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Mapping the passions: Toward a high-dimensional taxonomy of emotional experience and expression

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Mapping the passions:
Toward a high-dimensional taxonomy of emotional experience and expression

By

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Committee in charge

Professor Dacher Keltner, Chair
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Abstract

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What are the emotions? For 50 years, scientists have sought to map emotion-related experience, expression, physiology and recognition in terms of the "Basic 6" emotions– anger, disgust, fear, happiness, sadness, and surprise. Claims about the relationships between these six emotions and prototypical facial configurations have provided the basis for a longstanding debate over the diagnostic value of expression. Here, building upon recent empirical findings and methodologies, I offer an alternative conceptual and methodological approach that reveals a richer taxonomy of emotion. Dozens of distinct varieties of emotion are reliably distinguished by language, evoked in distinct circumstances, and perceived in distinct expressions of the face, body, and voice. Traditional models – both the Basic 6 and affective circumplex (valence and arousal) – capture a fraction of the systematic variability in emotional response. In contrast, emotion-related responses (e.g., the smile of embarrassment, triumphant postures, sympathetic vocalizations, blends of distinct expressions) can be explained by richer models of emotion. Determining the full extent of what emotional expressions can tell us, marginally and in conjunction with contextual cues, will require mapping the high-dimensional, continuous space of facial, bodily, and vocal signals onto richly multifaceted experiences using large-scale statistical modeling and machine learning methods.

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Chapter 1. Introduction

> "The strange thing about life is that though the nature of it must have been apparent to everyone for hundreds of years, no one has left any adequate account of it. The streets of London have their map; but our passions are uncharted."
> - Virginia Woolf, *Jacob's Room*

What are the emotions? This question has captivated great thinkers, from Aristotle to the Buddha to Virginia Woolf, each in a different form of inquiry seeking to understand the contents of conscious life. The question of what the emotions are was first brought into modern scientific focus in the writings of Charles Darwin and William James. Over the next century, methodological discoveries gradually anchored the science of emotion to a predominant focus on prototypical facial expressions of the "Basic 6": anger, disgust, fear, sadness, surprise, and happiness. By the late twentieth century, many scientists had come to treat these six prototypical facial expressions as if they were exhaustive of human emotional expression; methodological convenience had evolved into scientific dogma.

Clearly, even less astute explorers of the human psyche than Virginia Woolf are likely to question this approach. Isn't human emotional life more complex than six coarse, mutually exclusive emotional states? What about the wider range and complexity of emotions people feel at graduations, weddings, funerals, and births, upon falling in and out of love, in playing with children, when transported by music, and during the first days of school or on the job? Don't humans express emotions with a broader array of behaviors than only movements of facial muscles, by shifting our bodies and gaze and making sounds that actors, novelists, painters, sculptors, singers, and poets have long portrayed? Our answer to these questions today echoes Virginia Woolf's sentiment from nearly 100 years ago: the focus on six mutually exclusive emotion categories leaves much, even most, of human emotion uncharted.

This dissertation provides a map of the passions, one that—while still in the making—moves beyond models of emotion that have focused on six discrete categories or two core dimensions of valence and arousal and prototypical facial expressions. To appreciate where this will go, consider emotional vocalizations, such as laughs and cries, and varying ones at that. Exultant shouts. Sighs and Coos. Shrieks. Growls and groans. Oohs and ahhs and mmms. The human voice conveys upwards of two dozen emotions (Anikin & Persson, 2017; Laukka et al., 2013; Sauter, Eisner, Ekman, & Scott, 2010) that can be blended together in myriad ways (Cowen, Elfenbein, Laukka, & Keltner, 2018; Cowen, Laukka, Elfenbein, Liu, & Keltner, 2019). To visualize this high dimensional space of emotional expression, explore this map: https://s3-us-west-1.amazonaws.com/vocs/map.html. New studies like these are revealing that the realm of emotional expression includes more than six mutually exclusive categories registered in a set of prototypical facial muscle movements.

In fact, these new discoveries reveal that the two most commonly studied models of emotion – the Basic 6 and the affective circumplex (comprised of valence and arousal) – provide an incomplete representation of emotional experience and expression. As we shall see, each of those models captures at most 30% of the variance in the emotional experiences people reliably report, and in the distinct expressions people reliably recognize. That leaves 70% or more of the variability in our emotional experience and expression uncharted. The new empirical and theoretical work I summarize in dissertation review points to robust progress in arriving at a richer characterization – a high dimensional taxonomy -- of emotional experience and expression. And these findings echo suggestions long made by numerous emotion researchers – that a full understanding of emotion expression and experience requires an appreciation of a wide degree of variability in display, subjective experience, appraisal pattern, and physiology, both within and across emotion categories (Banse & Scherer, 1996; Roseman, 2011; Russell, 1991).

The focus on six mutually exclusive emotion categories: A brief history

In 1964, Paul Ekman traveled to New Guinea with photographs of prototypical facial expressions of six emotions – anger, disgust, fear, sadness, surprise, and happiness. He sought to answer the question of whether or not those photos capture human universals in the emotional expressions people recognize. Having settled into a village in the highlands of New Guinea, Ekman presented local villagers with brief, culturally appropriate stories tailored to these six emotions. His participants selected from one of three photos the facial expression that best matched each story. Accuracy rates for children and adults hovered between 80% and 90% for all six expressions (chance guessing would be 33%; Ekman & Friesen, 1971).

It is not an exaggeration to say that this research would launch the modern scientific study of emotion. Studies would replicate Ekman and Friesen's basic result 140 times (see Elfenbein & Ambady, 2002; by now, the number of replications is likely much higher). The photos themselves are among the most widely used methodological tools in the science of emotion, and a centerpiece of studies of emotion recognition in the brain, in children, in special groups such as individuals with autism, and in other species (Parr, Waller, & Vick, 2007; Sauter, 2017; Schirmer & Adolphs, 2017; Shariff & Tracy, 2011; Walle, Reschke, Camras, & Campos, 2017; Whalen et al., 2013). Ekman and colleagues' research would inspire psychological science to consider the evolutionary origins of many other aspects of human behavior (Pinker, 2002).

As the science of emotion has matured, one line of scholarship has converged on the thesis that the Ekman and Friesen findings overstate the case for universality of the recognition of emotion from facial expression. Those critiques have centered, often reasonably, upon the ecological validity of the photos, the forced-choice paradigm Ekman and Friesen used (Nelson & Russell, 2013; Russell, 1994), the strength of the cross-cultural evidence for universality (Crivelli, Russell, Jarillo, & Fernández-Dols, 2017), the fact that labeling of prototypical facial expressions can shift depending on context (Aviezer et al., 2008; Carroll & Russell, 1996), and questions about whether emotional expressions signal interior feelings, social intentions, or appraisals (Crivelli & Fridlund, 2018; Frijda & Tcherkassof, 1997; Scherer & Grandjean, 2007). Unfortunately, these limitations of the Ekman and Friesen approach are often misconstrued as limitations of the diagnostic value of emotional expression more generally.

Common assumptions about emotion

Many experts now suggest that little can be inferred from facial expressions, given that empirical findings regarding facial expression contradict what is seen as a "common view" of emotion (e.g., Barrett, Adolphs, Martinez, Marsella, & Pollak, 2019). This view, represented in Figure 1A, is comprised of three assumptions embedded in many scientific studies of emotion-related responses. A first, extrapolated from Ekman and Friesen's focus on six facial expressions (although never asserted by Ekman and Friesen themselves), is that emotional expressions can be sorted into six discrete categories. Indeed, many studies within the science of emotion—perhaps the majority—can be understood as asking whether emotion-related experiences, expressions, or physiological responses can be sorted into these categories, an assumption that has hampered the discovery of an underlying structure of emotion, as we shall see.

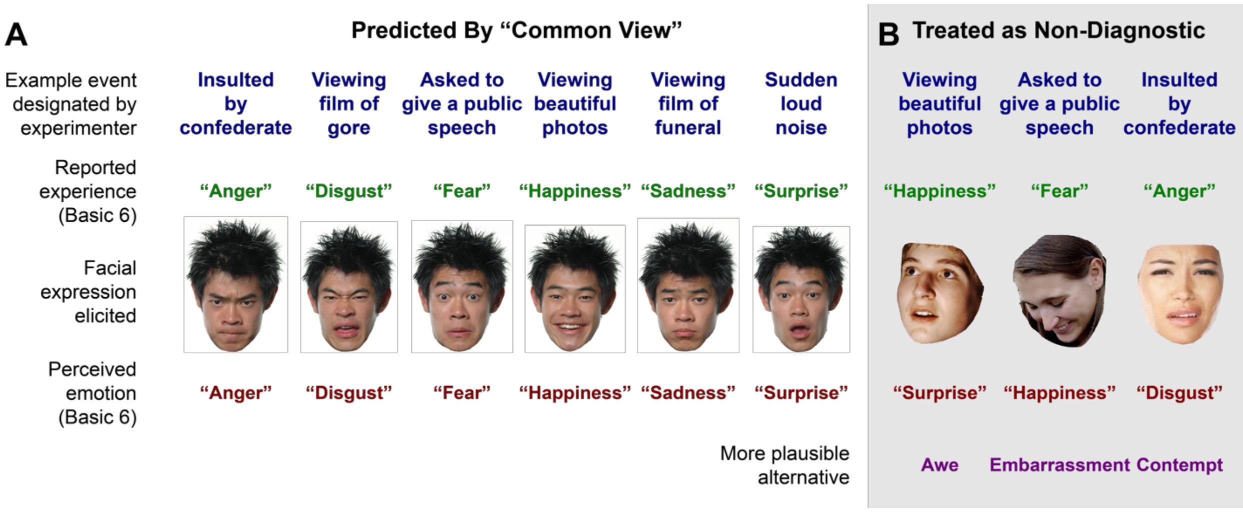

Figure 1 (A) Common scientific assumptions about emotion. Under a common view of emotion that guides many studies, particular emotion antecedents consistently elicit experiences that are captured by six coarse, mutually exclusive categories – "anger", "disgust", "fear", "happiness", "sadness", and "surprise." These experiences in turn give rise to prototypical facial configurations. Example antecedents that have been used experimentally to elicit each of the Basic 6 emotion categories are shown to the left, along with the prototypical facial configurations that they are expected to evoke. It is often assumed that any violations of this model can serve as evidence against the diagnostic value of facial expression more generally (e.g., Barrett et al., 2019; Crivelli et al., 2015). We illustrate some counterexamples to this tenet in (B). (B) Example violations of common assumptions about emotion. Plausible responses to some of the antecedents that have been used to elicit the Basic 6 also include the three expressions presented here, which are reliably recognized as signals of "awe," "embarrassment," and "contempt" (Cordaro et al., in press; Cowen & Keltner, under review; Keltner, 1995; Shiota, Campos, & Keltner, 2003). When compared in terms of facial muscle activation to the Basic 6 prototypes, they most closely resemble "surprise," "happiness," and "disgust," respectively, categories that notably contrast with the emotions people readily perceive in these expressions. In fact, emotional expressions convey a wide variety of states, including blends of emotion, that cannot be accounted for by the Basic 6.

A second assumption is that there is a one-to-one mapping between experiences and expressions of the Basic 6, and specific contexts in which they consistently occur. For example, as illustrated in Figure 1, being insulted should necessarily lead a person to express anger, and giving a public speech should lead to facial expressions of fear. This assumption, also a defining feature of many studies, overlooks how cognitive appraisals mediate relations between events and emotion-related responses (Moors, Ellsworth, Scherer, & Frijda, 2013; Roseman, 2011; Scherer, 2009; Smith & Ellsworth, 1985; Tracy & Randles, 2011). More specifically, individuals vary in basic appraisal tendencies toward perceiving threat, rewards, novelty, attachment security, coping potential, and other core themes as a function of their particular life histories, genetics, class, and culture of origin (e.g., Buss & Plomin, 1984; Kraus, Piff, Mendoza-Denton, Rheinschmidt, & Keltner, 2012; Mikulincer & Shaver, 2005; Tsai, 2007). These individual differences produce different emotional responses to the same event. Individual variation in emotional expression in response to the same stimulus – a stranger approaching with a mask on, winning a competition, or arm restraint – therefore does not serve as evidence against coherence between experience and expression. Instead, this variation in expression may follow from differences in individuals' evaluations of those stimuli. These differences have been worked out to a significant degree by appraisal theorists (Lazarus, 1991; Roseman, 1991; Roseman, 2013; Scherer, Schorr, & Johnstone, 2001), but are compatible with multiple theoretical perspectives (Scarantino, 2015).

Third, it is often assumed that each of the six emotions is expressed in a prototypical pattern of facial muscle movements. Hence, researchers for decades focused largely on this high constrained set of emotion-related responses, a tradition that continues today. Hundreds of more recent empirical studies, however, have documented that: a) people express upwards of 20 states with multimodal expressions which include movements of the face, body, and postural shifts, as well as vocal bursts, gasps, sighs, and cries (for review, see Keltner, Sauter, Tracy, & Cowen, 2019; Keltner, Tracy, Sauter, Cordaro, & McNeil, 2016) and that b) each emotion is associated with a number of different expressions, as Ekman himself predicted (Ekman, 1993). Thus, the mapping between emotion and expression is more complex than six prototypical patterns of facial muscle movement. Unfortunately, researchers still often take findings that stimuli do not reliably evoked six prototypical facial expressions as evidence against the broader diagnostic value of emotional expression (e.g., Duran & Fernandez-Dols, 2018). Based on the empirical and theoretical developments we have outlined so far and will address in greater detail below, studies that do not observe a predicted prototypical facial expression in response to an emotion induction are open to many interpretations: perhaps the emotion was expressed in one of many ways other than the prototypical facial expression; perhaps the stimulus elicited one or several of the other emotions than the Basic 6, or perhaps it elicited a complex blend of emotions (see Roseman, 2011).

Finally, it is often assumed that people around the world should label the six prototypical facial expressions of emotion with discrete emotion words. This assumption, also, is often disconfirmed, particularly when participants from different cultures use different words to label the same facial expression (e.g., Crivelli et al., 2016), but should not stand in for the broader diagnostic value of emotional expression. For instance, single emotion words vary in their meaning across cultures, calling into question whether cross-cultural comparisons using this approach are sound (Boster, 2005; Cordaro et al., in press; Russell, 1991). Moreover, the methodological reliance upon single word labeling paradigms introduces other problems related to more complex interpretations of emotional expression. Imagine that a person from one culture perceives an anger expression to be communicating 55% anger and 45% sadness, and a person from a second culture perceives the same expression to be communicating 45% anger and 55% sadness (e.g., Cowen et al., in press). Despite the considerable overlap in their interpretations, single word labeling paradigms would classify the two individuals as offering different responses. As a result of these and other ambiguities in single word paradigms, the field of emotion has moved on to other methods – matching expressions to situations, appraisals, and intentions, nonverbal tasks, and using free response data (e.g., Haidt & Keltner, 1999; Sauter, LeGuen, & Haun, 2011). Of course, such methods are limited in other important ways – for example, when matching expressions to situations, people across cultures may appraise the same situations in different ways, and free response does not measure recognition per se (i.e., it should never be assumed that a subject who calls a green apple “a fruit” is unable to recognize that it is green or an apple). Nevertheless, efforts to move beyond single emotion words have led to important advances in understanding how people conceptualize and categorize emotional expressions, a theme we develop later in this essay.

Ultimately, the model of emotion represented in Figure 1 offers one way to answer the question: What are the emotions? As this dissertation will make clear, empirical data now point to a different answer. This emergent view, synthesized here, reveals that with a careful attention to additional emotions beyond the Basic 6, additional modalities of expressive behavior, and the use of large-scale statistical modeling, we are arriving at a picture of a rich, high-dimensional taxonomy of emotional experience and expression.

Chapter 2. Deriving a high-dimensional taxonomy of emotion

Conceptual foundations

Emotions are internal states that arise following appraisals (evaluations) of interpersonal or intrapersonal events that are relevant to an individual's concerns – for example over threat, fairness, attachment security, the promise of sexual opportunity, violations of norms and morals, or the likelihood of enjoying rewards (Keltner, Oatley, & Jenkins, 2018; Lazarus, 1991; Roseman, Spindel, & Jose, 1990) – and promote certain patterns of response. As emotions unfold, people draw upon the language of emotion —hundreds and even thousands of words, concepts, metaphors, phrases, and sayings (Majid, 2012; Russell, 1991; Wierzbicka, 1999)—to describe the emotion-related responses, be they subjective experiences, physical sensations, or, the focus here, expressive behaviors.

Of the many ways people describe their emotions, how many correspond to *distinct* experiences and expressions? What are these experiences and expressions? How are they structured? To answer these questions empirically, it is first necessary to map the meanings people ascribe to emotion-related responses onto what we have called a *semantic space* (Cowen et al., 2018; Cowen & Keltner, 2017, 2018; Cowen et al., 2019). On page 1, I alluded to one such space, that of vocal bursts, whose study illustrates that a semantic space is defined by three properties. The first is its *dimensionality*, or the number of distinct varieties of emotion that people represent within a response modality. To what extent are emotional experience and expression captured by six categories? As I will show, this realm is in fact much richer than six coarse categories (see also Keltner et al., 2019; Sauter, 2017; Shiota et al., 2017).

Second, semantic spaces are defined by the *distribution* of expressions within the space. Are there discrete boundaries between emotion categories, or is there overlap (Barrett, 2006a; Cowen & Keltner, 2017)? Within a category of emotion, are there numerous varieties of expressions, as Ekman long ago observed (he claimed, for example, that there were 60 kinds of anger expressions; see Ekman, 1993)? Or do we recognize only a single maximally prototypical facial configuration?

Third, semantic spaces are defined by the *conceptualization* of emotion: what concepts most precisely capture the emotions people express, report experiencing, or recognize in others' expressive behavior (Scherer & Wallbott, 1994; Shaver, Schwartz, Kirson, & O'connor, 1987)? Of critical theoretical relevance is the extent to which emotion categories (e.g., "sympathy", "love", "anger") or domain-general affective appraisals such as valence and arousal provide the foundation for judgments of emotional experience and expression (Barrett, 2006a; Barrett, 2006b; Russell, 2003). It has been suggested that the emotions people reliably recognize in expressions may be accounted for by appraisals of valence and arousal (Barrett et al., 2019). Recently, rigorous statistical methods have been brought to bear on this question, and, as we will see, valence and arousal capture only a fraction of the information reliably conveyed by expressions. Moreover, these features seem to be inferred in a culture-specific manner from representations of states that are more universally conceptualized in terms of emotion categories.

Overall, the framework of semantic spaces highlights new methods of answering old questions (see, e.g., Roseman, Wiest, & Swartz, 1994; Scherer & Wallbott, 1994; Shaver et al., 1987): What are the emotions? Within my framework, this translates to: In a particular modality – the production or recognition of expressive behavior in the face or voice, peripheral physiological response, central nervous system patterning -- how many dimensions are needed to explain the systematic variance in emotion-related response? Are emotions discrete or continuous – that is, how are emotional experiences, expressions, or physiological responses distributed in a multidimensional space? And what concepts best capture emotion – do we need categories, or can the variance they capture be explained in simpler, more general terms, for example with an affective circumplex model (comprised of valence and arousal; see also Hamann, 2012; Kragel & LaBar, 2016; Lench, Flores, & Bench, 2011; Vuoskoski & Eerola, 2011)?

Methodological approaches

To arrive at rigorous empirical answers to these questions, research needs to be guided by certain methodological design features departing significantly from the methods of studies guided by the model portrayed in Figure 1A. In Table 2 I highlight these features of empirical inquiry, and then turn to illustrative studies and a summary of the empirical progress made thus far in capturing the semantic space of emotional experience and the recognition of emotional expression.

Whereas most studies of emotion have focused on ten or fewer stimuli, I will describe studies of emotional experience evoked by thousands of richly evocative videos and music samples, and thousands of facial expressions, vocal utterances, and speech samples, inquiry at a scale facilitated by online content, modern crowdsourcing platforms, and high-speed computing. Whereas most studies have focused on a five or six emotions (at most), I will describe how data driven frameworks and statistical methods (see Appendix 1) allow for the derivation of dozens of distinct dimensions of emotion that people reliably experience in distinct situations and identify in distinct emotional expressions. Whereas most studies have focused only on prototypical stimuli, reinforcing assumptions about the boundaries between emotion categories, I will describe new open-ended analytical techniques that allow for the discovery of blended emotions.

Table 2. Separate consideration of the dimensionality, distribution, and conceptualization of emotion clarifies past methodological limitations.

	Methodological feature	Approach of many emotion studies	Approach necessary to derive semantic space of emotion
Studying the dimensionality, or number of varieties, of emotion	Range of emotions studied	Focus on Basic 6	Open ended exploration of a rich variety of states and emotional blends
	Source of emotional states to study	Scientists' assumptions	Empirical evidence, including ethnological and free response data
	Measurement of expressive behavior	Facial muscle movements sorted into Basic 6	Multimodal expressions involving the face, body, gaze, voice, hands, and visible autonomic response measured
	Statistical methods	Recognition accuracy	Multidimensional reliability analysis (e.g., PPCA; see Appendix 1)
Studying the distribution of emotion, or how emotions are structured along dimensions (e.g., whether emotional-related responses fall into discrete categories or form continuous gradients)	Stimuli used in experiments	Small set of prototypical elicitors and expressions	Numerous naturalistic variations in elicitors and behavior
	Statistical methods	Recognition accuracy; confusion patterns	Large-scale data visualization tools and closer study of variations at the boundaries between emotion categories
Studying the conceptualization of emotion, including whether emotions are more accurately conceptualized in terms of emotion concepts or more general features	Labeling of expression	Choice of discrete emotion in matching paradigms	Wide range of emotion categories, affective features from appraisal theories, and free response data
	Statistical methods	Confirmatory analysis of assumed one-to-one mapping of stimuli to discrete emotion concepts	Inductive derivation of mapping from stimuli to emotion concepts using statistical modeling
		Qualitative examination of whether emotion-related responses seem like they could be accounted for by valence and/or arousal; sorting paradigms, factor analysis, and other heuristic-based approaches	Statistical modeling of the extent to which the reliable recognition of expression and elicitation of emotional experience can be accounted for by valence, arousal, and other broad concepts

Chapter 3. Language and emotional experience

What are the emotions? The focus on the Basic 6 in the scientific model portrayed in Figure 1 traces back to Ekman and Friesen's study, but has no rigorous empirical or theoretical rationale. Darwin, who was an inspiration of Ekman's, described the expressive behavior of over 40 psychological states (see Keltner, 2009). More recently, social functionalist approaches highlight how emotions are vital to human attachment, social hierarchies, and group belongingness. This theorizing makes a case for the distinctiveness of emotions such as love, desire, gratitude, pride, sympathy, shame, awe, and interest (e.g., Keltner & Haidt, 1999). What do emotion researchers believe? One recent survey found that 80% of emotion scientists believe that five out of the Basic 6 are associated with universal nonverbal expressions (Ekman, 2016). This statistic is unsurprising given that these expressions were the predominant focus of the first 50 years of emotion science. Of note, a significant proportion of scientists surveyed indicated that additional emotions, such as embarrassment and shame, have recognizable nonverbal expressions. Similarly, taxonomies proposed by emotion scientists most typically include more states than the Basic 6 (Keltner & Lerner, 2010; Panksepp, 1998; Roseman et al., 1994; Shaver et al., 1987).

The distinct emotions captured by language

Past studies of the semantic space of emotion have focused largely on the nature of the concepts people use to describe the different varieties of emotional experience in abstract terms (Russell, 1980; Shaver, 1987; Watson & Tellegen, 1985). Although these studies have derived compressed models of emotional experience that enabled early progress the field, such as the representation of emotion in terms of valence and arousal, the factor analytic methods used to derive these models are limited in important ways. First, they are inherently reductive—they have relied on heuristic methods such as the often-used scree test applied to data that is already limited in its features, which guarantees a low-dimensional solution. Second, these methods aim to represent the correlations between judgments and not the extent to which judgments are reliable across different participants. For example, if a stimulus reliably induces reports of a single emotion, such as "anger", but not any other emotion, factor analysis will fail to extract a dimension of "anger" (see Appendix 1). Understanding the dimensions that really underlie people's conceptualizations of emotion requires more extensive data that is typically relied upon, as well as new analytical approaches.

Figure 3.1 presents a recent study that captures using new methods what people believe about emotion, extracted from hundreds of thousands of individual judgments. 757 participants judged how similar 600 different English emotion words are to one another (see Table 3 for methods). Distinct dimensions, or kinds, of emotion are organized by color, with varieties of emotion loading most highly on the same dimension sharing the same color. As one can see, English speakers distinguish dozens of states (for examples of earlier studies that make a similar point, see Roseman, 1984; Scherer & Wallbott, 1994; Shaver, Murdaya, & Fraley, 2001). Moving clockwise from the top, one finds many varieties of emotions beyond the Basic 6 that have drawn the attention of recent scholars: contempt, shame, pain, sympathy, love, lust, gratitude, relief, triumph, awe, and amusement, among others. Ignoring these states limits the inferences to be drawn from studies of expression.

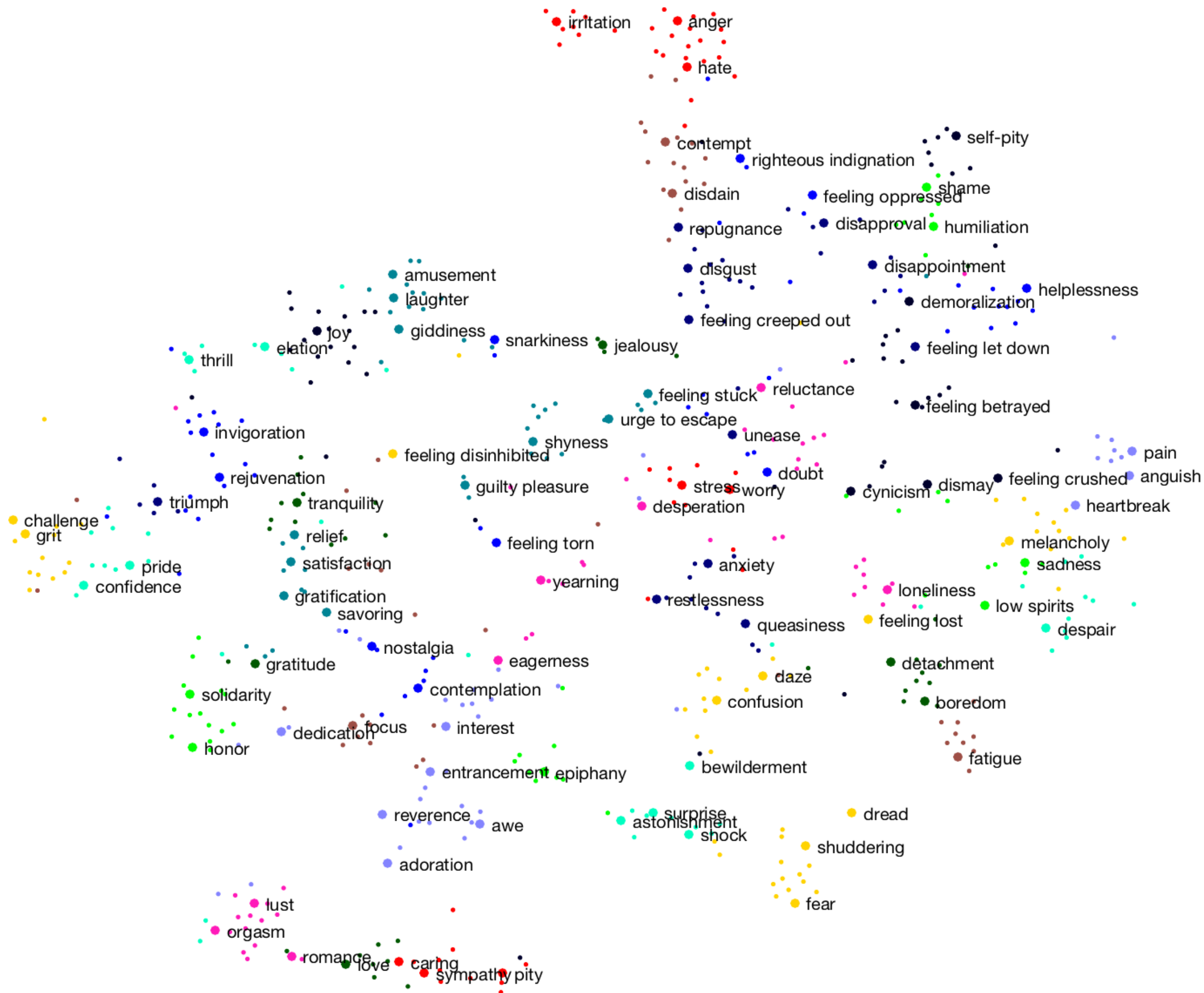

Figure 3.1 Map of 600 emotion concepts derived from similarity judgments (Cowen & Keltner, in prep.). 757 participants (348 female, mean age = 34.2) were presented with one "target" emotion concept and a list of 25 other pseudo randomly assigned concepts and asked to choose, from the 25 options, the most similar concept. We collected a total of 43,756 such judgments. Using these judgments, we constructed a pairwise similarity matrix and analyzed the dimensionality of the emotion concepts, by applying eigendecomposition and parallel analysis (Horn, 1965). These methods derived 49 candidate dimensions of emotion ($p \leq .024$), indicating that emotion concepts carry a much wider variety of meanings than the "basic" six. We map the distribution of individual concepts within this 49-dimensional space using a non-parametric visualization technique called t-distributed stochastic neighbor embedding (t-SNE), which extracts a two-dimensional space designed to preserve the local 'neighborhood' of each concept. Colors indicate the maximal-loading dimension. For interactive map, see https://s3-us-west-1.amazonaws.com/emotionwords/map.html.

Emotional experience evoked by video

Perhaps, though, when people label their own spontaneous emotional experiences, or recognize emotions in the expressive behaviors of others, the more complex space of emotion knowledge portrayed in Figure 3.1 reduces to the Basic 6, as commonly assumed. Perhaps our feelings of sympathy or shame, for example, are in fact simply variants of sadness. Perhaps our experiences of love, amusement, interest, or awe, are at their core simply shades of happiness.

Early investigations that have guided the study of emotional experience have assumed that emotions can indeed be reduced to the Basic 6 (Gross & Levenson, 1995), or an even more reduced representation along axes of valence and arousal (Russell, 1980; Watson & Tellegen, 1985). Empirical data suggest otherwise. In a study on this point, people reported on their emotional reactions to over 2100 short film clips (Cowen & Keltner, 2017) (see Table 3 for methods). Figure 3.2 presents the resultant semantic space of emotional experience, which can be explored in this interactive map (https://s3-us-west-1.amazonaws.com/emogifs/map.html). In mapping the dimensionality of emotion that emerged with this class of stimuli, reported emotional experiences cannot be reduced to six, but rather require at least 27 varieties of emotion to be explained (a lower bound, given that with different classes of stimuli different emotions can be elicited). Importantly, these findings converge with robust empirical literatures documenting distinctions in the experiences of 7 to 13 positive emotions total (Kreibig, 2010; Shiota et al., 2017; Tong, 2015), including several self-conscious emotions (Scherer & Wallbott, 1994; Tangney & Tracy, 2012; Tracy & Robins, 2007), attachment-related emotions (Diamond, 2003; Goetz, Keltner, & Simon-Thomas, 2010), and self-transcendent emotions such as gratitude, contentment, awe, and ecstasy (Cordaro, Brackett, Glass, & Anderson, 2016; Stellar et al., 2017).

Table 3. Materials and methods for studies of human emotional experience

	Emotion terms	Brief videos	Music samples
Study	Cowen & Keltner, in prep.	Cowen & Keltner, 2017	Cowen, Fang, Sauter, & Keltner, in prep.
Stimuli	600 terms compiled by reviewing a wide range of studies of emotion-related responses (e.g., Rozin & Cohen, 2003; Storm & Storm, 1987)	2185 1-20 second videos scraped from online repositories (Reddit, Google images, Tumblr) with diverse emotionally evocative content	2168 music samples gathered by asking participants to contribute music that evokes 28 categories (1,841samples) or 12 levels of valence and arousal (327 samples)
Participants	757 English-speaking US participants (328 females, mean age = 34.1 y)	853 English-speaking US participants (403 females, mean age = 36 y)	1,591 US (815 females, mean age = 35.6 y) and 1,256 native Chinese (805 females, mean age = 28.3 y) participants
Task	Presented with one emotion term at a time and asked to describe the feeling by choosing among 25 other pseudo-randomly presented terms	Presented with one video at a time and asked to describe it by selecting all that apply from 34 emotion categories, selecting from the Basic 6, rating it along 14 1-9 Likert scales such as valence and certainty, or using free response	Presented with one music sample at a time and asked to describe it by selecting all that apply from 28 emotion categories or rating it along 11 1-9 scales of affect such as valence and certainty
Dimensionality Analysis	Horn's parallel analysis applied in a leave-one-subject-out fashion to the matrix of average similarity judgments (proportion of times each cue was chosen for each target)	(1) Split-half canonical correlations analysis (SH-CCA) of emotion category judgments, applied in a leave-one-out-fashion to extract dimensions of reliable response across subjects; (2) CCA between emotion category and free response judgments, applied in a leave-one-subject-out fashion to extract consistent dimensions	A novel principal preserved component analysis (PPCA; see Appendix 1) between US and Chinese ratings of the same music samples, applied in a leave-one-subject-out fashion, to extract dimensions preserved across the two cultures

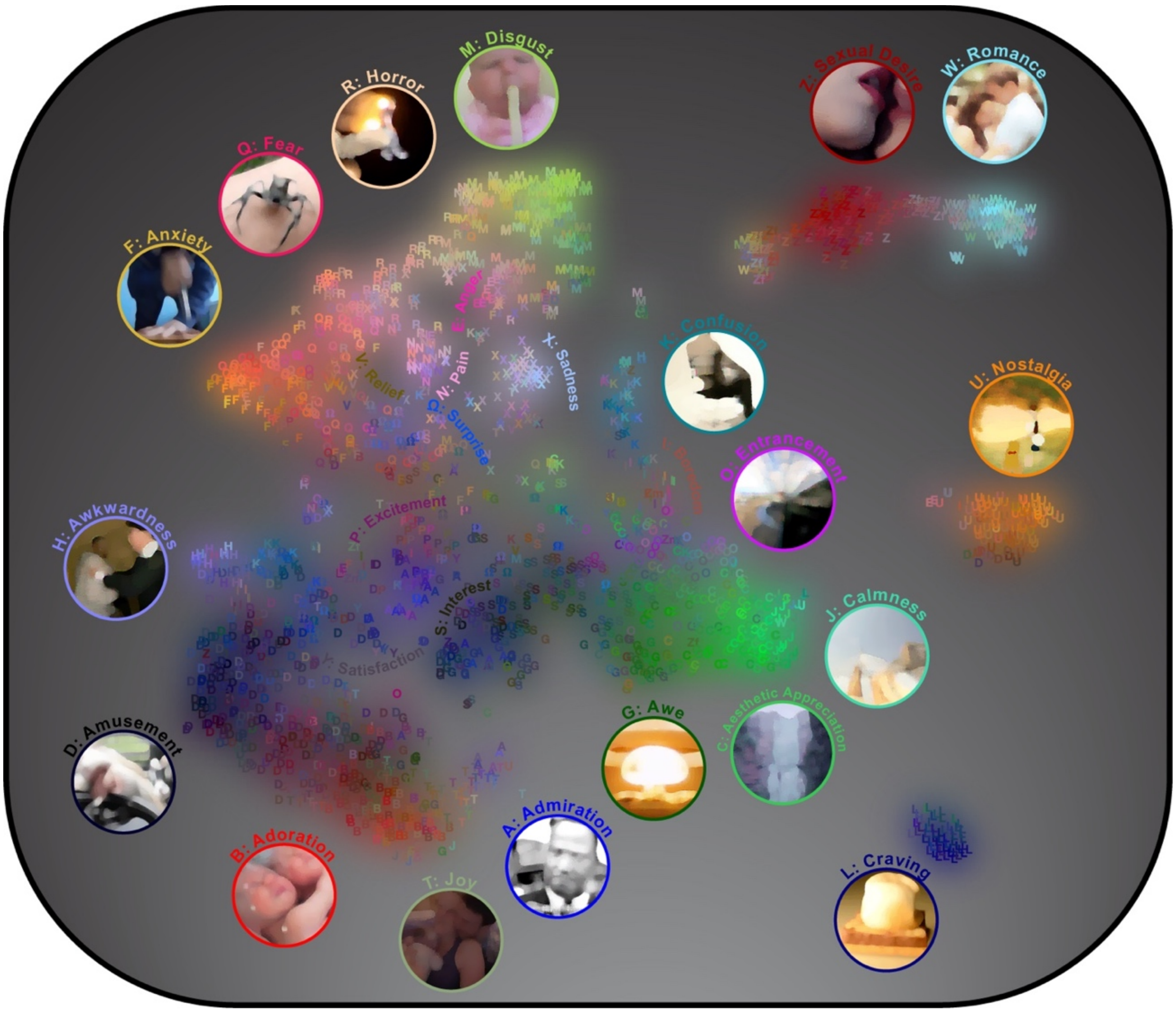

Figure 3.2 Map of 27 varieties of emotional experience evoked by 2185 videos. Participants judged each video in terms of 34 emotion categories, free response, and 14 scales of affective appraisal including valence, arousal, dominance, certainty, and more. At least 27 dimensions, each associated with a different emotion category, were required to capture the systematic variation in participants' emotional experiences. We visualize the approximate distribution of videos along these 27 dimensions using a technique called t-distributed stochastic neighbor embedding (t-SNE). We can see that emotion categories often treated as discrete are in fact bridged by continuous gradients, found to correspond to smooth transitions in meaning (Cowen & Keltner, 2017). See https://s3-us-west-1.amazonaws.com/emogifs/map.html for interactive map.

Emotional experience evoked by music across cultures

A remaining possibility is that only a small subset of these emotions are preserved across cultures—perhaps only the Basic 6, for example. Once again, empirical data suggest otherwise. In another recent study, people in both the US and China reported on their emotional reactions to over 2100 music samples (Cowen, Fang, Sauter, & Keltner, under review) (see Table 3 for methods). Figure 3.3 presents the resultant semantic space of emotional experience in response to music, and the extent to which it is preserved across the two cultures (also presented within an interactive map: https://s3-us-west-1.amazonaws.com/emogifs/map.html). In mapping the emotions evoked music in both cultures, reported experiences also cannot be reduced to six, but rather require at least 13 varieties of emotion to be explained. Within cultures, only 14 emotions were reliably evoked in total, so nearly all of them were preserved across cultures.

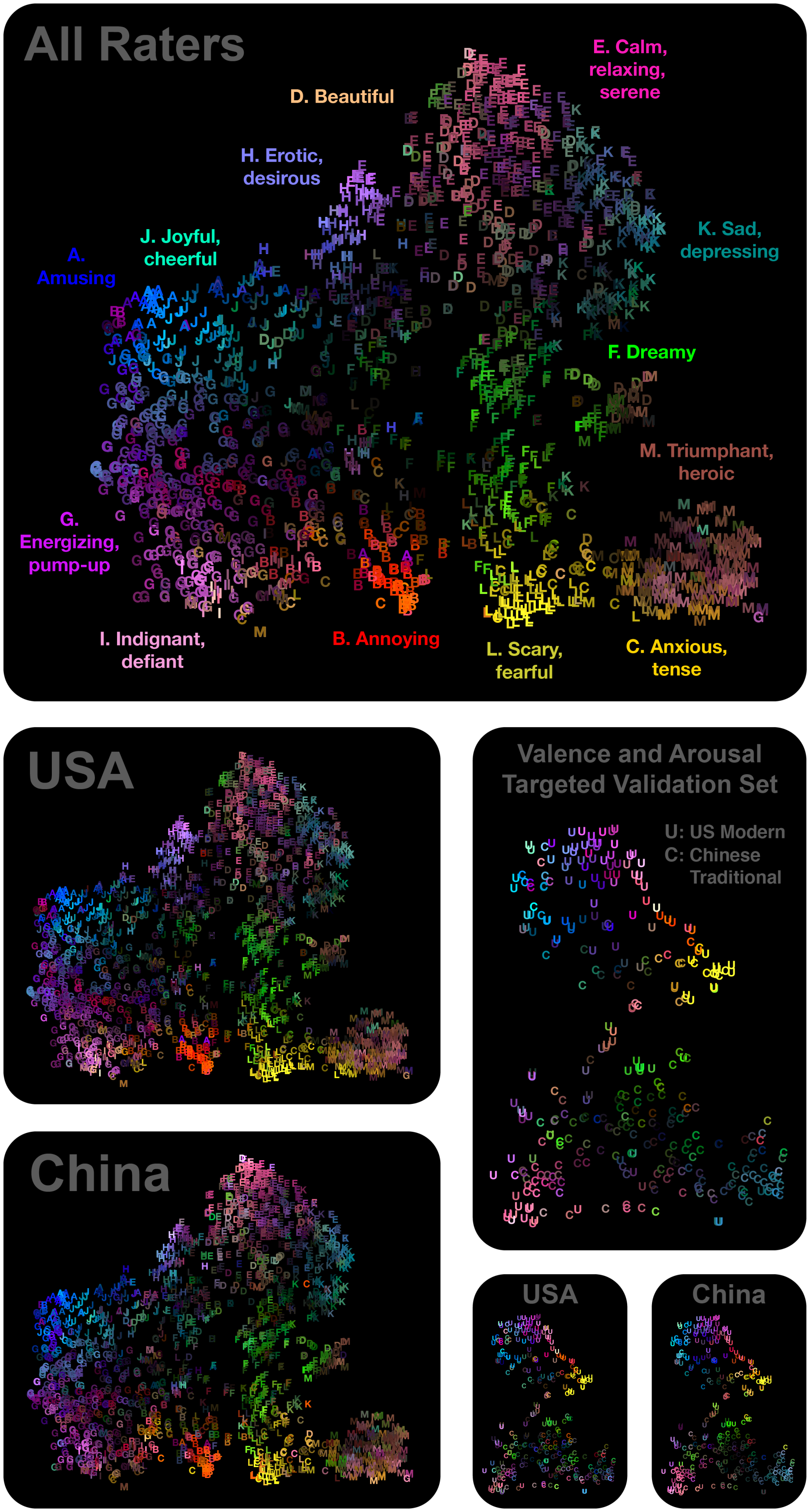
All Raters
E. Calm, relaxing, serene
D. Beautiful
H. Erotic, desirous
J. Joyful, cheerful
A. Amusing
K. Sad, depressing
F. Dreamy
M. Triumphant, heroic
G. Energizing, pump-up
I. Indignant, defiant
B. Annoying
L. Scary, fearful
C. Anxious, tense
USA
China
Valence and Arousal Targeted Validation Set
U: US Modern
C: Chinese Traditional
USA
China

Figure 3.3 Map of 13 varieties of emotional experience evoked by 2,168 music samples in the US and China (Cowen, Fang, Sauter, & Keltner, under review). US (N = 1,591) and Chinese (N = 1,258) participants judged each music sample in terms of 28 emotion categories and 11 scales of affective appraisal including valence, arousal, dominance, certainty, and more. At least 13 dimensions, each associated with a different emotion category, were required to capture the systematic variation in participants' emotional experiences. We can see that in emotional responses to music, as with video, emotion categories often treated as discrete are in fact bridged by continuous gradients, found to correspond to smooth transitions in meaning. In this study, a semantic space was derived from an initial study of 1,841 modern music samples targeting 28 emotion categories, and then subsequently validated on 327 modern and Chinese traditional music samples targeting different levels of valence and arousal (bottom right). The dimensionality and distribution of emotion evoked by music derived in the first study were both well replicated in the validation study. See https://s3.amazonaws.com/musicemo/map.html for interactive map of the 1,841 music samples targeting 28 emotion categories, and https://s3.amazonaws.com/musicemo/validationmap.html for interactive map of the 327 modern and Chinese traditional music samples targeting different levels of valence and arousal.

Figures 3.2 and 3.3 also visualize the regularity with which people experience complex emotional blends (Du, Tao, & Martinez, 2014; Watson & Stanton, 2017). Yes, there are prototypical experiences of amusement, for example, or fear, love (adoration), sympathy, or disgust. At the same time, many—even most – experiences of emotion are complex, involving blends, between disgust and horror, for example, or awe and feelings of aesthetic appreciation, or love and desire, or sympathy and empathic pain. The model portrayed in Figure 1A derives from the research conducted by Ekman and Friesen some 50 years ago. Emotion science, and Ekman himself (Ekman & Cordaro, 2011), have evolved considerably in the range of states considered emotions.

Traditional assumptions about emotion fail to capture the breadth and blending of emotional experience that contemporary emotion researchers study. This omission has problematic consequences for research on emotional expression. For example, a recent meta-analysis found that when facial expressions and reported emotional experiences evoked by laboratory stimuli are sorted into six discrete categories, the raw correlation between them averages to about .32 (Duran & Fernandez-Dols, 2018). However, this may be close to the highest correlation that could possibly be achieved by studies that sort emotional experiences and facial expressions into the Basic 6. Across several empirical studies we will review, the Basic 6 were found to represent 30%, at best, of the explainable variance in experience and, as discussed in Chapter 4, expression (Cowen et al., 2018; Cowen & Keltner, 2017, under review). Correlations between expression and antecedent elicitors, reported experience, and observer judgment sorted into the Basic 6 are thus relating measures that capture only 30% of the explainable variance to one another. The remaining 70% of variation in expression is left unaccounted for, but may still add to the total variance, which determines the denominator of the correlation between expression and other phenomena. When put into this perspective, the meta-analytic results imply that methods that capture the much wider range of the expressions people actually produce will likely have much greater diagnostic value in predicting an individual's subjective affective state. To truly address the diagnostic value of expression, studies will thus need to move beyond facial expressions of six discrete categories and instead use inductive methods to predict internal states from the high-dimensional, continuous space of dynamic expressions of the face, voice, and body.

The narrow focus on the Basic 6 also masks distinctions between emotions that have more recently been established in the literature. For example, studies that seek to document associations between expressions of "happiness" and self-reported experience or physiological response ignore established distinctions among different positive emotions and their accompanying expressions. As evident in Figures 3.2 and 3.3, and in dozens of empirical studies, the positive emotions are numerous – including love, desire, awe, amusement, pride, enthusiasm and interest, for example (Campos, Shiota, Keltner, Gonzaga, & Goetz, 2013; Shiota et al., 2017), and there are varieties of smiles and other facial expressions that covary with these distinct positive emotions (Cordaro et al., 2017; Keltner et al., 2016; Martin, Rychlowska, Wood, & Niedenthal, 2017; Oveis, Spectre, Smith, Liu, & Keltner, 2013; Disa A Sauter, 2017; Wood et al., 2016). As another illustration, the focus on sadness to the exclusion of sympathy and distress fails to capture the various emotions and blends engaged in responding to the suffering of others (Eisenberg et al., 1988; Singer & Klimecki, 2014; Stellar, Cohen, Oveis, & Keltner, 2015).

For instance, a recent study assumed that if facial expressions had diagnostic value, winning a judo match would consistently elicit a smile, and argued that since it does not, facial expressions must not have much diagnostic value (Crivelli et al., 2015). Contrary to this assumption, inductive and ecological studies indicate that body gestures such as arm raises, fist clenches, and chest expansions are diagnostic of triumph (or pride), but that a smile is not necessary to signal this emotion (Cowen & Keltner, under review; Matsumoto & Hwang, 2012; Tracy & Matsumoto, 2008). This confusion reinforces the need to move beyond the study of the Basic 6 and facial muscle movements, and a broader lesson: any study aiming to test the diagnostic value of an expression should derive empirically its mapping to experience, not assume it in advance.

Our capacity to understand and make predictions about the natural world relies critically upon the precision of the concepts that are the basis of inference. If meteorologists started from the assumption there were three kinds of clouds, the inferences they would draw about the processes – air temperature, air pressure, humidity, rainfall, wind, tides -- that produce such clouds would be simplistic and imprecise. Were they to form a science based on a much more differentiated taxonomy of clouds – 10, which is the case today – the understanding of the causes, dynamics, and consequences of clouds and the weather patterns they are the product of becomes necessarily more exact. The same is true for the science of emotion: the reliance upon six categories of emotion constrains attempts to understand how experience manifests in expressive behavior that is perceived and responded to by others. Such a narrow focus impedes progress in understanding the structure and dynamics of emotional response and answering questions such as: How do emotions organize human attachments and navigate social hierarchies? How does emotional expression and recognition change with development? What are the neurophysiological processes that underlie the experience, expression and recognition of emotion?

Chapter 4. The nature of emotional expression

Perhaps what is most striking, and divergent from everyday experience, regarding Figure 1A are the static photos of prototypical facial muscle configurations. Do people really express emotion in such caricature-like fashion, with unique configurations of facial muscle movements (for a relevant methodological critique, see Russell, 1994)? Although this question is often treated as interchangeable with that of whether expressions have diagnostic value, many studies of emotional expression have moved well beyond the focus on prototypical facial muscle configurations.

Since the Ekman and Friesen findings of fifty years ago, considerable advances have been made in understanding how we express emotion in nuanced, multimodal patterns of behavior (Bänziger, Mortillaro, & Scherer, 2012; Cordaro et al., 2019; Keltner & Cordaro, 2015; Paulmann & Pell, 2011; Scherer & Ellgring, 2007; Tracy & Matsumoto, 2008; Tracy & Robins, 2004). For example, shifts in gaze as well as movements in the face, head, body, and hands differentiate expressions of self-conscious emotions – pride, shame, and embarrassment (Keltner, 1995; Tracy & Robins, 2007). The same is true of positive emotions such as amusement, awe, contentment, desire, love, and sympathy, where subtle movements such as the head tilt back and open mouth of amusement or the gaze and head oriented upward of awe express these different emotions (Cordaro et al., 2017; Eisenberg et al., 1988; Gonzaga, Keltner, Londahl, & Smith, 2001; Keltner & Bonanno, 1997; Shiota, Campos, & Keltner, 2003). Recent empirical work finds that when these nuanced patterns of expressive behavior are captured in still photographs, 18 affective states are recognized across 9 different cultures with accuracy rates often exceeding those observed in studies of the Basic 6 (Cordaro et al., in press).

Consider the realm of touch, so important in parent-child relationships, friendships, intimate bonds, and at work. With brief, half second touches to a stranger's arm, people can communicate sympathy, gratitude, love, sadness, anger, disgust, and fear at levels of recognition 6 to 8 times that of chance guessing (Hertenstein, Holmes, McCullough, & Keltner, 2009). In a similar vein, people are adept at communicating a variety of emotions with postural movements (Dael, Mortillaro, & Scherer, 2012; Lopez, Reschke, Knothe, & Walle, 2017).

The voice may prove to be the richest modality of emotional communication (Kraus, 2017; Planalp, 1996). New empirical work, building upon the seminal theorizing of Klaus Scherer (Scherer, 1984; Scherer, Johnstone, & Klasmeyer, 2003) has documented that when people vary their prosody while uttering sentences with neutral content, they are able to convey at least 12 different emotions, which are reliably identified in distinct cultures (Cowen et al., 2019; Laukka et al., 2016). People also communicate emotion with vocal bursts, which predate language in human evolution and have parallels in the vocalizations of other mammals (Scott, Sauter, & McGettigan, 2010; Snowdon, 2003). In relevant empirical work, people can communicate upwards of 13 emotions with brief sounds, a finding that has replicated across 14 cultures, including two remote, small-scale societies (Cordaro, Keltner, Tshering, Wangchuk, & Flynn, 2016; Cowen et al., 2018; Sauter, Eisner, Ekman, & Scott, 2010; Simon-Thomas, Keltner, Sauter, Sinicropi-Yao, & Abramson, 2009).

Table 4. Materials and methods for studies of human emotional expression

	Facial-bodily signals	Vocal utterances	Speech prosody
Study	Cowen & Keltner., 2019	Cowen, Elfenbein, Laukka, & Keltner, 2018	Cowen, Laukka, Elfenbein, Liu, & Keltner, 2019
Stimuli	1500 naturalistic expressions scraped largely from Google images by querying diverse emotional evocative contexts	2032 vocal bursts recorded from 56 actors imagining a wide range of emotional evocative situations	2519 speech samples recorded from 100 actors in five countries imagining 19 different emotionally evocative situations
Participants	1794 English-speaking US participants (940 female, mean ages 18-76)	1105 English-speaking US participants (545 females, mean ages 18-76)	1969 US (1095 females, mean age = 36 y) and 376 native Indian English speakers (123 females, mean age = 30) participants
Task	Presented with one image at a time and asked to describe it by choosing among 28 emotion categories, choosing among the Basic 6, rating it along 13 1-9 Likert scales such as valence and certainty, or using free response	Presented with one vocal utterance at a time and asked to describe it by choosing among 30 emotion categories, rating it along 13 1-9 Likert scales such as valence and certainty, or using free response	Presented with one speech sample at a time and asked to describe it by choosing among 30 emotion categories or rating it along 23 1-9 scales of affect such as valence and certainty
Dimensionality Analysis	Canonical correlations analysis between emotion category and free response judgments, applied in a leave-one-subject-out fashion, to extract consistent dimensions	Canonical correlations analysis between emotion category and free response judgments, applied in a leave-one-subject-out fashion, to extract consistent dimensions	A novel principal preserved component analysis (PPCA; see Appendix 1) between US and Indian ratings of the same speech samples, applied in a leave-one-subject-out fashion, to extract dimensions preserved across the two cultures

Building upon these advances, two new studies guided by more open-ended methodological features motivated in Table 2 and detailed in Table 4 have revealed how the face and voice communicate a rich array of emotions (the dimensionality of the semantic space), and variations within each category of emotion (the distribution of expressions). In one study, participants made categorical and dimensional judgments of 2,032 voluntarily produced and naturalistic vocal bursts (Cowen et al., 2018). In another, participants judged 1500 facial expressions culled from naturalistic contexts (at funerals, sporting events, weddings, classrooms) (Cowen & Keltner, under review). Figures 4.1 and 4.2 present taxonomies of vocal and facial expression derived from these judgments.

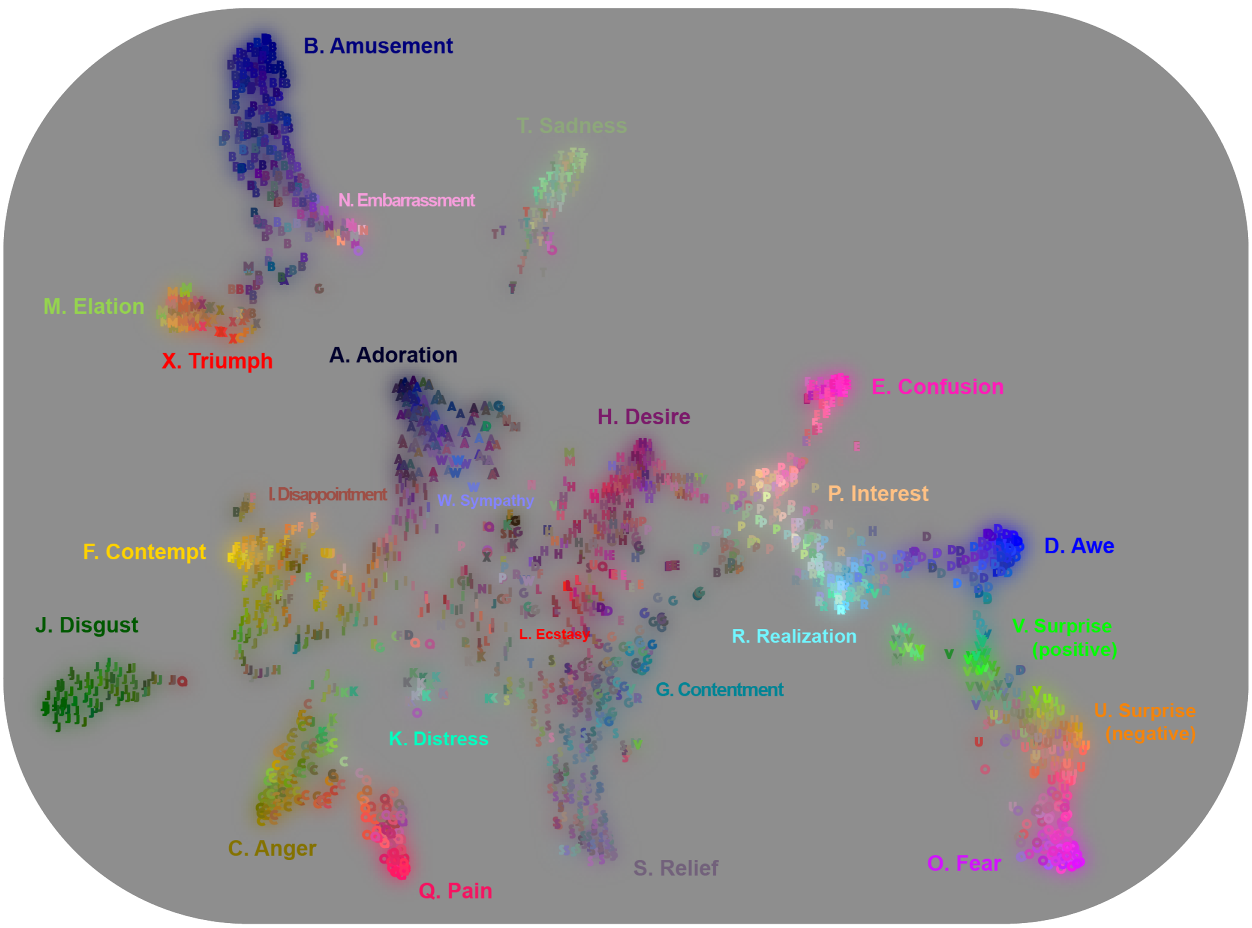

Figure 4.1 Map of 24 varieties of emotion recognized in 2032 vocal bursts (Cowen et al., 2018). Participants judged each vocal burst in terms of 30 emotion categories, free response, and 13 scales of affective appraisal including valence, arousal, dominance, certainty, and more. At least 24 dimensions were required to capture the systematic variation in participants' judgments. As with the emotions evoked by video and music (Figures 3.2 and 3.3), the emotions recognized in vocal expression were most accurately conceptualized in terms of the emotion categories. Visualizing the distribution of vocal bursts using t-SNE, we again see that categories often treated as discrete are bridged by continuous gradients, which we find correspond to smooth transitions in meaning. See https://s3-us-west-1.amazonaws.com/vocs/map.html for interactive map.

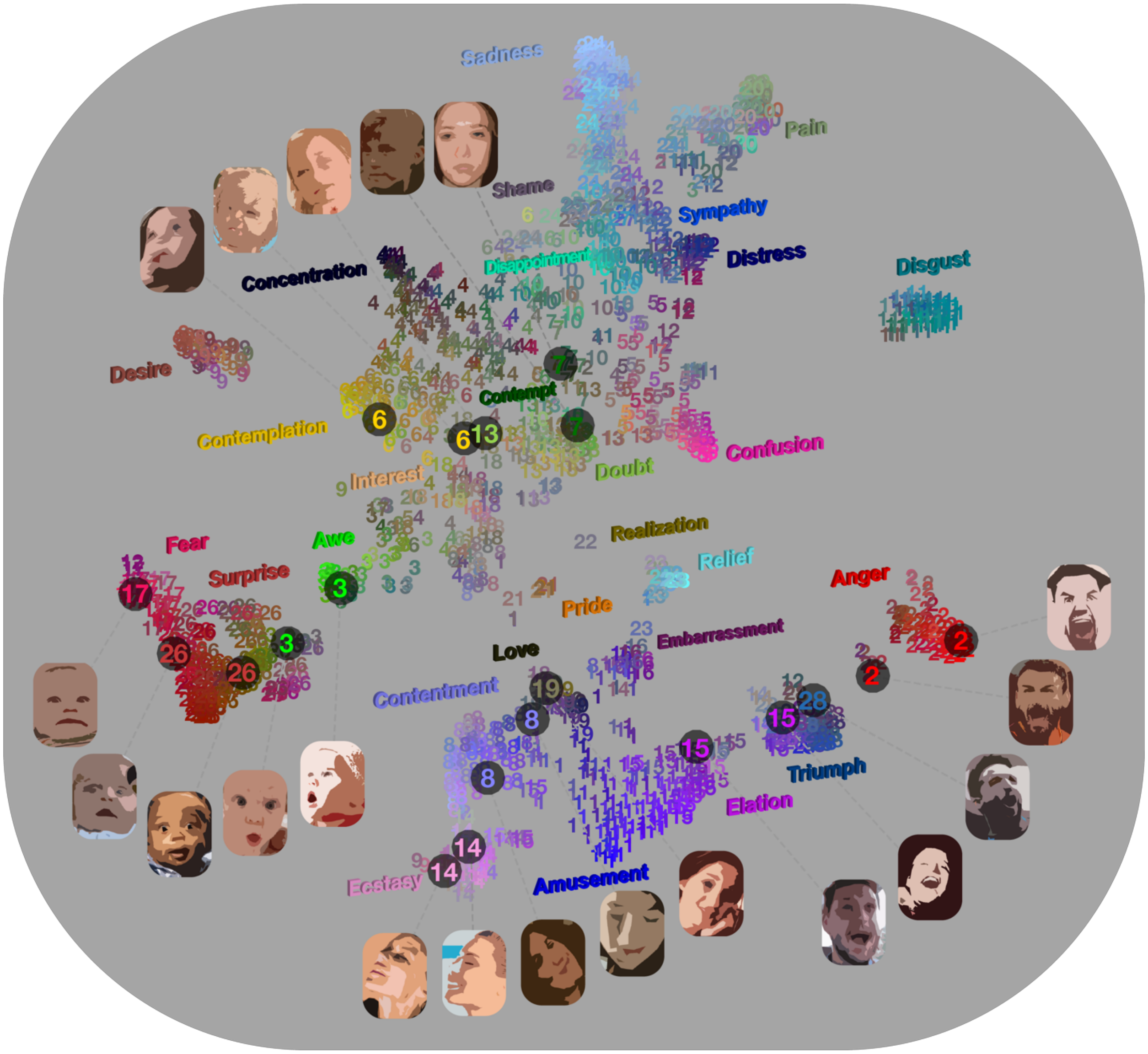

Figure 4.2 Map of 28 varieties of emotion recognized in 1500 facial-bodily expressions (Cowen & Keltner, 2019). Participants judged each expression in terms of 28 emotion categories, free response, and 13 scales of affective appraisal including valence, arousal, dominance, certainty, and more. All 28 categories were required to capture the systematic variation in participants' judgments. As with the emotions evoked by video and music and recognized in vocal expression (Figures 3.2, 3.3, and 4.1), the emotions recognized in facial-bodily expression were most accurately conceptualized in terms of the emotion categories, and we can see that emotion categories often treated as discrete are bridged by continuous gradients. See https://s3-us-west-1.amazonaws.com/face28/map.html for interactive map.

In terms of the dimensionality of emotional expression, at least 24 emotions can be reliably communicated with vocal bursts, and 28 through visual cues from the face and body. With respect to the *distribution* of emotional expression, each emotion category involves a rich variety of distinct expressions. There is no single expression of anger, for example, or embarrassment, but myriad variations. And at the boundaries between categories – say between awe and interest as expressed in the face, or amusement and love – lie expressions with blended meanings. For example, there are subtly varying ways in which people communicate sympathy with vocal bursts, or love in facial and bodily movements. Studies of expressions of embarrassment, shame, pride, love, desire, mirth (laughter), and interest in different modalities all reveal systematic variants within a category of emotion that convey the target emotion to varying degrees (Bachorowski & Owren, 2001; Gonzaga et al., 2001; Keltner, 1995; Tracy & Robins, 2007).

The shift away from the face to expressions in multiple modalities has yielded critical insights into understanding emotional expression. Here is but a sampling of recent discoveries; as the field matures, we expect many new insights. By the age of 2, children can readily identify at least five positive emotions from brief emotion-related vocalizations (Hertenstein & Campos, 2004; Wu, Muentener, & Schulz, 2017). Emotions vary in the degree to which they are signaled in different modalities (App, McIntosh, Reed, & Hertenstein, 2011): gratitude is hard to convey from the face and voice, but readily detected in tactile contact (Hertenstein et al., 2009); awe may be more readily communicated in the voice than the face (Cordaro et al., 2017); pride is best recognized from a combination of postural and facial behaviors (Tracy & Robins, 2004; 2007). And critical progress is being made in understanding the sources of within category variations in expression, in particular in terms of culture (Elfenbein, Beaupré, Lévesque, & Hess, 2007). Different populations develop culturally specific dialects in which they express emotion in ways that are partially unique yet largely consistent across cultural groups (Elfenbein, 2013). Occasionally, they produce expressions that are unique to their own cultures; for example, in India, embarrassment is expressed with an iconic tongue bite and shoulder shrug (Haidt & Keltner, 1999).

Expression across cultures

How culturally variable are expressions of emotion? In one study, participants belonging to five different cultures – China, India, Japan, Korea, and the USA – heard 22 emotion-specific situations described in their native language and expressed the elicited emotion in whatever fashion they desired (Cordaro et al., 2017). Intensive coding of participants' expressions of these 22 emotions revealed that 50% of an individual's expressive behavior was shared across the five cultural groups, and might be thought of as universal facial-bodily expressions of emotion. Fully 25% of the expressive behavior was culturally specific and in the form of a dialect shaped by the particular values and practices of that culture.

To make sense of these findings, it is critical to understand what is preserved across cultures in the broader organization of emotional expressions within a semantic space. How many dimensions of emotional expression are preserved across cultures, and how well is the structure of emotional expressions preserved along these dimensions?

Another recent study (Cowen, Laukka, Elfenbein, Liu, & Keltner, 2019) offers an initial answer to these questions, exploring the semantic space of emotion recognition across multiple cultures. US and Indian participants were presented with 2,519 speech samples of emotional prosody produced by 100 actors from five cultures, and asked, in separate response formats, to judge the samples in terms of 30 emotion categories and 23 more general appraisals (e.g., valence, arousal). Figure 4.3 presents the resultant semantic space of emotional recognition in speech samples, and the extent to which it is preserved across the two cultures. In mapping the emotions recognized in speech in both cultures, emotional expressions cannot be reduced to six, but rather require at least 12 varieties of emotion to be explained. (Within cultures, 14 emotions were reliably evoked in total, so most of them were preserved across cultures.)

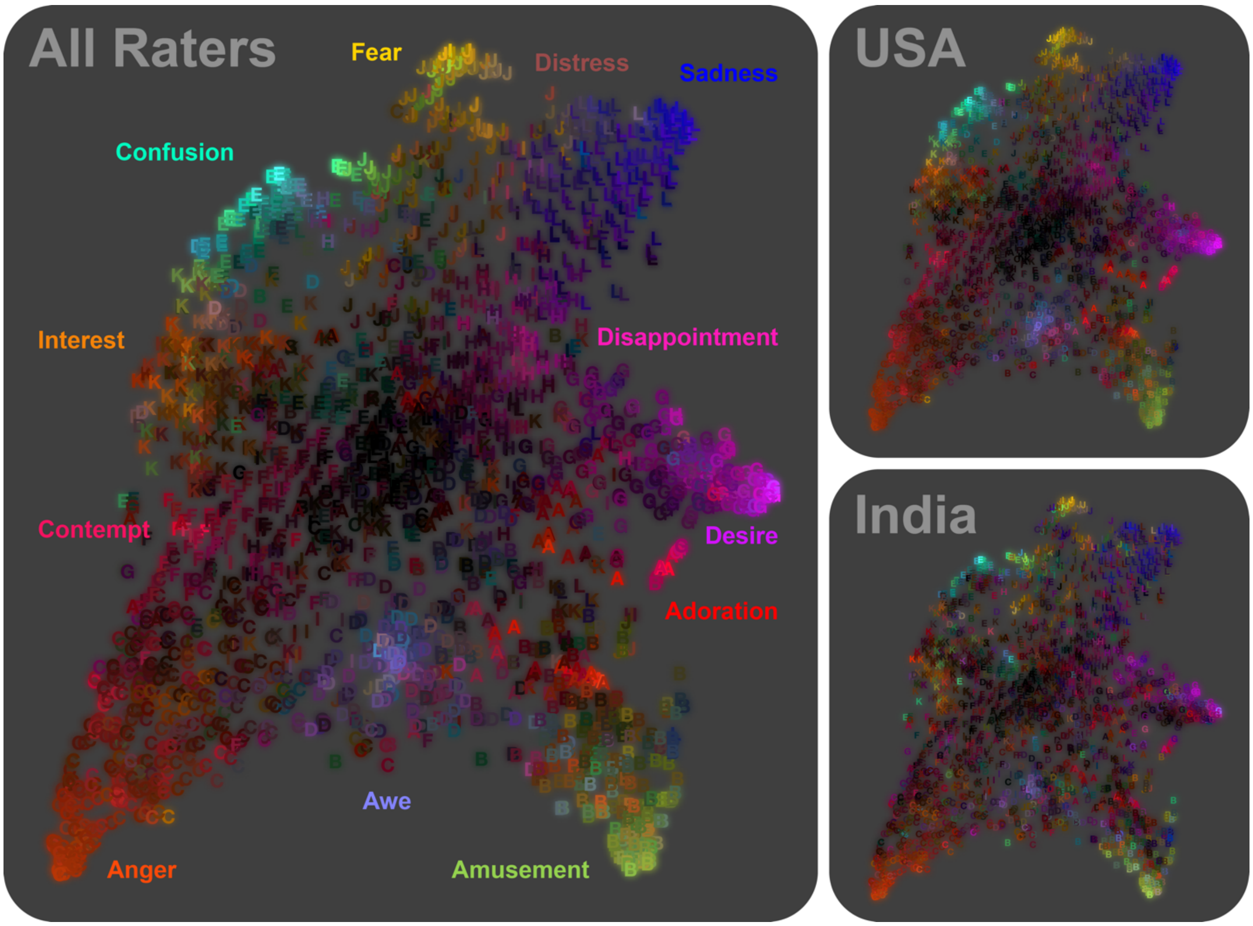

Figure 4.3 Map of 12 varieties of emotional expression recognized in 2,519 speech samples in the US and India (Cowen, Laukka, Elfenbein, Liu, & Keltner, in prep.). US (N = 1,969) and Indian (N = 376) participants judged each music sample in terms of 30 emotion categories and 23 scales of affective appraisal including valence, arousal, dominance, certainty, and more. At least 12 dimensions, each associated with a different emotion category, were required to capture the systematic variation in participants' recognition of emotion. We can see that in the recognition of speech prosody, as with vocal utterances, emotion categories often treated as discrete are in fact bridged by continuous gradients, found to correspond to smooth transitions in meaning. See https://s3-us-west-1.amazonaws.com/venec/map.html for interactive map.

We have shown that expressions convey dozens of distinct varieties of emotion, that categories of emotion conveyed by expression are bridged by continuous gradients, and that, at least across two globalized cultures and with speech prosody, the structure of the emotions recognized from expression is well preserved. By mapping the varieties of emotion expressed in multiple modalities and across cultures, we establish a roadmap for the study of emotion-related physiological response, brain representations of emotion, and affective computing.

What we have not yet addressed in detailed is how the emotions recognized from expression are best conceptualized. Are emotional expressions best described by categories such as “awe” and “fear”, broader features such as valence and arousal, or other concepts entirely? Answers to these questions, provided in Chapter 5, inform theories regarding the evolution and cultural acquisition of emotion-related responses, how emotions unfold in the brain, and how to treat dysfunctions in emotion-related processes and enhance emotional life.

Chapter 5. The conceptualization of emotion

Emotions involve the dynamic unfolding of appraisals of the environment, expressive tendencies, the representation of bodily sensations, intentions and action tendencies, perceptual tendencies such as seeing the world as unfair or worthy of reverence, and subjective feeling states. Labeling one's own experience or another person's expression as one of "interest," "love," or "shame," can therefore refer to many different internal processes: representations of likely causes of the expression, inferred appraisals, sensations, feeling states, and intended courses of action plausible for the person expressing the emotion (Shaver et al., 1987; Shuman, Clark-Polner, Meuleman, Sander, & Scherer, 2017). As long noted (Ekman, 1997; Fehr & Russell, 1984), emotion words can refer to many different phenomena.

Simplistic models of emotion like the shown in Figure 1 do not consider the multiple meanings inherent in labeling emotion-related responses with words (along with evidence that language is unnecessary for emotion-related processes, see Sauter, 2018). Moving beyond the emotion-to-face matching paradigms, now 50 years old, Fridlund's behavioral ecology view posits that what is most critical for perceivers is to discern in expressive behavior an individual's intentions (Fridlund, 2017). This theorizing has led to a broader consideration of the kinds of social information that people perceive in expressive behavior, beyond experiences of distinct emotions (Crivelli & Fridlund, 2018; Ekman, 1997; Keltner & Kring, 1998; Knutson, 1996; Scarantino, 2017). Important theoretical advances have illuminated how, in interpreting the expressive behavior of another person, observers might label that person's state in terms of: 1) a current feeling; 2) what is happening in the present context; 3) intentions or action tendencies; 4) desired reactions in others; and 5) characteristics of the social relationship. Should a person witness another individual's blush and awkward smile, the observer might label the behavior as expressing embarrassment, or as a marker of the uncomfortable nature of the present interaction, or as a signal of an intention to make amends, or a plea for forgiveness, or a signal of submissiveness and lower rank (Roseman et al., 1994). Emotional expressions convey multiple meanings, and distinct feeling states are but one of them.

This move beyond word-to-face matching paradigms raises the question of what people give priority to when recognizing emotion from others' expressive behavior. In a relevant study illustrative of where the field is going, observers matched dynamic, videotaped portrayals of five different emotions -- happiness, sadness, fear, anger, and disgust -- to either: feelings ("fear"), appraisals ("that is dangerous"), social relational meanings ("you scare me"), or action tendencies ("I might run") (Shuman et al., 2017). Consistent with other emotion recognition work, participants labeled the dynamic expressions with the expected response 62% of the time; greater accuracy was observed when labeling expressions with feeling states, and reduced accuracy with action tendencies (Horstmann, 2003). By contrast, recent work in the Trobriand Islands found that action tendencies were more prominent in the interpretation of facial expressions than were emotion words, pointing to cultural variations in the way that emotional expressions are interpreted (Crivelli, Russell, Jarillo, & Fernández-Dols, 2016). One of the most intriguing questions facing the field is how the multiple kinds of meaning people perceive in expressive behavior vary across cultures, with development, and in different contexts (Matsumoto & Yoo, 2007).

How, then, does emotion recognition from expressions work (Scherer & Grandjean, 2007)? Do observers recognize distinct emotion categories – "disgust," "awe," "shame"– and then make inferences about underlying appraisals, including valence, arousal, dominance, fairness, or norm appropriateness? Or is the process the reverse, such that people see an expression, automatically evaluate it in terms of basic affect dimensions – valence, arousal, and so on – and then arrive at a distinct emotion label for the expression?

One widespread approach to the conceptualization of emotion from expressions posits the following: people appraise the expression in terms of valence and arousal, and then infer categorical labels (e.g., anger, fear) depending on other sources of information, such as the present context (e.g., Barrett et al., 2019; Russell, 2003). However, my work has subjected this hypothesis to empirical scrutiny in more than five studies of emotional experience and expression across multiple cultures, and found support for a notably different conclusion.

Conceptualizing the variance in emotional responses

Figure 5.1 presents results from two of these studies. Most relevant to the present review, participants in my aforementioned study of facial expressions judged each of 1500 expressions using emotion categories (including in a free response format) and valence and arousal (along with 11 other appraisal dimensions that have been proposed to underlie emotion recognition, including dominance, certainty, and fairness; see Smith & Ellsworth, 1985; Roseman, Spindel, & Jose, 1990; Scherer, Schorr, & Johnstone, 2001). These large-scale data allowed us to ascertain whether distinct emotion categories or appraisals of valence and arousal explain greater variance in emotion recognition.

As one can see in the top row of Figure 5.1, a comprehensive array of 28 emotion categories such as "awe" and "love" were found to capture a much broader and richer space of emotion recognized in facial expression than could be explained by just valence and arousal (rightmost circles). These emotion categories also capture a substantially richer space than the six discrete emotion categories that comprise common scientific assumptions about emotion (left Venn diagrams). Namely, valence and arousal and the Basic 6 both capture only about 30% of the variance. We replicated this pattern of results in a study of emotional experience in response to videos, as portrayed in the bottom row of Figure 5.1 (Cowen & Keltner, 2017). To capture the richness of emotional experience and expression, then, we cannot rely on only the Basic 6, nor can we reduce the rich set of categories of emotion that people distinguish to simpler dimensions of valence and arousal. This does not mean that these models are never useful—it is possible that if we have to rely on just six categories to represent emotion, the Basic 6 are good categories to choose from—but it does mean that they fail to capture the majority of the variance in emotional experience and expression.

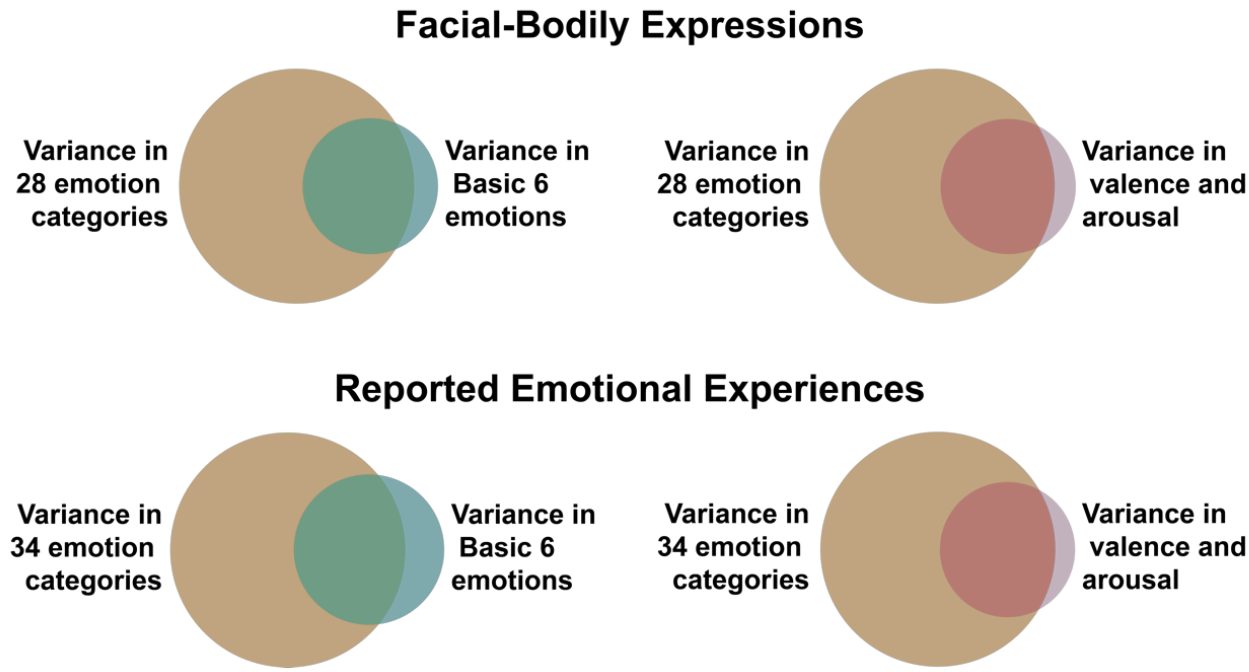

Figure 5.1 Variance captured by high-dimensional models of emotion versus the Basic 6 and valence plus arousal (Cowen et al., 2017; Cowen & Keltner, under review). By mapping reported emotional experiences and facial expressions into a high-dimensional space (see Figures 3.2 and 4.2), we can predict how they are recognized in terms of the Basic 6 emotions and valence and arousal. However, we can also see that these traditional models are highly impoverished. For these analyses, we collected separate judgments of 1500 faces and 2185 videos in terms of just the Basic 6 categories (anger, disgust, fear, happiness, sadness, and surprise). Each Venn diagram represents the proportion of the systematic variance in one set of judgments that can be explained by another, using non-linear regression methods (k-nearest neighbors). While high-dimensional models largely capture the systematic variance in separate judgments of the Basic 6 and valence and arousal, both the Basic 6 (left) and valence and arousal (right) capture around 30% or less of the systematic variance in the high-dimensional models (28.0% and 28.5%, respectively, for facial expressions; 30.2% and 29.1%, respectively, for emotional experiences). (Note that in predicting other judgments from the Basic 6, we use only the category chosen most often by raters, assigning equal weight when there are ties, in accordance with the assumption of discreteness inherent in many scientific measures of emotion).

Conceptualizing the preservation of emotional responses across cultures

Although valence and arousal capture a small proportion (around 30%) of the variance in emotional experience and emotion recognition, it is worth asking whether this variance represents what is preserved across cultures. The aforementioned large-scale studies of vocal prosody (Cowen et al., 2019) and emotions evoked by music (Cowen et al., in prep.) offer a convergent answer to this question by enabling us to explore the processes by which people across cultures conceptualize emotional experience and expression. By way of reminder, participants in disparate cultures in each study (the US and India or China) were presented with thousands of emotion-related stimuli—2,519 speech samples of emotional prosody produced by

100 actors from five cultures, and 2,168 music samples—and asked, in separate response formats, to judge the samples in terms of a broad array of emotion categories and more general appraisals (e.g., valence, arousal). Statistical analyses revealed that emotion categories (including many beyond the Basic 6, such as amusement, contentment, and desire) drove similarities in emotion recognition across cultures more so than many fundamental appraisals – even valence (pleasantness vs. unpleasantness), considered by many to be the foundational building block of the conceptualization of emotion (Barrett, 2006b; Colibazzi et al., 2010; Russell, 2003). These results are shown in Figure 5.2 and 5.3, which portray the degree to which emotion category judgments are similar across disparate cultures. These results cast doubt on the notion that cultural universals in the emotions people recognize in expression are constructed from the perception of valence, arousal, and other general appraisals.

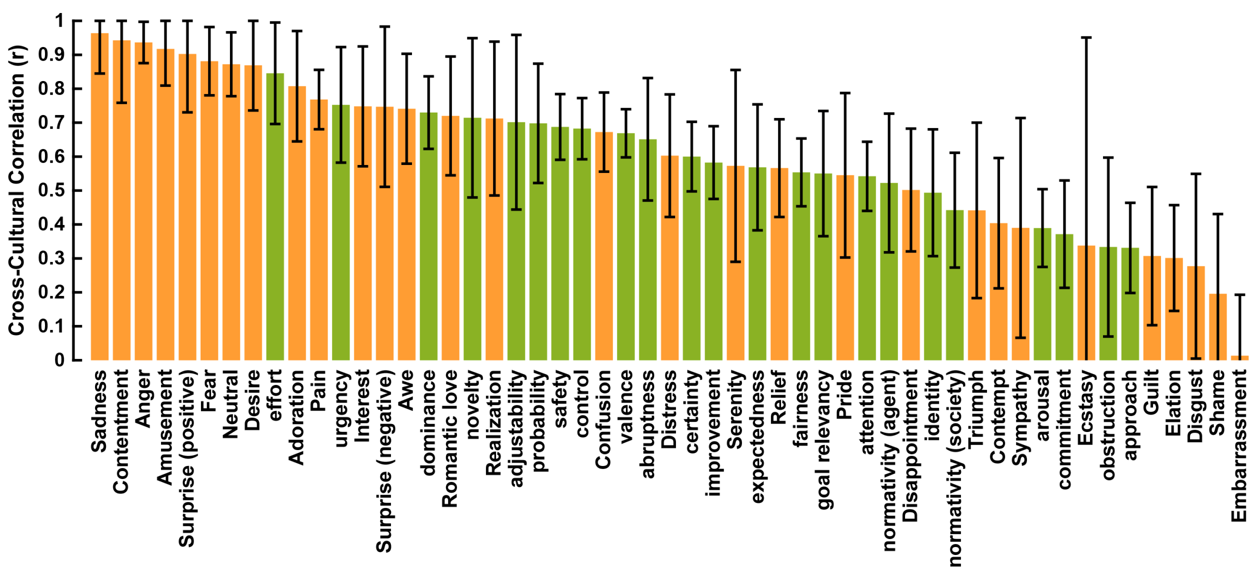

Figure 5.2 Correlations in the meaning of emotional speech prosody across cultures (Cowen, Laukka, Elfenbein, Liu, & Keltner, 2019). The correlation (r) for each emotion category (orange bars) and scale of appraisal (green bars) captures the degree to which each judgment is preserved across India and the US across 2519 vocalizations. The methods used in this study control for within-culture variation in each judgment (see Appendix 2). Error bars represent standard error.

That reported experiences and expressions of many emotion categories were better preserved across cultures than those of broader affective features raises an intriguing question about the conceptualization of emotional experience: perhaps affective features such as valence and arousal are in fact psychologically constructed from categories of emotion. In other words, perhaps emotional experiences and expressions are best captured by categories of emotion such as "triumph," and then levels of valence, arousal, and other affective features are inferred from these more primary representations. If so, the additional stages of inferences involved in affective feature judgments might introduce additional cultural variation. Given this reasoning, one might expect category judgments, rather than affective scale judgments, from one culture to be better predictors of affective scale judgments from another culture. Gathering separate judgments of a full complement of emotion categories and affective scales across thousands of music and speech samples allowed for a rigorous test of this possibility.

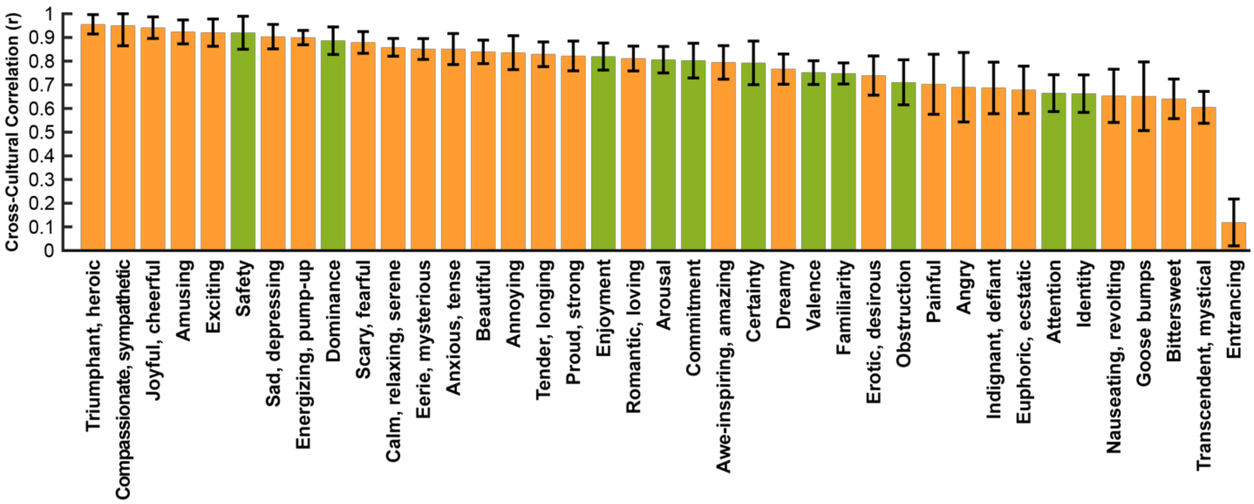

Figure 5.3 Correlations in the emotions evoked by music across cultures (Cowen, Fang, Sauter, & Keltner, under review). Correlations (r) for each emotion category (orange bars) and scale of appraisal (green bars) in the degree to which each judgment is preserved across India and the US across 1,841 music samples gathered to target the 28 emotion categories (see also Figure 5.4). The methods used in this study control for within-culture variation in each judgment (see Appendix 2). Error bars represent standard error.

To test this hypothesis concerning the primacy of emotion categories and affect scales in emotional experience, we used linear regression analyses to derive cross-cultural signal correlations in the mapping between category and affective scale judgments of the music samples (Figure 5.4) and speech samples (with similar results, see Cowen, Laukka, Elfenbein, Liu, & Keltner, 2019). These analyses ascertain whether emotion category ratings are stronger predictors of affective feature judgments across cultures, or vice-versa. In keeping with the idea that judgments of music in terms of affective features derive from the cross-culturally preserved experience of emotion categories, we find that category judgments consistently predict affective feature judgments from the other culture as robustly as, or more robustly than, affective feature judgments such as valence and arousal. By contrast, the affective feature judgments from each country generally do a poorer job of predicting the category judgments from the other culture (Cowen, Laukka, Elfenbein, Liu, & Keltner, 2019; Cowen, Fang, Sauter, & Keltner, under review).

Based on these results, it is more plausible that judgments of general affective features (valence, arousal, etc.) are psychologically constructed from experiences that are captured by emotion categories (amusement, fear etc.) than vice versa in emotional experience and expression. This would suggest that studying emotions such as “anger”, “awe”, “fear”,” and “triumph”, as opposed to broad features such as valence and arousal, may be a more fruitful approach to understanding the fundamental drivers of human behavioral and neurophysiological responses to ongoing events in the environment.

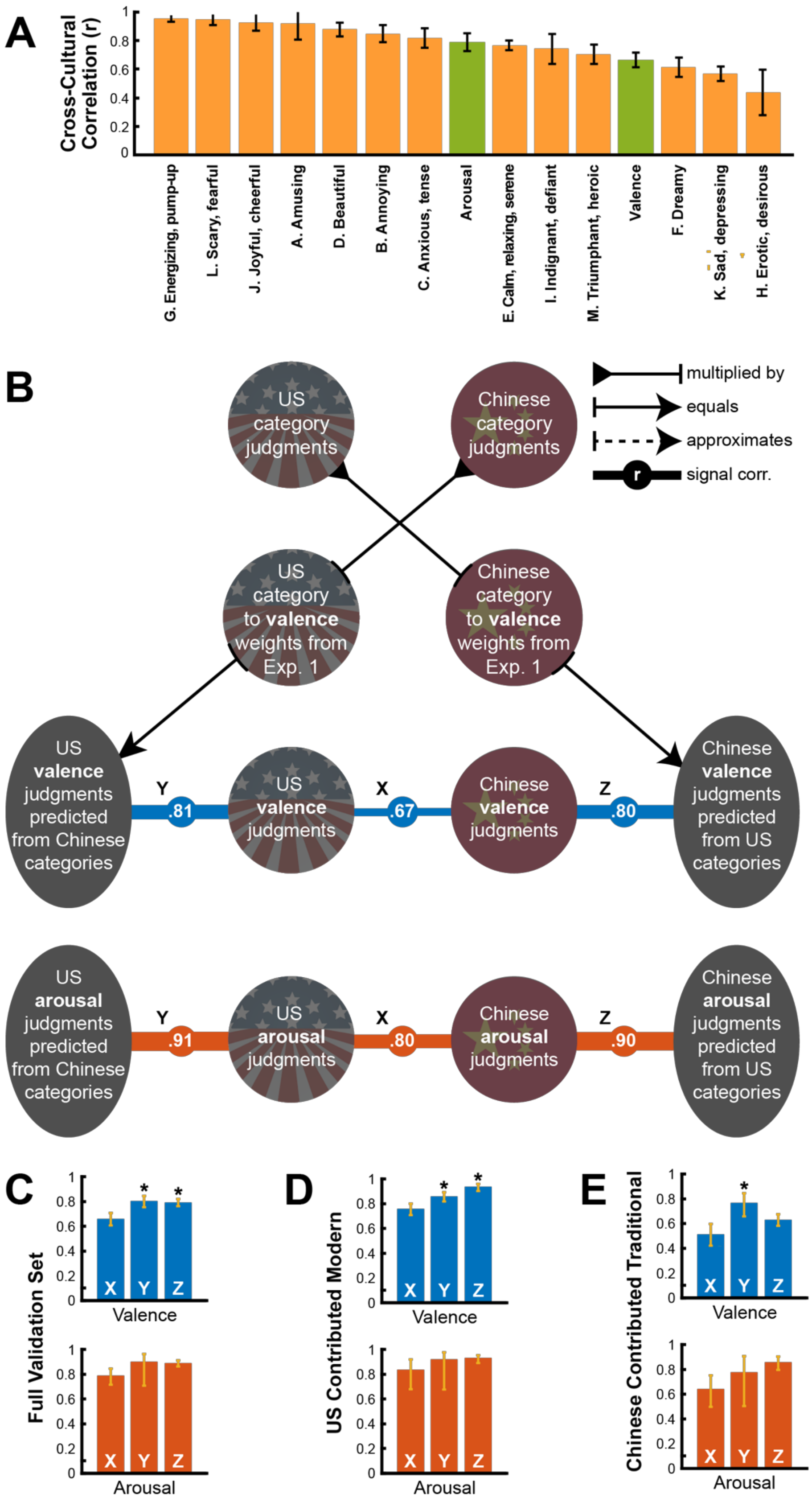
A
Cross-Cultural Correlation (r)
G. Energizing, pump-up
L. Scary, fearful
J. Joyful, cheerful
A. Amusing
D. Beautiful
B. Annoying
C. Anxious, tense
Arousal
E. Calm, relaxing, serene
I. Indignant, defiant
M. Triumphant, heroic
Valence
F. Dreamy
K. Sad, depressing
H. Erotic, desirous
B
multiplied by
equals
approximates
signal corr.
US category judgments
Chinese category judgments
US category to valence weights from Exp. 1
Chinese category to valence weights from Exp. 1
US valence judgments predicted from Chinese categories
US valence judgments
Chinese valence judgments
Chinese valence judgments predicted from US categories
Y .81
X .67
Z .80
US arousal judgments predicted from Chinese categories
US arousal judgments
Chinese arousal judgments
Chinese arousal judgments predicted from US categories
Y .91
X .80
Z .90
C
Full Validation Set
Valence
Arousal
D
US Contributed Modern
Valence
Arousal
E
Chinese Contributed Traditional
Valence
Arousal

Figure 5.4 Emotion categories account for the preserved experience of valence and arousal across cultures. A. Correlations in the emotions evoked by music across cultures in a validation set of music samples targeting levels of valence and arousal (Cowen, Fang, Sauter, & Keltner, under review). Correlations (r) for 13 dimensions derived in a separate experiment (orange bars) and valence and arousal (green bars) in the degree to which each attribute is preserved across the US and China across 327 modern and Chinese traditional music samples gathered to target levels of valence and arousal. Error bars represent standard error. **B-E. Emotion categories account for the preserved experience of valence and arousal across cultures.** Category judgments are used to predict affective feature judgments within each culture using ordinary least squares regression applied to a set of 1841 music samples. Then, in our separate validation set of 327 valence and arousal targeted music samples, regression weights from each culture are multiplied by category judgments from the other culture to predict affective feature judgments in each culture. **(B) Emotion categories account for the preserved experience of valence and arousal across cultures, even in response to valence and arousal targeted music samples.** Category judgments were used to predict affective feature judgments using the model trained in Experiment 1. (C) Category judgments from each culture were significantly better than valence/arousal judgments from each culture at predicting valence (*p < .002, .01; bootstrap test) judgments from the other culture, and nominally better at predicting arousal judgments. This held true for (D) the modern US samples (*p = .002, = .02) and (E) the traditional Chinese music samples (*p < .002). These results are consistent with the hypothesis that categories of emotion are elicited by music, and then subsequently used to construct valence/arousal judgments in a more culture-specific process of inference.

Chapter 6. Emotion expression as an evolved code of credible commitment: Semantic spaces organize findings from animal behavior, remote cultures, and neuroscience

I have thus far shown that across disparate cultures, people ascribe meaning in systematic fashion to dozens of distinct patterns of expressive behavior. These findings raise the question of where the complex meaning of emotional expressions actually comes from. The semantic space framework for emotion, when applied to organize recent empirical evidence from remote cultures, neuroscience, and nonhuman signaling behavior, enables new answers to this question. Expressions are constructed in part by a diverse set of innate, domain-specific mechanisms of credible commitment. In surveying this broad empirical landscape, one finds that emotional expressions echo our evolutionary past, flexibly structure our present social lives, and may help marshal technologies responsive to our future needs.

What expressions do: A language of social commitment

One way to interpret the accumulating evidence represented in Chapters 4-5 is as a complex lexicon of nonverbal displays, analogous to the dictionary of a language. But studies of the social functions of expressive behavior suggest that expressions have powers that words do not: they typically serve as devices not just of communication, but of credible commitment to communicated meanings and likely courses of action, evoking systematic inferences, emotional reactions, and actions in observers (Keltner & Kring, 1998; McCullough & Reed, 2016; Reed & DeScioli, 2017; Scarantino, 2017b). In particular, because it is easier to produce convincing expressions when they are consistent, rather than inconsistent, with our inner feelings (or acting would be easy (Anikin & Lima, 2017; Côté, Hideg, & van Kleef, 2013; Goldstein & Bloom, 2011; Hess & Hareli, 2015; Hess & Kleck, 1990; Juslin, Laukka, & Bänziger, 2018; Kappas, Bherer, & Thériault, 2000; McCullough & Reed, 2016; McLellan, Johnston, Dalrymple-Alford, & Porter, 2010)), expressions endow us with the power to signal our convictions and commitments in a manner that perceivers are impelled to take as credibly predictive of our state of mind and the contingent actions we might take as circumstances unfold (Brown, Palameta, & Moore, 2015; McCullough & Reed, 2016; L. Reed & DeScioli, 2017; Scarantino, 2017b). Endowed with this information, perceivers are often rationally motivated to respond in ways that will benefit an honest expresser—for example, through informal investment in a partnership, or avoidance of the need for violent altercation following a threat—processes that speak to the adaptive significance of emotional expression within evolutionarily significant social exchanges. For instance, to circumvent exploitation in reproductive relationships, budding romantic partners differentiate genuine commitment from instrumental seduction in part through expressive behaviors such as facial-bodily signals (head nods, gesticulation, forward leans), doting speech prosody, and affectionate patterns of touch (Gonzaga et al., 2001; Gottman & Levenson, 2000). Similarly, soccer referees differentiate real injuries from "flops" based in part on the credibility of players' pain expressions (David, Condon, Bywater, Ortiz-Barrientos, & Wilson, 2011). Laughter can mitigate conflict by signaling genuinely peaceful intentions (Kangasharju & Nikko, 2009; Dacher Keltner, Capps, Kring, Young, & Heerey, 2001; Norrick & Spitz, 2008). A CEO's credible expression of humility following a corporate transgression predicts shareholder confidence, likely because it signals a genuine commitment to more ethical action in the service of better returns (ten Brinke & Adams, 2015).

In conveying credible commitments to communicated meanings and possible courses of action, emotional expressions influence the unfolding of social interactions in systematic ways, as revealed by an ever-expanding body of experimental work. For example, people are more likely to cede to negotiators with "angry" facial expressions, which signal a credible commitment to retaliate against defectors even when punishment is costly to both parties (Henrich et al., 2006; L. I. Reed, DeScioli, & Pinker, 2014; van Leeuwen et al., 2014). Likewise, people make larger informal investments in beneficiaries with genuine smiles, which signal a commitment to share subsequent gains (Brown et al., 2015; Centorrino, Djemai, Hopfensitz, Milinski, & Seabright, 2015; L. I. Reed, Zeglen, & Schmidt, 2012), and in those whose patterns of pupil dilation and constriction mimic their own (M. E. Kret, Fischer, & De Dreu, 2015), which may also signal mutual affiliation (Prochazkova et al., 2018). "Contempt" expressions, which predict noncooperative intent, have the opposite effect (L. I. Reed et al., 2012). We are more likely to trust those who signal humility upon being overpraised through an averted gaze, downward head tilt, inhibited smile, blush, or face touch (Dijk, Koenig, Ketelaar, & de Jong, 2011; Keltner & Buswell, 1997), and to imitate those who express "pride", or confidence, when answering a trivia question through an expanded posture, upward head tilt, or subtle smile (Martens & Tracy, 2013). "Sad" and "fearful" facial expressions enhance the credibility of declarations of loss and danger, respectively (L. I. Reed & DeScioli, 2017a, 2017b), thereby promoting prosocial responding (Marsh & Ambady, 2007; Small & Verrochi, 2009). Infant distress cries rapidly trigger nurturant tendencies in adults nearby (Hernandez-Miranda et al., 2017; Parsons et al., 2014) (even across animal species (Lingle & Riede, 2014)), and infants themselves have been found to rely on credible expressive signals that guide behaviors from approaching strangers to exploring new sources of reward (Hertenstein & Campos, 2004; Peltola, Hietanen, Forssman, & Leppänen, 2013; Song, Over, & Carpenter, 2016; Sorce, Emde, Campos, & Klinnert, 1985; Walle et al., 2017; Wu et al., 2017).

One might wonder how expressions have acquired their specific meanings. In some cases, there seems to be a clear explanation. For instance, the acoustic properties that characterize the growl threat of many mammals and the expression of anger in humans (Cowen et al., 2019) depend on vocal tract length, and may therefore advertise size and strength (Sell, Cosmides, & Tooby, 2014; C.-G. Tsai et al., 2010). Likewise, the pride display in humans echoes the expansion of body posture that is used by many mammalian species to demonstrate strength, but potentially also "handicaps" (McCullough & Reed, 2016) the expresser by exposing vulnerable body parts to attack, thereby projecting confidence (Tracy, Shariff, & Cheng, 2010; Weisfeld & Beresford, 1982). Potential origins of the social bonding functions of touch can be observed in rats, whose patterns of huddling for warmth as pups shape the olfactory preferences that drive filial huddling behaviors into adulthood (at which point huddling is no longer helpful for thermoregulation) (Kojima, Stewart, Demas, & Alberts, 2012; Wilson, 2017). More immediate origins of the bonding function of touch can also be found in the reciprocal and conciliatory grooming behaviors of primates (De Waal, 2000; De Waal & Brosnan, 2006). And it turns out that the acoustic properties that set alarm calls apart from other vocalizations (e.g., acoustic roughness) (Arnal, Flinker, Kleinschmidt, Giraud, & Poeppel, 2015; Cowen et al., 2018; Magrath, Haff, Fallow, & Radford, 2015) allow both natural and synthetic sounds to be localized particularly rapidly and efficiently in the environment (Arnal et al., 2015; Magrath et al., 2015).

In other cases, the evolutionary foundation for expressive behaviors can be less obvious. Laughter, for example, disrupts the alignment between breathing and motor activity required to engage in effortful action (Fry, 2013). This would perhaps explain the co-occurrence of laughter-like behavior and rough-and-tumble play in many mammalian species (Bloom & Friedman, 2013; Fox, 1970; Ishiyama & Brecht, 2016; Llamazares-Martín, Scopa, Guillén-Salazar, & Palagi, 2017; Palagi et al., 2016; Parr, Cohen, & De Waal, 2005; Waller & Cherry, 2012), during which it could signal a commitment to non-effortful or non-serious aggression (Fry, 2013; Palagi et al., 2016). It also appears that this commitment to non-effortful intent may have acquired a broader array of functions in humans, corresponding to nuanced acoustic variations in laughter (Fry, 2013; Oveis et al., 2013; A. Wood, Martin, & Niedenthal, 2017). For example, evidence is emerging that nervous laughter following a faux pas signals that one meant no harm (Keltner & Buswell, 1997) and that affiliative laughter during teasing signals playful intent (Keltner et al., 2001). Sniggering laughter during more pernicious acts of bullying likely flaunts the lack of effort required to assert dominance over a victim (Keltner et al., 2001; Søndergaard, 2018). These theoretical insights broaden our understanding of the origin and complex nature of expressive behavior and point to several avenues to understanding how emotional expressions have acquired the power to convey nuanced psychological commitments in humans.

The domain specificity of emotional expression

Nonhuman homologies to human emotional expression, such as the chimpanzee play face and laughter-like utterances, speak to mounting evidence that certain expressive behaviors emerged over the course of mammalian evolution (Davila Ross, Owren, & Zimmermann, 2009; De Waal, 2019; Keltner et al., 2019; McCullough & Reed, 2016; Parr & Waller, 2006; Tracy et al., 2010). That expressions have an evolutionary origin does not, of course, imply that they always have the same meaning, independent of context and culture. Rather, expressive behavior exhibits evidence of an evolutionary origin in the form of *domain specific* adaptations: the involvement of biological mechanisms specifically adapted to solve a particular problem, which for expressive behavior is most always social in nature (Hirschfeld & Gelman, 2010; Spunt & Adolphs, 2017). This is a sharp distinction. In the realm of language, for example, hypotheses of domain specificity do not imply that all phonemes have similar meanings across languages, but rather that humans have adapted specialized biological mechanisms for learning and speaking languages (Hirschfeld & Gelman, 2010). Similarly, in the realm of expression, hypotheses of domain specificity should not be taken to imply that there are no cultural accents, display rules, or contextual influences on expressive behavior (Cordaro et al., 2018; Elfenbein et al., 2007)—only that expressions are constructed, in part, by domain-specific mechanisms (Scarantino, 2017b). For example, observations that people from the US, Japan, and the Trobriand Islands laugh in different ways (Sogon & Masutani, 2011) and at different kinds of jokes (Senft, 1985) should not be taken as evidence against the domain specificity of laughter. After all, it is in spite of the considerable influence of culture that people from all three places laugh at jokes.

The alternative to domain specificity in expressive behavior is captured in constructivist approaches to emotion, which assert that the meanings attributed to expressions are culturally learned and radically variable as a function of language and other learned meaning systems (Barrett, 2006; Russell, 2003; Russell, 1991). Under constructivism, we may, at best, have the innate capacity to extract general information about the valence (the degree of pleasantness or unpleasantness) and arousal (the degree of calmness or excitement) conveyed by certain expressions (Barrett, 2006; Russell, 2003; Russell, 1991). Beyond these two core features, however, the specific meanings of expressive behaviors are posited to be culture-specific, and profoundly so.

The debate between domain specificity and constructivism turns on evidence of whether expressions convey specific meanings, beyond valence and arousal, that cannot be explained culture. This evidence has emerged in three areas of scientific inquiry. (1) The study of remote cultures. People from cultures that have limited to no Western contact have been found to produce and recognize similar expressions. (2) The study of animal behavior. Nonhuman animals have been found to naturally produce and recognize, or systematically react to, a number of homologous expressive signals, ruling out the reliance on human culture for the development of these shared behaviors (although, of course, we expect differentiation in expressive behavior with increasing evolutionary distance). (3) The study of neural mechanisms. Specialized neural adaptations have been found to play a causal role in the communication of specific meanings with expressions and drawing specific inferences from expressions. When consistently structured brain mechanisms are implicated in similar behaviors across different people, such evidence speaks to the likelihood that genetically-based neurophysiological systems related to emotion emerged in human evolution.

The evidence from these diverse literatures for innate, domain-specific mechanisms is particularly clear-cut for at least eleven systems of expressive behavior with clear mappings to distinct emotional states: those related to aggression (Bloom & Friedman, 2013; Bryant & Barrett, 2008; Cowen et al., 2019; Elfenbein & Ambady, 2002; Faragó, Pongrácz, Range, Virányi, & Miklósi, 2010; Honk & Schutter, 2007; Lin et al., 2011; Parkinson, Walker, Memmi, & Wheatley, 2017; Parr et al., 2005; C.-G. Tsai et al., 2010), alarm (Arnal et al., 2015; Bryant & Barrett, 2008; Cordaro, Keltner, et al., 2016; Cowen et al., 2019; Keifer, Hurt, Ressler, & Marvar, 2015; Senn et al., 2014; Slocombe, Townsend, & Zuberbühler, 2009; Zuberbühler, 2009), aversion to pathogens ("disgust") (Calder, Keane, Manes, Antoun, & Young, 2016; Caruana, Jezzini, Sbriscia-Fioretti, Rizzolatti, & Gallese, 2011; Cordaro, Keltner, et al., 2016; Elfenbein & Ambady, 2002; Sauter et al., 2010; Sauter et al., 2011; Schaller, Miller, Gervais, Yager, & Chen, 2010; Shenhav & Mendes, 2014; Snowdon & Boe, 2003; Steiner, Glaser, Hawilo, & Berridge, 2001; Wicker et al., 2003), bonding and intimacy (Broesch & Bryant, 2015; Bryant & Barrett, 2007; Cowen et al., 2019; Dunbar, 2010; Feldman, Gordon, Schneiderman, Weisman, & Zagoory-Sharon, 2010; Feldman, Weller, Zagoory-Sharon, & Levine, 2007; Gonzaga et al., 2001; Kojima et al., 2012; Seltzer, Ziegler, & Pollak, 2010; Shaver, Morgan, & Wu, 1996; Snowdon et al., 2010; Strathearn, Fonagy, Amico, & Montague, 2009; The Walters Art Museum, n.d.), concern and consolation (Burkett et al., 2016; Goetz et al., 2010; Lindegaard et al., 2017; Parsons et al., 2014; Romero, Castellanos, & de Waal, 2010; Webb, Romero, Franks, & De Waal, 2017), displaying status (Hosaka, 2015; Sznycer et al., 2017; Tracy & Matsumoto, 2008; Tracy & Robins, 2008; Tracy et al., 2010; Tracy, Shariff, Zhao, & Henrich, 2013; Weisfeld & Beresford, 1982), submission (Sznycer et al., 2018; Tracy & Matsumoto, 2008; Weisfeld & Dillon, 2012), sensory pleasure (Garrod et al., 2018; LACMA, n.d.; "Pre-Columbian Moche culture erotic ceramic - Peru - 19 cm," n.d.; Steiner et al., 2001; Ueno, Ueno, & Tomonaga, 2004), loss and vulnerability (Cordaro, Keltner, et al., 2016; Cowen et al., 2019; Houston, 2001; Witteman et al., 2019), pain (Arif-Rahu & Grap, 2010; Cordaro, Keltner, et al., 2016; Descovich et al., 2017; Garrod et al., 2018; Langford et al., 2010; Zaki, Wager, Singer, Keysers, & Gazzola, 2016), and play (Bennett, Bendersky, & Lewis, 2002; Bloom & Friedman, 2013; Caruana et al., 2015; Cowen et al., 2019; Fox, 1970; Ishiyama & Brecht, 2016; Llamazares-Martín et al., 2017; Palagi et al., 2016; Parr et al., 2005; Sauter et al., 2010; Senft, 1985; Waller & Cherry, 2012; Yamao et al., 2015). Examples include the play face and laugh-like behaviors in a wide variety of mammals (Fox, 1970; Ishiyama & Brecht, 2016; Llamazares-Martín et al., 2017; Palagi et al., 2016; Parr et al., 2005; Waller & Cherry, 2012) (Figure 6A), representations of grief and mourning found in ancient Mayan art (Houston, 2001), and the specialized processing of scream-like sounds by the amygdala (Arnal et al., 2015) (Figure 6B). We document this ever-expanding base of empirical evidence for domain specificity in each of these response systems more systematically in Table 7, along with emerging evidence for innate expressive behaviors related to another 8 to 12 states.

Table 7 organizes the evidence for domain specificity along dimensions uncovered by a semantic space approach to the study of expression. By identifying the constellations of vocal utterances, facial expressions, and bodily movements that people map to distinct mental states, semantic space approaches structure hypotheses regarding the domain specificity of expressive behavior. For example, that people link "amusement" to both open-mouth smiles and laughter (Anikin & Lima, 2017; Caruana et al., 2015; Cowen et al., 2018; Cowen & Keltner, 2019; Davila-Ross, Allcock, Thomas, & Bard, 2011; Martin et al., 2017; Palagi et al., 2016; Parr et al., 2005) informs hypotheses regarding the role of animal homologies of the play face (Llamazares-Martín et al., 2017; Palagi et al., 2016; Parr et al., 2005; Waller & Cherry, 2012) and laugh-like utterances (Davila-Ross et al., 2011; Davila Ross et al., 2009; Ishiyama & Brecht, 2016), organizing social functional accounts that aim to explain why these expressions often occur concurrently (Crockford & Boesch, 2005; Parr et al., 2005) and why their neural correlates overlap with those of play behaviors (Caruana et al., 2015; Ishiyama & Brecht, 2016; Yamao et al., 2015). Similarly, that "love" is linked to both tactile and vocal signals (Dunbar, 2010; Feldman et al., 2010, 2007; Gonzaga et al., 2001; Hertenstein et al., 2009; Kojima et al., 2012; Seltzer et al., 2010; Wilson, 2017) informs hypotheses regarding the animal homologies of filial touch (Dunbar, 2010; Feldman et al., 2010; Kojima et al., 2012; Snowdon et al., 2010; Wilson, 2017) and nurturant prosody (Broesch & Bryant, 2015; Bryant & Barrett, 2007; Feldman et al., 2007; Seltzer et al., 2010), and helps explain their overlapping endocrinological underpinnings, such as why both of these behaviors covary with the release of oxytocin (Feldman et al., 2007; Kojima et al., 2012; Seltzer et al., 2010). Semantic spaces also inform hypotheses regarding subtle differences in the meaning of distinct expressive behaviors. For example, expressions of "amusement" and "love" are differentiated from, but share gradients with, emotions such as "pride" and "sympathy" (Cowen et al., 2018; Cowen & Keltner, 2017, 2019), informing social functional accounts (Campos et al., 2013; D. Keltner, Young, Heerey, Oemig, & Monarch, 1998; Keltner, 1995; Keltner et al., 2001; Martin et al., 2017; Sauter, 2017; A. Wood, 2018) of the interacting roles of these emotions and structuring hypotheses regarding the organization of animal homologies (Burkett et al., 2016; Davila-Ross et al., 2011; Lindegaard et al., 2017; Parr et al., 2005; Romero et al., 2010; Webb et al., 2017), cultural universals (Broesch & Bryant, 2015; Bryant & Barrett, 2007; Tracy & Matsumoto, 2008; Tracy & Robins, 2008), and psychophysiological correlates (Bartz, Zaki, Bolger, & Ochsner, 2011; Burkett et al., 2016; Dunbar, 2010; Feldman et al., 2010, 2007; Kojima et al., 2012; Mariska E. Kret & De Dreu, 2017; Leknes et al., 2013; Seltzer et al., 2010; Snowdon et al., 2010; Strathearn et al., 2009) of each emotion. As Table 7 details, these emotions are but a subset of the wide range of mental states that have been linked to distinct constellations of facial-bodily and vocal expressions and in turn have been found to correspond to distinct animal homologies, cultural universals, and neural mechanisms.

Domain Specificity in Response Systems Associated with Distinct Mental States

	System	Examples	System	Examples
Definitive Evidence	“Anger”, aggression (☺◀🐈🌎B)	Growling/snarl homologies in mammals (Faragó et al., 2010; C.-G. Tsai et al., 2010) Recognition in disparate cultures (Bryant & Barrett, 2008; Cordaro, Keltner, et al., 2016; Cowen et al., 2019; Elfenbein & Ambady, 2002; Parkinson et al., 2017; Sauter et al., 2010; Sauter et al., 2011) Hypothalamic aggression mechanisms (Falkner, Grosenick, Davidson, Deisseroth, & Lin, 2016; Lin et al., 2011; Todd et al., 2018)	“Pain” (physical/ empathic) (☺◀🐈🌎B)	Pain grimace in nonhuman animals (Descovich et al., 2017; Langford et al., 2010) Pain grimace in infants (Amanda, 2002) Pain recognition in disparate cultures (Cordaro, Keltner, et al., 2016) Pre-contact Old/New World depictions (Maitre, n.d.; The Barakat Collection, n.d.-b) ACC & pain recognition/experience (Carrillo et al., 2019; Singer & Lamm, 2009; Zaki et al., 2016)
	“Sadness” crying, loss (☺◀🐈🌎B)	Cry face & whimper in chimpanzees (Snyder, Graham, Bowen, & Reite, 1984) Sadness recognition in disparate cultures (Cordaro, Keltner, et al., 2016; Cowen et al., 2019; Elfenbein & Ambady, 2002; Sauter et al., 2010) Pre-contact Old/New World depictions (Houston, 2001; Shapiro, 2006; Valdesogo, 2015) Midbrain responses to infant cries (Parsons et al., 2014; Witteman et al., 2019)	“Pride”, status (☺🐈🌎)	Erect posture & bipedal swagger in apes (De Waal, 2019; Hosaka, 2015; Weisfeld & Beresford, 1982) Recognition of pride in disparate cultures (Tracy & Robins, 2008; Tracy et al., 2013) Pride expression by the congenitally blind (David Matsumoto & Hwang, 2012; Tracy & Matsumoto, 2008) Link to audience valuation in disparate cultures (Sznycer et al., 2017) Pre-contact Old/New World depictions (The Barakat Collection, n.d.-a; Wardropper, 2011)
	“Disgust”, aversion (☺◀🐈🌎B)	Sour/bitter response in newborns/primates (Steiner et al., 2001; Ueno et al., 2004) Recognition in disparate cultures (Bryant & Barrett, 2008; Cordaro, Keltner, et al., 2016; Elfenbein & Ambady, 2002) Insula in disgust recognition/experience (Calder et al., 2016; Caruana et al., 2011; Wicker et al., 2003) Gastric & immune system disgust response (Schaller et al., 2010; Shenhav & Mendes, 2014)	“Fear”, screams, alarm (☺◀🐈🌎B)	Alarm calls in nonhuman animals (Fallow, Gardner, & Magrath, 2011; Zuberbühler, 2009) Fear recognition in disparate cultures (Bryant & Barrett, 2008; Cordaro, Keltner, et al., 2016; Elfenbein & Ambady, 2002; Sauter et al., 2010) Amygdala response to scream-like sounds (Arnal et al., 2015) Amygdala response to alarm faces (Méndez-Bértolo et al., 2016) Primate amygdala & cross-modal alarm signals (Kuraoka & Nakamura, 2006)
	“Ecstasy”, pleasure (☺◀🐈🌎)	Hedonic response in newborns/primates (Steiner et al., 2001; Ueno et al., 2004) Pleasure face across cultures (Garrod et al., 2018) Pre-contact Old/New World depictions (LACMA, n.d.; “Pre-Columbian Moche culture erotic ceramic - Peru - 19 cm,” n.d.; Rabe, 1996; The British Museum, n.d.)	“Shame”, submission (☺◀🐈🌎)	Submission displays in mammals (van Hooff, 1970; Weisfeld & Dillon, 2012) Link to audience devaluation across cultures (Sznycer et al., 2018) Shame expression by the congenitally blind (Tracy & Matsumoto, 2008) Pre-contact Old/New World depictions (Rodriguez, 2011; The University of Sydney, n.d.)
	“Love”, bonding (☺◀🐈🌎B)	Filial touch in nonhuman animals (Dunbar, 2010; Feldman et al., 2010; Snowdon et al., 2010; Wilson, 2017) Infant-directed speech in disparate cultures (Broesch & Bryant, 2015; Bryant & Barrett, 2007) Pre-contact Old/New World depictions (Holloway, 2011; The Walters Art Museum, n.d.) Oxytocin role in human bonding (Dunbar, 2010; Feldman et al., 2010, 2007; Seltzer et al., 2010; Strathearn et al., 2009) Oxytocin role in rat/vole/tamarin bonding (Kojima et al., 2012; Snowdon et al., 2010) Oxytocin-moderated pupil dilation & affiliation [172-3]	“Sympathy”, consolation (☺◀🐈B)	Nonhuman consolation behaviors (Burkett et al., 2016; Lindegaard et al., 2017; Romero et al., 2010; Webb et al., 2017) Cross-species care response to distress cries (Lingle & Riede, 2014) ACC oxytocin role in consolation behaviors (Burkett et al., 2016) ACC/“empathy” network response & altruism [204-6]
	"Mirth”, laughter, play (☺◀🐈🌎B)	Play face in nonhuman mammals (Llamazares-Martín et al., 2017; Parr et al., 2005; Waller & Cherry, 2012) Laughter & play in mammals (Davila-Ross et al., 2011; Ishiyama & Brecht, 2016) Laughter in disparate cultures (Bryant & Barrett, 2008; Cordaro, Keltner, et al., 2016; Sauter et al., 2010; Senft, 1985) Brain stimulation & mirthful laughter (Caruana et al., 2015; Yamao et al., 2015)		

Convergent	"Anxiety" (☺🔈🐈)	Nonhuman displacement behaviors (Coleman & Pierre, 2014; Latzman, Young, & Hopkins, 2016; Schino, Perretta, Taglioni, Monaco, & Troisi, 1996) & their relief via consolation in chimps (Fraser, Stahl, & Aureli, 2008) & reduction by anti-anxiety drugs in macaques (Schino, Troisi, Perretta, & Monaco, 1991)	"Embarrassment" (☺🔈B)	Face/body expression & blush (Dijk et al., 2011; Keltner & Buswell, 1997) Specific deficits in frontotemporal dementia (Sturm, Rosen, Allison, Miller, & Levenson, 2006) Possible neural mechanisms (Müller-Pinzler et al., 2015)
	"Awe" (☺🔈)	Chills/goosebumps across cultures (McCrae, 2007) Awe recognition across cultures (Cowen et al., 2019)	"Surprise" (☺🔈🌎)	Surprise recognition in disparate cultures (Cordaro, Keltner, et al., 2016; Elfenbein & Ambady, 2002; Sauter et al., 2010)
	"Contempt" (☺🔈🌎)	Snigger, lip raise/tighten across cultures (Cordaro, Keltner, et al., 2016; Cowen et al., 2019; Elfenbein & Ambady, 2002)	"Interest" (☺🔈🌎)	Eyebrow raise across disparate cultures (Grammer, Schiefenhövel, Schleidt, Lorenz, & Eibl-Eibesfeldt, 1988; Levinson, 2015) "Interested" prosody across cultures (Cordaro, Keltner, et al., 2016; Cowen et al., 2019)
	"Contentment" (☺🔈)	Content vocalization across cultures (Cordaro, Brackett, et al., 2016; Cordaro, Keltner, et al., 2016) Content face across cultures (Cordaro et al., 2018, 2019)	"Triumph", posturing (☺🔈🌎)	Arm raise in congenitally blind athletes (David Matsumoto & Hwang, 2012) Vocalization in disparate cultures (Scott et al., 2010)
Emergent	"Confusion"	"Confused" prosody across cultures (Cowen et al., 2019)	"Doubt"	The "not" face across cultures (Benitez-Quiroz, Wilbur, & Martinez, 2016)
	"Concentration /determination"	Pre-contact Old/New World depictions (Christies, n.d.; Harmon-Jones, Schmeichel, Mennitt, & Harmon-Jones, 2011; The Cleveland Museum of Art, n.d.)	"Desire" (☺🔈)	"Sultry" voice across cultures (Cowen et al., 2019)

Table 7. Domain specificity in response systems associated with distinct mental states
☺: Facial-bodily (Cowen & Keltner, 2019), 🔈: Vocal (Cowen et al., 2018), 🐈: Animal homology, 🌎: Remote culture, B: Brain mechanism

Contextual and cultural influences

A parallel line of research has highlighted contextual and cultural influences on expression recognition. For example, perceptions of a "triumph" facial expression vary markedly as a function of the body posture it is paired with (Aviezer, Trope, & Todorov, 2012) (Figure 6C), and certain "gasp" faces—which look to most Westerners like "fear" expressions—are interpreted as threat displays in one culture (Crivelli et al., 2016). Such findings, however, are not in consistent with hypotheses of domain specificity in expressive behavior (Mariska E. Kret & Straffon, 2018). By analogy, powerful contextual and cultural effects can also be found in the realm of color vision (Davidoff, 2001; Lotto & Purves, 2002) (Figure 6D), for which domain-specific mechanisms (e.g., retinal cones) are well established. Contextual and cultural influences on mental state attribution instead shed light on the multi-componential, situated nature of expressive behavior, which has largely been ignored this far given the focus on the face. What they indicate is that the recognition of expression is based on the integration of contextual cues, multiple modalities of expression, and learned accents and display rules (Chen & Whitney, 2019; Keltner & Cordaro, 2015; Klaus R. Scherer & Ellgring, 2007). In many cases, facial expression does not take center stage (Keltner & Cordaro, 2015; Kraus, 2017); pride and triumph expressions are one such case (Cowen & Keltner, 2019; David Matsumoto & Hwang, 2012; Tracy & Matsumoto, 2008). The relative importance of the face, body, voice, and context vary as a function of the state being inferred (Figure 6C,F) and culture (Cordaro, Keltner, et al., 2016; Cordaro et al., 2018; Cowen & Keltner, 2019).

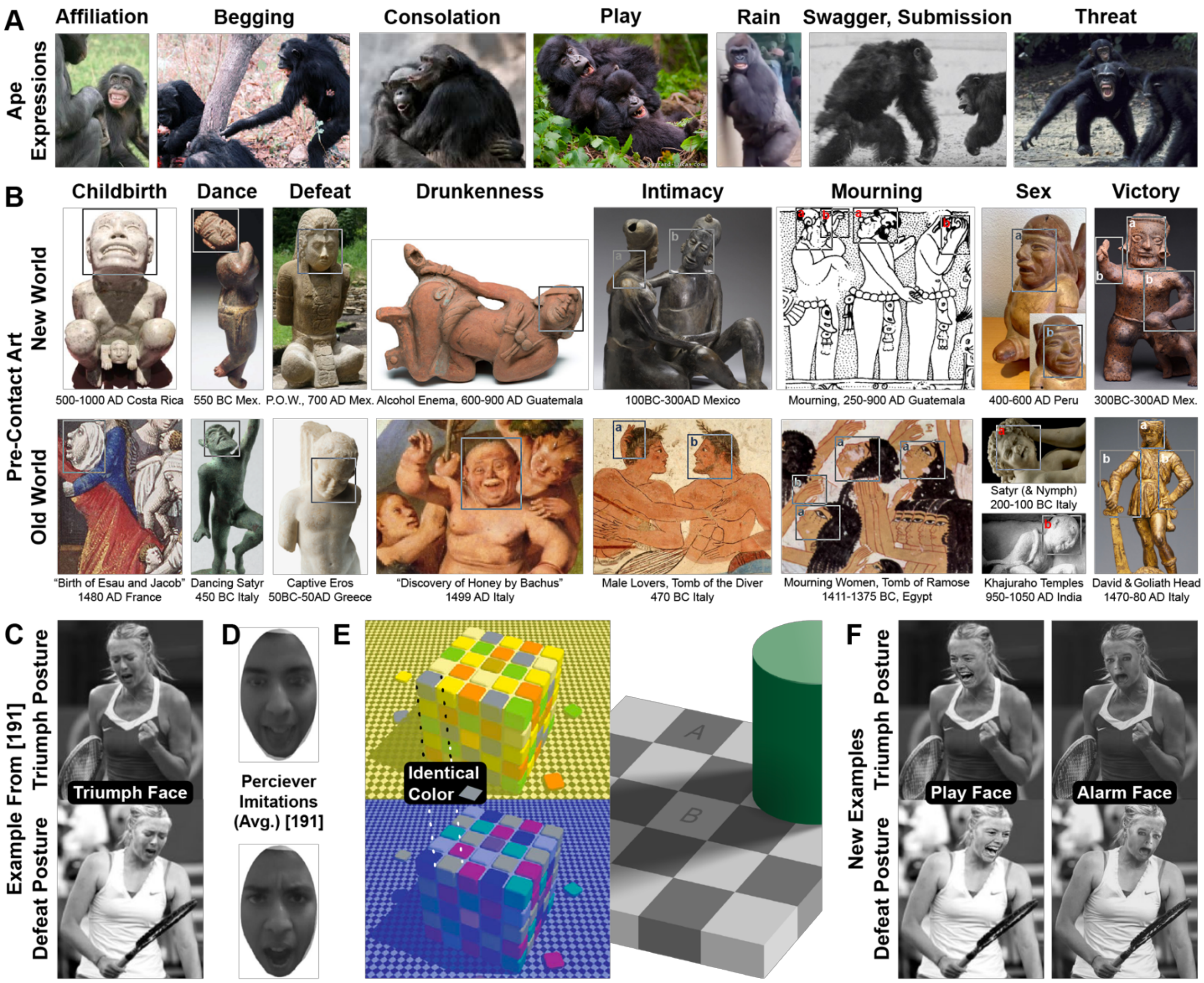

Figure 6. Domain specificity is not inconsistent with contextual influences on the recognition of expression. (A) Common chimpanzee expressive behaviors. From left to right: The silent bared-teeth affiliative display (Parr & Waller, 2006), begging gesture (Hobaiter & Byrne, 2011), consolation hug (De Waal, 2019; Romero et al., 2010), play face (De Waal, 2019; Parr et al., 2005; Waller & Cherry, 2012), bipedal swagger (a display of status) (De Waal, 2019; Hosaka, 2015; Weisfeld & Beresford, 1982), "rain face" (a response to rain (De Waal, 2019); for video see https://www.youtube.com/watch?v=zodLhwW5FSI) submissive crouch or bow (van Hooff, 1970), and threat display (De Waal, 2019; Parr et al., 2005) have close parallels to human affiliative smiles (Martin et al., 2017), soliciting gestures, consoling behaviors (Lindegaard et al., 2017), laughs (Parr et al., 2007), "disgust" faces (De Waal, 2019), "pride" and "shame" displays (Tracy & Matsumoto, 2008; Tracy et al., 2010; Weisfeld & Beresford, 1982), and "anger" expressions (Parr et al., 2007), respectively. **(B) Parallels between pre-Columbian Old and New World art reveal expressive similarities that cannot be explained by cultural contact.** From left to right: Depictions of childbirth (Maitre, n.d.; The Barakat Collection, n.d.-b), dance (Christies, n.d.; The Cleveland Museum of Art, n.d.), drunken revelry (LACMA, n.d.; Mathews, 1963), defeat (Rodriguez, 2011; The University of Sydney, n.d.), intimacy (Holloway, 2011; The

Walters Art Museum, n.d.), mourning (polychrome vessel, sketched for clarity) (Cavanagh & Mee, 1995; Houston, 2001), sexual acts ("Pre-Columbian Moche culture erotic ceramic - Peru - 19 cm," n.d.; Rabe, 1996; The British Museum, n.d.), and victory (The Barakat Collection, n.d.-a; Wardropper, 2011) in both Old and New World ancient cultures bear nonverbal displays closely resembling modern empirically validated expressions of pain (Arif-Rahu & Grap, 2010; Cowen & Keltner, 2019; Garrod et al., 2018), "determination" or "concentration" (Cowen & Keltner, 2019; Harmon-Jones et al., 2011), mirthful pleasure (Cowen & Keltner, 2019; Keltner, 1995), shame (Tracy & Matsumoto, 2008), "love" (neck touch [a], mutual gaze and Duchenne smile [b]) (Cowen & Keltner, 2019; Dunbar, 2010; Gonzaga et al., 2001), "sadness" ("sad" facial expression and tears [a], cupped hands over face [b]) (Bonanno, 2013; Cowen & Keltner, 2019), multiple faces of sexual pleasure ([a] and [b]) (Cowen & Keltner, 2019; Garrod et al., 2018), and "pride" (slight smile [a] and expanded posture [b]) (Tracy & Matsumoto, 2008; Tracy & Robins, 2008). Cultural universals in these expressions precede globalization. Their nuance also lays bare the narrow scope of traditional "Basic 6" models that only account for one or two of these expressive behaviors. **(C) The meanings attributed to individual components of expression can be influenced to a surprising extent by their behavioral context.** Here, for example, the facial expression is identical in each image, but can convey either triumph or disappointment depending on the body posture it is paired with (Aviezer et al., 2012). **(D) Holistic processing of expression is automatic.** Shown here are morphed averaged facial expressions of subjects asked to mimic the expressions in (C). Body posture unwittingly affected subjects' imitations of identical facial expressions. Effects of this sort, operating beneath awareness, are indicative of domain specificity (Fodor, 1983; Robbins, 2013). **(E) For instance, similar contextual influences are found in the realm of color and shading perception, for which humans also have domain-specific adaptations (retinal cones and rods, cells with color- and lightness-dependent receptive fields in visual cortex)** (Lotto & Purves, 2002)**.** In each image, the two indicated squares are perceived remarkably differently based on their context, despite being composed of identical pixels. (For comparable contextual influences on audition, see Mcgurk & Macdonald, 1976)). **(F) Contextual influences can be overgeneralized when taken out of context.** While studies have emphasized the role of body posture in triumph expressions (Aviezer et al., 2012; Lisa Feldman Barrett, Mesquita, & Gendron, 2011), it is worth acknowledging that these are perhaps the most body-dependent of all expressive behaviors (Cowen & Keltner, 2019; David Matsumoto & Hwang, 2012; Tracy & Matsumoto, 2008). Here we can see that play and alarm expressions are less dependent on body posture. Broader empirical studies have found that facial expressions can usually explain a substantial proportion of the variance in emotion attribution to images (Chen & Whitney, 2019; Cowen & Keltner, 2019).

Of note, there are sources of cultural variation in expression labeling behaviors other than differences in the meanings of expressions. For example, free response paradigms (Gendron, Roberson, van der Vyver, & Barrett, 2014a) are not tests of recognition per se, but rather of lexical choice (Brennan & Clark, 1996). We cannot rule out that someone who calls a scream "unhappy" recognizes it as a signal of danger, any more than we can rule out that someone who calls an apple a "fruit" recognizes it as an apple. Likewise, card sorting paradigms, in which expressions are freely placed into different piles (Gendron, Roberson, van der Vyver, & Barrett, 2014b), test a culture's ontology (grouping) of expressions, not recognition, and also tend to reveal cultural differences in color perception (Davidoff, 2001). Furthermore, most studies have focused on Western expressions posed in the laboratory. Participants vary in how they evaluate people of an ethnicity with which they have had no direct contact (Elfenbein & Ambady, 2002)—for example, participants in some remote cultures rate all Western faces as "angry" (Elfenbein & Ambady, 2002; Sorenson, 2012), perhaps a fitting inference given culture-related patterns of colonialization. By contrast, Westerners typically recognize expressions from remote cultures (Sauter et al., 2010). Additionally, most laboratory posed expressions look feigned and artificial (Hess & Hareli, 2015; McLellan et al., 2010); thus, the question "what is this person feeling" must be understood as "what is this person performing", perhaps a non sequitur in cultures without traditions of caricature (Goldstein & Bloom, 2011) (or, for that matter, of photography).

Indeed, participants from remote cultures often interpret expression recognition tasks differently than experimenters expect. When experimenters ensure that participants in a remote culture understand the feelings described in a story by having them explain it—which tends to require repeating the story to them several times (Sauter, Eisner, Ekman, & Scott, 2015)—they are better at subsequently matching the story to an expression (Gendron et al., 2014a; Sauter et al., 2010; Sauter et al., 2015). However, experimenters who have omitted this kind of procedure, arguing that it is problematic to ensure participants understand the story "in a Western way" (Gendron, Roberson, & Barrett, 2015), obtain weaker evidence of universality (Sauter et al., 2015). Clearly, whether people in different cultures attribute the same mental states to characters in stories is a separate question from whether they recognize those mental states in similar expressions. Likewise, studies that rely on single words for mental states (Crivelli et al., 2016, 2017) cannot assume that their closest translations in remote languages have the same meaning. Mental state concepts, like color concepts, are often difficult to translate in remote languages (Kollareth & Russell, 2017; Sauter et al., 2011), and likely become more granular as languages spread and evolve (Haynie & Bowern, 2016).

In sum, differences found with particular expression labeling paradigms in particular cultures (Crivelli et al., 2016, 2017; Elfenbein, 2013; Gendron et al., 2014b; Russell, 1994; Russell, 1991) are compatible with the broader evidence that expressions are partly universal (Broesch & Bryant, 2015; Bryant & Barrett, 2007, 2008; Cordaro, Keltner, et al., 2016; Cowen, Fang, Sauter, & Keltner, under review; Cowen et al., 2019; Elfenbein & Ambady, 2002; Houston, 2001; Parkinson et al., 2017; Sauter et al., 2010; Sauter et al., 2015, 2011; Tracy & Matsumoto, 2008; Tracy & Robins, 2008; Tracy et al., 2013). Studies with strong procedures in place to ensure that participants fully understand the mental states they are being asked to match with expressions have found that participants in disparate cultures attribute similar meanings to a range of facial-bodily (Elfenbein & Ambady, 2002; Parkinson et al., 2017; Tracy & Robins, 2008; Tracy et al., 2013) and vocal (Bryant & Barrett, 2008; Cordaro, Keltner, et al., 2016; Sauter et al., 2010; Sauter et al., 2015) expressions. Moreover, the evidence suggests that these similarities go well beyond the recognition of valence and arousal (Cowen et al., 2019; Elfenbein & Ambady, 2002; Sauter et al., 2015).

Lessons from neuroscience

Skeptics of domain specificity in expressive behavior have also pointed to inconsistencies in neuroimaging studies (Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012). These critiques presume that domain specificity implies coarse locationism—the belief that domain specific neural adaptations are represented in coarse, multi-millimeter chunks of brain tissue (Lindquist et al., 2012) whose activation can reliably be captured with available neuroimaging technologies (see (Boubela et al., 2015; Turner, Paul, Miller, & Barbey, 2018; Woo, Krishnan, & Wager, 2014) for limitations in the reliability of common neuroimaging methods). However, given that appraisals of the environment, expressive muscle movements, and decision-making are all handled by very different parts of the brain, the biologically-prepared links between situations, expressions, and implied courses of action are more likely to be represented in widely dispersed neuromodulatory projections—likely originating in intricately overlapping networks within deep brain nuclei (Beyeler et al., 2016; Janak & Tye, 2015; Kim, Pignatelli, Xu, Itohara, & Tonegawa, 2016; Lin et al., 2011; Nieh, Kim, Namburi, & Tye, 2013; Seo et al., 2019; Todd et al., 2018)—than in discrete regions of dedicated grey matter (Pessoa, 2012; Scarantino, 2012).

Indeed, support for distributed neural representations of expressive behavior is emerging from studies of how emotion-related responses are encoded in complex patterns of neural activation guided in part by long-range neuromodulatory projections (Burkett et al., 2016; Janak & Tye, 2015; Kim et al., 2016; Koide-Majima, Nakai, & Nishimoto, 2018; Kojima et al., 2012; Kragel & LaBar, 2016; Kragel, Reddan, LaBar, & Wager, 2018; Nieh et al., 2013; Saarimäki et al., 2016; Seltzer et al., 2010; Senn et al., 2014; Seo et al., 2019). This emerging work is exploring how the brain mechanisms that give rise to a given mental state and its corresponding expressive behaviors can simultaneously span distinct regions responsible for processing sensory input (Kragel et al., 2018; Schirmer & Adolphs, 2017), learning and prioritizing associations (Ciocchi et al., 2010; Duvarci & Pare, 2014; Keifer et al., 2015; Senn et al., 2014; Whalen et al., 2013), producing facial and vocal responses (Adolphs, Damasio, Tranel, Cooper, & Damasio, 2000; Gothard, 2014; Whalen et al., 2013), transitioning among different operational modes of central and peripheral nervous system activity (Beyeler et al., 2016; Burkett et al., 2016; Falkner et al., 2016; Lin et al., 2011; Nieh et al., 2013; Seo et al., 2019; Todd et al., 2018), and understanding and predicting others' behavior (Skerry & Saxe, 2015). Moreover, whereas many past studies have aggregated mental states into coarse categories—for example, by sorting pictures of rotten food and gory injuries into a single category of "disgust" elicitors, or adorable, beautiful, and erotic images into a single category of "happiness" elicitors—more open-ended methods reveal that the brain encodes mental states along dozens of nuanced dimensions (Koide-Majima et al., 2018; Kragel et al., 2018; Skerry & Saxe, 2015) that we know based on the research outlined above correspond to different mental states and expressive behaviors (Figure 6).

Altogether, given the evolving status of human neuroscience, the absence of a complete account of the neural mechanisms underlying expressive behavior cannot be treated as evidence of the absence of specialized mechanisms, especially given that relevant evidence is still rapidly accumulating (Carrillo et al., 2019; Caruana et al., 2015; Ishiyama & Brecht, 2016; Koide-Majima et al., 2018; Kragel et al., 2018; Lin et al., 2011; Parsons et al., 2014; Saarimäki et al., 2016; Senn et al., 2014; Seo et al., 2019; Witteman et al., 2019; Yamao et al., 2015). For now, it is safe to say that consistently structured brain mechanisms have been found to be reliably implicated in a number of distinct mental states and associated expressive behaviors across people (e.g., (Arnal et al., 2015; Caruana et al., 2015, 2011; Falkner et al., 2016; Feldman et al., 2010; Parsons et al., 2014; Seltzer et al., 2010; Strathearn et al., 2009; Todd et al., 2018; Yamao et al., 2015; Zaki et al., 2016)), rendering it unlikely that these associations were installed by culture within fully multipurpose brain regions.

Chapter 7. Toward a future science of emotion and its applications

The model of emotion portrayed in Figure 1A is incomplete in essential ways. Events or stimuli do not elicit single emotions; they instead elicit a wide array of emotions and emotional blends, mediated by appraisals. Emotional experience does not reduce to six emotions, but instead a complex space of 25 or so kinds of emotional experience and emotion blends (e.g., Figures 3.1-3.3). Emotional experience does not manifest in prototypical facial muscle configurations alone, but multimodal expressions involving the voice, touch, posture, gaze, head movements, and the body, and varieties of expressions within a given modality (e.g., Figures 4.1-4.3; Cordaro et al., 2016, in press; Cowen et al., 2019, in press). Social observers do not necessarily label expressions with single emotion words but instead use a richer conceptual language of inferred causes and appraisals, ascribed intentions, and inferred relationships between the expresser and their environment, including the observer. The realm of emotion is a complex, high-dimensional space.

These empirical advances bring into sharp focus the problems with attempts to draw conclusions about the diagnostic value of facial expression, or any other emotional expression modality for that matter, from studies that sort facial expressions and reported emotional experiences into six discrete categories. Namely, those studies ignore the majority of explainable variance in emotion, and thus reduce the validity of those conclusions. The basic six – anger, disgust, fear, happiness, sadness, and surprise – it is now clear, are a small subset of the emotions people might experience and express in any context. Moreover, facial muscle movements are just a portion of expressive behavior. The same is true of labeling expressive behavior with single words representing just six emotions. When studies seek to link elicitors to single experiences, or experiences to prototypical facial expressions, or expressions to observer judgments, those studies ignore potential variance to be explained, which is all the more amplified by the narrow focus on the Basic 6.

More specifically, note that the Basic 6 represent 30%, at best, of the explainable variance in experience and expression. Given this, correlations between expression and antecedent elicitors, reported experience, and observer judgment sorted into the Basic 6 are relating measures that capture only 30% of the explainable variance to one another. As depicted in Figure 7, 70% of the variation in expression is left unaccounted for, but still adds to the total variance, which determines the denominator of the correlation between expression and other phenomena. As a result, it is likely that the narrow focus on the Basic 6 greatly underestimates the relations between events and expressive behavior, experiences and expressive behavior, and expressions and observer inference. This point is illustrated visually in Figure 7.

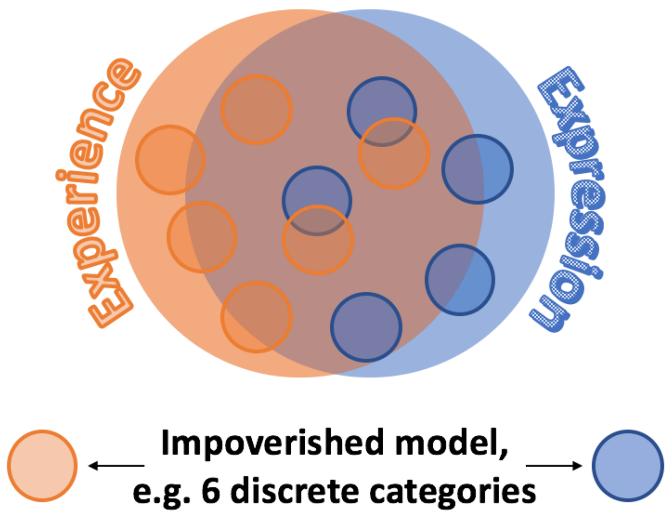

Figure 7. Illustration of why a Basic 6 model of emotion should be expected to generate low estimates of coherence between emotional experience and expression. Treating emotional experience and expression as six discrete categories captures about 30% of the systematic variance in each. As this diagram illustrates, measures that capture 30% of the variance in each of two phenomena may only capture a fraction of the shared variance between them. This is likely true when we measure emotional experience and expression in terms of the Basic 6. For example, a model in which happiness encompasses all positive emotion and has a one-to-one mapping to a smile is unable to account for degrees of happiness, for positive emotions that do not necessarily involve smiles (e.g., awe, desire, triumph, ecstasy, pride), and for emotions and communicative displays that are not necessarily positive but also involve smiles (e.g., embarrassment, posed smiles). These are sources of systematic variance disregarded by the Basic 6 (area of outside of the small circles in the above diagram).

These concerns, and the high-dimensional taxonomy of emotion uncovered in the studies we have reviewed, point to an alternative approach to the future scientific study of emotional expression, and emotion more generally (see Table 2) as follows: (a) To capture experience, measure appraisals (e.g., valence, arousal) and emotion categories. (b) Use methods that can account for numerous dimensions of emotion, including those we have brought into focus here, and that capture emotional blends, rather than focusing narrowly on the Basic 6. (c) Look beyond prototypical facial expressions to varying multimodal expressions. (d) Capture the more complex inferences observers make in ascribing meaning to expressive behavior.

From studies guided by these methods, answers to intriguing questions await. How do appraisals produce the dozens of distinct varieties of emotional response we observe and their fascinating blends? How do complex blends of emotional experience map onto the different modalities of expressive behavior? To what extent do the different modalities of expressive behavior – face, voice, body, gaze, and hands – signal the dozens of emotions that, as we have shown, people conceptualize and communicate? And building upon findings reviewed here showing that perceivers conceptualize emotion at a basic level, from which they may infer broader appraisals (valence, arousal), and perhaps intentions and causes, what is the nature of that inferential process, and how might it vary with development, culture, and personality? What is the neurophysiological patterning that maps onto these 25 or so emotions considered in this article?

To fully understand the diagnostic value of expression, more advanced methods will be required to account for the complex structures of emotional experience, expression, and real-world emotion attribution. Studies will need to accommodate the dozens of distinct dimensions of facial muscle movement, vocal signaling, and bodily movement from which people reliably infer distinct emotions. They will need to capture the equally complex and high-dimensional space of emotional experiences that people reliably distinguish. Finally, they will need to account for social contingencies – including how expressive signals may reflect goals for communication when they diverge from emotional experience – and how real-world emotion attribution incorporates information about a person's circumstances, temperament, expressive tendencies, and cultural context. Accommodating all of these factors requires statistical models sufficiently complex that they will call for the application of large-scale data collection, statistical modeling, and machine learning methods. (This approach to capturing the diagnostic value of expression is, of course, complementary to controlled experiments that probe the mechanisms underlying specific expressive signals.)

It is important to note that in many ways, this work is well underway in the realm of neuroscience. For example, brain imaging studies that have attempted to map the Basic 6 emotions to activity in coarse brain regions have yielded inconsistent results (Hamann, 2012; Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012; Pessoa, 2012; Scarantino, 2012), but more recent studies have found that multivariate patterns of brain activity can reliably be decoded into the Basic 6 categories (Kragel & LaBar, 2015, 2016; Saarimäki et al., 2016). These seemingly discrepant findings can be explained in part by the limitations of a Basic 6 model of emotion. Studies designed to uncover neural representations of the Basic 6 inevitably confound many distinct emotional responses – for example, by sorting adorable, beautiful, and erotic images into a single category of "happiness", or empathically painful injuries and unappetizing food into a single category of "disgust". Their results could thus vary depending on the profile of emotions that are actually evoked by stimuli placed into each category. Multivariate predictive methods are more robust to these confounds because they can discriminate multiple brain activity patterns from multiple other brain activity patterns by taking into account the levels of activation or deactivation in many regions at once. However, an alternative approach, one more conducive to nuanced inferences regarding the brain mechanisms emotion-related response, is to incorporate a more precise taxonomy of emotion. Indeed, recent neuroscience investigations incorporating high-dimensional models of emotion – informed by the work we have reviewed – are beginning to uncover more specific neural representations of upwards of 15 distinct emotions (Koide-Majima et al., 2018; Kragel et al., 2018). This ongoing work has the promise of significantly advancing our understanding of the neural mechanisms of emotion-related response.

Similar work is well underway in the study of the peripheral physiological correlates of emotion. In one recent meta-analysis of peripheral physiological responses associated with a wide range of distinct emotions, several positive emotions – e.g., amusement awe, contentment, desire, enthusiasm – as well as self-conscious emotions were found to have subtly distinct patterns of peripheral physiological response (Kreibig, 2010). Other, more focused work has dissociated the physiological correlates of food-related disgust (decreases in gastric activity) from those of empathic pain (decelerated heart rate and increased heart rate variability) (Shenhav & Mendes, 2014), emotions that would be grouped under "disgust" by a Basic 6 approach but distinguished within a high-dimensional emotion taxonomy. Similarly, recent work has uncovered distinct peripheral physiological correlates for five different positive emotions –

enthusiasm, romantic love, nurturant love, amusement, and awe, (Shiota, Neufeld, Yeung, Moser, & Perea, 2011) — all of which would be grouped under "happiness" by a Basic 6 approach. As this growing body of work moving beyond the Basic 6 indicates, studies will need to incorporate a high-dimensional taxonomy of emotion and inductive modeling approaches to fully capture the diagnostic value of peripheral physiological response.

By moving beyond the Basic 6 to a high dimensional taxonomy of emotion, we believe the application of this science will benefit our culture more generally. Richer approaches to empathy and emotional intelligence can orient people to learn how to perceive subtler expressions of emotion, emotions invaluable to relationships (compassion, desire, sympathy) and work (gratitude, awe, interest, triumph). Children might learn to hear the similarities in how the human voice conveys emotion in ways that resemble how they perceive emotion in a cello or guitar solo (Juslin & Laukka, 2003). The high dimensional taxonomy of emotion language (Figure 3.1), experience (Figure 3.2-3.3), and expression (Figures 4.1-4.3) we have detailed here should provide invaluable information to programs that seek to train children who live with autism, and other conditions defined by difficulties in representing and reading one's own and others' emotion. Technologies that automatically map emotional expressions into a rich multidimensional space may have life-altering clinical applications, such as pain detection in hospitals, which call for close collaboration between science and industry.

The narrow focus on the Basic 6, something of an accidental intellectual byproduct of the seminal Ekman and Friesen research 50 years ago, has inadvertently led to an entrenched state of affairs in the science of emotion, with diametrically opposed positions, derived from the same data, about the recognition of six emotions from six discrete configurations of facial muscle movements. However, emotional expression is far richer and more complex than six prototypical patterns of facial muscle movement. By opening up the field to a high-dimensional taxonomy of emotion, more refined and nuanced answers to central questions are emerging, as are entire new fields of inquiry.

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Appendix 1. Finding shared dimensions of emotional response across cultures: Principal preserved component analysis

Traditional dimensionality reduction methods such as principal components analysis (PCA) or factor analysis are limited in two very important ways. First, methods of testing the number of significant PCs or factors are based at least in part on correlations or covariance between judgments. However, they do not typically consider the reliability of reports of individual items – they cannot identify whether an individual category, like fear, is reliably distinguished from every other category. This is a serious limitation in most factor analytic studies of emotion which, incorporating only a subset of the wide variety of emotion terms people use, cannot be presumed to include multiple judgments corresponding to every significant dimension.

Second, PCA and factor analytic methods do not explicitly separate signal variance from noise variance; rather, they rely on the assumption that high variance components contain signal whereas low variance components contain noise. This assumption can be useful, but it is not always valid. For example, in fMRI studies, noise components are often high in variance (see (Benjamini & Yu, 2013)). Similarly, here, a category applied frequently but randomly to music samples could have high variance in spite of the fact that it has no signal. Likewise, two judgments that are rated together may be exhibiting *noise correlations* rather than *signal correlations*. That is, they may always align for a single rater (e.g., if the rater reports high "approach" and "valence" whenever a voice resembles their own) but there may be no consistency across raters. Where PCA and factor analysis do not explicitly separate signal and noise (except in cases where signal components are always higher variance than noise components), multidimensional reliability analysis methods such as PPCA sort dimensions based on their reliable covariance across independent or repeated measures, a measure of signal variance. (Note that averaging or concatenating datasets and then applying PCA would not separate dimensions that explain variance within one dataset from dimensions that explain covariance across datasets.)

We developed PPCA to extract the shared dimensions of emotion recognition (components of variance) across the same judgments made in two cultures (datasets composed of matched variables). PPCA first seeks a unit vector α_1 that maximizes the objective function

$$\mathrm{Cov}(\mathbf{X}\alpha_1, \mathbf{Y}\alpha_1)$$

We call α_1 the first principal preserved component. Subsequent components are obtained by seeking additional unit vectors α_i that maximize the objective function $\mathrm{Cov}(\mathbf{X}\alpha_i, \mathbf{Y}\alpha_i)$ subject to the constraint that α_1 is orthogonal to the previous components, $\alpha_1, \ldots, \alpha_{i-1}$.

In the special case that $\mathbf{X} = \mathbf{Y}$, PPCA is equivalent to PCA, given that the latter method maximizes the objective function

$$\mathrm{Var}(\mathbf{X}\alpha_i) = \mathrm{Cov}(\mathbf{X}\alpha_i, \mathbf{X}\alpha_i)$$

(substituting another $\mathbf{X}$ for $\mathbf{Y}$ in $\mathrm{Cov}[\mathbf{X}\alpha_1, \mathbf{Y}\alpha_1]$). Also note the similarity to the PLSC objective, which seeks to find two separate bases α and ß to maximize

$$\mathrm{Cov}(\mathbf{X}\alpha_i, \mathbf{Y}ß_i)$$

as well as the CCA objective, which seeks to maximize

$$\mathrm{Corr}(\mathbf{X}\alpha_i, \mathbf{Y}\beta_i)$$

However, given our aim of finding *preserved* dimensions of emotion recognition across two cultures, PPCA derives only one basis, α, that applies to both datasets. In PPCA, therefore, the data matrices must be commensurate: observations in both datasets must be of the same dimension (i.e. the number of rows in **X** and **Y** must be equal). This is certainly true in the present study, given that we collect the same judgments of each music sample in each culture.

To solve the PPCA objective and find an α_1 we apply eigendecomposition to the addition of the cross-covariance matrix between datasets and its transpose: $\mathrm{Cov}(\mathbf{X},\mathbf{Y})/2 + \mathrm{Cov}(\mathbf{Y},\mathbf{X})/2$. We claim that the principal eigenvector of this symmetric matrix maximizes $\mathrm{Cov}(\mathbf{X}\alpha_1, \mathbf{Y}\alpha_1)$. To derive this, first recall a general property of cross-covariance, $\mathrm{Cov}(\mathbf{X}a, \mathbf{Y}b) = b^T\mathrm{Cov}(\mathbf{X}, \mathbf{Y})a$. Thus,

$$\mathrm{Cov}(\mathbf{X}\alpha_1, \mathbf{Y}\alpha_1) = \alpha_1^T\mathrm{Cov}(\mathbf{X}, \mathbf{Y})\,\alpha_1 \qquad \text{(Property 1)}$$

In addition, because both $\mathbf{X}\alpha_1$ and $\mathbf{Y}\alpha_1$ are vectors, $\mathrm{Cov}(\mathbf{X}\alpha_1, \mathbf{Y}\alpha_1) = \mathrm{Cov}(\mathbf{Y}\alpha_1, \mathbf{X}\alpha_1)$. Thus,

$$\mathrm{Cov}(\mathbf{X}\alpha_1, \mathbf{Y}\alpha_1) = \mathrm{Cov}(\mathbf{X}\alpha_1, \mathbf{Y}\alpha_1)/2 + \mathrm{Cov}(\mathbf{Y}\alpha_1, \mathbf{X}\alpha_1)/2 \qquad \text{(Property 2)}$$

Combining these two properties, we can see that

$$\begin{aligned}\mathrm{Cov}(\mathbf{X}\alpha_1, \mathbf{Y}\alpha_1) &= \mathrm{Cov}(\mathbf{X}\alpha_1, \mathbf{Y}\alpha_1)/2 + \mathrm{Cov}(\mathbf{Y}\alpha_1, \mathbf{X}\alpha_1)/2 && \text{(By property 2)}\\ &= \alpha_1^T\mathrm{Cov}(\mathbf{X}, \mathbf{Y})\,\alpha_1/2 + \alpha_1^T\mathrm{Cov}(\mathbf{Y}, \mathbf{X})\,\alpha_1/2 && \text{(By property 1)}\\ &= \alpha_1^T[\mathrm{Cov}(\mathbf{X}, \mathbf{Y})/2 + \mathrm{Cov}(\mathbf{Y}, \mathbf{X})/2]\,\alpha_1\end{aligned}$$

Now, letting $\mathbf{R} = [\mathrm{Cov}(\mathbf{X},\mathbf{Y})/2 + \mathrm{Cov}(\mathbf{Y},\mathbf{X})/2]$, we see that maximizing $\alpha_1^T\mathbf{R}\alpha_1$ is equivalent to maximizing $\mathrm{Cov}(\mathbf{X}\alpha_1, \mathbf{Y}\alpha_1)$, the originally stated PPCA objective. (Note that if $\mathbf{X} = \mathbf{Y}$, we are applying eigendecomposition to $\mathrm{Var}[\mathbf{X}\alpha_i] = \mathrm{Cov}[\mathbf{X}\alpha_i, \mathbf{X}\alpha_i]$, which performs PCA.)
Finally, the min-max theorem dictates that the principal eigenvector of **R** maximizes $\alpha_1^T\mathbf{R}\alpha_1$ subject to α_1 being a unit vector ($|\alpha_1|=1$)

We have thus found a unit vector α_1 that maximizes $\mathrm{Cov}(\mathbf{X}\alpha_1, \mathbf{Y}\alpha_1)$—the covariance between the projections of **X** and **Y** projected onto the first component. Based on the min-max theorem, subsequent eigenvectors α_i will maximize $\mathrm{Cov}(\mathbf{X}\alpha_i, \mathbf{Y}\alpha_i)$ subject to their orthogonality with previous components α_1 through α_{i-1} and to each α_i also being a unit vector ($|\alpha_i|=1$).

We note that the min-max theorem also provides that the last eigenvector, α_n, will minimize $\mathrm{Cov}(\mathbf{X}\alpha_n, \mathbf{Y}\alpha_n)$, equivalent to maximizing $-\mathrm{Cov}(\mathbf{X}\alpha_n, \mathbf{Y}\alpha_n)$. Hence, if there are dimensions of negative covariance between the two datasets, then some eigenvectors will maximize the negative covariance.

With respect to the corresponding eigenvalues, each eigenvalue λ_i will be equal to $\mathrm{Cov}(\mathbf{X}\alpha_i, \mathbf{Y}\alpha_i)$. To see this, note that:

$$\begin{aligned}[\mathrm{Cov}(\mathbf{X}, \mathbf{Y})/2 + \mathrm{Cov}(\mathbf{Y}, \mathbf{X})/2]\,\alpha_i &= \lambda_i\,\alpha_i && \text{(Eigenvalue equation)}\\ \alpha_i^T[\mathrm{Cov}(\mathbf{X}, \mathbf{Y})/2 + \mathrm{Cov}(\mathbf{Y}, \mathbf{X})/2]\,\alpha_i &= \alpha_i^T\lambda_i\,\alpha_i\end{aligned}$$

$$\text{Cov}(\mathbf{X}\alpha_i, \mathbf{Y}\alpha_i) \quad = \lambda_i \alpha_i^T\alpha_i \qquad \text{(By property 1)}$$

Now $\alpha_i^T\alpha_i = 1$ because the α_i are orthonormal. Hence,

$$\text{Cov}(\mathbf{X}\alpha_i, \mathbf{Y}\alpha_i) \quad = \lambda_i$$

This also entails that there will be negative eigenvalues corresponding to negative covariance.

To ascertain whether each component was significant, we determined whether it reliably captured positive covariance in a separate (held-out) sample of ratings. We generated p-values corresponding to the null hypothesis that the out-of-sample covariance explained by each component was no greater than zero by applying PPCA in a leave-one-rater-out fashion. Specifically, we iteratively applied PPCA to extract components from the judgments of all but one of the raters and projected the held-out rater's judgments onto the components. We then assessed the partial Pearson correlation between the component scores derived from each held-out rater's ratings and those derived from the mean ratings from the other culture, partialing out each previous component. Finally, we tested whether these held-out, statistically independent correlation values were consistently positive for each component using a non-parametric Wilcoxon signed-rank test[85].

See Fig. 3 for results of repeated Monte Carlo simulations validating these methods. Each simulation specifies a sampling distribution that closely matches our actual data after it is projected onto some number of orthonormal components of covariance (varying from one to the maximum, 29). The results of these simulations confirm that PPCA combined with our leave-one-rater-out approach accurately recovers the number of shared components and yields conservative p- and q-values.

We note that PPCA generates conservative estimates even though traditional cross-covariance measures are suboptimal for binomial proportion data. We believe this is the case because we use leave-one-out procedures and non-parametric techniques to test the significance of each dimension—such statistical tests avoid distributional assumptions. Nevertheless, techniques specially adapted to the distribution of the data might achieve greater statistical power and less often underestimate the dimensionality reliably shared by the two datasets. Future work should therefore focus on developing variations of PPCA with different distributional assumptions.

In addition, to verify that we would obtain comparable results using a more established method, we applied canonical correlation analysis (CCA) between the US and Indian judgments. We did so in a similar leave-one-rater-out fashion to PPCA. Specifically, we iteratively applied CCA to extract components from the judgments of all but one of the raters and projected the held-out rater's judgments onto the components. We then assessed the partial Pearson correlation between the component scores derived from each held-out rater's ratings and those derived from the mean ratings from the other culture, partialing out each previous component. Finally, we tested whether these held-out, statistically independent correlation values were consistently positive for each component using a non-parametric Wilcoxon signed-rank test (Wilcoxon, 1945).

Note that we excluded the "Neutral" category from these analyses to avoid matrix degeneracy, resulting in dimensions that can be conceived as variations from neutrality. After determining the number of significant PPCs, we generate more interpretable components by applying varimax rotation.

Appendix 2. Explainable variance and maximum attainable correlation

Correlations can be divided by the maximum attainable correlation to estimate what would be obtained with an infinite sample of raters (adjusting for downward bis due to sampling error). The maximum attainable correlation is the square root of the explainable variance.

To calculate explainable variance, we note that the variance of a given rating across stimuli is equal to the explainable variance plus the unexplainable variance. The unexplainable variance can be estimated as the mean of the squared standard errors across stimuli. Hence, the proportion of explainable variance can be estimated by simply dividing the mean of the squared standard errors by the total variance and subtracting this quantity from 1.

More formally, let $\bar{Y}_j$ be the mean judgment of stimulus j, ${\sigma_j}^2$ be the standard error of the mean judgment $\bar{Y}_j$, and σ^2 be the variance of $\bar{Y}_j$ over all stimuli j. Note that the actual proportion of explainable variance in the mean is given by

$$r^2_{\text{exp}} = 1 - \frac{\frac{1}{J}\sum_{j=1}^{J} {\sigma_j}^2}{\sigma^2}$$

Now, if $\bar{Y}$ is the observed mean over all $\bar{Y}_j$, then we estimate σ^2 with $s^2 = \frac{1}{J}\sum_{j=1}^{J}(\bar{Y}_j - \bar{Y})^2$. We estimate the standard error for each stimulus, ${\sigma^2}_j$ with ${s^2}_j$, the sample standard error. The maximum attainable correlation can be estimated as the square root of r^2_{exp}. See Cowen et al., 2019 (Cowen, Laukka, Elfenbein, Liu, & Keltner, 2019) for results of repeated Monte Carlo simulations further validating these methods.

To calculate the explainable variance and maximum attainable correlation in expression judgments across the 14 contexts (rather than across the 161 individual expressions), standard errors ${s^2}_c$ were estimated using the formula for the standard deviation of the mean of random variables, ${s^2}_c = \frac{1}{J}\sum_{j=1}^{J} {s^2}_j$ across the J expressions in each context. The proportion of explainable variance and maximum attainable correlation across the 14 contexts was then calculated as above, replacing ${s^2}_j$ with ${s^2}_c$ and taking $s^2 = \frac{1}{14}\sum_{c=1}^{14}(\bar{Y}_c - \bar{Y})^2$ for the 14 contexts.