) *Mind, language and reality*. Cambridge University Press. [aMDL]
Qiu. P, Yang, R. & Potegal, M. (submitted) Semiparametric modeling of the time course of tantrum anger. *Biometrics*. [MP]
Quigley, B. M. & Tedeschi, J. T. (1996) Mediating effects of blame attributions on feelings of anger. *Personality and Social Psychology Bulletin* 22:1280–88. [MP]
Rafal, R. (2002) Cortical control of visuomotor reflexes. In: *Principals of frontal lobe function*, ed. D. T. Stuss & R. T. Knight, pp. 149–58. Oxford University Press. [aMDL]
Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A. & Shulman, G. L. (2001) A default mode of brain function. *Proceedings of the National Academy of Science USA* 98(2):676–82. [GN]
Raizada, R. & Grossberg, S. (2003) Towards a theory of the laminar architecture of cerebral cortex: Computational clues from the visual system. *Cerebral Cortex* 13:100–13. [SG]
Ramirez, J. M., Andreu, J. M. & Fujihara, T. (2001) Cultural and sex differences in aggression: A comparison between Japanese and Spanish students using two different inventories. *Aggressive Behavior* 27:313–22. [MP]
Ramsay, R. W. (1997) Behavioural approaches to bereavement. In: *The best of behavior research and therapy*, ed. S. Rachman & H. J. Eysenck. Pergamon. [GA]
Reber, R., Winkielman, P. & Schwarz, N. (1998) Effects of perceptual fluency on affective judgments. *Psychological Science* 9:45–48. [PW]
Reisenzein, R. (2001) Appraisal processes conceptualized from a schema-theoretic perspective: Contributions to a process analysis of emotions. In: *Appraisal processes in emotion: Theory, methods, research*, ed. K. R. Scherer, A. Schorr & T. Johnstone, pp. 187–201. Oxford University Press. [aMDL]
Reisenzein, R. & Hofmann, T. (1993) Discriminating emotions from appraisal-relevant situational information: Baseline data for structural models of cognitive appraisals. *Cognition and Emotion* 7:271–93. [aMDL]
Ressler, N. (2004) Rewards and punishments, goal-directed behavior and consciousness. *Neuroscience and Biobehavioral Reviews* 28:27–39. [JvH]
Richell, R. A., Mitchell, D. G. V., Newman, C., Leonard, A., Baron-Cohen, S. & Blair, R. J. R. (2003) Theory of mind and psychopathy: Can psychopathic individuals read the "language of the eyes"? *Neuropsychologia* 41:523–26. [CEI]
Rizzolatti, G., Fadiga, L., Fogassi, L. & Gallese, V. (1997) The space around us. *Science* 277:190–91. [GC]
Robinson, M. D. (1998) Running from William James' bear: A review of preattentive mechanisms and their contributions to emotional experience. *Cognition and Emotion* 12:667–96. [aMDL]
Rolls, E. T. (1990) A theory of emotion, and its application to understanding the neural basis of emotion. Special Issue: Development of relationships between emotion and cognition. *Cognition and Emotion* 4(3):161–90. [PB]
(1999) *The brain and emotion*. Oxford University Press. [PB, aMDL]
Rolls, E. T. & Treves, E. T. (1998) *Neural networks and brain function*. Oxford University Press. [aMDL]
Rosaldo, R. (1984) Grief and a headhunter's rage. In: *Text, play, and story: The construction and reconstruction of self and society*, ed. E. Bruner, pp. 178–95. American Ethnological Society. [GD]
Roseman, I. J. (1984) Cognitive determinants of emotion: A structural theory. In: *Review of personality and social psychology, vol. 5. Emotions, relationships, and health*, ed. P. Shaver, pp. 11–36. Sage. [aMDL]
(1991) Appraisal determinants of discrete emotions. *Cognition and Emotion* 5:161–200. [aMDL]
Roseman, I. J., Antoniou, A. A. & Jose, P. E. (1996) Appraisal determinants of emotions: Constructing a more accurate and comprehensive theory. *Cognition and Emotion* 10:241–77. [aMDL]
Roseman, I. J. & Smith, C. A. (2001) Appraisal theory: Overview, assumptions, varieties, controversies. In: *Appraisal processes in emotion: Theory, methods, research*, ed. K. R. Scherer, A. Schorr & T. Johnstone, pp. 3–19. Oxford University Press. [aMDL, DAP]
Ruby, P. & Decety, J. (2001) Effect of subjective perspective taking during simulation of action: A PET investigation of agency. *Nature Neuroscience* 4(5):546–50. [GN]
Ruelle, D. (1991) *Chance and chaos*. Princeton University Press. [RMG-L]
Rumelhart, D. E., Hinton, G. E. & McClelland, J. L. (1986a) A general framework for parallel distributed processing. In: *Parallel distributed processing: Explorations in the microstructure of cognition*, ed. J. L. McClelland, D. E. Rumelhart & the PDP Research Group, pp. 45–76. MIT Press. [aMDL]
Rumelhart, D. E., McClelland, J. L. & the PDP Research Group (1986b) *Parallel distributed processing: Explorations in the microstructure of cognition*. MIT Press. [RMG-L]
Sacks, O. (2004) In the river of consciousness. *New York Review* 51(1), January 15. [WJF]
Sander, D., Grafman, J. & Zalla, T. (2003) The human amygdala: An evolved system for relevance detection. *Reviews in the Neurosciences* 14(4):303–16. [DS]
Sander, D. & Koenig, O. (2002) No inferiority complex in the study of emotion complexity: A cognitive neuroscience computational architecture of emotion. *Cognitive Science Quarterly* 2:249–72. [DS]
Sartre, J.-P. (1939/1948) *The emotions: Sketch of a theory*, trans. B. Frechtman. Philosophical Library. [GA]
Sashin, J. (1985) Affect tolerance – A model of affect-response using catastrophe-theory. *Journal of Social and Biological Structures* 8:175–202. [RMG-L]
Sashin, J. & Callahan, J. (1990) A model of affect using dynamical systems. *Annual of Psychoanalysis* 18:213–31. [RMG-L]
Scherer, K. R. (1984) On the nature and function of emotion: A component process approach. In: *Approaches to emotion*, ed. K. R. Scherer & P. Ekman, pp. 293–317. Erlbaum. [arMDL, DS]
(1993a) Neuroscience projections to current debates in emotion psychology. *Cognition and Emotion* 7:1–41. [DS]
(1993b) Studying the emotion-antecedent appraisal process: An expert system approach. *Cognition and Emotion* 3:325–55. [aMDL]
(1999) Appraisal theory. In: *Handbook of cognition and emotion*, ed. T. Dalgleish & M. Power, pp. 637–63. Wiley. [aMDL]
(2000) Emotions as episodes of subsystem synchronization driven by nonlinear appraisal processes. In: *Emotion, development, and self-organization: Dynamic systems approaches to emotional development*, ed. M. D. Lewis & I. Granic, pp. 70–99. Cambridge University Press. [GC, arMDL, DS]
(2001) Appraisal considered as a process of multilevel sequential checking. In: *Appraisal processes in emotion: Theory, methods, research*, ed. K. R. Scherer, A. Schorr & T. Johnstone, pp. 92–120. Oxford University Press. [aMDL, DS]
(2004) Feelings integrate the central representation of appraisal-driven response organization in emotion. In: *Feelings and emotions: The Amsterdam Symposium*, ed. A. S. R. Manstead, N. H. Frijda & A. H. Fischer, pp. 136–57. Cambridge University Press. [DS]
Scherer, K. R. & Peper, M. (2001) Psychological theories of emotion and neuropsychological research. In: *Handbook of neuropsychology: Vol. 5: Emotional behavior and its disorders*, ed. F. Boller & J. Grafman. (2nd revised edition, ed. G. Gainotti). Elsevier. [DS]
Scherer, K. R., Schorr, A. & Johnstone, T., eds. (2001) *Appraisal processes in emotion: Theory, methods, research*. Oxford University Press. [rMDL, DS]
Scherg, M., Ille, N., Bornfleth, H. & Berg, P. (2002) Advanced tools for digital EEG review: Virtual source montages, whole-head mapping, correlation, and phase analysis. *Journal of Clinical Neurophysiology* 19:91–112. [aMDL]
Schneirla, T. C. (1959) An evolutionary and developmental theory of biphasic processes underlying approach and withdrawal. In: *Nebraska Symposium on*

Motivation, vol. 7, ed. M. R. Jones, pp. 1–42. University of Nebraska Press. [PB]
Schore, A. N. (1994) *Affect regulation and the origin of the self: The neurobiology of emotional development*. Erlbaum. [aMDL, ANS]
(1997) Early organization of the nonlinear right brain and development of a predisposition to psychiatric disorders. *Development and Psychopathology* 9:595–631. [ANS]
(2000) The self-organization of the right brain and the neurobiology of emotional development. In: *Emotion, development and self-organization: Dynamic systems approaches to emotional development*, ed. M. D. Lewis & I. Granic, pp. 155–85. Cambridge University Press. [aMDL, ANS]
(2001) The effects of a secure attachment relationship on right brain development, affect regulation, and infant mental health. *Infant Mental Health Journal* 22:7–66. [ANS]
(2003a) *Affect dysregulation and disorders of the self*. W. W. Norton. [ANS]
(2003b) *Affect regulation and the repair of the self*. W. W. Norton. [ANS]
Schulkin, J. (2003) *Rethinking homeostasis: Allostatic regulation in physiology and pathophysiology*. MIT Press. [JvH]
Schultz, W. (1998) Predictive reward signal of dopamine neurons. *Journal of Neurophysiology* 80:1–27. [aMDL]
Schutter, D. J. L. G. & Van Honk, J. (2004) Decoupling of midfrontal delta-beta oscillations after testosterone administration. *International Journal of Psychophysiology* 53:71–73. [JvH]
(2005) Basal cortisol levels and the coupling of midfrontal delta-beta oscillations. *International Journal of Psychophysiology* 55:127–29. [JvH]
Schutter, D. J. L. G., Van Honk, J. & Panksepp, J. (2004) Introducing repetitive transcranial magnetic stimulation (rTMS) and its property of causal inference in investigating the brain-function relationship. *Synthese* 141:155–73. [JP]
Sederberg, P. B., Kahana, M. J., Howard, M. W., Donner, E. J. & Madsen, J. R. (2003) Theta and gamma oscillations during encoding predict subsequent recall. *Journal of Neuroscience* 23:10809–814. [JP]
Seidenbecher, T., Laxmi, T. R., Stork, O. & Pape, H.-C. (2003) Amygdalar and hippocampal theta rhythm synchronization during fear memory retrieval. *Science* 301:846–50. [aMDL]
Shallice, T. (2002) Fractionation of the supervisory system. In: *Principals of frontal lobe function*, ed. D. T. Stuss & R. T. Knight, pp. 261–77. Oxford University Press. [aMDL]
Shiller, V. M., Izard, C. E. & Hembree, E. A. (1986) Patterns of emotion expression during separation in the strange-situation procedure. *Developmental Psychology* 22:378–82. [CEI]
Shimamura, A. P. (2002) Memory retrieval and executive control processes. In: *Principals of frontal lobe function*, ed. D. T. Stuss & R. T. Knight, pp. 210–20. Oxford University Press. [aMDL]
Shin, L. M., Dougherty, D. D., Orr, S. P., Pitman, R. K., Lasko, M., Macklin, M. L., Alpert, N., Fischman, A. J. & Rauch, S. L. (2000) Activation of anterior paralimbic structures during guilt-related script-driven imagery. *Biological Psychiatry* 48:43–50. [aMDL]
Shizgal, P. & Conover, K. (1996) On the neural computation of utility. *Current Directions in Psychological Science* 5:37–43. [GA]
Shultz, T. R. & Lepper, M. R. (1996) Cognitive dissonance reduction as constraint satisfaction. *Psychological Review* 103:219–40. [aMDL]
Shweder, R. A. (1991) *Thinking through cultures: Expeditions in cultural psychology*. Harvard University Press. [HF]
Sinha, R. & Parsons, O. A. (1996) Multivariate response patterning of fear and anger. *Cognition and Emotion* 10:173–98. [MP]
Skarda, C. A. & Freeman, W. J. (1987) How brains make chaos in order to make sense of the world. *Behavioral and Brain Sciences* 10:161–95. [WJF, aMDL]
Skinner, J. E. & Molnar, M. (1999) Event-related dimensional reductions of the primary auditory cortex of the conscious cat are revealed by new techniques for enhancing the nonlinear dimensional algorithms. *International Journal of Psychophysiology* 34:21–35. [aMDL]
Smith, C. A. & Kirby, L. D. (2001) Toward delivering on the promise of appraisal theory. In: *Appraisal processes in emotion: Theory, methods, research*, ed. K. R. Scherer, A. Schorr & T. Johnstone, pp. 187–201. Oxford University Press. [aMDL]
Smith, C. A. & Lazarus, R. S. (1993) Appraisal components, core relational themes, and the emotions. *Cognition and Emotion* 7:233–69. [aMDL]
Solms, M. & Turnbull, O. (2002) *The brain and the inner world: An introduction to the neuroscience of subjective experience*. Other Press. [RMG-L]
Spitzer, M. (1999) *The mind within the net: Models of learning, thinking, and acting*. MIT Press. [RMG-L]
Spruiell, V. (1993) Deterministic chaos and the sciences of complexity. *Journal of the American Psychoanalytic Association* 41:3–44. [RMG-L]
Stapel, D. A. & Koomen, W. (2000) How far do we go beyond the information given? The impact of knowledge activation on interpretation and inference. *Journal of Personality and Social Psychology* 78:19–37. [NHF]
Stemmler, G., Heldmann, M., Pauls, C. & Scherer, T. (2001) Constraints for emotion specificity in fear and anger: The context counts. *Psychophysiology* 38:275–91. [MP]
Stenberg, C. R. & Campos, J. L. (1990) The development of anger expressions in infancy. In: *Psychological and biological approaches to emotion*, ed. N. L. Stein, B. Leventhal & T. Trabasso, pp. 247–82. Erlbaum. [MP]
Stenberg, C. R., Campos, J. L. & Emde, R. N. (1983) The facial expression of anger in seven-month-old infants. *Child Development* 54:178–84. [MP]
Stern, D. (1985) *The interpersonal world of the infant*. Basic Books. [ASW-A]
Strasberg, L. (1988) *A dream of passion: The development of the method*. Dutton. [GA]
Strumwasser, F. (2003) The human mind: Building bridges between neuroscience and psychiatry. *Psychiatry* 66:22–31. [HF]
Sullivan, R. M. & Gratton, A. (2002) Prefrontal cortical regulation of hypothalamic-pituitary-adrenal function in the rat and implications for psychopathology: Side matters. *Psychoneuroendocrinology* 27:99–114. [ANS]
Szentagothai, J. (1993) Self organization: The basic principle of neural functions. *Theoretical Medicine* 14:101–16. [arMDL]
Teasdale, J. D. (1983) Negative thinking in depression: Cause, effect or reciprocal relationship? *Advances in Behavior Research and Therapy* 5:3–25. [aMDL]
Teasdale, J. D. & Barnard, P. J. (1993) *Affect, cognition, and change: Remodelling depressive thought*. Erlbaum. [PB, aMDL]
Thagard, P. & Verbeurgt, K. (1998) Coherence as constraint satisfaction. *Cognitive Science* 22:1–24. [aMDL]
Thatcher, R. W. (1998) A predator–prey model of human cerebral development. In: *Applications of nonlinear dynamics to developmental process modeling*, ed. K. M. Newell & P. C. M. Molenaar, pp. 87–128. Erlbaum. [aMDL]
Thayer, J. F. & Friedman, B. H. (1997) The heart of anxiety: A dynamical systems approach. In: *The (non) expression of emotions in health and disease*, ed. A. Vingerhoets, F. van Bussel & J. Boelhouwer, pp. 39–49. Tilburg University Press. [aMDL]
(2002) Stop that! Inhibition, sensitization, and their neurovisceral concomitants. *Scandinavian Journal of Psychology* 43:123–30. [JFT]
Thayer, J. F., Friedman, B. H., Borkovec, T. D., Johnsen, B. H. & Molina, S. (2000) Phasic heart period to cued threat and non-threat stimuli in generalized anxiety disorder. *Psychophysiology* 37:361–68. [JFT]
Thayer, J. F. & Lane, R. D. (2000) A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders* 61:201–16. [aMDL, JFT]
(2002) Perseverative thinking and health: Neurovisceral concomitants. *Psychology and Health* 17:685–95. [JFT]
Thelen, E. (1995) Motor development: A new synthesis. *American Psychologist* 50:79–95. [GD]
Thelen, E., Schöner, G., Scheier, C. & Smith, L. B. (2001) The dynamics of embodiment: A field theory of infant perseverative reaching. *Behavioral and Brain Sciences* 24:1–86. [aMDL]
Thelen, E. & Smith, L. B. (1994) *A dynamic systems approach to the development of cognition and action*. MIT Press/Bradford. [aMDL, ASW-A]
Thinschmidt, J. S., Kinney, G. G. & Kocsis, B. (1995) The supramammillary nucleus: Is it necessary for the mediation of hippocampal theta rhythm? *Neuroscience* 67:301–12. [BK]
Thompson, E. (forthcoming) *Radical embodiment: The lived body in biology, human experience, and the sciences of mind*. Harvard University Press. [GC]
Thompson, E., Lutz, A. & Cosmelli, D. (in press) Neurophenomenology: An introduction for neurophilosophers. In: *Cognition and the brain: The philosophy and neuroscience movement*, ed. A. Brook & K. Akins. Cambridge University Press. [GC]
Thompson, E. & Varela, F. J. (2001) Radical embodiment: Neural dynamics and consciousness. *Trends in Cognitive Sciences* 5:418–25. [arMDL]
Titchener, E. B. (1910) *A textbook of psychology*. Macmillan. [PW]
Tomkins, S. S. (1982) Affect theory. In: *Approaches to emotion*, ed. K. R. Scherer & P. Ekman, pp. 163–96. Erlbaum. [PB]
Tononi, G. & Edelman, G. M. (1998) Consciousness and complexity. *Science* 282(4):1846–51. [HF, aMDL]
Tooby, J. & Cosmides, L. (1992) The psychological foundations of culture. In: *The adapted mind: Evolutionary psychology and the generation of culture*, ed. J. H. Barkow, L. Cosmides & J. Tooby, pp. 19–136. Oxford University Press. [HF]
Touzani, I. & Velley, L. (1998) Electrical self-stimulation in the central amygdaloid nucleus after ibotenic acid lesion of the lateral hypothalamus. *Behavioral and Brain Research* 90:115–24. [GA]
Tsuda, I. (2001) Toward an interpretation of dynamics of neural activity in terms of chaotic dynamical systems. *Behavioral and Brain Sciences* 24:793–847. [WJF]
Tucker, D. M. (2001) Motivated anatomy: A core-and-shell model of corticolimbic architecture. In: *Handbook of neuropsychology: Vol. 5. Emotional behavior and its disorders*, 2nd edition, ed. G. Gainotti, pp. 125–60. Elsevier. [aMDL]
Tucker, D. M., Derryberry, D. & Luu, P. (2000) Anatomy and physiology of human

emotion: Vertical integration of brainstem, limbic, and cortical systems. In: *The neuropsychology of emotion*, ed. J. C. Borod. Oxford University Press. [aMDL]
Tucker, D. M., Hartry-Speiser, A., McDougal, L., Luu, P. & deGrandpre, D. (1999) Mood and spatial memory: Emotion and the right hemisphere contribution to spatial cognition. *Biological Psychology* 50:103–25. [aMDL]
Tucker, D. M., Luu, P., Desmond, R. E., Hartry-Speiser, A. L., Davey, C. & Flaisch, T. (2003) Corticolimbic mechanisms in emotional decisions. *Emotion* 3:127–49. [aMDL]
Tucker, D. M. & Williamson, P. A. (1984) Asymmetric neural control systems in human self-regulation. *Psychological Review* 91:185–215. [aMDL]
Vallacher, R. R. & Nowak, A. (1997) The emergence of dynamical social psychology. *Psychological Inquiry* 8:73–99. [aMDL]
(1999) The dynamics of self-regulation. In: *Advances in social cognition, vol. 12*, ed. R. S. Wyer, Jr., pp. 241–59. Erlbaum. [PW]
van Geert, P. & van Dijk, M. (2002) Focus on variability: New tools to study intra-individual variability in developmental data. *Infant Behavior and Development* 25:340–74. [rMDL]
Van Gelder, T. (1995) What might cognition be, if not computation? *Journal of Philosophy* 92(7):345–81. [CD]
(1998) The dynamical hypothesis in cognitive science. *Behavioral and Brain Sciences* 21:615–65. [aMDL]
Van Gelder, T. & Port, R. F. (1995) It's about time: An overview of the dynamical approach to cognition. In: *Mind as motion: Explorations in the dynamics of cognition*, ed. R. F. Port & T. Van Gelder, pp. 1–43. MIT Press. [aMDL]
Van Honk, J. & Schutter, D. J. L. G. (in press) Unmasking feigned sanity: A neurobiological model of emotion processing in primary psychopathy. *Cognitive Neuropsychiatry*. [JvH]
Van Honk, J., Schutter, D. J. L. G., Hermans, E. J. & Putman, P. (2003) Low cortisol levels and the balance between punishment sensitivity and reward dependency. *NeuroReport* 14:1993–96. [JvH]
Van Honk, J., Schutter, D. J. L. G., Hermans, E. J., Putman, P., Tuiten, A. & Koppeschaar, H. P. F. (2004) Testosterone shifts the balance between sensitivity for punishment and reward in healthy young women. *Psychoneuroendocrinology* 29:937–43. [JvH]
Van Honk, J., Tuiten, A., Van den Hout, M., Koppeschaar, H., Thijssen, J., De Haan, E. & Verbaten, R. (1998) Baseline salivary cortisol levels and preconscious selective attention for threat: A pilot study. *Psychoneuroendocrinology*, 23:741–47. [JvH]
(1999) Correlations among salivary testosterone, mood, and selective attentions to threat in humans. *Hormones and Behavior* 36:17–24. [JvH]
van Reekum, C. M. & Scherer, K. R. (1997) Levels of processing in emotion-antecedent appraisal. In: *Cognitive science perspectives on personality and emotion*, ed. G. Matthews, pp. 259–300. Elsevier. [aMDL]
van Rullen, R. & Koch, C. (2003) Is perception discrete or continuous? *Trends in Cognitive Sciences* 7:207–13. [aMDL]
van Veen, V. & Carter, C. S. (2002) The timing of action-monitoring processes in the anterior cingulate cortex. *Journal of Cognitive Neuroscience* 14:593–602. [aMDL]
van Veen, V., Cohen, J. D., Botvinick, M. M., Stenger, V. A. & Carter, C. S. (2001) Anterior cingulate cortex, conflict monitoring, and levels of processing. *Neuroimage* 14:1302–08. [aMDL]
Vanderwolf, C. H. (1988) Cerebral activity and behavior: Control by central cholinergic and serotonergic systems. *International Review of Neurobiology* 30:225–340. [aMDL]
Varela, F. J. (1996) Neurophenomenology: A methodological remedy for the hard problem. *Journal of Consciousness Studies* 3:330–50. [GC]
Varela, F. J. & Depraz, N. (2000) At the source of time: Valence and the constitutional dynamics of affect. *Arob@se. Journal de Lettre et de Sciences Humain* 4(1–2). Available at: http://www.arobase.to. [Also appearing in: *Ipseity and alterity: Interdisciplinary approaches to intersubjectivity*, ed. S. Gallagher & S. Watson. Presses Universitaires de Rouen. (in press).] [GC]
Varela, F. J., Lachaux, J.-P., Rodriguez, E. & Martinerie, J. (2001) The brainweb: Phase synchronization and large-scale integration. *Nature Reviews Neuroscience* 2:229–39. [GC, aMDL]
Varela, F. J., Thompson, E. & Rosch, E. (1991) *The embodied mind: Cognitive science and human experience*. MIT Press. [GC, aMDL]
Vertes, R. P., Albo, Z. & Viana Di Prisco, G. (2001) Theta-rhythmically firing neurons in the anterior thalamus: Implications for mnemonic functions of Papez's circuit. *Neuroscience* 104:619–25. [aMDL]
Vertes, R. P. & Kocsis, B. (1997) Brainstem-diencephalo-septohippocampal systems controlling the theta rhythm of the hippocampus. *Neuroscience* 81:893–926. [aMDL, JP]
Viau, V. (2002) Functional cross-talk between the hypothalamic-pituitary-gonadal and -adrenal axes. *Journal of Neuroendocrinology* 14:506–13. [JvH]
Vinogradova, O. S. (1995) Expression, control, and probable functional significance of the neuronal theta-rhythm. *Progress in Neurobiology* 45:523–83. [DAP]
von Bertalanffy, L. (1933/1962) *Modern theories of development: An introduction to theoretical biology*. Harper. [RDE]
von Neumann, J. (1958) *The computer and the brain*. Yale University Press. [aMDL]
von Stein, A. & Sarnthein, J. (2000) Different frequencies for different scales of cortical integration: From local gamma to long range alpha/theta synchronization. *International Journal of Psychophysiology* 38:301–13. [aMDL]
Waddington, C. H. (1962) *New patterns in genetics and development*. Columbia University Press. [rMDL]
Waldvogel, D., van Gelderen, P., Muellbacher, W., Ziemann, U., Immisch, I. & Hallett, M. (2000) The relative metabolic demand of inhibition and excitation. *Nature* 406:995–98. [JFT]
Walker-Andrews, A. S. & Lennon, E. (1991) Infants' discrimination of vocal expressions: Contributions of auditory and visual information. *Infant Behavior and Development* 14:131–42. [ASW-A]
Wallace, D. M., Magnusson, D. J. & Gray, T. S. (1992) Organization of amygdaloid projections to brainstem dopaminergic, norandrenergic and andrenergic cell groups in the rat. *Brain Research Bulletin* 28:447–54. [aMDL]
Wang, X. F. & Chen, G. R. (2003) Complex networks: Small-world, scale-free and beyond. *IEEE Transactions on Circuits and Systems* 31:6–20. [WJF]
Ward, L. M. (2002) *Dynamical cognitive science*. MIT Press. [aMDL]
Watson, D. & Clark, L. A. (1992) Affects separable and inseparable: On the arrangement of the negative affects. *Journal of Personality and Social Psychology* 62:489–505. [CEI]
Watt, D. F. (1998) Emotion and consciousness: Implications of affective neuroscience for extended reticular thalamic activating system theories of consciousness. Electronic publication of the Association for the Scientific Study of Consciousness. Available at: http://server.philvt.edu/assc/watt/default.htm. [GC]
Weissenberger, A. A., Dell, M. L., Liow, K., Theodore, W., Frattali, C. M., Hernandez, D. & Zametkin, A. J. (2001) Aggression and psychiatric comorbidity in children with hypothalamic hamartomas and their unaffected siblings. *Journal of the American Academy of Child and Adolescent Psychiatry* 40:696–703. [MP]
Wells, A. & Matthews, G. (1994) *Attention and emotion: A clinical perspective*. Erlbaum. [aMDL]
Wenzlaff, R. M., Rude, S. S., Taylor, C. J., Stultz, C. H. & Sweatt, R. A. (2001) Beneath the veil of thought suppression: Attentional bias and depression risk. *Cognition and Emotion* 15:435–52. [aMDL]
Whalen, P. J., Shin, L. M., McInerney, S. C., Fischer, H., Wright, C. I. & Rauch, S. L. (2001) A functional MRI study of human amygdala responses to facial expressions of fear versus anger. *Emotion* 1:70–83. [DS]
Wiener, N. (1948) *Cybernetics; or, control and communication in the animal and the machine*. Wiley. [RMG-L]
(1950) *The human use of human beings cybernetics and society*. Houghton Mifflin. [RMG-L]
Wiener, N. & Schadé, J. P. (1965) *Cybernetics of the nervous system*. Elsevier. [RMG-L]
Wierzbicka, A. (1999) *Emotions across languages and cultures: Diversity and universals*. Cambridge University Press. [HF]
(2003) Emotion and culture: Arguing with Martha Nussbaum. *Ethos* 31(4):577–600. [GD]
Wikan, U. (1990) *Managing turbulent hearts: A Balinese formula for living*. University of Chicago Press. [GD]
Williams, B. (1972) Descartes, René. In: *The encyclopedia of philosophy*, ed. P. Edward, pp. 344–54. MacMillan. [JP]
Williams, G. V. & Goldman-Rakic, P. S. (1995) Modulation of memory fields by dopamine D1 receptors in prefrontal cortex. *Nature* 376:572–75. [aMDL]
Williams, J. M. G., Watts, F. N., MacLeod, C. & Mathews, A. (1997) *Cognitive psychology and emotional disorders*, 2nd edition. Wiley. [aMDL]
Winkielman, P. & Cacioppo, J. T. (2001) Mind at ease puts a smile on the face: Psychophysiological evidence that processing facilitation increases positive affect. *Journal of Personality and Social Psychology* 81:989–1000. [PW]
Winkielman, P., Schwarz, N. & Nowak, A. (2002) Affect and processing dynamics: Perceptual fluency enhances evaluations. In: *Emotional cognition: From brain to behaviour*, ed. S. Moore & M. Oaksford, pp. 111–36. John Benjamins. [PW]
Witherington, D. C., Campos, J. J. & Hertenstein, M. J. (2001) Principles of emotion and its development in infancy. In: *Blackwell handbook of infant development*, ed. G. Bremner & A. Fogel, pp. 427–64. Blackwell. [ASW-A]
Wood, J., Mathews, A. & Dalgleish, T. (2001) Anxiety and cognitive inhibition. *Emotion* 1:166–81. [aMDL]
Wood, R. I. (1996) Functions of the steroid-responsive neural network in the control of male hamster sexual behavior. *Trends in Endocrinology and Metabolism* 7:338–44. [JvH]
Yaniv, D., Vouimba, R. M., Diamond, D. M. & Richter-Levin, G. (2003) Simultaneous induction of long-term potentiation in the hippocampus and the

amygdala by entorhinal cortex activation: mechanistic and temporal profiles. *Neuroscience* 120:1125–35. [aMDL]
Zajonc, R. B. (1980) Feeling and thinking: Preferences need no inferences. *American Psychologist* 35:151–75. [PW]
(1984) On the primacy of affect. *American Psychologist* 39:117–23. [aMDL]
Ziabreva, I., Poeggel, G., Schnabel, R. & Braun, K. (2003) Separation-induced receptor changes in the hippocampus and amygdala of *Octodon degus*: Influence of maternal vocalizations. *Journal of Neuroscience* 23:5329–36. [ANS]
Zillmann, D. (1994) Cognition-excitation interdependencies in the escalation of anger and angry aggression. In: *The dynamics of aggression: Biological and social processes in dyads and groups*, ed. M. Potegal & J. Knutson, pp. 45–72. Erlbaum. [MP]
Zochowski, M., Lewenstein, M. & Nowak, A. (1993) Memory that tentatively forgets. *Journal of Physics A* 26:2453–60. [PW]
(1995) SMARTNET: A neural network with self-controlled learning. *Network* 6:93–101. [PW]