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.

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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-organi-

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