

Affective Computing

PH.D. COMPREHENSIVE EXAM

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May, 26 2015

1 Introduction to Affective Computing

Studies show that the decision making of humans is not always logical [20], and in fact, not only is pure logic not enough to model human intelligence, but it also shows failures when applied in artificial intelligence systems [12]. Emotions impact fundamental parts of cognition including perception, memory, attention and reasoning [9]. This impact is caused by the information emotions carry about the environment and event values.

Emotions are involved in developing social context. Brian Parkinson in [36] argues that many of the causes of emotions are interpersonal and communicative rather than internal and reactive phenomena. Beside the fact that social context can cause eliciting emotions in individuals, social context provides information about what emotion should be expressed, by whom, and in what situations. Humans are emotional and social beings. Their emotions and the social context in which they are involved have mutual impacts on each other. But, what if humans can share their emotions with others just as they share their thoughts, resources and their environment. Sharing an emotion with others may alter the experience of an event.

Emotions can also play the role of a motivator in a social context. Humans need to communicate their emotions within the social context for different reasons. Although emotions undeniably have personal aspects, they are usually experienced in a social context and acquire their significance in relation to this context [30]. A successful and effective emotional communication necessitates ongoing reciprocal adjustments between interactants that can happen by interpreting each other's behaviors [30]. It not only requires proper interpretation of the other's expressions, but also correct assessment of the extent to which others can read an individual's expressions. In emotional communication, individuals are constantly exchanging messages about their mental states, and modifying each other's emotional responses as they occur. One aspect of expressing and communicating emotion in a social context is to express one's social motives and intentions [23]. Another aspect of communicating emotions is to reveal the underlying mental states of an individual [37]. In other words, emotions constitute two

different functionalities of expressing communicative signals associated with one's social motives and intentions as well as expressing one's internal states and how one feels about something.

If we want the robots and virtual agents to be more believable and efficient partners for the humans, we require to consider the personal and social functionalities and characteristics of emotions for our robots to coexist with humans as emotional beings. There are several major emotion theories some of which have corresponding computational models. Modeling and applying these theories can help the robots and virtual agents to achieve communicative, evaluative and regulatory aspects of emotions, as I mentioned above. This document provides major computational emotion theories as well as the related psychological background. In Section 2, I review the existing influential computational emotion theories. In this section, I also provide the underlying psychological theories. Some of these theories provide structure of emotions and some of them describe the underlying processes of emotions and their antecedents. Section 3 provides similarities and differences between these major emotion theories. Then, in Section 4, I talk about how these emotion theories have been applied to build autonomous agents and robots. And finally, in Section 5, I provide a brief conclusion about the artificial emotions, emotion theories.

2 Computational Theories of Emotion/Affect

There are different types of computational theories of emotion. These theories differ in type of relationships between their components and whether a particular component play a crucial role in an individual emotion. For instance, the basic component of an emotion can be the behavioral tendencies, cognitive elements, or somatic processes. Emotion theories can also differ based on their representational distinction.

2.1 Appraisal Theory

Appraisal theories of emotion were first formulated by Arnold [5] and Lazarus [28] and then were actively developed in the early 80s by Ellsworth and Scherer and their students [39] [42] [43] [49] [47]. The emotional experience is the experience of a particular situation [17]. Appraisal theory describes the cognitive process by which an individual evaluates the situation in the environment with respect to the individual's well-being and triggers emotions to control internal changes and external actions.

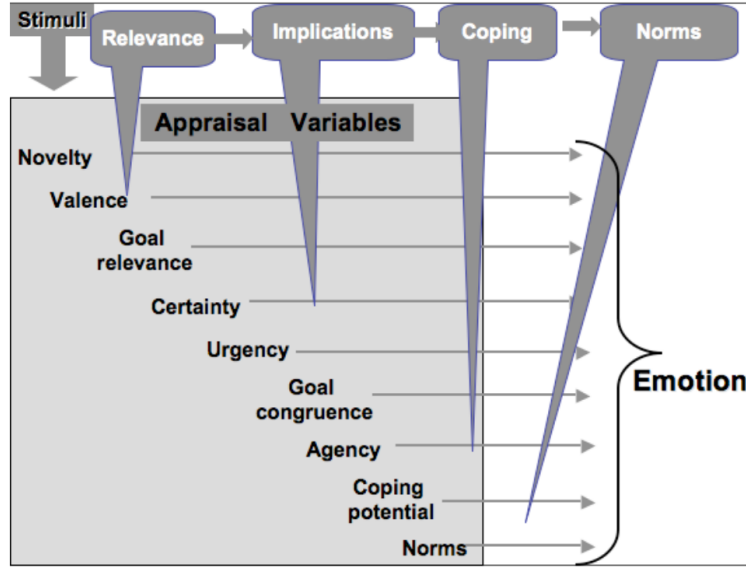


Figure 1: Schematic View of the Componential Theory of Emotion [24].

2.1.1 Componential approach

This approach emphasizes the distinct components of emotions, and is often called the *componential* approach [29]. The “components” referred to in this approach are the components of the cognitive appraisal process. These are referred to as *appraisal variables*, and include *novelty*, *valence*, *goal relevance*, *goal congruence*, and *coping abilities* (further on, in this section, some of the appraisal variables used in computational models are introduced) [43, 49]. A stimulus, whether real or imagined, is analyzed in terms of its meaning and consequences for the agent, to determine the affective reaction. The analysis involves assigning specific values to the appraisal variables. Once the appraisal variable values are determined by the organisms evaluative processes, the resulting vector is mapped onto a particular emotion, within the n-dimensional space defined by the n appraisal variables. The semantic primitives for representing emotions within this model are thus these individual appraisal variables. Figure 1 shows the relationship of the individual appraisal dimensions to the broader categories of evaluations taking place during appraisal (Relevance, Implications, etc.).

2.1.2 Component Process Model

The Component Process Model (CPM) is Scherer’s influential and major theory of emotions [44, 49]. This theory focuses on the dynamic unfolding of emotions. The CPM suggests that an event and its consequences are appraised with a set of criteria on multiple levels of processing (the appraisal component). The result of the appraisal will generally have a motivational effect, often changing or modifying the motivational state before the occurrence of the event. Based on the appraisal results and the motivational changes, some effects will occur in the autonomic and somatic nervous system. The CPM considers emotions as the synchronisation of many different cognitive and physiological components. Emotions are identified with the overall process whereby low level cognitive appraisals, in particular the processing of relevance, trigger bodily reactions, behaviours and subjective feelings. The model suggests that there are four major appraisal objectives to adaptively react to a salient event [46]:

- a) **Relevance:** How relevant is this event for the agent? Does it directly affect the agent or its social reference group?
- b) **Implications:** What are the implications or consequences of this event and how do they affect agent’s well-being and its immediate or long-term goals?
- c) **Coping Potential:** How well can the agent cope with or adjust to these consequences?
- d) **Normative Significance:** What is the significance of this event for the agent’s self-concept and for social norms and values?

To attain these objectives, the agent evaluates the event and its consequences on a number of criteria or *Stimulus Evaluation Checks* (SECs), with the results reflecting the agents subjective assessment of consequences and implications on a background of personal needs, goals, and values [49]. Figure 2 shows the postulated sequence, the cognitive and motivational inputs and the effects on response systems. Also, the bidirectional effects between appraisal and other cognitive functions are illustrated by the arrows in the upper part of Figure 2.

2.1.3 Appraisal Process

According to this theory, appraisals are separable antecedents of emotion, that is, the individual first evaluates the environment and then feels an ap-

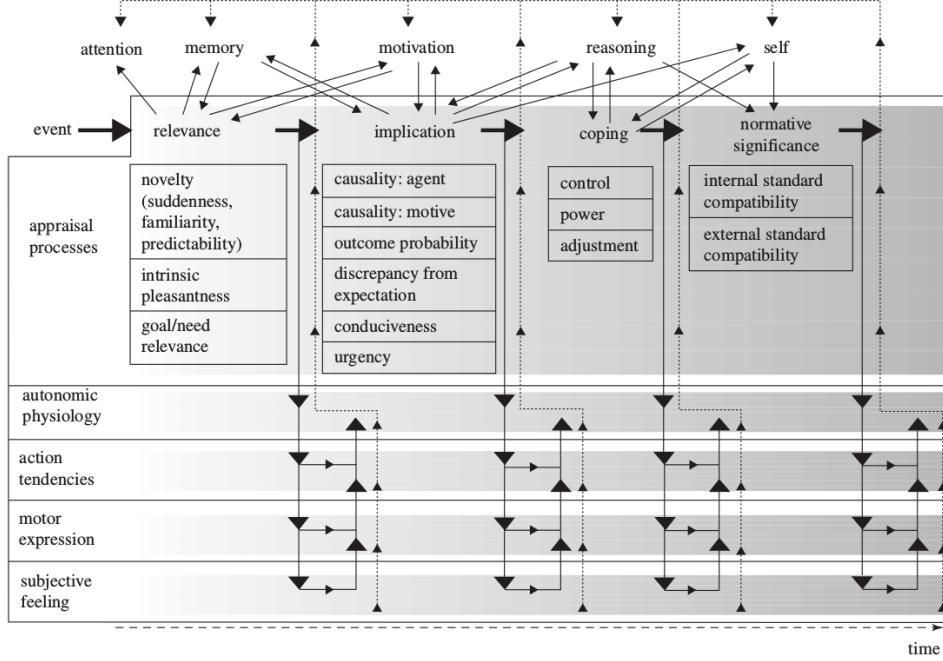


Figure 2: Comprehensive illustration of the CPM of emotion [46, 49].

appropriate emotion [49]. The appraisal procedure begins with the evaluation process of the environment according to the internalized goals and is based on systematic assessment of several elements [44]. The outcome of this process triggers the appropriate emotions. In many versions of the appraisal theory, appraisals also trigger cognitive responses often called *coping strategies*. In fact, the coping mechanism manages the individual's action with respect to the individual's emotional state and the existing internal and/or external demands [16]. The large majority of computational models of emotions are based on this theory. An individual can also use knowledge about the emotional reactions of others to make inferences about them. According to the appraisal patterns, different emotions can be experienced and expressed. Since expression of emotions reflects one's intentions through the appraisal process, the *reverse appraisal* mechanism helps one to infer other's mental states based on their expressions. [11, 22].

Appraisal process is typically viewed as the cause of emotion and the cognitive and behavioral changes associated with emotion. For instance, which particular pattern of the appraisal variables (i.e., individual judgements)

would elicit certain emotion or an emotional expressions. These appraisal variables include [32]:

- **Relevance:** A relevant event has non-zero utility for an agent. This relevancy can either be based on negative influence of an event on the agent or a positive one.
- **Perspective:** The point of view in which an event will be judged, e.g. self or other.
- **Desirability:** A desirable event advances a state of the utility for an agent whose perspective is being taken, or inhibits that.
- **Likelihood:** A measure of likelihood of the outcome.
- **Expectedness:** The extent to which the truth value of a state could have been predicted from causal interpretation.
- **Causal Attribution:** The agent who deserves the credit/blame.
- **Controllability:** Whether the outcome can be altered by the agent whose perspective is taken (this variable is related to coping process).
- **Changeability:** Whether the outcome can be altered by some other causal agent (this variable is related to coping process).

Another key process involved in appraisal is the coping process. This process determines whether and how the agent should respond with respect to the outcome of the appraising the events. There are several coping strategies that computational models like EMA [19] use as control signals. These control signals enable or suppress the cognitive processes that operate on the causal interpretation of the appraisal patterns. Coping process controls the congruency of the actions according to these patterns. As it is shown below, in [19] coping strategies are organized into two categories of *problem-focused* and *emotion-focused* coping strategies. Problem-focused coping strategies can be applied when the agent requires to do something with respect to the problem, whereas Emotion-focused coping works by changing one's interpretation of circumstances. The following is a short list of a broad range of coping strategies [19]:

Problem-focused coping

- **Active coping:** Taking active steps to remove or circumvent the stressor,
- **Planning:** Coming up w/ action strategies,
- **Seeking social support for instrumental reasons:** Seeking advice, assistance, or information.

Emotion-focused coping

- **Seeking social support for instrumental reasons:** Getting sympathy, moral support or understanding,
- **Acceptance:** Accepting the stressor and learn to live with it,
- **Restraint coping:** Waiting till the appropriate opportunity (holding back).

2.1.4 OCC, a Structural Appraisal Theory of Emotion

OCC model, similar to Lazarus' [27] and Scherer's [43] cognitive views, considers emotions to arise from affective or valenced reactions subsequent to the appraisal of a stimulus as being beneficial or harmful to ones concern [34]. The model categorizes emotions based on their underlying appraisal patterns. These patterns are fundamental criteria a person employs for evaluating the situation. They involve the persons focus of attention, their concern, and their appraisal preceding an affective reaction. Figure 3 shows main building blocks of OCC model.

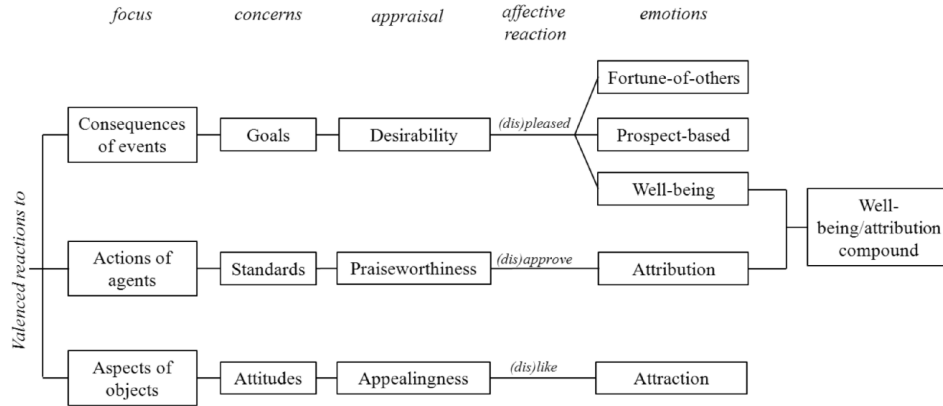


Figure 3: A simple visualization of OCC model [34].

As shown in Figure 3, a person could alternatively have three types of focuses. These types of focuses are consequence of events, actions of agents, and aspects of objects. The person evaluates the significance of causes behind these three types of focuses based on her personal concern. As a result, an affective reaction will be elicited resulting in an emotion. Various combinations of the elements depicted in Figure 3 create specific patterns demonstrating six main groups of emotions in which all emotion types in a group share the same cognitive pattern. Emotion groups are *fortune-of-others*, *prospect-based*, *well-being*, *attribution*, *well-being/attribution- compound*, and *attraction*. The OCC model introduces 22 emotion types. These emotions are introduced each as a representative of a family of similar emotions with various intensities (since relying on a list of discrete emotions that is understood by everyone equally is impossible due to people’s language barriers and various interpretations of the actual words). For instance, happiness can be referred to by other emotion terms such as joy, cheerful, glad, delighted while they all share the same eliciting conditions. Thus the emotion types used in the model (e.g., relief, love, pride, and shame) are meant to represent an emotional experience rather than a lexical taxonomy.

For instance, as shown in Figure 3, the appraisal criterion for consequences of events is their *desirability* (see Section 2.1) for achieving one’s goals. This generates the affective reaction of being *pleased* in positive cases, or *displeased* in negative ones. Figure 4 shows the resulting emotion groups in OCC model such as *fortune-of-others* (e.g., gloating, pity), *prospect-based* (e.g., satisfaction, relief), and *well-being* (e.g., joy, distress) [34]. The appraisal of the praiseworthiness of the actions of an agent against one’s personal standards, as well as the appealing aspects of objects happens in the same way as shown in Figure 3.

Finally, the OCC model introduces some global variables of emotions intensity to distinguish all types of emotions that a person could experience when encountering events, agents or objects. These variables are as follows:

1. Sense of reality (representing the degree to which the event, agent or object in focus appear real to the person),
2. Proximity variable (representing the psychological proximity of event, agent or object),
3. Unexpectedness (representing how unexpectedly one is taken by surprise, either positive or negative),
4. Arousal (representing how arousing an event, agent or object is).

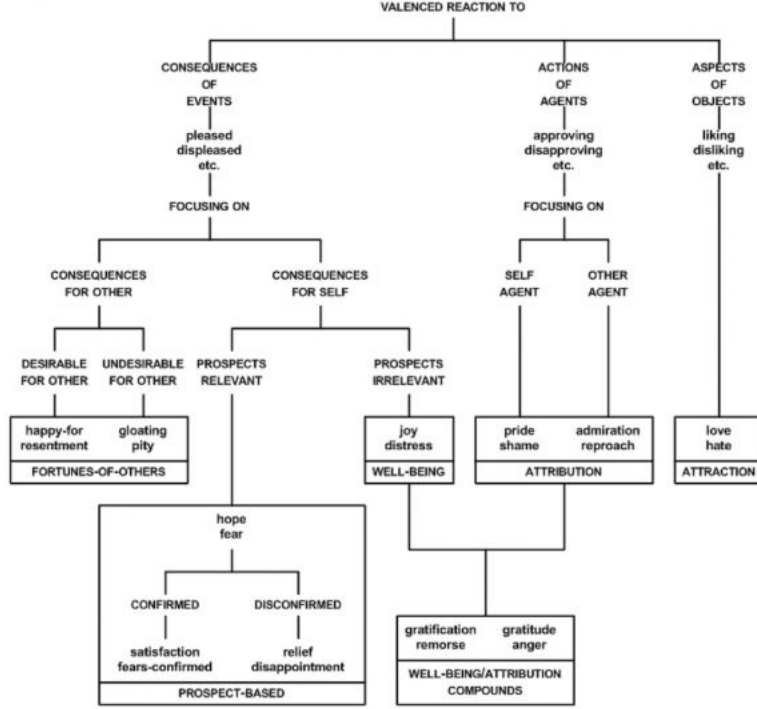


Figure 4: OCC taxonomy of emotion triggers and emotions [34].

2.2 Constructivist (dimensional) emotion Theories

The components and dimensions of emotions were the subject of much speculation since the 19th century. Dimensional models of emotion attempt to conceptualize human emotions by defining where they lie in two or three dimensions. Dimensional theories of emotion argue that emotion should be conceptualized, as points in a continuous (typically two or three) dimensional space rather than looking at them as discrete entities (see Section 2.3) [8] [33] [41] [54].

Two dimensions that are commonly proposed to describe emotions are valence and physiological arousal [5] [27] [40]. Models based on dimensional theories contrast theories of basic emotion, which propose that different emotions arise from separate neural systems [38]. Many dimensional theories

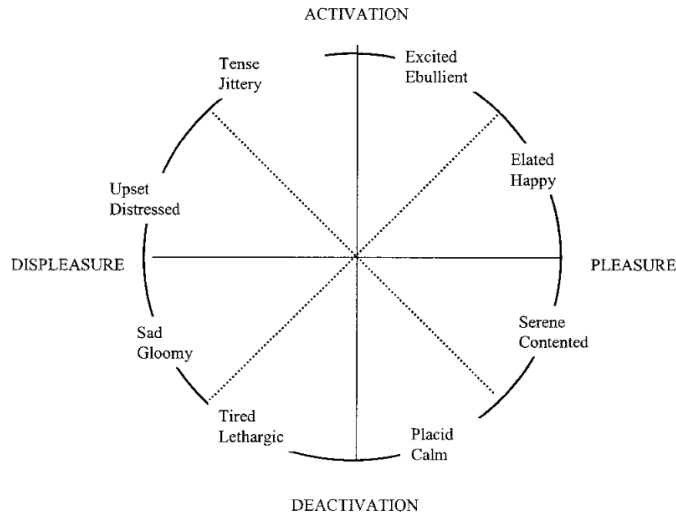


Figure 5: Core affect [41].

argue that discrete emotion categories (e.g., sadness, fear and anger) have no “reality” in that there are no specific brain regions or functions that correspond to specific emotions [7]. Dimensional theories do not emphasize the term emotion.

One of the two-dimensional models that are most prominent is Russell’s circumplex model [40]. Russell suggested that affective states are all related to each other systematically through what is called core affect [40, 41] (see Figure 5) and emotions are best described as a change in core affect which, in turn, is describable as a point in a space between two bipolar dimensions. One dimension is *valence* or how good or bad are objects and events for a being ranging from pleasant to unpleasant. The other dimension is *arousal*, ranging from calm to excited. Russell put a number of affective states around a circular space between those two dimensions (see Figure 5) which is also known as *circumplex*, representing the variety of core affects [40, 41]. Since sometimes two-dimensional space cannot easily differentiate among emotions that share the same values of arousal and valence, e.g., anger and fear (both characterized by high arousal and negative valence), some of the dimensional models incorporate valence and arousal as well as *intensity*, or *dominance* or *stance* dimensions. Many computational dimensional models build on the three dimensional PAD model of Mehrabian and Russell [33] where these dimensions correspond to pleasure (a measure of

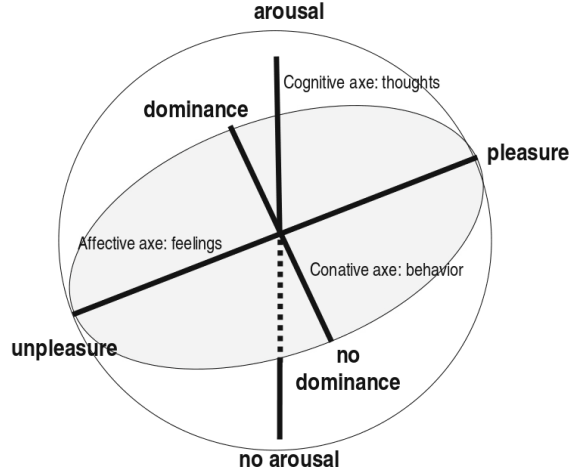


Figure 6: Three dimensional model of pleasure, arousal and dominance as tripartite view of experience [6].

valence), arousal (indicating the level of affective activation) and dominance (a measure of power or control). Figure 6 shows these three dimensions.

2.3 Basic (discrete) emotion theories

Basic emotion theories are inspired by Tomkins’ [53] rediscovery of Darwin’s work [10, 23] which later were developed by Ekman [13] and Izard [25]. These theories emphasize a small set of discrete and fundamental emotions. The underlying assumption of this approach is that these emotions are mediated by associated neural circuitry, with hardwired component [13]. Different emotions are then characterized by stable patterns of triggers, behavioral expression, and associated distinct subjective experiences. The emotions addressed by these theories are typically called the *basic* emotions. Emotions including happiness, sadness, fear, anger, surprise, and disgust are often considered to comprise the most prototypical basic emotions [13]. The theory of basic emotions holds that there is a set of emotions shared by all humans that evolved to deal with ancestral life challenges [13]. For instance, disgust evolved to deal with the challenge of avoiding noxious stimuli, and fear evolved to deal with the challenge of avoiding dangers. Because of the emphasis on discrete categories of states, this approach is also termed the *categorical* approach [35]. Much of the supporting evidence offered for the theory comes from experiments that show how certain facial expressions

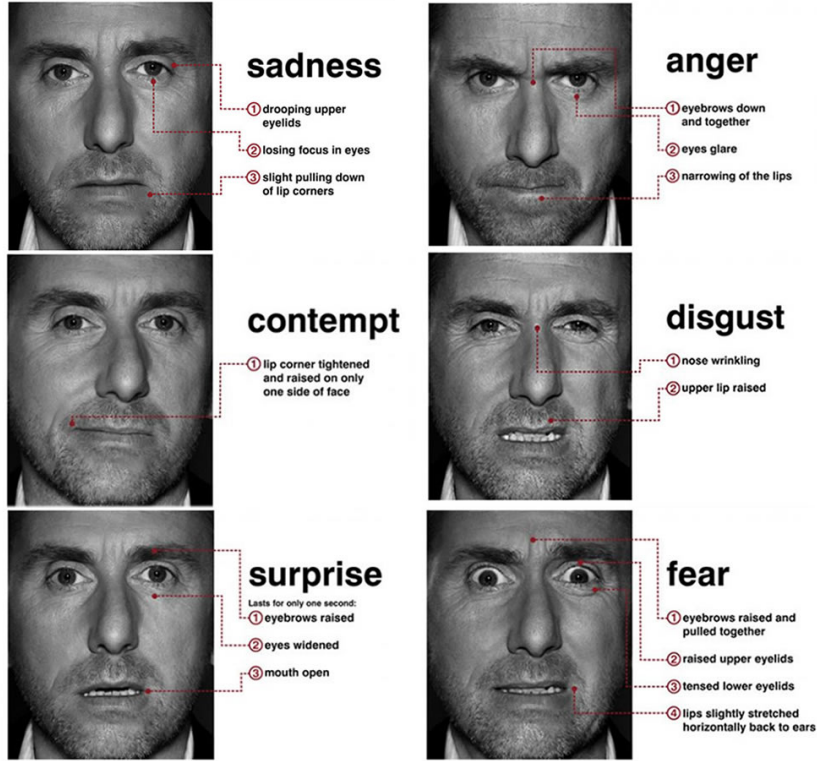


Figure 7: Basic emotions and corresponding expressions.

are universally associated with specific basic emotions, regardless of the observer's cultural background. This universality has a production side and a recognition side. On the production side, a particular emotional state is said to elicit a facial expression comprised of a fixed set of facial muscles. On the recognition side, observers are able to infer the emotional state of the person who expresses an emotion, due to the direct correspondence between emotional states and the facial expressions they cause. Computational models inspired by the basic emotions or discrete approach often focus on low-level perceptual-motor tasks and encode a two-process view of emotion that argues for a fast, automatic, undifferentiated emotional response and a slower, more differentiated response that relies on higher level reasoning processes (e.g., [4]).

2.4 Other Approaches

There are other approaches that different researchers take based on their emphasis on the applicability of emotions in their systems.

2.4.1 Rational Approaches

Rational approaches start from the question of what adaptive function does emotion serve and then attempt to incorporate these functions into a model of intelligence. Emotion, within this approach, is simply another set of processes and constraints that have adaptive value. Models of this sort are most naturally directed towards the goal of improving theories of machine intelligence [3] [50] [51].

2.4.2 Communicative Approaches

Communicative theories of emotion argue that emotion processes function as a communicative system. They can function first, as a mechanism for informing other individuals of one's mental state (thereby facilitate social coordination), and second, as a mechanism for requesting/demanding changes in the behavior of others. Communicative theories emphasize the social-communicative function of expressions [18]. Computational models inspired by communicative theories focus on machinery that decides when an emotional expression can have a desirable effect on a human counterpart.

3 Similarities and Differences

Different theoretical perspectives should not be viewed as competing for a single ground truth. They should be seen as distinct perspectives, each arising from a particular research area (e.g., biological vs. social psychology), focusing on different sets of affective phenomena, considering distinct levels of resolution and fundamental components (e.g., emotions vs. appraisal variables as the distinct primitives). These different perspectives also provide different degrees of support for the distinct processes of emotion, e.g., the componential theories provide extensive details about cognitive appraisals [24]. Therefore, I am going to provide a pairwise comparison between these fundamental theories.

3.1 Dimensional Vs. Discrete (Basic) Emotion Theories

The fundamental assumption of the basic emotion theory is that a specific type of event triggers a specific affect programme corresponding to one of the basic emotions and producing characteristic expression patterns and physiological response configurations [47]. Dimensional theory’s main criticism of basic emotions theory is based on the observation that affective phenomena appear to be both qualitatively and quantitatively diverse.

Russell in [41] argues the labels such as “fear”, “anger”, “happiness” do not capture this diversity. For instance, one might say: a) a person being chased by an assailant brandishing a knife, b) a person who retreats from an insect moving across the floor, and c) a person who is concerned they will never find a career that is fulfilling are all in a state of fear. On the basic emotions account, an emotional episode involves fixed patterns of neurophysiological and facial expression changes in response to an eliciting stimulus that are distinct between emotions, but are the same within the same emotional category [13]. If this were the case, one would expect that the three individuals described above would respond to their eliciting stimuli in the same way, yet the similarity of behavioral responses between these three cases seem unlikely. Dimensional theorists, in contrast, would argue that the individuals in the above three cases are applying the concept of fear to experience, despite the fact that each individual has a unique core affect. While basic emotion theorists would hold that since all three individuals are experiencing fear, they would perform the same behavioral responses to the stimuli, dimensional theorists would argue this is not the case, as each individual bears a core affective state that is distinguished from the other two. For instance, the individual’s arousal in response to an armed assailant should be higher than the individual in response to an insect, as the former case poses a threat to their life. As a result, the individual in the first case would likely make every effort to escape from the assailant, including trying to negotiate and plead with the assailant, while the individual in the second case would be relatively less dedicated to escaping the insect.

In sum, dimensional theory is compatible with the differences in the behavioral responses to eliciting stimuli, while basic emotions theory only allows for a single fixed behavior of responses to a given emotion. Furthermore, dimensional theories can represent instances of basic emotions (see Figure 8), for example, fear elicited by a snake (green rectangle), in terms of variation along affective dimensions, i.e., arousal and valence.

Also, basic emotion theory fails to account for affect that lacks object-directedness [41]. In basic emotions approach, an emotion is supposed to

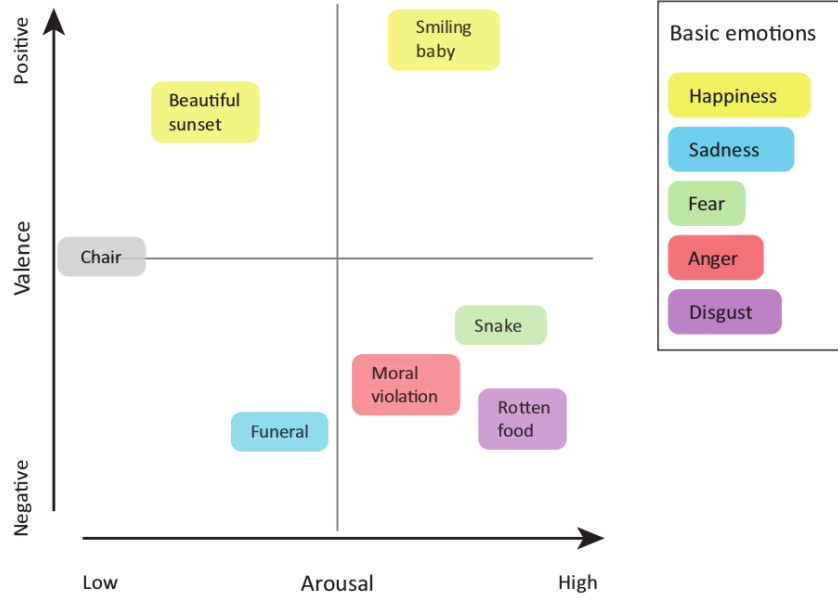


Figure 8: Representing basic emotions within a dimensional framework [21].

have an intentional object it is directed towards (e.g., being angry at someone, or being sad for someone). The dimensional theory argues that emotion may not necessarily be aimed at a particular object. For instance, an individual can experience a certain type of emotion (e.g., anger) without knowing of anything in particular that has offended them. Dimensional models of emotion are therefore capable of accounting for a wider range of affective phenomena than basic emotions theory.

Another difference between dimensional and basic emotion theories is that the basic emotion categorization of emotions captures facets of the experience of an emotion not conveyed by the dimensional description, such as elicitation of a facial expression of the emotion. In fact, this attribute of the basic emotions theory is one of the major differences with all other emotion theories. As it is argued in basic emotion theory, basic emotions are hard-wired to their corresponding facial expressions. Ekman who elaborated the concept of basic emotions, developed the *Facial Action Coding System* (FACS) which encodes movements of individual facial muscles and it is a common standard to systematically categorize the physical expression of emotions [14].

3.2 Appraisal Vs. Dimensional Emotions Theories

Dimensional theories might suffer to adequately distinguish emotions because of the existence of the limited dimensions.

To compare the appraisal and dimensional theories of emotion, we can argue that there is a relationship between the dimensions in the constructivist or dimensional theory of emotion and appraisal dimensions. For instance, the pleasure dimension roughly maps onto appraisal dimensions that characterize the valence of an appraisal-eliciting event (e.g., intrinsic pleasantness –desirability–, or goal congruence), dominance roughly maps onto the appraisal dimension of coping potential, and arousal can be considered as a measure of intensity. However, they also have quite different meanings. Appraisal (as I mentioned earlier) is a relational construct characterizing the relationship between some specific object/event in the environment and the individual’s mental constructs including beliefs, motives and intentions and several appraisals may be simultaneously active; whereas emotions in dimensional emotion theory are non-relational constructs, each summarizing a unique overall state of the individual.

Furthermore, dimensional emotion theories emphasize different components of emotion than appraisal theories and link these components quite differently. In contrast to appraisal theories, dimensional emotion theories do not address affects antecedents in detail. However, dimensional theorists question the tight causal linkage between appraisal and emotion that is central to appraisal accounts. As mentioned earlier, dimensional theorists believe that the emotion is not necessarily about some object (as in “I am angry at him”). In such theories, many factors may contribute to a change in emotion including intentional judgments (e.g., appraisal). However, in dimensional emotion theories the link between any preceding intentional meaning and emotion is broken and most of the time can not be recovered correctly. For example, Russell argues for the following sequence of emotional components: some external event occurs (e.g., a bear walks out of the forest), it is perceived in terms of its affective quality; this perception results in a crucial change in core affect; this change is attributed to some “object” (e.g., the bear); and only then is the object cognitively appraised in terms of its goal relevance, causal antecedents and future prospects [31].

We can also compare the dimensional emotion theories to OCC model as cognitive appraisal model. The major similarity between these two models is that they both consider emotions to descend from valenced reactions to the stimuli. Furthermore, they acknowledge the role of arousal in determining emotional reactions. As we mentioned in Section 2.2 Russell considered

arousal as one of the two key dimensions of emotions which could be used to partially discriminate emotional states [40]. In a different manner, the OCC model recognizes arousal as a necessary condition for eliciting emotions, and regards the arousal as a major determinant of emotions intensity which distinguishes among various emotions of a particular type (e.g., fearful and scared). In [45] Scherer speculates that arousal dimension in dimensional models gives little information about the underlying appraisal of the elicited emotion and he proposes to replace it with coping potential which is an appraisal dimension referring to individuals perceived control in a given situation.

Furthermore, models based on dimensional emotions theory pursue the idea of eliciting an emotion according to the joint features in circumplex space (2D or 3D – see Section 2.2) while OCC or other models of appraisal theory are based on patterns of antecedent of emotions. This is the fundamental difference between OCC, or appraisal theories in general, and the circumplex approach of Russell [40] or Mehrabian’s PAD model [6, 33]. Also, models based on appraisal theory of emotion employ causation, attribution and eliciting conditions in order to distinguish emotions while the eliciting conditions are not directly accessible from dimensional approach. A dimensional model might fall short in establishing why certain emotions are elicited. However, when the objective is to identify the generated emotions and their level of pleasantness and intensity, circumplex model brings about a perfect opportunity [2].

Finally, here, I discuss how a model based on dimensional emotions theory (i.e., Russell’s 2D circumplex) relates to a cognitive model based on appraisal theory (i.e., OCC model). Figure 9 shows the relationship between Russell’s circumplex and OCC model in terms of categorization of the actual emotions. The number of emotions in a section of Russell’s circumplex that fall into an emotion group of OCC are shown in parentheses (see Figure 9). For instance, all three emotions on the top section (highly excited, neutrally valenced emotions) fall into prospect based emotion group, hence number (3) is indicated. Or, as another example, emotions in the left section (neutral arousal value, negative valenced emotions) make a one to one relationship between disappointment and prospect based emotion group, contempt and attribution emotion group, and jealousy and fortune of others emotion group, hence number (1) is indicated in front of each.

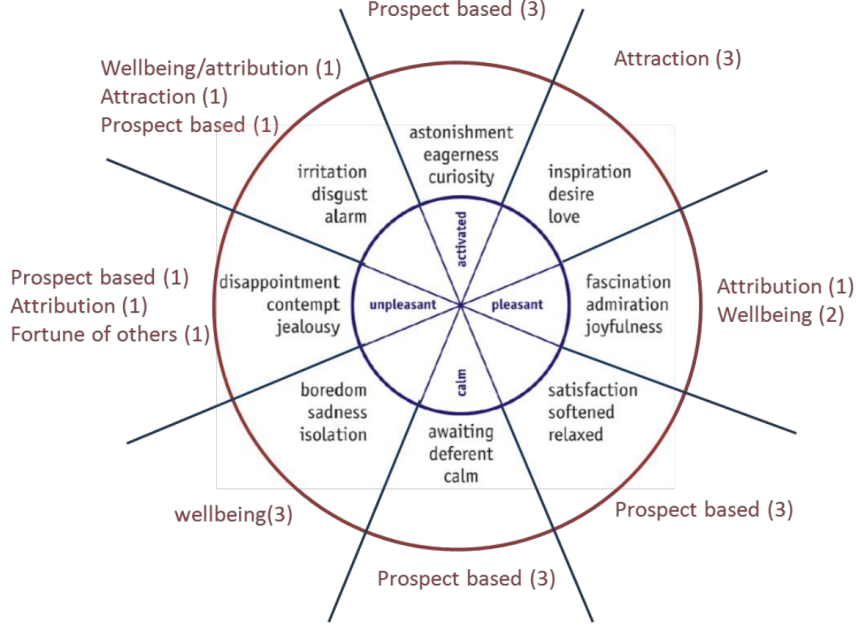


Figure 9: A rough projection of emotion groups of OCC on the circumplex of affect [2].

4 Applications in Autonomous Agents and Robots

There are several examples in artificial intelligence and robotics of applying emotion theories such as appraisal theory [1, 26, 32]. In [42] authors describe a system approach to appraisal processes based on Scherer’s work on appraisal and the Component Process Model (CPM) [43]. They show how the temporal unfolding of emotions can be experimentally tested. They lay out a general domain-independent computational model of appraisal and coping.

Models derived from appraisal theories of emotion, not surprisingly, emphasize appraisal as the central process to be modeled. Computational appraisal models often encode elaborate mechanisms for deriving appraisal variables such as decision-theoretic plans (Gratch and Marsella, 2004a, Marsella and Gratch, 2009), reactive plans (Rank and Petta, 2005, Neal Reilly, 2006, Staller and Petta, 2001), Markov-decision processes (El Nasr et al., 2000, Si et al., 2008), or detailed cognitive models (Marinier et al., 2009). Emotion itself is often less elaborately modeled. It is sometimes treated simply as

a label (sometimes with an intensity) to which behavior can be attached (Elliott, 1992). Appraisal is typically modeled as the cause of emotion with specific emotion label being derived via if-then rules on a set of appraisal variables. Some approaches make a distinction between a specific emotion instance (allowing multiple instances to be derived from the same event) and a more generalized affective state or mood (see discussion of core affect, below) that summarizes the effect of recent emotion elicitations (Neal Reilly, 1996, Gratch and Marsella, 2004a, Gebhard, 2005). Some more recent models attempt to model the impact of momentary emotion and mood on the appraisal process (Gebhard, 2005, Paiva et al., 2005, Marsella and Gratch, 2009, Gratch and Marsella, 2004a).

Computational appraisal models have been applied to a variety of uses including contributions to psychology, AI and HCI. For example, Marsella and Gratch have used EMA to generate specific predictions about how human subjects will appraise and cope with emotional situations and argue that empirical tests of these predictions have implications for psychological appraisal theory (Gratch et al., 2009b, Marsella et al., 2009). Several authors have argued that appraisal processes would be required by any intelligent agent that must operate in real-time, ill-structured, multi-agent environments (e.g., Staller and Petta, 2001). The bulk of application of these techniques, however, has been for HCI applications, primarily for the creation of real-time interactive characters that exhibit emotions in order to make these characters more compelling (e.g., Neal Reilly, 1996), more realistic (e.g., Traum et al., 2003, Mao and Gratch, 2006), more able to understand human motivational state (e.g., Conati and MacLaren, 2004) or more able to induce desirable social effects in human users (e.g., Paiva et al., 2005).

Models influenced by dimensional theories, not surprisingly, emphasize processes associated with core affect and other components (e.g., appraisal) tend to be less elaborately developed. Core affect is typically represented as a continuous time-varying process that is represented at a given period of time by a point in 3-space that is pushed around by eliciting events. Computational dimensional models often have detailed mechanisms for how this point changes over time – e.g., decay to some resting state – and incorporating the impact of dispositional tendencies such as personality or temperament (Gebhard, 2005).

Computational dimensional models are most often used for animated character behavior generation, perhaps because it translates emotion into a small number of continuous dimensions that can be readily mapped to continuous features of behavior such as the spatial extent of a gesture. For

example, PAD models describe all behavior in terms of only three dimensions whereas modelers using appraisal models must either associate behaviors with a larger number of appraisal dimensions [48] [52] or map appraisals into a small number of discrete, though perhaps intensity-varying, expressions [15]. For a similar reason, dimensional models also frequently used as a good representational framework for systems that attempt to recognize human emotional behavior and there is some evidence that they may better discriminate user affective states than approaches that rely on discrete labels [7].

The relationship between core affect and cognition is generally less explored in dimensional approaches. Typically the connection between emotion-eliciting events and current core-affective state is not maintained, consistent with Russells view of emotion as a non-intentional state (e.g., Becker-Asano and Wachsmuth, 2008). Interestingly, we are not aware of any computational models that follow the suggestion from Zajonc and Russell that appraisal is a post hoc explanation of core affect. Rather, many computational models of emotion that incorporate core affect have viewed appraisal as the mechanism that initiates changes to core affect. For example Gebhards (2005) ALMA model includes Ortony, Clore and Collins (1988) inspired appraisal rules and WASABI (Becker-Asano and Wachsmuth, 2008) incorporates appraisal processes inspired by Scherers sequential-checking theory into a PAD-based model of core affect. Some computational models explore how core affect can influence cognitive processes. For example, HOTCO 2 (Thagard, 2003) allow explanations to be biased by dimensional affect (in this case, a one-dimensional model encoding valence) but this is more naturally seen as the consequence of emotion on cognition (e.g., the modeling of an emotion-focused coping strategy in the sense of Lazarus, 1991).

5 Conclusion

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