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Emotional States from Affective Dynamics

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Abstract

Psychological constructivist models of emotion propose that emotions arise from the combinations of multiple processes, many of which are not emotion specific. These models attempt to describe both the homogeneity of instances of an emotional "kind" (why are fears similar?) and the heterogeneity of instances (why are different fears quite different?). In this article, we review the iterative reprocessing model of affect, and suggest that emotions, at least in part, arise from the processing of dynamical unfolding representations of valence across time. Critical to this model is the hypothesis that affective trajectories—over time—provide important information that helps build emotional states.

Keywords
dynamics, emotion, psychological constructivism

A major debate regarding the psychological processes of emotion has surrounded whether emotions are natural kinds (e.g., the basic emotions models) or whether they result from the interaction of more elemental units combined in various ways (e.g., appraisal or dimensional models). According to natural kind models, specific emotions, such as fear or anger, developed independently to help an organism respond adaptively to specific challenges in the environment (Ekman, 1992). For example, the widening of the nose and eyes in the facial expression of fear are the result of increasing vigilance and sensitivity to incoming information when threatened, whereas the narrowed nose and eyes in the facial expression of disgust comes from the need to reduce input from a source of potential contamination (Susskind et al., 2008). Similarly, patterns of autonomic responses and body posture have been taken to suggest that emotions, once triggered, activate a unified whole body response (Levenson, 1988). In contrast, "elemental models" propose that emotions are not unitary modular phenomena, but rather reflect the interaction of more general processes arising from more basic affective and/or cognitive representations. For example, some models propose that emotions originate from a core affect (a two-dimensional space representing valence and arousal; Russell, 1980; see also Thayer, 2012; Watson & Tellegen, 1985) that is translated into emotions through cognitive elaboration (Russell, 2003). Sadness and fear share negative valence, but differ in arousal (sadness involves negative valence and low arousal, while fear involves negative valence and high arousal). Other models state that events are appraised on a number of goal relevant dimensions (e.g., goal relevance and goal congruence), and the resulting emotion is a function of these interpretations (e.g., Lazarus, 1991; Scherer, 2009). Despite the fact that these two broad families of models (natural kind and elemental) have fundamentally different views on the nature of emotion, how emotions arise, and the consequences of emotion, neither

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perspective has been able to completely rule out the other in order to establish dominance.

Due in part to the fundamental disagreements regarding the nature of emotion, new perspectives have surfaced that attempt to understand both the great homogeneity of emotions (different instances of fear seem more similar to one another, on average, than they do to different instances of anger) as well as the great heterogeneity of emotions (not all instances of fear are the same, and indeed some "fears" may more resemble anger than other fears). Under the general rubric of psychological constructivism, these new models attempt to understand the basic elements of emotion, and how these basic elements combine to result in the emergent states of emotional experience and behavior (Barrett, 2009). Although these models agree that emotions arise from more elemental units, and agree that these units combine to create emergent states, the exact number and nature of these elements is just beginning to be explored. In this article, using the iterative reprocessing (IR) model, we propose that emotions arise, at least in part, from the processing and interpretations of *changes* in valenced states over time.

The Psychological Construction of Mind

In developing models to articulate the form and function of the human mind, psychologists and philosophers have worked to develop and refine numerous shorthand categories to reduce the overwhelming complexity of the human experience into elemental units that could be more readily comprehended. For thousands of years, categories such as cognition, emotion, and attitude have been used to simplify the challenge of understanding behavior and thought. Yet, however useful these categories have been as starting points and simplifying devices, we argue that modern behavioral and brain sciences have made the conceptual mistake of reifying these heuristics into "natural kind" categories. In doing so, psychological theory has imbued these shortcuts with dissociable causal properties, while neuroscientific research has sought to find localized neural tissue associated with a particular category to further objectify it, and to argue for its "realness." Indeed, there is a growing consensus that some brain regions are "cognitive," others "emotional," and there has been an ongoing pursuit to find the neural homes of specific emotions like "fear" and "disgust," or specific evaluative concepts such as the "implicit attitude" or the "explicit attitude."

We, in line with other psychological constructivist approaches, argue that the tactic of searching for natural kind modules within the brain may not be ideal for understanding how nature is carved at its joints—proposing instead that greater attention should be directed toward more elemental and computational aspects of mind. As one important example, we believe that the distinction between "emotion" and "cognition" is a false dichotomy (Cunningham & Kirkland, 2012). Instead, we take a broad view of cognition as encompassing *any* information processing (see Newell, 1990; Oatley & Johnson-Laird, 1987). In this way, "emotion" as we experience it is inseparable from cognition, in that all mental operations require some form of information processing. Indeed, when considering the subjective experience of emotion, it is probable that the underlying cognitive processes are complex and multifaceted, and possible that when more fully articulated may not even correspond to current linguistic categories. By refocusing our examination to the information processing elements that underlie emotion, with an eye toward linking levels of analysis (how the elements combine is as important as knowing what the elements are), we believe that it will be possible to understand not only the homogeneity of emotional experiences (there are likely similarities among instances of anger), but also the heterogeneity of emotional experience (not all instances of anger are the same). In this article we use the IR model (Cunningham & Zelazo, 2007; Zelazo & Cunningham, 2007) to understand affect and emotion as the dynamic emergent result of hierarchically organized brain systems.

The Iterative Reprocessing Model

The IR model is a dynamical systems account of human information processing rooted in the hierarchical organization of brain function. Importantly, instead of drawing strict distinctions along the lines of traditional dichotomies, IR views all information processing as an emergent property of more general processes. Fundamental to the IR model is the observation that although the brain is organized hierarchically, it allows for bidirectional influences, such that processes that are typically considered automatic or reflexive can influence, and are influenced by, processes that are typically considered controlled or reflective. When faced with environmental changes, or internal changes from cognitive processing (e.g., imagery or reconstrual), people quickly process active information to determine its meaning. Yet this initial processing following a perceived change does not necessarily provide a final state (or even a state that lasts for more than a few milliseconds). Rather, the information is continuously reprocessed through iterative cycles potentially creating richer evaluations of the information and thereby more nuanced interpretations and thus affect.

Importantly, although reprocessing allows an event to be understood in a more nuanced manner by situating it in an ever-broadening array of considerations, additional iterations do not always lead to more nuanced or complex evaluations. Rumination, for example, may involve multiple iterations, but this does not necessitate updating of the information. Rather, the same information may be gated such that a dominant representation remains rigid, despite the fact that it is not useful for a goal. Moreover, by considering the reciprocal (feedforward and feedback) nature of these activations, we can see the continuum of human information processing that extends from what is traditionally considered relatively simple and automatic, to more complex and reflective.

IR Model and the Hierarchical Brain

As humans interact with their environment they strive to maintain a healthy internal environment while making accurate predictions about the external world. Therefore, any discrepancy between the expectation and experience of either the internal states or external world initiates a sequence of evaluative processes in which the information is interpreted and reinterpreted in iterative cycles. Sometimes the processing and reprocessing is accomplished quickly and effortlessly, and other times more complex, meaningful, and multifaceted representations need to be constructed. Specifically, whenever any new information is encountered, be it a stimulus in the world or an experience generated in our own mind, it is initially evaluated for goal valence (i.e., harmful/beneficial) and relevance (Sander, Grafman, & Zalla, 2003), resulting in an affective state including some degree of arousal/relevance (e.g., Russell, 2003; Scherer, 1984, 2009). These initial responses result in unreflective motivational behaviors such as approach or avoidance, and occur within the first few hundred milliseconds of perception (Oya, Kawasaki, Howard, & Adolphs, 2002). Given the rapidity of these initial responses they typically involve processing in the subcortical brain, specifically the amygdala and ventral striatum (nucleus accumbens) are likely based on innate biases (e.g., LeDoux, 1996; Öhman & Mineka, 2001) and learning (e.g., Armony & Dolan, 2002; Phelps et al., 2001; Whalen et al., 1998). Previous functional magnetic resonance imaging (fMRI) research has demonstrated that the amygdala quickly and consistently responds to a wide variety of valenced cues (e.g., Anderson et al., 2003; Canli, Zhou, Brewer, Gabrieli, & Cahill, 2000; Isenberg et al., 1999; Morris et al., 1996; Morris, Öhman, & Dolan, 1998; Small et al., 2003; Whalen et al., 1998; Williams et al., 2006; Winston, Strange, O'Doherty, & Dolan, 2002). In addition to producing relatively automatic responses, these subcortical areas probably also play an important role in generating and updating representations in light of subsequent reflective processes. Importantly, although these initial undifferentiated responses allow individuals to quickly prepare and respond to experiences, they rarely take into consideration the full range of motivational implications of any particular piece of information.

With additional iterations, current experience can be reinterpreted in light of a larger range of more complex considerations such as active goal states, expected rewards and punishments, and current context (Beer, Heerey, Keltner, & Scabini, 2003; Blair, 2004; Frank & Claus, 2006; Rolls, 2000). By reinterpreting the current experience in light of these constraints, it is possible to make more nuanced evaluations that are consistent with more stable long-standing goals, desires, and intentions. Indeed, in order to enact an appropriate response, it is important to know what caused the change being processed, how much power one has in a situation, and critically what behavioral options are available (see Arnold, 1960; Lazarus, 1991; Ortony, Clore, & Collins, 1988; Roseman, 1984; Scherer, 2009, for examples). These more nuanced interpretations are aided through direct reciprocal connections between the orbitofrontal cortex (OFC) and the amygdala and hypothalamus. Given these connections, the OFC is in a special, and particularly effective, position to modulate initial responses in order to fit with a particular context. By integrating input from multiple sensory modalities the OFC allows for more nuanced stimulus evaluations (posterior medial orbitofrontal cortex) and the integration of novel information with more long-standing goals and motivations (anterior medial orbitofrontal cortex; Cunningham, Kesek, & Mowrer, 2009).

Often the reprocessing of information in order to come to a more nuanced and an appropriate interpretation requires the integration of complex rules and goals. To that end, additional regions of the prefrontal cortex (PFC; such as lateral PFC) can bias representations to reduce residual uncertainty. Mirroring the hierarchical structure of the whole brain, the PFC is also organized hierarchically. As information is reprocessed in the prefrontal cortex, it spreads from ventrolateral, to dorsolateral, to rostrolateral prefrontal cortex (e.g., Badre & D'Esposito, 2007; Botvinick, 2008; Bunge & Zelazo, 2006; Koechlin, Ody, & Kounelher, 2003). Within the PFC there is a segregation of the processing of rules at different levels of complexity: Conditional rules are processed in the ventrolateral prefrontal cortex (VLPFC) and dorsolateral prefrontal cortex (DLPFC), whereas the rostrolateral prefrontal cortex (RLPFC) deals with explicit considerations of task sets (Bunge & Zelazo, 2006). Importantly, the integration of the lateral prefrontal cortex allows for the regulation and biasing of activate representations, not by creating entirely new low-level states, but by affecting attention to various aspects of the stimulus through the selective amplification and/or suppression of attention (e.g., Cunningham, Raye, & Johnson, 2004; Cunningham, van Bavel, Arbuckle, Packer, & Waggoner, 2012; Ochsner, Bunge, Gross, & Gabrieli, 2002; Ochsner et al., 2004; Todd, Cunningham, Anderson, & Thompson, 2012). The lateral frontal lobes play an essential role in the reprocessing of information because of their influence on working memory (allowing relevant aspects of the stimulus to be kept in mind) and inhibitory control (allowing information to be selectively attended to), two key abilities required for reflective interpretations (Ochsner, 2004).

The Nature of Change and Its Representation

IR utilizes connectionist approaches to information processing developed in the area of computational cognitive neuroscience to understand how representations are organized (e.g., O'Reilly, Munakata, Frank, & Hazy, 2012). Connectionist models view higher order mental activity (such as an evaluation or an affective state) as an emergent property of the patterns and interactions of interconnected networks (e.g., units of neurons). These frameworks have several properties that help explain how the dynamic nature of information can be used to generate affective states, and how affect emerges over time. A fundamental premise of connectionist models is that meaningful information resides in the variable and dynamic patterns of activation across multiple units, as opposed to a single specific activation within a unit (for in-depth reviews of connectionist models in social psychology, see E. R. Smith, 1996, 2009).

A critical component of connectionist models is that the units within the network gravitate towards stable patterns of activation called attractor states. An attractor state is the most probable pattern of activation given a wide array of neuronal activations. This means that, given different inputs, the network will settle on a single internal representation. For example, if one were to visit a pet store each dog has unique characteristics based on things like breed, age, and sex, yet despite all the variations we can still settle on a single representation—dog. The diverse array of inputs gravitates toward the same internal representation (e.g., categorization). The strength of these attractor states is that they allow us to quickly come to a stable internal representation even in cases where inputs are ambiguous, uncertain, or novel. Yet, this "dog" representation is not processed in isolation, and contributes to a sum total of experience that includes not only the percepts related to the dog, but also activations associated with the context in which the dog is encountered. This is particularly important in light of the processing goals to build a stable representation of the environment that allows for prediction and appropriate reactions (Bar, 2009). The process of the network settling into a given pattern of activation allows us to predict how the event or stimulus will interact with the environment, thus giving our representations greater nuance. So when a fluffy blur comes running at you, you can quickly categorize it as a "dog," and you can predict that and anticipate a future state that includes some cuddles and fetch. Most of the time, the settling process is quick and accurate. However, the network can settle into an incorrect internal representation, resulting in inaccurate predictions (incorrectly categorizing as "dog" instead of "wolf" and the incorrect predictions that follow).

Connectionist models store information via a distributed pattern of neural activation. When stimuli are detected in the environment, multiple individual neurons fire in response to different aspects of the stimulus and it is the combined activation of these distinct neurons that leads to the representation of the current stimulus (see O'Reilly et al., 2012, for a review). Because the recognition of any given stimulus is the function of the probabilistic sum of activation from multiple independent neurons, distributed representations allow for both stability and flexibility. The active representation of any given piece of information, be it an attitude, emotion, or self-perception, is the function of *both* the preexisting connection weights (that are relatively stable and stored in memory) and the current state of activation (which is a function of factors such as goals, context, and current hedonic experiences, and serves to make certain attractor states more or less gravitational). Indeed, stronger connection weights (which are a function of previous experience) make it more likely that similar patterns of activation will be generated, given a perceptual input, whereas foregrounding can change stimulus construals by reflectively creating distinct patterns of activation and altering the starting weights by which a stimulus is processed.

The goal of the mind is to settle into a stable, predictive internal representation of the environment, similar to a system going from a high entropy state to a low entropy state (see Friston, 2012, for a formal discussion of these principles for biological systems). Here, what we mean by entropy is the degree of organization of active representations. Representations that have not yet settled into an attractor state have a possibility of settling into a number of different stable internal representations, and thus there is greater uncertainty about how they will settle. Put another way, unstable, uncategorized representations have many possible configurations—the same (unstable) representation can be generated by many different patterns of activation. As the stimulus or event settles into a stable pattern of activation, the number of probable forms the representation will take decreases, thereby reducing entropy. Successive iterations allow for more nuanced representations and therefore less entropy and greater prescriptive predictions.

Boltzmann defines entropy as the number of possible microstates that can account for a given observable macrostate (Boltzmann, 1877; Shannon, 1948; see also Hirsch, Mar, & Peterson, 2012). Applied to representations (i.e., a stable representation that the network has settled into), entropy can be thought of as the number of possible unique patterns of activation within the neuronal network that could produce that representation. In other words, entropy is the number of possible patterns of neuronal activation (microstates) that could create the observed representation (macrostate). A stimulus that has just been encountered, and has not yet settled into a stable internal representation, produces a representation that is disorganized and not unique from many other disorganized representations (though it does not usually stay in this form for very long). This is a high entropy state because many arrangements of the neuronal network can produce a disorganized representation (just about any set of inputs can result in a disorganized representation at first). Generally, a representation won't stay in this state for very long (e.g., far less than a second) before subsequent iterations refine the representation, for example going from a jumbled mess of fur, activity, to "my dog." Along the way, the associated affect of the active representation can change, as an unknown dog may be more threatening than my own dog.

Many fewer arrangements of the network could produce these more specific representations, and as such the entropy of the network is successively lowered as the iterative refinement process progresses. An equivalent way of saying this is that each iteration of processing allows for the reduction of the number of potential higher-order representations that can be implied by a given set of representations, or in other words, the number of potential stable representations that the pattern can easily fall into at that time. With the reduction of entropy comes predictive power, since more refined representations carry more specific predictions. Thus, as the mind progresses through iterative cycles, it simultaneously reduces network entropy and increases predictive power.

This conceptualization has several implications. First and foremost is that any change creates entropy—be it small changes, such as encountering a new dog in your neighborhood, or big changes, such as your beloved family dog unexpectedly biting you (a giant error in prediction from what was anticipated). The increase in entropy will be proportional to the degree to which one's internal representations shift based on the event (and will usually correspond to how novel or expectancy-violating the event is). This is because such events launch representations out of their stable state and thus require the neuronal network to resettle. It also suggests that some sources of entropy (e.g., your dog's appearance on return from the groomer) are easily reducible because the network can easily settle into a new stable representation, whereas other sources may create entropy that is much more difficult to reduce (e.g., your dog reciting a Shakespearean sonnet). Entropy can be difficult to reduce for a number of reasons, but two important sources of persistent entropy are either novel stimuli that do not settle easily into a preset attractor state, or violations of expectation that not only fundamentally alter one's current representation, but can also disrupt other representations in the network (or at other layers of the network), thus launching them out of their attractor states as well. Since the brain is trying to reduce entropy, these persistent entropy sources will warrant further iterations in order to reduce the entropy by arriving at a stable internal representation for that event.

One of the crucial implications of a dynamic iterative system is that the prior state of the system is extremely important. Because the system is constantly updating its representations through rerepresentation, and because these rerepresentations are at least in part dependent on the previous representation, taking into account the state of the system at Time $_{(n-1)}$ is necessary to understand and predict the state of the system at the time of interest. In this way, the previous states of the system act as powerful biasing factors for the further processing of information. Put another way, from an IR perspective, there is no such thing as "time zero"—the previous states of the system are always influencing the representation process in principled and important ways, for example by altering the attractor state weights for subsequent processing (see Figure 1). From this perspective, the traditional distinctions between emotional reactivity and emotion regulation somewhat fall away. Because the prior state of the system influences how information is processed, all information is regulated to some degree.

This formulation is consistent with the proposals of control theory (Carver & Scheier, 1982) in that a source of affect is the direct result of discrepancies in representations related to goal directed action. In their cybernetic model, progress toward goals is constantly monitored in feedback loops, and to the extent that a discrepancy (as the result of a comparator process) is found, the direction of the discrepancy generates an affective state. If the discrepancy is beneficial (e.g., faster than expected progress toward a goal), the resulting affect is positive, whereas if the discrepancy is harmful (e.g., slower than expected progress toward a goal), the resulting affect is negative (Carver & Scheier, 1982). In the case of intense emotions, it is likely that these incompatible representations are not easily resolved, and as such an ongoing emotional episode will be experienced until resolution can occur. This reduction can come from cognitive processing (such as reappraisal; Gross, 2008) or by changing one's actions (and one's physiological state to perform those actions).[1]

It is important to note that although we have focused nearly exclusively on central nervous system processes of emotion, the peripheral nervous system (e.g., "the body") provides important signals and constraints. Autonomic feedback is a key feature of emotional experience. For example, Barrett and Bliss-Moreau (2009) suggest that sensory information from the world is represented in somatovisceral, kinesthetic, proprioceptive, and neurochemical fluctuations and that these bodily representations form a "core" affective state. This body state is cortically rerepresented in the somatosensory cortex, particularly the insula, which can then be integrated into subsequent steps of affective processing through connections to the amygdala and OFC. Cortical interpretations of these body states can provide information about the state of the individual and, following some cognitive interpretation, lead to the development of more nuanced emotional experiences. In addition to using information from the body to inform brain states, changes in affectively related brain states often lead to changes in body states. For example, once a potential threat has been detected, the body may need to organize in preparation for an immediate fight or flight response. This organization of body into action provides an important cue for future iterative reprocessing of valenced information.

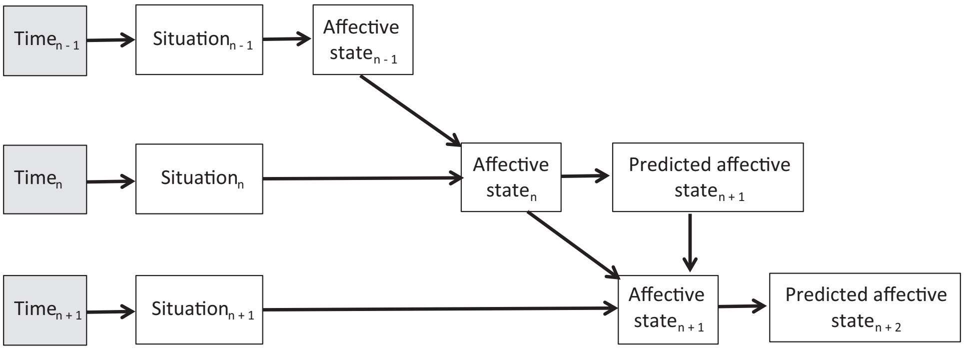

Figure 1. Multiple determinants of emotional state. At any given moment in time, an individual's current affective state is partially determined by (a) the situation, or what is occurring in the environment and (b) the individual's affective trajectory: comparing the current state of the world with what the individual had predicted for himself. A current affective state also naturally leads to a prediction for the future: whether things will improve, worsen, or remain the same. For example at Time (n + 1), the individual's affective state is jointly determined by his representation of the world at Time (n + 1) and what he had predicted for himself at Time (n). This composite affective state informs a prediction for his affective state at Time (n + 2).

From a computational viewpoint, then, “the body” serves as an important biasing agent for the generation of representations and rerepresentations. Previously, we discussed how structures such as the prefrontal cortex can influence representations both by allowing for more sophisticated rerepresentation or by altering the attractor state landscape such that stimuli are more likely to settle into a certain internal representations. The body can serve a similar role—body input can alter and constrain the attractor landscape, therefore biasing subsequent representations to make certain representations more or less likely. In the early stages of an emotion (when entropy has just spiked and the mind is trying to resolve it) the mind sends signals to the body to act in some way. This action is then reinterpreted by the mind and serves to constrain or bias the way information can be rerepresented. In this way, the body may make the experience of an emotion more likely or more rapid via biasing input towards settling into certain attractor sets, which can then be subsequently refined by further iterations. As an example, if you are frightened by something and begin running, the act of running is reinterpreted by the mind to further constrain subsequent representations to be consistent with the notion that you are frightened (somewhat akin to James, 1890).

Conceptualizing an origin of an emotional episode as arising from persistent unresolvable entropy in the network of the mind means that the body is not necessary for emotions per se. That said, the body gives important cues to the mind and contributes to emotions in meaningful ways, and our experience of emotions would likely be qualitatively different without the body. Without the preexisting constraints that the body provides, emotions would likely be muted and differ in important ways. For example, the unfolding of an emotional experience likely takes longer without bodily feedback to help constrain incoming inputs to a certain representational space. The extent to which the body is important for emotions will differ, however, depending both on the specific emotion and the particular instantiation of a given emotional experience. If the bodily constraints are less necessary for representations to settle in certain ways, then the body will be less important for a given emotional experience. This approach also suggests that valence and salience do not need to be dependent on the body, but rather that they are a function of innate reinforcement circuitry which, at any given time, may or may not be receiving input from the body. Although bodily experiences can influence and constrain the experience of valence and arousal, they are not obligatory for the affective experience.

The body is also necessary for action, and different emotional states are correlated to a greater or lesser degree with different action tendencies (Frijda, Kuipers, & ter Schure, 1989). Once one makes the prediction that something bad is about to happen, and that this threat is imminent, there are a limited number of behavioral (and organized action patterns) options available to the organism. One can hide/freeze, run, or attack (or perhaps attempt to negotiate). Each of these behavioral responses has functional utility, and may have clearly differentiated physiology. For example, Susskind et al. (2008) suggest that the facial expressions associated with fear may enhance sensory processing, whereas the facial expressions associated with disgust may enhance sensory rejection—appropriate responses for many instances of these emotional states. Yet, to use this example, there may be many pathways to sensory enhancement or rejection, only one of which may be fear or disgust, respectively. Indeed, there may be cases when one is afraid, but the appropriate response may be to reduce intake, and as such the expression in that situation may more reflect canonical disgust than fear.

Considering the temporal unfolding of an emotional episode, it could be that whereas the antecedents of emotional processing may be varied, and the processes may be numerous, once a specific action is required, different instances may look more similar *to the extent* that the resultant actions are similar. That there are more finite behavioral responses (only a certain number of muscle and autonomic patterns make sense), and more infinite combinations of cognitive processes that can get one to an emotional state (no two emotional situations are likely identical), may help reconcile the differences found by researchers in the basic emotions and the constructivist camps. In his review of affective neuroscience, Berridge (2003) notes that whereas the animal work tends to focus on brain stem and limbic regions, human work tends to focus on cortical regions. The animal work seems to suggest more basic emotions and motor programs, whereas the human work emphasizes more domain general processes and flexibility. As he notes, it is quite possible that these two lines of work converge rather than diverge. The animal work may highlight the finite behavioral options (correlated with antecedents that are correlated with emotional states), whereas the human work highlights the numerous ways in which one can process the environment. As such, what is typically taken as evidence of basic emotions from the literature may be better labeled survival circuits (LeDoux, 2012). In other words, a given emotional state (however it is generated) may be probabilistically associated with an appropriate response (which may come prepackaged evolutionarily), but the activation of a survival circuit is not the emotion, but rather the consequence of the organism operating within the environment.

Together, this suggests that the heterogeneity of emotional experience comes from the dynamic nature of the emotional episode. As shown in Figure 2, an emotional episode can begin with any affective change, whether it be a discrepancy between what one was feeling and what one is now feeling, between what one expected to feel and what one actually feels, or changes in what one expects to feel in the future. Each of these discrepancies result in information entropy that needs to be resolved, and it is in the resolution of this entropy that the emotional episode is experienced. For example, one can cognitively change one’s representations, perhaps through reappraisal processes (Ray, Wilhelm, & Gross, 2008) such as reducing the importance of an event, changing the affective meaning of an outcome, or altering one’s memory to create less discrepancy. Alternatively, one can act behaviorally to change the situation, such as fleeing from a fearful event or attacking a potential threat. In these cases, discrepancy reduction can be achieved through situation modification (Gross, 2008). As an emotional

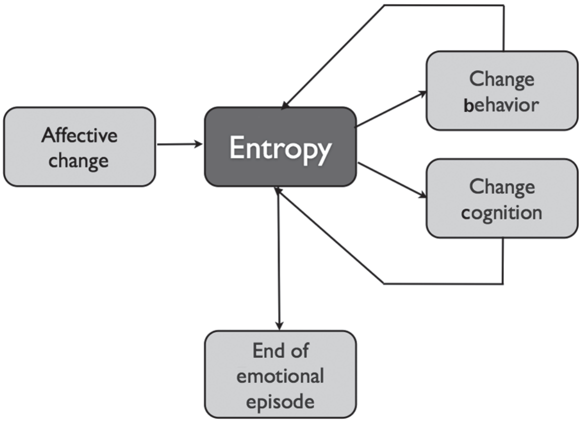

Figure 2. The dynamics of emotion generation as a function of entropy reduction. Affective changes result in increases in entropy, which can be resolved either behaviorally or cognitively. The emotional episode lasts until this entropy is sufficiently reduced.

episode unfolds, the strategies can shift as the situation itself changes (either internally or externally), with the episode ending once entropy levels are at a lower rate.[2]

The Emergence of Differentiated Emotion Categories

From a psychological constructivist perspective, we take as a starting point the premise that the wide variety of emotional experiences can be generated through the interactions of a more limited number of basic mental ingredients (Barrett, 2006a, 2006b, 2009). On our view, however, the affective ingredients typically proposed are not sufficient to capture the processes of affect as they too are constructed from more elemental processing units. That is, although affect experientially may comprise a circumplex structure of two axes capturing some degree of valence and arousal (Plutchik, 1962; Russell, 1980, 2003; Watson & Tellegen, 1985; Yik, Russell, & Barrett, 1999), this does not suggest that valence and arousal are unitary processing elements. Rather, the processing of valence occurs dynamically in time, with separable representations of valence for the present, past, and future (Cunningham & van Bavel, 2009; Kirkland & Cunningham, 2012). As described earlier, evaluative states are constructed dynamically through a series of iterative neural loops occurring multiple times per second. These multiple mental systems serve as a way of tracking our affective trajectories through time. Incoming information is compared to previous information and the discrepancy between these two states is computed (see also Scherer, 2009). This in turn informs interpretation and future prediction. Thus, our affective space is comprised of our past, our present, and what we predict for our future. The current affective state is constructed based on the newest incoming information (what just happened, including comparisons to previous predictions) and the information that existed before (past events or feeling states) as well as any predictions being made about what may occur next (see also Carver & Scheier, 1990, for a similar argument about goal pursuit and the experience of general positive and negative states). The emotion categories used by humans are thus a way to label and differentiate the various affective trajectories we experience as we move continuously through time.

To the extent that affect is dynamic, and reprocessed from moment to moment, it is likely that the affective states labeled as emotional also reflect the ongoing dynamics of affective experience within a temporally sensitive framework. *Previous* affective states are composed of memory representations of an individual's immediate affective past. The *current* affective state is an evaluation of one's current state as a function of outcomes. *Predicted* affective states are evaluations of what is likely to happen next. Critically, comparisons can be made between these time points through communication among the relevant neural circuits, allowing us to map out our particular affective place in time (Cunningham & van Bavel, 2009; Kirkland & Cunningham, 2012). By focusing on affective dynamics as a starting point for emotional processing, this suggests that emotional states result primarily from changes in the representation of affect within or between systems. That is, just as our perceptual systems are sensitive to changes in sensory input, our affective system is sensitive to changes in valence. Importantly, change or discrepancy, especially if it cannot be resolved quickly, leads to an increase in the entropy of the system and a motivation to reduce the entropy either through behavioral or cognitive modifications. According to this view, a predicted negative state may be labeled fear, whereas a current negative state may be labeled sadness. Differentiating between these categories is important because they provide information as to where in the system the change has occurred. A negative event that can still be avoided may lead to a different set of behavioral options than one that has already occurred (Lazarus, 1982).

As an emotional experience unfolds, these processes continuously interact to generate an emotion episode. Because the episode lasts until entropy is reduced, different emotions can last quite different periods of time, from an instant of joy quickly resolved, to a week of anxiety regarding a lost dog. Thus, although emotions are generated through a dynamic cycle of processing, some emotions may result from attention to only parts of the system. For example, the emotion category fear may simply require labeling the feeling state generated by a negative prediction signal (e.g., the moment between when you notice the front door being left open and finding Fido curled up safely in the hall). Others, such as joy or sadness, may require more comparison; in these instances the comparison might reveal an upward or downward affective trajectory, respectively. For example, when a new dog is first introduced in the family it may not be immediately clear if this is cause for celebration (because the animal quickly bonds with the family, thus increasing affective trajectory) or will be cause for concern (because the animal is unable to be left alone, resulting in a negative affective trajectory). In contrast to models that tacitly begin emotional processing after stimulus presentation (at a figurative "time zero"), this perspective suggests that emotional states are rarely separate from the affective and motivational context in which they arise and may, in fact, necessarily require changes in affective processing from previous to current states (i.e., the addition of a second dog may improve family relations if the existing family dog has trouble being alone, but may damage family relations if it causes a previously relaxed dog to become aggressive and territorial). Within this frame, the hard distinction between cognition and emotion falls away—each referring to a different aspect of a unified dynamic system.

To the extent that these changes in dynamic affect, at least in part, underlie the construction of emotional experience, we should expect that the linguistic categories that we use should mirror our predictions. To test this hypothesis, Kirkland and Cunningham (2012) presented participants with information about affective trajectories and recorded which emotion they thought best fit the scenario. To eliminate any semantic information that could be used to determine emotional categories, participants were simply provided with information about past, present, and predicted valence. For example, "you are feeling good, and you predict that something bad will happen. Which emotional label best characterizes this situation?" or "you expect something good to happen, but something worse than expected happens. Which emotional label best characterizes this situation?" Importantly, participants were given the option of reporting that they would not experience any emotion. As expected, each of the "basic emotions" fits into particular quadrants of the affective space. For example, when a worse-than-expected outcome follows the prediction that something good will happen, that situation is labeled as causing anger, while when a worse-than-expected outcome follows the prediction that something bad will happen, that situation is labeled as causing sadness. Additionally, emotion categories are differentiated to a greater extent when participants are required to think categorically than when participants have the option to consider the possibility of multiple emotions and degrees of emotions. This work indicates that information about affective movement through time and changes in affective trajectory may be a fundamental aspect of emotion categories. Another important factor of the model is that as we often experience a particular affective trajectory in conjunction with a suite of behavioral and regulatory strategies, associated thoughts and interpretations, as well as the labels that we used to categorize it. Through time, these pairings can become self-organizing such that a particular trajectory becomes associated with a specific suite of behavioral strategies and a certain emotional label (see Lewis, 2005). The repeated experience of similar affective trajectories and their behavioral correlates eventually alter the attractor-state landscape, resulting in the categorization of a particular suite of prototypical elements as a specific emotional experience. Similar to how bodily feedback influences the unfolding of emotions by constraining them via altering the attractor landscape, one's categories constrain one's experience by making certain representations more likely. This makes the prediction that different people can have a similar label for an emotional experience (e.g., fear), but that label corresponds to different attractor-state landscapes. Indeed, depending on the representations associated with a particular emotional label, a particular "emotion" may have vastly different consequences for the two individuals. For example, fear experiences often differ in the extent to which they suggest "fight" versus "flight" responses. For example, an individual who is typically in fight-appropriate situations might have their attractor landscape altered in such a way that fight is activated even when flight is more appropriate, in part because their emotional experience of fear has been developed around the behavioral affordance of "fight," making it harder to activate the "flight" response. In this way, our emotional categories—developed over time and repeated emotional experiences—constrain and alter our emotional experiences as well.

Interactions: Cognitive Representations, Appraisals, and Construction

Although comparisons among the temporal valence representations can provide information for the construction of a particular emotional experience, iterative reprocessing allows for processing to become more refined with time. That is, although affective responses begin with some combination of physiological activation and neural evaluations, emotional episodes also appear to involve some degree of cognitive interpretation. Indeed, a primary goal of appraisal theorists has been to understand which cognitive interpretations are necessary and/or sufficient for an emotional response. According to appraisal theory, different emotions arise from the cognitive interpretation of the environment and the implications that these environments have for the perceiver. Although the specific dimensions vary from theory to theory (Frijda et al., 1989; Ortony et al., 1988; Roseman, 1984; C. A. Smith & Ellsworth, 1985), most involve a calculation of whether an event is self-relevant, predictable, consistent with one's goals, caused internally (by the self) or another, and whether one has the capacity to deal with the change (Scherer, 1988). If one considers these appraisals in multidimensional space, different emotions occur in different quadrants. Thus, our appraisals about affect—such as who or what is causing it, how much control we have, whether the state is consistent with our goals, and so forth—help us to understand and even define our emotional experience. The particular emotion that is experienced may be largely dependent on the aspects of the situation or object to which one attends. The situation reflects the perceiver's unique interpretation of his or her surroundings in terms of personal relevance. Given the computational nature of these appraisals, current models propose an iterative sequence of appraisal checks that begin with a basic sense of relevance and valence and build in complexity toward a differentiated emotional experience (Scherer, 2009).

As with the conceptual act model (Barrett, 2006a, 2006b), our model of emotion requires the integration of aspects of valence processing with cognitive categories to fully explain the full range of emotional behavior and experience. Especially, although we have articulated how the processing of valence across time can lead to emotions, we do not believe that these trajectories alone are sufficient to create all emotional experiences. Rather, we propose that these trajectories are one of the ingredients that are used in combination with other processes. On this view, a pattern of valence information regarding the past, the present, and the anticipated future prime our cognitive systems toward a particular emotional state. If one is predicting that something bad will happen, emotional responses typically associated with fear are more likely. If one also experiences a change toward negative valence, but this is a downward trajectory, then emotional responses typically associated with sadness are more likely. Yet the increased probability that the state will be labeled as sadness is not the same as saying that the particular pattern of valence representations is sadness. Rather, this information needs to be combined with our interpretations of the environment (appraisals) and the different behavioral options that are available at the moment. A predicted bad event that can have the potential for escape is likely experienced quite differently from one when trapped. Thus, the trajectory model can be thought of as providing a "preappraisal" of dynamic valence.

The combination of trajectory information with additional ingredients allows for multiple expressions of emotional experiences. Not all situations are the same, and not all options are present given the same cues. As such, the ways in which people choose to engage with the environment shape the experience, the body with respect to the environment, and the actual event itself (Gross, 2008), giving rise to a heterogeneity of emotional experience and behavior.

The Development of Emotion Ingredients

To the extent that emotions result from the interaction of hierarchically organized neural systems, and that these systems provide important constraints across levels of processing, this perspective suggests important hypotheses regarding the development of emotional experiences. As discussed previously, the experience of any particular affective state is the emergent property of the integration and evaluation of multiple representations (e.g., valence, current goals, expected outcomes, etc.). Moreover, resolution of much uncertainty is thought to occur as information is processed at increasing higher-order brain areas (such as the OFC and PFC), thus neuronal maturation plays an important role in the development and experience of emotions.

Although PFC function is first observed towards the end of the first year of life (e.g., Chugani & Phelps, 1986; Diamond & Goldman-Rakic, 1989), the area continues to develop throughout childhood and well into adolescence (e.g., Giedd et al., 1999; Gogtay et al., 2004). Similarly, infant's emotional experiences begin in the first year of life and increase in diversity and complexity with development. Early research on infant emotion (e.g., Wolff, 1987) suggests that babies are born with relatively undifferentiated, simple affective systems that mainly comprise positive and negative affect. These two broad classes of affective experience can be linked to basic motivational drive states resulting in a general tendency to approach positive and avoid negative stimuli. For example, within the first few months of life infants begin to smile in response to positive stimulation, including gentle touches, high-pitched voices, and engaging images (such as static faces; Sroufe, 1995); whereas infants respond negatively with cries and distress in the face of negative stimulation like medical injections (Izard, Hembree, & Huebner, 1987), or frustration (Camras, 1992; Hiatt, Campos, & Emde, 1979; Lewis, Alessandri, & Sullivan, 1990). Importantly, as infants age and gain better control over their self and their environment they can move beyond simple environmental based reactions.

Indeed, through maturation children start to pair environmental cues with affective expectations (potentially through activation in the amygdala-striatal circuits; Cunningham & Zelazo, 2009), resulting in more complex affective experiences. For example, at around 3 months of age infants start to pair people with the pleasure of social interactions and start exhibiting social smiles (White, 1985), eliciting reciprocal delight from others in their environment (Camras, Malatesta, & Izard, 1991; Huebner & Izard, 1988). At the same time, these more complex expectations also lead to the experience of negative emotions such as fear and frustration (e.g., Alessandri, Sullivan, & Lewis, 1990). Thus, as the PFC develops, children can move beyond their immediate hedonic experience, to have affective experiences associated with expectations.

As children move into their second year of life, increasing neuronal maturation allows for the representation of absent stimuli and the ability to imagine different affective states. This maturation also allows for better affective predictions and more complex emotional experiences. A good example of this association between the development and emotion is the relation between prefrontally maintained working memory (e.g., Baird et al., 2002; Liston & Kagan, 2002) and the emergence of stranger anxiety (Kagan, 1972, 1981). Specifically, it is the ability to anticipate a negative trajectory in one's current affective state that results in the experience of anxiety at the approach of an unknown individual. Indeed, it is orbitofrontal cortex function that is thought to be critical for the ability to integrate present, previous, and predicted hedonic states.

Finally, in the third year of life children can begin to integrate self-reflection with their understanding of the mental states of others. As children begin to integrate the thoughts, beliefs, and evaluations of others into their affective predictions, the result is more "complex" affective experiences that rely on social comparison, such as shame, guilt, empathy, and pride (Lewis, Sullivan, Stanger, & Weiss, 1989). Interestingly, children's recognition and labeling of others' emotional experiences follows a similar, albeit protracted, developmental trajectory with children first making broad, valenced attributions (i.e., overgeneralizing from "happy" and "sad") that narrow into more specific emotional states over the preschool years (Widen & Russell, 2003, 2008). Taken together, the IR model in general, and the affective trajectories hypothesis in particular, grounded in the hierarchical function of the brain, make predictions consistent with the emergence of emotions over time from early undifferentiated, body based affect (e.g., positive vs. negative), to emotions based on environmental predictions (e.g., anxiety and frustration), to more complex socially based affective experiences (e.g., empathy, shame, guilt).

Conclusion

Neuroscience methodologies and perspectives have been useful tools in the continuing process of understanding how affect manifests in the human brain, and the implications of these findings for models of emotion. Much is now known about the neural systems involved in affective processing that was relatively inaccessible even 20 years ago. In our review of the literature, we identify four aspects of affective processing that fall out of the consideration of dynamic cognition (and in particular the IR model). These include the generation of affective predictions for the future, the representation of current affective states, the integration of information from the body, and the engagement of reflective processing to integrate appraisals, interpretation, categorization, and meaning. This perspective should allow for new research aimed at not only understanding the homogeneity of emotional experience (the similarities among instances of "fear"), but also the heterogeneity of emotional experiences (the differences among the "fear" episodes). By taking into consideration the role of time in both the short (moment by moment) and long (life-span development) term, we can better understand how emotions unfold and transform to adapt to changing environments.

Notes

1 According to this view, a sharp distinction between motivation and affect/emotion is not necessary. High entropy states entail a set of processes to resolve the entropy and return to a low entropy state. When considering the full episode it may be labeled an emotional state, but when considering the time course and actions performed it may be labeled a motivated state. Thus, emotion and motivation computationally may be, in turns of a core ingredient, two sides of the same coin.

2 It is possible that different people have different ideal levels of entropy, and this may lead to different types of trait emotionality.

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