Emotions Are Physical and Cognitive

How do you recognize another person's emotional state? What is it about their face, their voice, their gait, or other mannerisms and behaviors that communicate how they feel? What are the links between someone's emotions and what their body expresses? How reliable, or how universal, are physiological measurements such as heart rate and skin conductivity as indicators of mood or emotion? What is the difference between mood and emotion? What causes emotions, and how do they influence decisions and behavior? How do you know if someone "likes" someone or something? How are emotions "induced"? Are emotions purely "cognitive" like thoughts, purely "physical" like the pounding of a heart, or some kind of combination? Why do we need emotions? These are a handful of the questions that arise when considering how computers might recognize, express, and "have" emotions. Unfortunately, the literature on emotion and cognition has no clear answers to most of these questions; in fact, emotion theorists still do not agree even on a definition of emotion. Nearly a hundred definitions of emotion have been recorded and categorized (Kleinman and Kleinman, 1981).

It is tempting to entirely avoid the word "emotion" since it is so imprecise. However, avoidance is an extreme position since ill-defined words can still be very useful. To quote John McCarthy, "We can't define Mt. Everest precisely—whether or not a particular rock or piece of ice is or isn't part of it; but it is true, without qualification, that Edmund Hillary and Tenzing Norgay climbed it in 1953. In other words, we can base solid facts and knowledge on structures that are themselves imprecisely defined." Given that most people's intuitive concept of emotion is well-established and that the word remains in broad use, I will continue to use the word and base solid facts and knowledge upon it.

There is a wealth of literature overviewing theories in emotion and cognition, including Plutchik and Kellerman's (1980-1990) edited collections of
research on emotion, as well as several other books by prominent emotion theorists that set forth their own theories as well as provide general backgrounds (Bock, 1984; Mandler, 1984; Frijda, 1986; Lazarus, 1991). This book will not repeat the efforts of these extensive resources. However, the reader is also not assumed to be familiar with emotion theory. Instead, this chapter distills the issues necessary to provide a background for the development of affective computing. The sections below clarify terminology to be used in this book, and provide background material for those unacquainted with emotion theory. The focus will be on the issues most relevant to giving computers affective abilities.

**Physical vs. Cognitive**

The myriad theories on emotion can be largely examined in terms of two components: 1) emotions are cognitive, emphasizing their mental component; and 2) emotions are physical, emphasizing their bodily component. Research on the cognitive component focuses on understanding the situations that give rise to emotions; for example, "That was an important goal to me and you prevented me attaining it; therefore, I am angry." Numerous "cognitive appraisal theories" exist to delineate which mental appraisals give rise to which emotions; I will say more about these in Chapter 7, since a few of them have inspired computer implementations. Historically, the focus on the brain-centered aspects of emotion is attributed to Walter Cannon, who emphasized that emotion is experienced centrally by the brain, and that its experience is possible without sensations of or from the body (Cannon, 1927).

Research on the physical component emphasizes the physiological response that co-occurs with an emotion or rapidly follows it. Historically, William James was the major proponent of emotion as an experience of bodily changes, such as your heart rate increasing or your hands perspiring (James, 1890). This view was challenged by Cannon and again much later by Schachter and Singer who argued that the experience of physiological changes was not sufficient to discriminate emotions. Schachter and Singer conducted experiments that induced the same state of bodily arousal in subjects, but placed the subjects in different situations. The subjects reported different moods afterward. Schachter and Singer argued that physiological responses such as sweaty palms and a rapid heart beat inform our brain that we are aroused, and that then the brain must approximate the situation we are in before it can label the state with an emotion such as fear or love (Schachter, 1964).

Today we know that both brain and body interact in the generation of emotion and its experience. Not only can thoughts lead to emotions, but emotions can occur without obvious cognitive evaluation, such as by changes in bodily chemistry. Moreover, there is growing evidence that emotions can be discriminated by distinct physical signatures (Ekman, Levenson, and Friesen, 1983; Winton, Putnam and Krauss, 1984; Frijda, 1986; Cacioppo and Tassinary, 1990; Levenson, 1992; Scherer, 1993; Viana, 1993). Bradley, Cuthbert, and Lang, 1996). The viewpoints on the relative importance of the physical or cognitive components today depend largely on how "cognitive" and "physical" are defined. At the root of the division is a debate rooted in Descartes' separation of mind and body—where thoughts, and often the brain, are treated separately from the rest of the body. In this book I will emphasize emotions in both mind and body, and the role of both physical and cognitive components for affective computing.

The distinction—are emotions physical first or cognitive first—is not as important to us as the question, "How can emotions be generated in computers, recognized by computers, and expressed by computers?" What is the mapping that connects the emotion that you are cognitively or physically experiencing to the way in which it is expressed to others? In particular, there are usually visible or audible signs of emotion. If a computer is trying to recognize or understand your emotion, it should be able to get information not just from you telling it the name of your emotion, but also from looking at your face, listening to your voice, noticing your gestures, and appraising the situation you are in. The development of affective computers requires understanding of both physical and cognitive components of emotion.

**The Wheelchair Scenario**

Rafe's friends always describe him as a happy person. He likes to play tennis and finds great enjoyment in watching the top professionals play the game. After watching his favorite player win in the semifinals of a grand prize tennis tournament, Rafe contentedly stood in line under a hot August sun waiting to get a cool drink. As the glow of his victorious victory faded, the heat and humidity became more and more oppressive. Suddenly, Rafe felt a piercing pain from a blow to his lower back. Rafe turned rapidly with an angry expression and clenched fist. Rafe saw that he had been hit by Rebecca, a person with hemiplegia whose wheelchair had gone out of control and caused her to crash into Rafe and to spill her drink on her dress. Rafe's understanding that the cause of his pain was an uncontrollable event that had embarassed Rebecca immediately changed his anger to sadness and sympathy. Though still in pain, his happy nature surfaced, and he began helping Rebecca recover from the incident.

In this scenario, there are a variety of factors that activate Rafe's emotions. They include bodily responses to heat, humility, and pain, as well as cognitive responses such as the appraisal that the collision was unintentional and now presented an opportunity to help Rebecca.
Note that it is possible to fiddle with semantics and erase these distinctive causes—for example, one could argue that cognitive responses include all responses of the brain, which includes neurophysiological controls and subconscious appraisal mechanisms, and therefore all emotions are cognitive. On the other hand, one could argue that all cognitive events reduce to physiological events, and therefore all thoughts and emotions are purely physiological. What is clear however, is that emotions can be caused by thoughts and they can be caused by physical mechanisms of which we are not conscious. One can emphasize both cognitive and physical aspects of emotion. In this chapter, I’ll consider the two components separately—first, the physical, and second the cognitive. This division is not precise, and the terms “physical” and “cognitive” are deliberately not carefully defined, but are used in their most common senses.

**Terminology**

Before proceeding, it is helpful to clarify a few pieces of terminology: “Emotional” and “affective” will be used interchangeably as adjectives describing either physical or cognitive components of emotion, although “affective” will sometimes be used in a broader sense than “emotional.” I will occasionally use the adjective sentic from the Latin sentire, the root of the words “sentiment” and “sensation,” interchangeably with the adjectives emotional and affective, especially when I emphasize physical mechanisms of emotion expression. “Sentic” was coined by Marder Clynes (Clynes, 1977), a pioneer in linking emotional states to physical measurement.

An emotional state refers to your internal dynamics when you have an emotion. The state is multi-variate—including aspects of both your mental state and physical state. It changes with time and with a variety of other activating and conditioning factors. Emotional state cannot be directly observed by another person, but may be inferred. In the wheelchair scenario when Rafe was standing in line, the strangers next to him could not reliably guess his emotional state. However, when he turned around with clenched fists, they could infer that he was in a state of anger.

An emotional experience refers to all you consciously perceive of your own emotional state. In the wheelchair scenario, Rafe’s emotional experiences probably included contentment, mild distress, anger, sympathy, and happiness. Some authors equate emotional experience with emotional “feelings.” However, sometimes the word “feelings” is used strictly for sensory stimuli, e.g., feeling a slimy surface or a pinprick. To add to the confusion, some theorists lump feelings such as hunger and pain in with emotions, while others distinguish feelings such as hunger as “drivers” and feelings such as pain as “sensations.” This book will not treat hunger or pain as emotions, but will recognize that they can influence the activation of emotional states. For example, hunger can increase irritability, and pain can spur anger. Generally, the term “feelings” refers to not just sensations as of pain and hunger, but also to subjective experience of affective phenomenon, which will become an important topic later in this book.

The term emotional expression will be used to describe what is revealed to others, either voluntarily, such as by a deliberate smile, or involuntarily, such as by a nervous twitch. Emotional expression via the motor system or other bodily systems, or “sentic modulation,” is usually involuntary, and provides clues that others may observe to guess your emotional state.

Finally, the term mood, although defined in many different ways in the literature, will be used to refer to a longer-term affective state. The precise duration is not well-defined, although moods can apparently last for hours, days, and maybe longer. In contrast, psychologists say that emotions are events that last at most a few minutes. A mood may arise when an emotion is repeatedly activated, for example a bad mood may arise during a half hour of reinforced negative thoughts or actions, or may be induced by taking drugs or medications.

**Physical Aspects of Emotion: Sentic Modulation**

The emotional character is expressed by a specific subtle modulation of the motor action involved which corresponds precisely to the demands of the sentic state.

—Marder Clynes, in Sentic (1977)

A bodily component of emotions is accepted by most theorists today, although they differ on its nature. In particular, William James’s 1890 view of this response being the emotion is not generally accepted today. Nonetheless, the motor system acts as a carrier for expressing emotional state. The influence of emotion on bodily expression is what I’ll call “sentic modulation.”

Sentic modulation, such as voice inflection, facial expression, and posture, is the physical means by which an emotional state is typically expressed, and is the primary means of communicating human emotion. In fact, few people are good at articulating their emotional state, but expressing it through sentic modulation is natural, and usually subconscious. A number of emotion and cognition theorists have studied the physiological correlates of emotions, arguing that each emotion probably has its own unique somatic response pattern. Paul Ekman, the foremost authority on facial expressions, has argued that there are “basic” emotions, each of which has its own set of unique facial muscle movement patterns (Ekman, 1992).
If computers are to utilize the natural channels of emotional communication used by people, then when computers learn to recognize human emotion, they will have to rely primarily on sentic modulation, as opposed to having people explicitly tell them the names of their emotional feelings. To give computers affect recognition requires understanding the physical manifestations of emotion.

Facial Expression
Facial expressions are one of the most widely acknowledged forms of sentic modulation. Beethoven, after he became deaf, wrote in his conversation books that he could judge from the performer’s facial expression whether or not the performer was interpreting his music in the right spirit. The face is where our eyes linger during conversation. In a videoteleconference, where the camera is free to point anywhere, the default is to have it point to the faces of the people in the room. Whether by person or over a videotelephone, we tend to communicate most affectively “face-to-face.”

Facial expressions are subject to what Ekman has termed “social display rules” that limit the range of acceptable expression, such as in business or social settings. For example, it is inappropriate for a businessman to contort his face in extreme disgust or disappointment during a negotiation session. In serious meetings he knows to express only mild emotion, regardless of his feelings. However, at a sporting event the social display rules are different. There he is not only free to contort his face, but also to vociferate, to wave his arms and torso, and to jump up and down.

In his 1862 thesis, Duchenne identified independent expressive muscles in the face, such as the muscle of attention, muscle of lust, muscle of disdain or doubt, and muscle of joy (Duchenne, 1990). Based on his work, Ekman and his colleagues have developed a “Facial Action Coding System,” that provides mappings between muscles and an emotion space. Presently, most attempts to automate recognition of facial expression are based on Ekman’s system. Some of the latest results in this area will be described in the second part of this book.

Vocal Intonation
The second widely acknowledged form of sentic modulation is vocal modulation. Emotions in speech can be understood by young children before they can understand what is being said (van Boesvoo, 1984). Dogs can recognize vocal affect, even though they presumably cannot understand what is being said. If Fido is on the sofa and you yell angrily, “Get down off the sofa!” he may not only get down, but he will probably acknowledge the emotion physically, with the position of his ears, tail, and head. The same behavior will likely result if, when he is on the sofa, you yell with the same angry tone of voice, “Get up on the sofa!” Voice, of course, is why the phone tends to communicate affective information more accurately than email or a written letter. Spoken communication transcends the message of the words—alerting the listener to states such as anxiety, nervousness, or love.

Most emphasis on computers and speech has focused on teaching computers to understand what is said. More recently, researchers have focused on teaching the computer to recognize who is speaking. The challenge for affective computers is to understand how something is said. In fact, often it is not what is said that is most important, but how it is said.

Vocal Inflection is also important in applications where people and computers depend upon the use of synthetic voices. Many people who have lost the ability to speak rely on typing at a computer, and having the computer synthesize speech for them. However, they are still handicapped when it comes to being able to raise their voice in anger when anger peaks during an argument, or soften it lovingly when they feel loving. Their synthetic voices are much more useful if they include affective intonation. It would be especially beneficial if the computer could directly sense the typist’s affect, and modulate the synthetic speech accordingly. Some early results getting computers to synthesize and recognize affective expression in speech will be presented in the second part of this book.
Motor Forms of Expression

Alternate forms of sentient modulation have been explored by Clynes (1977). One of his principles, that of "sentient equivalence," allows a person to select an arbitrary motor output of sufficient degrees of freedom for expressing emotion. For example, a device called a "sentograph" measures pressure along two degrees of freedom—vertical pressure and horizontal deflection—from a person pushing a finger on the device while expressing an emotion. Measurements of these two pressure signals represent an "essentic form," a precise spatiotemporal form produced by the nervous system, which carries the emotional message.

A note on "essentic form" is appropriate, as the work of Clynes is controversial among psychologists. What is it in a piece of music that makes it sound sad to listeners? Or in a piece of animation that makes it tender, joyful, touching? Clynes has suggested that there is a spatiotemporal form, with clear beginning and end, that embodies the emotional message. It can exist in a human's movement, in a piece of music or art, or in a variety of forms. In sentient modulation, the essentic form is captured from various motor system outputs—a finger moving, a foot moving, whatever can express sufficient degrees of freedom. Through essentic forms, emotions can be communicated by many means, not just facial and vocal expression.

The motor output explored most carefully by Clynes is the transient pressure of a finger during emotional expression. In these experiments the subject deliberately expresses an emotional state by pressing against a measuring surface while experiencing that state. The person does not feel the surface move, but a sensor underneath the surface records pressure changes horizontally and vertically. The person repeatedly expresses a given emotion, pressing upon the device with each expression, as the felt emotion builds in intensity. The resulting pressure traces are hypothesized to be indicative of an underlying essentic form, the carrier of the emotional message. To emphasize the existence of an underlying form, independent of the channel of expression, Clynes measured other channels of motor output. For example, he measured also foot pressure and chin pressure, the latter for a patient who was paralyzed from the neck down. These different channels of motor expression revealed comparable characteristic essentic forms.

Although this form of emotional expression is contrived in the sense that it is not a natural form of communication that people usually use, nonetheless it has been measured for thousands of people and found to provide repeatedly stable distinct traces for states such as no emotion, anger, hate, grief, love, joy, sex, and reverence (Clynes, 1977). The repeatability holds across groups of individuals, and to some extent, cultures. People who observed the forearm and hand of someone expressing emotion with the sentograph recognized which emotion was being expressed with significantly higher than chance probability. It should be emphasized that the pressure curves are made with deliberate expression, as frequently done in experiments where an actor or actress is asked to express an emotion. The person is consciously and willingly trying to feel and communicate the particular emotional state, while applying pressure to the recording device. Hence, this factor may influence the results, as deliberate expression can differ from spontaneous or naturally generated expression, although to the extent that physiological feedback is at work, these distinctions become blurred.

Other Physiological Responses

There are many physiological responses that vary with time and that might potentially be combined to assist in recognition of emotional states. These include heart rate, diastolic and systolic blood pressure, pulse, pupillary dilation, respiration, skin conductance and color, and temperature. The most commonly measured of these are summarized in Table 1.1. These forms of sentient modulation will be revisited later in this book in discussions about computer recognition of affect, particularly when the computers are "wearable." Wearable computers can be in long-term physical contact with a person.

Here are some examples how emotions can map to physical expression: Given that a person is experiencing an emotion, e.g., hate, then sentient modulation may result in a tense voice, glaring expression, or finger pressure strongly away from the body. Respiration rate and heart rate may also increase. In contrast, given feelings of joy, the voice might go up in pitch, the face reveal a smile, and the finger pressure have a slight bounce-like character. Even the more complex "self-conscious" emotions, such as guilt and shame, exhibit marked postural differences that might be observed in how you stand, walk, gesture, or otherwise behave (Lewis, 1995). A state of interest is indicated by gestures such as leaning toward the person or object of interest, and by less-easily controlled responses such as pupillary dilation.

The physiological influences of emotion have many implications other than for emotional expression. It has long been known anecdotally that depression, chronic anger, anxiety, and stress influence your body; in particular, increasing the likelihood that you get sick. Many a student has noticed that they become ill the week after exams. More recently, there have been a variety of scientific studies not only confirming these influences of emotion, but highlighting how negative emotions can hinder the functioning of the immune system, suppressing the body's ability to fight off infection or disease and impeding its ability to heal itself. Researchers in the new medical field of psychoneuroimmunology have found mechanisms whereby emotion directly influences the immune system, neurochemically, as well as through
regulation of the autonomic nervous system, which has been found to directly interact with the cells of the immune system such as lymphocytes and macrophages. Hormones that are released during stress have also been found to impact immune cells. There is no evidence that affect can make you sick, but there is evidence that it strongly influences your body's effectiveness in warding off and recovering from illness.9

Affective computers equipped with cameras, microphones, physiological sensors, and sophisticated pattern recognition tools, can begin to recognize physiological components of emotion, and to infer the likely emotional state underlying these components. Although such tools cannot yet directly measure the impact of emotions on other bodily systems such as the immune system, they can begin to provide information about emotions that would aid in many applications, including preventive medicine. This is likely despite the lack of a solid definition of emotions, and the lack of a universal theory of how people respond physically when experiencing emotions. I will discuss these issues further below. First, let us consider some of the physiological factors that complicate the development of affective computing.

Complicating Conditions: Physical Aspects of Emotion

Computers and people would have a relatively easy time recognizing emotions if they were always displayed in a consistent way. However, this is not the case. Most emotions do not map to a fixed form of sentic modulation all the time. The good news in the Cybex experiments above are obtained when the person is freely expressing the emotion, repeatedly, in a relaxed context, where the intensity of the emotion is being strengthened and the state is relatively pure. Under ordinary human-human or human-computer interaction, the possibilities are much more varied.

Studies attempting to associate bodily response with emotional state are complicated by a number of factors that influence the mapping between an emotion and how it is expressed:

1. Intensity of the emotion;
2. Type of the emotion, e.g., there are many types of love;
3. How the state was induced, e.g., imagining a situation, watching a film, or being in the midst of a genuine conflict;
4. Social display rules, and whether the person was encouraged to express or suppress emotion.

For example, claims that people can experience emotions such as love cognitively, without a corresponding physiological response (such as increased heart rate) may be due to it only being a weak feeling induced in a laboratory by asking the subject to think of an object of affection.

Mappings of emotion to physical expression are tricky partly because of the many ways in which emotions are defined. Some theorists do not consider "love" to be a basic emotion because it does not elicit a characteristic facial expression. Others define emotions to include the mildest thoughts, such as "He failed to show, therefore he let me down," even if they are not accompanied by a bodily feeling, e.g., of disappointment.

Another complicating factor is that physiological responses similar to those in an emotional state can arise without corresponding to an emotion. For example, heart rate increases when exercising. In theory, these responses can be disambiguated by perceiving the context of the situation. For example, a wearable computer that is trying to measure emotions might also have a miniature camera and other sensors attached, such as for footprint rate, so that it can recognize (1) you are moving fast, and (2) this is the time of day you usually go for a jog. Activities that are common to your daily routine can be designed into the affective recognition model as conditioning variables.

Hormones, medications, and diet present additional complicating variables, as all of these can modulate mood changes. These factors are difficult to monitor without blood-sampling or other invasive methods. A person may wake up feeling angry, and yet have cognitive thoughts such as, "Why do I feel so angry? I'm not angry at anything; everything is going quite fine." She may continue to feel irritable, tense, prone to negative thoughts, and inclined to lash out at small things. The angry feeling can be caused by a recent biochemical change; pre-menstrual hormone changes are one common example. Similarly, diet, sleep, and drugs affect neurotransmitter levels and mood.10

To further complicate the matter, a mood-state cues memories that are consistent with that mood: positive moods tend to make it easier to remember positive things, and negative moods tend to make it easier to remember negative things. If groups of people are asked to learn a list of positive and negative words, then those who are in a good mood at the time of retrieval have significantly better recall of the positive words. The positive result is not as significant, perhaps because positive mood retrieval of negative words reinforces a negative mood, which is not as desirable as reinforcing a positive mood.11 Emotions influence cognition, and cognition influences emotions. Apparently, a good mood and its corresponding physiological state bias a person toward good thoughts, which may trigger good emotions and cause the good mood to endure.

Some theorists have treated physiological changes solely as consequences or concomitants of emotional states, and it is certainly the case that cognitive thoughts can arouse emotions that lead to physiological changes. However, the opposite is also true—emotional responses can trigger bodily changes before signaling the cortex, before we are consciously aware of any emotional
state. The work of LeDoux and others has demonstrated that subcortical pathways can activate emotions and their bodily expression independently of the neocortex. The pathways to the limbic structure of the amygdala and the amygdala's initiation of a bodily response happen before the first signals arrive in the cortex. In particular, the neurological evidence supports the conclusion that emotions can "hijack" the cognitive centers of the brain, such as when you jump out of the way in fear, only to realize later that it was nothing to be afraid of. This quick and dirty mechanism may often be an error, causing a false alarm, but it has the advantage of getting you out of the way of danger, which justifies the high false alarm rate.

"Person-independent" Emotion Recognition

One of the outstanding problems in trying to recognize emotions is that different individuals may express the same emotion differently. Patterns of expression vary in many ways—for example, one person's feet may perspire when he is nervous, while another person's hands may perspire. Temperament and personality give clues to these patterns of expression. Extroverts tend to be more expressive than introverts. Extroverts in the United States speak with a louder voice and fewer hesitations than do American introverts. Adults and children who show the most facial expressions have lower skin conductivity responses. Facially expressive newborns show evidence of lower arousal on heart rate measures than do less expressive infants.

Expressive patterns also depend on gender, context, and social and cultural expectations. Adult women are more expressive than adult men in studies where they are shown slides and observed with a hidden camera. Children are more expressive in front of a hidden camera than when they are aware that an observer is present, and they are least expressive with anger and fear, two less socially acceptable emotions.

In other words, given that a particular emotion is felt, a variety of factors influence how the emotion is displayed. Ekman writes, "The site qua non for emotion should not be a unique pan-cultural signal" (Ekman, 1993). The present lack of consistent universal patterning mechanisms may appear to dim the outlook for constructing computers that can recognize affect. How can a machine be expected to recognize emotions if everyone expresses them differently?

This situation parallels that of another classic signal-processing problem, the problem of constructing "speaker-independent" speech recognition systems. I propose that it can be solved in a similar way. The goal of speaker-independent systems is to recognize what was said regardless of who said it. Even among people who use the same language, this goal is complicated by the fact that two people saying the same sentence produce different sound signals. They may have a different accent, different pitch, and other differing qualities to their speech. The computer has difficulty separating the language part of the signal from the part of the signal that identifies the speaker and his or her expression. Consequently, the computer has a hard time recognizing what was said unless it was trained on the individual speaker, or on someone who sounds like that speaker.

Although it would be a terrific accomplishment to solve this universal recognition problem, it is unnecessary. Nicholas Negroponte pointed out years ago that an alternative solution is to solve the problem in a speaker-dependent way, so that your personal computer can understand you and your language; thereafter, your computer can translate what you said to the rest of the world. Now that personal computers are becoming smaller and able to be with you all the time, this is becoming a viable solution. Therefore, experiments in recognizing emotional states from observations of physical expression only need to demonstrate consistent patterning for an individual in a given perceivable context. In many applications it is only necessary that your personal computer be able to recognize your affect; it can then translate this information to others if you wish.

The individual's personal computer will respond best if it is also able to perceive context—sense if you're climbing stairs, if the room temperature changed, or if you just read a news story about a tragic bombing. In other words, an affective computer will be more effective if it is also a perceptual computer. The computer can therefore identify autonomic responses conditioned on perceivable factors. For best performance, perceivable context should ultimately include not only the public milieu such as the comfort index of the weather, but also the private milieu—for example, the information that you have family in the town where the earthquake just happened.

For example, affect recognition for one context, such as commuting home, may be most reliable if it considers measures of blood flow and heart rate for one person, and measures of skin temperature, electrodermal response, and respiration for another person. These might change for an individual when the context changes, such as once they are home. Everyone need not be the same—it is only necessary that an individual respond relatively consistently under the same circumstances.

The affect recognition problem can be posed as a computer learning and pattern recognition problem, to determine which features are the best predictors for each individual, for each context. Moreover, we can expect that there will often be similarities across individuals, just like some people's voices sound similar, and across certain contexts. As reliable features are learned for individuals, they can be used to cluster individuals into categories based on
similar features. A "universal" recognizer then would first ask "Which category is this person most similar to?" In speech, this might be likened to asking who sounds like this—both accent-wise and voice-quality wise? Subsequently, a recognizer can be used that was trained on the prototype person for that category. A benefit of this approach is that it is also likely to reveal categories of affective expression that theorists have not yet identified. Another benefit arises from this "lack of universality" problem. Some people will not want their emotions to be recognized except by those people or computers with whom they have a good relationship, i.e., those whom they know well, and who know them well. We are all acquainted with the phenomenon of having to spend some time interacting with someone before we figure out their sense of humor or, more subtly, before we learn how to tell if they are pleased or upset. If everyone communicated these emotions in the same way all the time, then emotions would be easy to recognize. Although some emotions do appear to be universally communicated on faces, all emotions are not communicated the same way by all people. We appear to be best at recognizing emotions in those people that we know well. However, even with close friends, people are not 100% accurate at recognition. Expecting perfect recognition from computers would also be foolish; however, we should expect them to be better than random, and certainly better than they are presently.

Studies out of the Laboratory

The complications noted above have particularly plagued laboratory studies of human emotion. For example, certain subjects might feel inhibited about expressing disgust or sadness during a laboratory study. Other subjects might find the situations in the study contrived, and exhibit a much smaller repertoire of emotions than they would experience in their natural world. Or, they might express emotions they think they should express, instead of letting them arise "naturally." The ability to express emotions is believed to differ among subjects, Actors and musicians, for whom expressing emotions is part of their profession, show some of the greatest fluidity in expression. Most studies on emotion and cognition have been confined to artificial lab scenarios, where they have been severely limited. Not only have they been limited by the environmental context of being in a laboratory, but they have focused on finding universal human patterns of expression rather than finding personal patterns. It is no surprise, therefore, that their results about how emotions map to expressions have been mixed.

Affective computers that read sentic modulation and infer underlying emotions can in theory help fix these problems. As the computers become lightweight and wearable, they can measure emotional responses wherever and whenever they occur, both for individuals and for larger groups. Affective computing allows the laboratory to visit the subject, instead of the other way around. The engineering details are not all solved yet; affective computers are in their infancy. However, this book will describe the steps toward their development, steps that should also lead to greater progress in understanding emotions.

Cognitive Aspects of Emotion

Now, let us consider the other side of emotion: its cognitive aspects. Both fast-track experience and scientific studies indicate that cognitive appraisal can precede the generation of emotions. In the first scenario of this book, "waiting for a colleague," the tardy person's facial expression was appraised before an emotional response was selected. Similarly, in the wheelchair scenario, Rafe's cognitive assessment of Rebecca's accident caused him to change his anger to sympathy. In America in the late 80's, Bobby McFerrin's song, "Don't worry, be happy," filled the airwaves. All of these examples illustrate the message that thoughts can change emotions. In general, the influences can be considered to be "cognitive" when they involve appraisal, comparison, categorization, inference, attribution, or judgment.

Primary vs. Secondary Emotions

A helpful distinction for sorting nongeneratively and cognitively-generated emotions is that of Damasio, who distinguishes between "primary" and "secondary" emotions (Damasio, 1994). Damasio writes that there are certain features of stimuli in the world that we respond to emotionally first, and that activate a corresponding cognitive state secondarily. Such emotions as startle upon hearing a loud bang, or the fear that causes an infant to retreat when a large object approaches rapidly, are "primary" and reside in the limbic system. These are the innate emotions, Jamesian in their accompanying physical response. But all emotions are not like this. Damasio defines "secondary" emotions as those that arise later in an individual's development when systematic connections are identified between primary emotions and categories of objects and situations. An example is grief, where physical responses occur in conjunction with cognitive understanding of an event such as the death of a loved one. Secondary emotions still activate limbic structures, but prefrontal and somatosensory cortices are also involved. In particular, secondary emotions can be initiated merely by cognitive thoughts.

The problems that plagued Damasio's patients such as "Elliot" illuminate the differences between primary and secondary emotions. Elliot's primary emotions were apparently intact; he could be startled by a loud noise. Also,
if he watched a horrific movie scene, say where a human head exploded, then he knew cognitively that he should feel disturbed. This knowledge was evidently acquired before his brain damage. However, he no longer had the accompanying disturbing feeling, which he used to have before the damage to his frontal cortex. Physiologically, he registers no significant response to such scenes, in contrast with normals whose electrodermal response changes with such stimuli. In essence, his “cognitive” thoughts that would normally induce emotion can be activated, but these do not communicate with the subcortical structures needed to produce the rest of the emotional response. In a rather literal sense, Elliot is emotionally “detached.” His limbic-cortical connections no longer function normally. His primary emotions are intact, but the connections are no longer in place for his secondary emotions to be fully present.

An analogy for a healthy person might be as follows. Suppose you hear of the death of a woman whom you’ve never met. Although you may feel sympathy and sorrow for the dear friends of the deceased, and think about their loss, it is unlikely you will feel grief since you had no attachment to her. In contrast, the loss of your beloved friend is likely to cause you not only to think about your loss but to have feelings of grief. In both cases there is cognitive appraisal—loss of a loved one—but only in the latter case is it associated with a persistent feeling of grief, an accompanying change in physiological state. Moreover, the physiological state of grieving can affect cognitive tasks, causing a “perturbation” in one’s ability to concentrate on non-preserving intellectual activities.18 Damasio’s patients do not receive the accompanying physiological feeling.

In other words, there is a distinction between thinking about an emotion, e.g., “this is disturbing” and feeling disturbed. In healthy people, this distinction can happen, but more often the thought and the feeling co-occur, as in the case where a good feeling accompanies the event of seeing someone that you really like. In Damasio’s patients with frontal-lobe damage, the two functions remain separate. The patients can cognitively know they should feel disturbed by something they are looking at, but they do not feel disturbed.

Developing and Learning Emotions

Emotional development begins in the womb. The fetus can be startled. In the womb, and many babies exit the womb with a loud expression of distress. Babies demonstrate a less complicated repertoire of emotions than cognitively adults, presumably because of their lack of experience and not because of usage of social display rules. Babies also apparently lack the ability to construct “self-conscious” cognitive emotions such as shame and guilt, which develop later in childhood once a sense of identity is established (Lewis, 1993). In theory, as a child develops she learns how to generalize events that give rise to primary emotions, leading to the development of secondary emotions. The cortical involvement in secondary emotions is hypothesized to help generalize primary emotional responses. For example, a primary response of flight from a rapidly approaching large object can be cognitively generalized to a principle such as “stay out of the paths of large moving objects such as cars, trucks and trains.” The links develop as people mature, enabling them to learn and to generalize—for example, to learn to stay away from most things appraised as harmful, based on similarity to what has been harmful in the past.

Damasio’s emotion-damaged patients were not able to learn like typical people. When Elliot made a bad investment, he recognized cognitively that it was harmful to his business and his family. However, he did not have the usual accompanying feelings, such as of harm or shame, and he did not learn to avoid the harmful behavior. Consequently, he repeatedly made bad decisions, eventually losing his job, his wife, and more. His emotional impairment manifested itself as a general lack of reasonableness and intelligence, even though he still scored above average on IQ tests and written tests of social behavior.

Cortical-limbic links can work in either direction, attaching feelings to thoughts or thoughts to feelings. Recalling a frightening incident can stir up feelings of fear, although they tend not to be as intense as when they were first experienced. A successful school of acting—“method acting” pioneered by Konstantin Stanislavsky—is based on imagining previously experienced emotional scenarios to arouse feelings as if actually experiencing them again.19 An emotional state of fear can prompt the recall of other fearful situations, reinforcing the links between thoughts and feelings.

Complicating Conditions: Cognitive Aspects of Emotion

A number of factors confound attempts to understand the cognitive aspects of emotion. Several of the factors mentioned earlier that complicate physiological studies of emotion also complicate cognitive studies of emotion, for example social display rules, such as “It’s inappropriate to show emotion during a scientific fact-finding presentation.” Problems also occur in cognitive studies of emotion in the laboratory, where subjects are usually asked to verbalize their emotional state, as opposed to or in addition to its being physically measured. These problems concern the attaching of adjectives to emotions (Wallbott and Scherer, 1989). Two people might feel exactly the same way physically, and yet name the same feeling with two different names, depending on the cognitive events surrounding the state. Or, two people who say they are cognitively “very happy” might vary tremendously in terms of
how they feel. How often these discrepancies may occur is not known; relatively few studies have simultaneously measured both physical and cognitive responses.

One of the big complicating factors is cognitive interpretation of the environment. Under controlled environments, or with the assistance of some wearable acoustic and visual scene analysis, a computer will eventually be able to recognize what is happening in the perceivable milieu, e.g., “the room is tiny and hot, a stranger enters and quickly walks toward the subject.” However, these perceptions are only part of the entire perception that also includes things like: how this stranger’s eyes and gait indicate malice or long-lost love, and other subtleties on which a response can depend greatly.

A bigger problem is that even if a computer could perceive all these stimuli, how would it reason which should be interpreted as “good,” “likely,” “interesting” and so forth? Scientists do not yet know how people arrive at the valenced decisions they so readily make, of good vs. bad, like vs. dislike, important vs. unimportant, interesting vs. uninteresting, and so forth. These are often made unconsciously, without lists of pros and cons on paper or in the mind. Sometimes these kinds of judgments are lumped in with “common sense reasoning,” and largely ignored in formal research efforts. However, these kinds of affective judgments are critical in human decision making and need to be better understood. In particular, because these kinds of judgments are accompanied by and influenced by valenced feelings, they could arise naturally in computers that have mechanisms of emotion.

Successful cognitive emotion models are likely to depend on other factors such as an individual’s experience. For example, someone who has never seen a neighborhood cat run over by a car might be deeply disturbed the first time they are close to such an event, whether or not they are a cat lover. The man who works for the city and has to routinely remove animal carcasses from the roads may no longer have an emotional response, unless the carcass belongs to his beloved pet. The person’s history, values, attachment, and general emotional maturity combine to influence their cognitive responses.

As data is collected from a variety of situations, patterns may be found that would improve a computer’s ability to predict cognitive emotional responses to situations. Nonetheless, it is unlikely that every factor that influences emotion will be recognized. Therefore, one cannot expect a cognitive predictive model to work perfectly. To really predict how a person might respond emotionally requires knowing not just a person’s situation, but also her goals, standards, and preferences. An affective computer should improve at this task as it collects and learns these things about an individual.

Cognitively generated emotions are often not expressed in readily observable ways, but may occur as thoughts. In this case, the emotions may be impossible for another person to recognize, since people cannot recognize each other’s thoughts. I have heard some people suggest that science might be able to find a process of recovering somebody’s thoughts by looking at various brain signals produced while thinking those thoughts. This recovery problem may be posed as a so-called “inverse problem,” where the goal is to invert the signal generation process to reconstruct the thoughts that gave rise to the signals. However, inverse problems are notoriously difficult. Thought-reading may be the biggest “inverse problem” imaginable. In other words, people need not worry about any person or machine reading their emotional thoughts.

**Emotions and Creativity**

“Men have called me mad: but the question is not yet settled, whether madness is or is not the highest intelligence—whether much that is glorious—whether all that is profound—does not spring from disease of thought—from moods of mind excited at the expense of the general intellect.”

—Edgar Allan Poe

Creativity—an ability to create—is associated with the ability to combine ideas or elements in such a way as to form new and original connections or constructions. The cognitive mechanisms of creativity are not very well understood, although creativity is highly valued in most professions. Most would agree that today’s computers are not creative in the sense that humans are, although certain behaviors of computers are occasionally declared to be creative. One can argue that many tasks given to computers do not require creativity. However, as computers take on more complex situations where problem solving is required, they could benefit from the abilities humans prize as creative.

Is there a link between creativity and emotions? If there is, then one would expect to find higher proportions of highly creative people, such as artists, poets, and writers, to exhibit greater emotionality. Indeed, anecdotal evidence is in abundance—scores of influential 18th- and 19th-century poets, notably William Blake, Lord Byron, and Lord Tennyson, wrote about the extreme mood swings they endured. Poets and writers John Berryman, Ernest Hemingway, Randall Jarrell, Robert Lowell, Sylvia Plath, William Styron, and Anne Sexton were all hospitalized for either mania or depression during their lives. And many painters and composers, among them Vincent van Gogh, Georgia O’Keeffe, Charles Mingus, Robert Schuman, and Virginia Woolf, have been similarly afflicted. William James, the profoundly creative and influential psychologist, battled depression for many years.
Of course, mood disorders do not necessarily breed creative genius, nor does creative genius imply a mood disorder. However, scientists have, over many years, documented evidence of a correlation between these effects, through controlled studies on thousands of artists, writers, and other creative professionals. The conclusion has been confirmed by a growing body of research: renowned writers, artists, and composers have been far more likely to experience mood disorders and to commit suicide than the general population. Moreover, there is an unusually high occurrence of alcoholism, which points another curious finger of accusation at the limbic seat of emotions and its link to creativity. Centuries of artists and writers have described using substances such as alcohol to enhance their imaginations and creativity. In the brain, alcohol suppresses cortical activity, enhancing blood flow in the limbic system relative to that in the cortex. The result is often increased emotional fluidity—an ability to move more easily among different states, less hindered by cortical regulation. The maudlin drunk is another example of this phenomenon, but without the constructive intentions; his depressed cortical functions lead to emotional silliness. In people with synesthesia, alcohol's boost on the limbic system also boosts the vividness of synesthetic perceptions. Studies with synesthetes indicate that their synesthetic epiphanies are more vivid after alcohol, and less vivid before caffeine, the latter of which boosts the cortex relative to the limbic system.

Emotions influence creativity not just in extraordinarily creative people, but also in ordinary folks. In particular, positive mood has been shown to have a significant impact on several aspects of creativity: recognizing relations between features of problems, giving unusual or creative first associates to neutral cues, discovering principles to integrate and remember information, and responding to Duncker's candle task. In this task, subjects are given one of two situations: (1) a box of thumbtacks, a candle, and a book of matches, or (2) a box, a pile of thumbtacks, a candle, and a book of matches. In both cases they are asked to affix the candle to a cork board on the wall in such a way as to keep it from dripping on the floor when it is lit. Subjects are given ten minutes to find the solution. In the first case, most subjects cannot find the solution; in the second case, most succeed. When subjects were put into a good mood before being presented with the first situation, a significantly higher proportion of them succeeded (Ison, Daubman, and Nowicki, 1987).

Emotions and Memory
Much of emotion's influence on cognition may happen through emotion's influence on memory. Memory enters into nearly every cognitive task—perception, decision making, learning, planning, prioritizing, creativity, and more. From studies of the brain, we know that the cortex and limbic system exert influences on each other. In fact, it is known that there are many more connections carrying signals from the limbic system to the cortex than vice versa. It is not surprising that emotions, as part of a "low-focus" dreamy-state kind of thinking, might lead to creative analogies. David Gelernter writes about this phenomenon in his book The Muse in the Machine, where he calls it "affect linking" (Gelernter, 1994). However, it is a less obvious, but far more compelling result, that emotions influence "high focus" reasoning.

One of the most reliable phenomena in the cognition-emotion literature is the effect of mood on evaluative judgment (Clore, 1992). Consider, for example, the study of Forgas and Moylan where over a thousand people were interviewed about their views on political figures, crime, future events, and life satisfaction. Patrons were interviewed after exiting a movie theater, where they had seen one of several movies, which had been previously classified as happy, sad, or aggressive in affective tone. In response to the interviewers' questions, the viewers made judgments that reflected the tone of the film they had just seen. No such bias was found among patrons who were entering the theatre (Forgas and Moylan, 1987).

Not only does mood influence judgments about seemingly objective events, but it also influences memory retrieval. Positive moods tend to make it easier to remember positive things, and negative moods tend to make it easier to remember negative things. When you are playing with your child and suddenly see his immense disappointment when a toy does not work the way he expects, then you might recall a long-lost memory of your own childhood disappointment. It may be a memory of a very different event, one that did not have anything to do with a toy. The primary thing in common between your child's event and the event you remembered may be a feeling, such as the feeling of playful enjoyment and expectation interrupted by immense disappointment. Memory retrieval is largely a mystery, but there is increasing evidence that emotions play a role in its function. Memory may be the chief mechanism through which emotions enter into the mental associations active in analogical thinking and creativity. Hence, we see the influence of emotions in both high-focus reasoning and low-focus generation of associations, as a consequence of emotional influences on memory.

Intentional vs. Spontaneous Smiles
It is said that the attentive observer is always able to recognize a false smile (Duchenne, 1862)—that is, a smile generated by the will instead of by a genuine feeling of happiness. Duchenne observed:

The muscle that produces this depression on the lower eyelid does not obey the will; it is only brought into play by a genuine feeling, by an agreeable emotion. Its twinita in smiling unmasks a false friend.
Neurological studies indicate that true emotions travel their own special path to the motor system. If the neurologist asks a patient who is paralyzed on one side to smile, then only one side of the patient's mouth raises. But when the neurologist cracks a funny joke, then a natural two-sided smile appears. For facial expression, it is widely accepted that the will and the emotions control separate paths (Ekman, 1990). If the lesion is in the pyramidal system, the patients cannot smile deliberately but will do so when they feel happy. Lesions in the nonpyramidal areas produce the reverse pattern; patients can smile on request, but will not smile when they feel a positive emotion.

In other words, an intentional smile travels a different path than a spontaneous one. The cognitively-generated command to smile does not express itself in the same way as a genuine feeling of happiness expresses itself. Not only does this imply that, physiologically, false and sincere smiles may be discriminated, but it illustrates the existence of multiple paths, multiple causes, for emotional expression.

**Inducement of Emotion**

Certain physical acts are peculiarly effective, especially the facial expressions involved in social communications; they affect the sender as much as the recipient.

—Minsky, *In Society of Mind*

There is emotional inducement ever at work around us—a good marketing professional, playwright, actor, or politician knows the importance of appealing to your emotions. Aristotle devoted much of his teachings on rhetoric to instructing speakers how to arouse the desired emotions in their audience (Aristotle, 1960). Adolf Hitler took this to a horrific extreme with his mind-washing propaganda to instill hatred for the Jewish people. Hitler also exploited the increased susceptibility of people when they were weary by gathering them in the evenings, and when they were in large crowds, and hence more inclined to respond according to a herd-like instinct. Although weakness and herd-instinct are not considered emotions, they are underlying factors that, once induced, made it easier to manipulate people's thoughts and emotions.

The most frequent example of mood inducement, however, is choosing forms of entertainment, especially music. We enjoy selecting a recording that affects our mood in a particular way—a piece to lift one's mood, or to console one in a state of grief. We tend to believe that we are also free to choose our response to the stimulus. An open, and somewhat ominous question is, are we always free to do so? It is known that internal direct stimulation of the brain can elicit various emotions (Hees, 1957). However, can some part of our nervous system be externally activated to force experience of an emotion? A number of theorists have postulated that sensory feedback from muscle movements, such as facial movements, is sufficient to induce a corresponding emotion. The saying, "smile and you'll feel happier" has some truth to it. For example, Laid (1982) divides people into "cuing" categories based on whether or not posturing their faces in a particular expression induces the corresponding emotional experience. Ekman has shown that posing people's faces gives rise not only to a subjective emotional experience consistent with the posed expression, but also gives rise to other physiological signals that distinguish the emotions (Ekman, 1983). Experiments by Levenson and colleagues also showed that facial actions can initiate emotions; in that work, Levenson predicts that other physical components of emotion might assume this initiating role (Levenson, 1993). Izard and Ekman overview some of the evidence for and against various claims about sensorimotor influence (Izard, 1993; Ekman, 1993).

Whether or not such sensorimotor inputs induce emotion, they appear to be effective in maintaining and expressing emotion. Posture is correlated with expressions of self-esteem (Izard, 1993; Lewis, 1995), and good actors study how to align their body position in accord with an imagined emotion, to help reinforce its effects. Instead of imagining previously experienced emotional events like his teacher Stanislavsky, Chekhov's school of acting taught that you could imagine fictional events and the external movements of a character suffering such events, and so take them upon your character. For example, to capture sadness he suggested imagining the grieving sounds of a rural village mourning the accidental and gruesome deaths of a little boy and a little girl (Chekhov, 1991). When the body's emotional expression, e.g., a sad face, forward trunk, bowed head, and drooping shoulders, agrees with the cognitive emotion, "My character is depressed," then the combined emotional experience is enhanced, and the actor may "feel depressed." Consequently, the communication of the emotion can be more powerful. Of course, these actors adjust their physical state in accord with a cognitive goal. Hence, this is an example where emotions are initially cognitively generated and the body-mind reinforcement intensifies and regulates the experience.

Body-mind reinforcement may provide subliminal ways to induce emotion, perhaps by engaging parts of a person's body in movements that they are unaware of. The potential of such methods to induce emotion is unclear at this point, but may hinge on only a slight willingness of an individual to be open to inducement.

There is also strong evidence that emotional biases can be induced subliminally. Simply presenting a person with an image of a face subliminally,
repeatedly, can bias them toward liking that face. This phenomenon is at
the root of the now illegal advertising practice of inserting promotional im-
ages into a movie in such a way that movie-goers do not see the advertise-
ment consciously. In fact, apparently we humans are more greatly influenced
by emotional responses to unconsciously presented stimuli than by emo-
tional responses to the same stimuli, presented consciously (LeDoux, 1996).
The possibility of subliminal inducement may evoke disturbing thoughts
of potentially harmful mind and mood control; or potentially beneficial
mental enhancement and increased affective freedom. It is not an area to
be entered into without considering both negative and positive aspects of
how such new understanding could be used. As computers develop affective
abilities, they potentially may be used not only for monitoring emo-
tion, but also for manipulating it, for both helpful and harmful purposes.
Chapter 4 addresses several concerns for undesirable applications of affective
technology.

There are other subtle ways in which emotions are not induced per se
but in which they are deliberately influenced. Simply being sincerely kind
and respectful to someone can have the effect of positively influencing their
emotions. However, this kind of influence is rarely achieved if the kindness
is part of a manipulative goal. Unselfish kindness, especially acts such as
forgiveness, are some of the most powerful influences on a person’s emotions.

Summary

This chapter has provided several basics about human emotion theory, em-
phasizing two aspects of emotion: physical and cognitive. I highlighted find-
ings that will be important for affective computing, particularly in giving
computers the ability to recognize, express, and “have” emotions. In par-
ticular, I have described social display rules, universal vs. person-specific
responses, primary vs. secondary emotions, the role of emotions in creativity
and general memory processes, the existence of multiple paths for emotion
expression in humans, and emotion inducement.

In order for computers to be equipped to recognize human emotion, it is im-
portant that mappings between emotional states and emotional expressions
be understood so that the former can be inferred from the latter. Computers
can begin to see, hear, and otherwise sense responses from people that they
are in physical contact with. This chapter has highlighted ways in which
emotion can be expressed through sentient modulation—including facial ex-
pression, vocal intonation, gesture, posture, and other bodily changes. Part
II will address pattern recognition methods for computers to use in emotion
communication.

Additionally, a computer can observe human behavior and language, and
analyze a situation to infer which emotions are likely to be present. The focus
in this case is on cognitive reasoning, which can be used not only to reason
about what emotions are present, but also to give rise to an emotional state
in a computer. The key problem in this aspect of emotion is to understand
what situations give rise to which emotions, at least typically, and then how
these emotions influence behavior in a situation. Computers are only recently
receiving the ability to perceive and reason about situations in terms of the
emotions they raise, a topic I will delve deeper into in Part II. Once these
abilities are in place, a cognitive assessment of a situation can also be used to
help a computer decide which emotions might be appropriate for it to have
or express, and when, where, and how.