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

Stephen Grossberg

Department of Cognitive and Neural Systems, Boston University, Boston, MA 02215. **steve@bu.edu** **http://www.cns.bu.edu/Profiles/Grossberg**

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;

https://doi.org/10.1017/S0140525X05360043 Published online by Cambridge University Press

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

Carroll E. Izard, Christopher J. Trentacosta, and Kristen A. King

Department of Psychology, University of Delaware, Newark, DE 19716.
izard@udel.edu cjt@udel.edu kking@udel.edu
http://www.psych.udel.edu/people/detail.php?firstname=Carroll&lastname=Izard
http://www.psych.udel.edu/people/detail.php?firstname=Chris&lastname=Trentacosta
http://www.psych.udel.edu/people/detail.php?firstname=Kristen&lastname=King

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 exempli-

https://doi.org/10.1017/S0140525X05360043 Published online by Cambridge University Press