Affective Computing

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Introduction

This book proposes that we give computers the ability to recognize, express, and in some cases, "have" emotions. Is this not absurd? Computers are supposed to be paradigms of logic, rationality, and predictability. These paradigms, to many thinkers, are the very foundations of intelligence, and have been the focus of computer scientists working fervently to build an intelligent machine. After nearly a half century of research, however, computer scientists have not succeeded in constructing a machine that can reason intelligently about difficult problems or that can interact intelligently with people.

Three decades ago, Nobel laureate Herb Simon, writing on the foundations of cognition, emphasized that a general theory of thinking and problem solving must incorporate the influences of emotion (Simon, 1967). Emotion theorists have also argued for the role of emotion as a powerful motivator, influencing perception, cognition, coping, and creativity in important ways. Other results have emerged from neuroscience, cognitive science, and psychology, indicating a pivotal role for emotion in attention, planning, reasoning, learning, memory, and decision making. Some scientists have argued that the demands of a system with finite resources operating in a complex and unpredictable environment naturally give rise to the need for emotions, to address multiple concerns in a flexible, intelligent, and efficient way. Nonetheless, the consideration of emotions for computing has been largely ignored.

Although scientists bicker about a definition of emotion, they agree that emotion is not logic, and that strong emotions can impair rational decision making. Introductory psychology texts have described emotion as "a disorganized response, largely visceral, resulting from the lack of an effective adjustment."[1] Acting "emotionally" implies acting irrationally, with poor judgment. Emotional responses tend to be inappropriate, and even embarrassing. At first blush, emotions seem like the last thing we would want in an intelligent machine.

However, this negative face of emotion is less than half of the story. Before telling the rest of the story, it is prudent to acknowledge that emotions have a stigma, especially among those who prize rational thinking, such as scientists and engineers. Emotions are regarded as inherently non-scientific. Scientific principles are derived from rational thought, logical arguments, testable hypotheses, and repeatable experiments. There is room *alongside* science for "non-interfering" emotions such as those involved in curiosity, frustration, and the pleasure of discovery. Curiosity drives much of scientific inquiry—and the greatest reward of the scientist is often the pure joy of learning. Fear also contributes to science. One can argue that scientific funding via defense budgets has been prompted by fear, such as the fear of not being able to protect our children from attack by another country, or the fear of losing technical superiority. Despite these influences, emotions are usually regarded as acceptable only when they are on the sidelines. If brought more actively into scientific thinking and decision making, then we assume they are negative—wreaking havoc on reasoning. If emotions play a direct and positive role, then it has been overshadowed by this negative one. The negative bias has repelled many a scientist from careful analysis of the role of emotions.

Why do I propose to bring emotion into computing, into what has been first and foremost a deliberate tool of science? Emotion is probably good for something, but its obvious uses seem to be for entertainment and social or family settings. Isn't emotion merely a kind of luxury, that, if useful for computers, would only be of small consequence? This book claims that the answer is a solid "no." Scientific findings contradict the conclusion that human emotions are a luxury. Rather, the evidence is mounting for an essential role of emotions in basic rational and intelligent behavior. Emotions not only contribute to a richer quality of interaction, but they directly impact a person's ability to interact in an intelligent way. Emotional skills, especially the ability to recognize and express emotions, are essential for natural communication with humans.

What about emotion and computers? Shouldn't emotion be completely avoided when considering properties with which to endow computers? After all, computers control significant parts of our lives—nuclear power plants, phone systems, the stock market, airplane flights, automobile engines, and more. We need computers to be predictable and reliable, with clear rational judgment. Our lives sometimes depend on it. Who wants a computer to be able to "feel angry" at them? To feel contempt for any living thing? In the worst case, the consequences might be life-threatening, as in the film "2001" where the emotional computer HAL kills its crewmates, ostensibly out of fear. These questions skitter across the much deeper subject at hand, and I will devote a chapter to potential ethical concerns and less-than-desirable uses of this technology.

In this book I will lay a foundation and construct a framework for what I call "affective computing," computing that relates to, arises from, or deliberately influences emotions. This is different from presenting a theory of emotions; the latter usually focuses on what human emotions are, how and when they are produced, and what they accomplish. Affective computing includes implementing emotions, and therefore can aid the development and testing of new and old emotion theories. However, affective computing also includes many other things, such as giving a computer the ability to recognize and express emotions, developing its ability to respond intelligently to human emotion, and enabling it to regulate and utilize its emotions. Along the way I will weave in both existing work and my own ideas, to begin to fill in the framework.

To complicate matters, nobody knows the answers to basic questions in emotion theory such as: "what are emotions?" "what causes them?" and "why do we have them?" For a list of twelve open questions in the theory of emotion, see Lazarus (1991). These are all openly debated, and evidence lacks on all sides of the debates. To minimize speculation, my treatment of these topics will be limited to those questions essential to the development of affective computing. I will also make suggestions as to how affective computing can help us get closer to answering these important theoretical questions. On the practical side, I will describe new applications of affective computing to areas such as computer-assisted learning, perceptual information retrieval, creative arts and entertainment, and human health and preventive medicine. Most of these are implementable in the near to distant future, but some are being realized today.

I should state a couple of things that I do not intend "affective computing" to address. The first is the pursuit of computers to perform surgical procedures such as cingulotomies—the making of small wounds in the ridge of a part of the brain's limbic system known as the cingulate gyrus, a controversial operation to aid severely depressed patients. Although the use of computers in "tele-surgery" and other medical advances is a significant area of research, such uses are not the focus here. Nor do I plan to discuss how people feel about their computers, and how and why their feelings evolve as they do, even though these are important topics.[2]

On the other hand, I will address how *computers* will be able to recognize, express, and "have" some of these "feelings." The reason for the quotes on "have" and "feelings" will be clarified later, when I carefully describe these concepts. Affective computing is an area of research in need of diligent and sensitive exploration, since machines with affective abilities will need to be skillful and prudent in their use of such abilities. The potential contributions of this research are significant both theoretically and practically—for progress in understanding emotion and cognition, for improvements in how computers reason about and solve problems, for advances in how we may communicate with them, and for how they will influence our own human development.

Songs vs. Laws

Let me write the songs of a nation; I don't care who writes its laws.
—Andrew Fletcher

Emotion pulls the levers of our lives, whether it is love that leads to an act of forgiveness, or curiosity that drives scientific inquiry. As humans, our behavior is greatly influenced by the so-called "song in our heart." Parents, rehabilitation counselors, pastors, and politicians know that it is not laws that exert the greatest influence on people—there are laws prohibiting murder, but there are still murders. Instead, to change the way people behave, one cannot merely change the laws; people's hearts must change. The death penalty has not lowered the murder rate in states where it has been instituted as law; however, murder rates are significantly lower in certain cultures, e.g., in Japan vs. in the United States.

Music, sometimes called "the finest language of emotion," is an apt metaphor, whether it refers to people being influenced by the cultural "tune" or refers to someone with different behavior as "marching to a different drummer." Of course there is no audible tune, and no actual drummer; rather, the metaphor is one of subtle and powerful influence on our behavior—not described simply by laws or rules. To illustrate this influence, imagine the following scenario:

Your colleague keeps you waiting for an important engagement to which you are both strongly committed. You wait with reason, but with increasing puzzlement at her unusual tardiness. You think of promises this delay is causing you to break, except for the promise you made to wait for her. Perhaps you swear off future promises like these.

She is completely unreachable; you ponder what you will say to her about her irresponsibility. But you still wait, because you gave her your word. You wait with growing impatience, frustration, and anger. You waver between wondering "is she ok?" and feeling so irritated that you mutter under your breath, barely joking, "I'll kill her when she gets here."

Finally you give up on your promise to wait. Then she appears. How do you respond?

Whether you greet her with rage or relief, consider the effect of her expression on your response. Suppose she shows up looking carefree and unabashed. You may feel angry and lash out at her. Or suppose she shows up harried, apologetic, with woeful, grieving countenance. You might feel a sudden mixture of relief and forgiveness, and question her compassionately. In other words, the look on her face—her expression of affect—may powerfully influence how you respond. A small communication of emotion can change an entire course of behavior.

In saying that emotions, or "songs," pull the levers of our lives, I am *not* suggesting that laws are unimportant. The legal system has its raison d'etre, despite its notorious abuses and shortcomings. Similarly, systems of laws or rules used by computers have useful applications, despite the acknowledged brittleness of artificial intelligence (AI) rule-based expert systems. Laws are clearly important. However, laws and rules are not sufficient for understanding or predicting human behavior and intelligence.

In fact, evidence indicates that laws and rules do not operate without emotion in two highly cognitive tasks: decision making and perception. Some of the emotional influences for perception have even received special names—such as the fear-induced phenomenon of "tunnel vision," or the joy-induced state of "seeing through rose-colored glasses." But what other evidence is there besides such subjective experiences? Let's consider the role of emotion in perception and decision making, beginning with a somewhat bizarre scenario about perception. Perception is a task that, until recently, was presumed to be primarily cortical, occurring in the highest parts of the brain, together with other high-level rational processes.

Limbic Perception

"Oh, dear," he said, slurping a spoonful, "there are not enough points on the chicken."
—Michael Watson, from *The Man Who Tasted Shapes* (Cytowic, 1993)

Some people feel shapes on their palms as they taste food, like the "points" Michael usually feels when the chicken dish is seasoned correctly. Others see colors as they hear music. These are not drug-induced or voluntary experiences, but rather happen in a natural and involuntary way to people with *synesthesia,* a condition that occurs in an estimated ten people out of every million. A synesthete's brain behaves as if the senses are cross-wired, as if there are no walls between what is seen, felt, touched, smelled, and tasted. The result is heightened perceptual experience. But these crossed perceptions are not explained merely by neurologically "crossed wires."

One would expect that during synesthesia, there would be an increase in cortical activity because of the heightened perceptual experience. The cortex is the physically highest part of the brain, and contains the visual cortex and auditory cortex, the well-studied sites for processing the senses of vision and hearing. The neurologist Richard E. Cytowic studied a variety of aspects of synesthetic experience (Cytowic, 1989), in search of an understanding for how it occurs. He expected to find his explanations in parts of the brain where the senses come together, perhaps in the parietal lobe's tertiary association area where the three senses of vision, touch, and hearing converge. However, to his surprise, Cytowic found that scans of cerebral blood flow[3] during synesthesia episodes indicated a collapse of cortical metabolism. An overall increase of brain metabolism occurred, but it was not in the "higher" cortex, where it was expected.

Instead, Cytowic's studies pointed to a corresponding increase in activity in the limbic system. The limbic system (or more accurately, *systems* since it involves many individual components and functions) is a collection of parts of the brain that lie predominately between the brain stem and the two hemispheres of the cortex (see the "triune brain" in Fig. I.1). Although there is not complete agreement on what parts of the brain constitute the limbic system, it is typically considered to include the hypothalamus, the hippocampus in the temporal lobe, and the amygdala. The limbic system is the seat of emotion, memory, and attention.[4] It helps determine valence (i.e. whether you feel positive or negative toward something) and salience (i.e. what gets your attention). In so doing, the limbic system contributes to the flexibility, unpredictability, and creativity of human behavior. It contains vast interconnections with the neocortex, so that brain functions tend not to be purely limbic or cortical, but a mixture of both.

The degree of limbic activity during synesthesia indicates that the limbic system plays a significant role in perception. In other words, perception is occurring not just in the cortex, but also below the cortex, in the region of the brain that is the primary home of the emotions. Things are not being perceived without going through a system that attaches valence to the memory—positive or negative, like or dislike.

Research on synesthesia is only one of many examples that points to an intervening role for emotions in perception. For example, studies have shown that mood influences perception of ambiguous stimuli. If healthy subjects are asked to quickly jot words they hear, then they are more inclined to spell "presents" than "presence" if they are happy, and to spell "banned" than "band" if they are sad. Subjects resolve lexical ambiguity in homophones in a mood-congruent fashion.[5] Similar results occur when subjects look at ambiguous facial expressions. Depressed subjects judge the faces as having more rejection and sadness.[6] Moods also bias perception of the likelihood of events—an individual in a negative mood perceives negative events as more

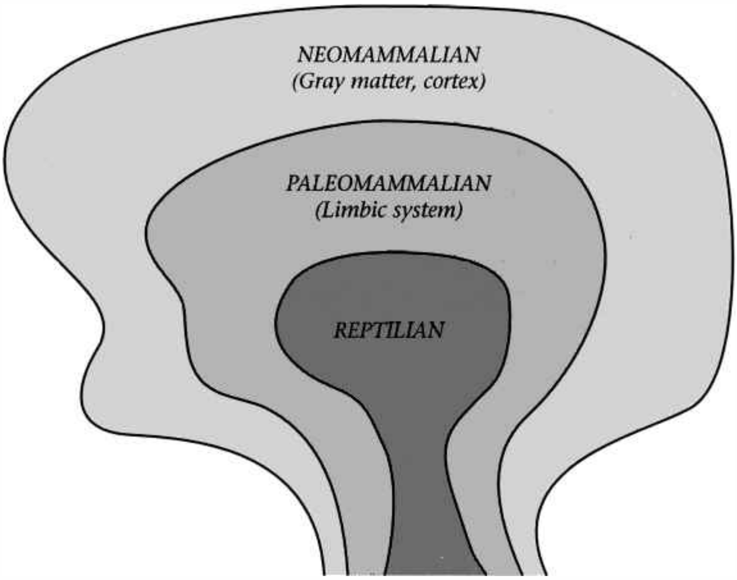

Figure I.1
Paul MacLean's "triune brain" divided the brain into three regions: neocortex, limbic system, and reptilian brain (MacLean, 1970). The neocortex is traditionally the best studied, and contains the visual cortex and auditory cortex; it is where the majority of perceptual processing has been assumed to occur. The limbic system is considered the primary seat of emotion, attention, and memory. Although clear dividing lines are shown here, the functions of the regions are not neatly divided.

likely and positive events as less likely, and the reverse holds true for people in positive moods.[7] In the words of the prominent emotion theorist Carroll Izard, emotion is "both a motivating and a guiding force in perception and attention" (Izard, 1993).[8]

The Limbic-Cortical Tangle

The distinction here between cortical and limbic functions is for emphasis only; in practice, normal limbic and cortical brain areas do not operate in isolation, but are functionally intertwined. The two areas have been artificially separated in how they have been studied, with most emphasis on the cortex. The cortex is easiest to probe as it lies closest to the scalp, and hence has been easiest to study. The limbic system lies below the cortex. Its common adjective of "subcortical" reinforces the old impression that it functions at a level lower than the cortex. However, discoveries such as that of the limbic role in the "high" function of perception imply that a high or dominating function is not necessarily cortical. Even more strongly than the synesthesia findings mentioned above, the research of Joseph LeDoux has shown that other kinds of processing thought to be cortical can be achieved *without* the cortex.

One surprising example of this is that the audio cortex is not always needed for auditory fear conditioning. In particular, if a rat learns that an audible tone is usually accompanied by a shock to its feet, then it will soon exhibit fear when it hears that tone. The rat cannot tell us it is afraid, but it exhibits fear-like behavior, where its blood pressure and heart rate change, it startles easily, and if in a cage, it "freezes" its movement. The surprising result found by LeDoux and his colleagues is that the same behavior occurs even when the audio cortex of the rat is removed. Without an audio cortex, a rat can still learn to fear a tone. But how can hearing happen without an auditory cortex? For decades scientists have assumed that higher perceptual functions such as vision and hearing were cortical.

What LeDoux and colleagues found was that for simple tones, the subcortical structures could recognize the tone, associate it with the likelihood of a shock, and generate the fear response. In particular, they found parts of the thalamus and midbrain that process auditory signals *before* they go to the cortex. Lesions in these regions eliminated the rats' ability to learn to fear the tone. Looking more closely, they found fibers going not only from these regions to the cortex, but also going to the amygdala, a structure central to the limbic system. After extensive careful experiments, they determined that the amygdala is where the learning for fear conditioning occurs initially (LeDoux, 1990). Moreover, this agreed with earlier results found in rabbits and other mammals—and the mechanisms are thought to be similar in all animals that exhibit fear conditioning, including humans (LeDoux, 1994).

Of course, not all perceptual processing occurs in the limbic system. More complex auditory stimuli have been found to require cortical processing. In other words, within its massively parallel system, the brain appears to have at least two paths for perception. The first path—"quick and dirty"—goes straight to the limbic system. When you spontaneously jump out of the way of a suddenly looming large object, then the processing probably occurred by this first path. The second path goes through the cortex and is slower, but more accurate. It allows us to recognize, a moment later, that the big object was an inflatable beach ball, and there was no need to be afraid.

There are substantially more connections from the limbic system to the cortex than vice-versa. These discoveries suggest that not only can the limbic system "hijack" the cortex, such as when it tells you to jump out of the way, but the limbic influence may actually be the greater of the two.[9] This might seem to imply that we are "run by our passions" as might be spoken of someone who does not act reasonably; however, more accurately it implies that even reasonable behavior is neurologically directed by these so-called passions.

Although for decades people have thought that the higher cortical parts of the brain control the lower parts, it is clear now that the lower can also control the higher. Nonetheless, it is commonplace to overlook the role of the lower systems, and especially the pervasive role of emotions and feelings. Cytowic, in remarking on the subtle pervasiveness of emotion's influence, points out that we often hear people say, "Sorry, I wasn't thinking," but we almost never hear "Sorry, I wasn't feeling." Whatever our perception of the role of low-level feelings, the sub-cortical limbic system is a crucial player in our mental activity. It is hard to say conclusively which system of the brain is *directing* the show, but it is clear that the limbic system is a vital part of the performance, even if it is not in the limelight.

Reevaluating Decision Making

Perception is not the only function mistakenly thought of as being purely cortical. Decision making, especially rational decision making, is thought of as a higher cognitive function in the human brain. We all know that "emotional decisions" are generally undesirable—that emotions can derail a rational decision-making process. However, emotions also play a more important role. Let us look at a surprising neurological finding that indicates a critical and paradigm-changing role for emotions.

The Thinking–Feeling Axis

"Scientific conclusions must be decided with the head; whom you choose to marry may be decided with the heart."
—folk advice

"Head" and "heart" are English-language metaphors for thinking and feeling. Most people consider that both head and heart are useful for decision making, as long as they are used suitably for separate purposes, as in the folk advice above. In fact, a tendency is to polarize thoughts and feelings, as if they were opposing phenomena.

The popular Myers-Briggs personality-type indicator provides a good example of this polarization. It characterizes personality via four axes, one of which has the labels "thinking" (T) and "feeling" (F) as opposite endpoints. Most students in technical graduate research programs are biased toward the "T" side. These types of personalities place relatively small emphasis on emotions or feelings relative to thoughts and logical reasoning. Since the developers of computers are largely members of this unusually biased population, it is no surprise to see affect marginalized in models of intelligence constructed by computer scientists.

The Myers-Briggs personality type indicator, when applied to large populations of men and women, reveals a gender bias along only this T-F axis. Two-thirds of men tend to lie closer to the "T" side and two-thirds of women tend to lie closer to the "F" side (Kroeger and Thuesen, 1992). This bias agrees with male-female stereotypes, and is increasingly supported by studies examining what men and women value in communication.[10] It is reasonable to expect that these differences might also extend to how men and women prefer to interact with computers.

Acknowledging the gender bias, affective computers might tend to be considered more feminine for incorporating emotions. However, this conclusion is short-sighted. The human brain, in both males and females, relies on emotion in normal *thinking*. In other words, even the most rational thinking requires participation from the emotion-mediating parts of the brain. Consequently, affective computers should not be considered more feminine, but more human.

The notion of a triune brain simplifies how we look at the systems involved in thinking and feeling, but its simplicity is also a bit dangerous. In particular, it is wrong to deduce from it that there is a clean line between "thinking" and "feeling." Any such line is particularly blurred when we look at decision making. In fact, we find something completely unexpected. First, recall that the brain does not separate cortical and limbic activity. Quoting from the *The Neurological Side of Neuropsychology* (Cytowic, 1996):

> Authorities in neuroanatomy have confirmed that the hippocampus is a point where everything converges. All sensory inputs, external and visceral, must pass through the emotional limbic brain before being redistributed to the cortex for analysis, after which they return to the limbic system for a determination of whether the highly-transformed, multi-sensory input is salient or not.

Not only do functions traditionally thought of as cortical pass through the limbic brain, but the experience of emotion also engages parts of the cortex. In particular, the "frontal lobe" part of the cortex, which lies approximately behind the forehead, communicates significantly with the limbic brain. Damage to this area impairs the normal cortical-limbic interaction, effectively leaving a person with too little emotion.

Too Little Emotion Impairs Decision Making

We all know that too much emotion can wreak havoc on reasoning, but now there is evidence that *too little* emotion also can wreak havoc. This evidence requires a shift from the usual notion of how people separate emotions and rationality. I will give a brief explanation below, and refer the reader to the careful arguments and references assembled by Antonio Damasio in his book, *Descartes' Error* (Damasio, 1994), for the justification such a far-reaching paradigm shift demands.

Damasio's patients have frontal-lobe disorders, affecting a key part of the cortex that communicates with the limbic system. Otherwise, the patients appear to have normal intelligence, scoring average or above average on a variety of tests. At first encounter, these patients appear to be like *Star Trek*'s Mr. Spock—unexpressive of emotions and *unusually rational*. Consequently, one might expect them to be highly intelligent, like Spock.

In real life, however, Damasio's patients make disastrous decisions. Suppose they lose a lot of money with an investment. Unlike healthy people who would learn that the investment is a bad one and stop investing in it, they might continue to invest until all their money is gone. Moreover, this pattern of behavior repeats itself with relationships and other social interactions, usually resulting in the loss of jobs, friends, family, colleagues, and more. Such behavior is far from intelligent. These patients with impaired emotional abilities are, ironically, unable to act rationally.

This disorder is exemplified by "Elliot," whose IQ and cognitive abilities are all normal or above average, but who suffered damage to frontal lobe brain tissue as the result of a brain tumor. When confronted with a simple decision such as when to schedule an appointment, Elliot will disappear into an endless rational search of "Well, this time might be good," or "Maybe I will have to be on that side of town so this time would be better," and on and on. Although a certain amount of indecisiveness is normal, in Elliot it is apparently not accompanied by the usual feelings, such as embarrassment, if someone is staring at you for taking so long to make up your mind. Instead, Elliot's tendency is to search an astronomically large space of rational possibilities. Moreover, Elliot seems to be unable to learn the links between dangerous choices and bad feelings, so he repeats bad decisions instead of learning otherwise. Elliot's lack of emotions severely handicaps his ability to function rationally and intelligently.

Damasio has hypothesized that Elliot's brain is missing "somatic markers" that associate positive or negative feelings with certain decisions. These feelings would help limit a mental search by nudging the person away from considering the possibilities with bad associations (Damasio, 1994). These markers are those that healthy people identify as subjective feelings, "gut" feelings, or intuition.

Apparently, a balance is needed—not too much emotion, and not too little emotion. I suggest that computers, with the exception of some science-fiction creations, have erred on the side of having too little emotion. Artificial intelligence systems produced so far are not too unlike Elliot—they have above average knowledge of some area of expertise, usually encoded as huge set of rules, but they are relatively unintelligent at making decisions. They are unable to associate judgments of value and salience with important decisions. These judgments are products of interactions between the limbic system and the cortex. Little has been done to imitate them in computers.

Damasio's findings point to an essential role of emotion in rational thinking. This is not the first time researchers have come to this conclusion. Johnson-Laird and Shafir have written to the cognition community about the inability of logic to determine which of an infinite number of possible conclusions are sensible to draw, given a set of premises (Johnson-Laird and Shafir, 1993). Even the massive parallelism of the human brain cannot fully search the large spaces of possibilities involved in many day-to-day decisions. How do you decide which paths to search? There is not time to consider *every* possible logical constraint and associated path.

By no means should anyone conclude that logic or reason are irrelevant; they are as essential as the laws of a nation. Additionally, the neurological evidence describes an essential role for emotions, the "songs of the nation" that Fletcher implied were so influential. Therefore, these findings indicate that further study of emotion is essential if we are to understand human cognition, perception, and decision making.[11] The implications are significant also for computer science and industry: computers, if they are to be truly effective at decision making, will have to have emotions or emotion-like mechanisms working in concert with their rule-based systems. If not, we can expect them to have problems like those of Elliot and others who suffer from inadequate emotional abilities. "Pure reason" may continue as a Platonic ideal, but in successful cognitive systems, it is a logical howler.

Tests of Thinking and Intelligence

In normal human cognition, thinking and feeling are partners. If we wish to design a device that "thinks" in the sense of mimicking a human brain, then must it also "feel?"

Consider briefly the classic test of whether or not a machine can think: the Turing test.[12] This test examines whether, in a typical conversation between two participants who have no sensory contact with each other, a human tester cannot tell if the replies are being generated by a human or a machine. There have been competitions to see if a machine could pass this test and, in limited domains, some machines have passed. However, some intelligent people have *not* passed. The test cannot *prove* that a machine (or person) does or does not think; nonetheless, it is a terrific exercise in thinking about thinking.

A test of true thinking must involve emotion. Consider that one might converse with the computer passionately about a song or a poem, or describe to it the most tragic of accidents. To pass the test, computer responses should be indistinguishable from human responses. If a human is put into a highly emotional situation, then he or she will tend to respond with emotion. This observation is an old one, even recognized by Aristotle when he wrote about audiences in his *Rhetoric* :

> Indeed they are always in sympathy with an emotional speaker even when there is nothing in what he says; and that is why many an orator tries to stun the audience with sound and fury.

A Turing test of an affective computer needs to include stunning it with sound and fury, so to speak. To fool the test-giver, the computer would need to be capable of recognizing emotion and synthesizing a suitable affective response.

Although the Turing test is usually performed with text communication, so that sensory expression such as voice intonation and facial expression does not play a role, this does not mean that emotions are not communicated. The power of influencing emotion through language was a primary tenet of Aristotle's *Rhetoric*. In fact, most users of text email find that recipients infer emotion from the email, regardless of whether they intended to communicate emotion through the mail. A machine, even limited to text communication, will communicate more effectively with humans if it can perceive and express emotions.

The crux of testing a computer's intelligence is in determining what questions should be asked of the computer. Hofstadter has suggested that "humor, especially emotion," would comprise the acid test of intelligence for a "thinking machine" (Hofstadter, 1981). The media have exploited this idea in movies where, for example, a human is finally convinced of a robot's intelligence when the robot understands a joke.

Debates still rage, however, about what constitutes thinking, and especially intelligence. As Howard Gardner establishes in his landmark book *Frames of Mind*, human intelligence consists of multiple forms, including social intelligence, which consists of interpersonal and intrapersonal skills (Gardner, 1983). Peter Salovey and John Mayer identify these latter skills as *emotional intelligence*, which they define as "the ability to monitor one's own and others' feelings and emotions, to discriminate among them and to use this information to guide one's thinking and actions" (Salovey and Mayer, 1990). The importance of these skills has been underscored by Dan Goleman in his book, *Emotional Intelligence* (Goleman, 1995), which argues that emotional abilities are more important than traditional IQ for predicting success in life.

Emotional intelligence involves factors such as self-motivation, empathy, self-awareness, impulse control, persistence, and social deftness. Empathy, in particular, requires an ability to recognize and express emotions and, in humans, the ability to experience another's emotions as one's own. Such abilities are tricky to test, and no widely accepted tests exist yet. Nevertheless, emotional skills have profound consequences for how humans perform and interact. I will discuss what these affective abilities would mean for computers in Chapter 2.

Affective Communication

Today it is easy to find people who spend more time interacting with a computer than with other humans. Every day people enter the online communities of the Internet where they communicate with each other *through* computers. Daily interaction between humans and computers has billions of dollars of economic impact, not to mention psychological impact, which is harder to quantify. I will not take space here to review the field of human-computer interaction, which is covered in numerous books and conferences; however, I would like to describe one set of intriguing studies, to motivate another reason for creating affective computers.

This particular set of studies was conducted by Clifford Nass, Byron Reeves, and their colleagues at Stanford University, and is described more fully in their book, *The Media Equation* (Reeves and Nass, 1996). They performed a number of classical tests of human social interaction, substituting computers into a role usually occupied by humans. Hence, a test that traditionally studies a human-human interaction was used to study a human-computer interaction.

For example, one experiment examined how what is said by human A about human B's performance changes when A gives the evaluation face-to-face with B, versus when A gives the evaluation about B to another presumably neutral person. Studies of human social interaction indicate that, in general, humans are nicer face-to-face. In a variation on the traditional test, human B is replaced with computer B. Human A now has to evaluate the computer's performance, say, after the computer gives him a short lesson. Human A gives B its evaluation "face-to-face," and then is asked by a different computer for an evaluation of how B did. The classic human-human results still hold, for example the tendency to be nicer face-to-face remains.

Numerous similar experiments were done by Reeves and Nass, revealing that the classic results of human-human studies are maintained in human-computer studies. The findings hold true even for people who "know better," such as computer science students who know that computers don't have emotions. After accounting for potential biasing factors, the researchers concluded that individuals' interactions with computers are inherently natural and social.[13] Affect is a natural and social part of human communication; therefore, people naturally use it when they interact with computers.[14]

It is not unusual for intelligent people to attribute emotion to things that clearly do not have emotion. For example, someone might wind up a toy dog to make it wag its tail, and say, "How cute—it likes us." Although people *know* that wind-up toys and computers do not have emotions, their default model for relating to others apparently assumes them, most likely because humans are strongly biased for human-human interaction.

Emotion plays an essential role in communication, even in its subtlest form where it merely indicates that communication has succeeded—that we are understood. If you reprimand someone and their facial expression does not change, then the inclination is to continue your communication until you receive a visible or verbal sign that your communication has succeeded. For example, when a look of pain or sorrow appears on their face, then you know you have been understood, and you can cease your reprimand. Body language is also read for signs that communication has succeeded. People watch each other's body language for a response signal to indicate that their message has been interpreted, often repeating their message until the response signal occurs. This tendency to repeat sending the same message may be at the root of the practice of many computer users to repeatedly type the same wrong thing at the computer, or to repeatedly click on something that does not work, as if the computer would notice their increasing frustration and acknowledge it in some way.

Affect recognition and expression are necessary for communication of understanding, one of the greatest psychological needs of people.[15] Suppose someone is terribly upset at you, and you gleefully respond "I understand!" They are not likely to feel understood at all. In contrast, a reflection of their emotion, a sign of empathy, is a sign of understanding. Nicholas Negroponte, in *Being Digital*, reminds us that even a puppy can tell when you are angry with it (Negroponte, 1995). How do we know it can tell? Because it signals this understanding to you. It does not keep wagging its tail during a rebuke, but may put its ears back, its tail down, and drop its head. These are signs that communication has succeeded, that in some simple form, the puppy understands your feelings.

Basic affect recognition and expression are expected by humans in communication. However, unlike the puppy, computers today cannot even tell if you are pleased or displeased. They will scroll screenfulls of information past you regardless of whether you are sitting forward eagerly in your seat, or have begun to emit loud snoring sounds. Computer-based communication is affect-blind, affect-deaf, and generally speaking, affect-impaired. A quantum leap in communication will occur when computers become able to at least recognize and express affect.

Example: The Effective and Affective Tutor

Before moving to the key issues and challenges in affective computing, let's consider an example of its use. One of the research interests at the MIT Media Lab is the building of better piano-teaching computer systems; in particular, systems that can grade some aspects of a student's expressive timing, dynamics, phrasing, etc. This goal contains many challenges, one of the hardest of which involves expression recognition, distilling the essential pitches of the music from its expression. Recognizing and interpreting affect in musical expression is important, and I will return to it later. But first, consider another influence of expression, in a scenario where you are receiving piano lessons from a personal computer tutor:

> Imagine you are seated with your computer tutor, and suppose that it not only reads your gestural input, musical timing and phrasing, but that it can also read your emotional state. In other words, it not only interprets your musical expression, but also your facial expression and perhaps other physical changes corresponding to your emotional feelings—maybe heart rate, breathing, blood-pressure, muscular tightness, and posture. Assume it could have the ability to distinguish the three emotions we all appear to have at birth—distress, interest, and pleasure.[16] Given affect recognition, the computer tutor might gauge if it is maintaining your interest during the lesson, before you quit out of frustration and it is too late for it to try something different. "Am I holding your interest?" it would consider. In the affirmative, it might nudge you with more challenging exercises. If, however, it detects you are frustrated and making lots of errors, then it might slow things down and proffer encouraging feedback. Detecting user distress, without the user making mechanical playing errors, might signal to the computer the performance of a moving requiem, or the presence of a sticky piano key, or the need to ask the user afterward for more information.

The computer tutor should not always just try to make the user happy. Nor should it simply make the lesson easier if the user is upset. Instead, there are intelligent responses that, if given information about what the user is experiencing, can improve the pupil's learning experience. Having access to the user's affective expression is a critical aspect of formulating an intelligent response.

The principles in the piano tutor scenario hold also for non-musical learning tasks—learning a software package, a new game, a foreign language, and more. The topic can vary, but the problem is the same: how should the computer adapt the pace and presentation to the user? How can it know when to provide encouraging feedback or to offer assistance? Certainly, the user should have the option to ask for this at any time; however, it has also been demonstrated that systems that proactively offer suggestions can provide a better learning experience.[17] The tutor probably should not interrupt a user who is doing well, but it might offer help to one who has been getting increasingly frustrated. Human teachers know that a student's affective response provides important cues for discerning how to help the student.

Book Overview

This book is written in two parts: Part I provides the intellectual framework for affective computing and is written to be accessible to all readers. Part II is written for those who are interested in the design and construction of affective computers—fellow researchers, scientists, and engineers—and provides descriptions of tools and progress in this area. Even in Part II, however, I have tried to keep explanations at a level that can be understood by a broad audience.

Part I provides background, motivation, main ideas, applications, and a discussion of potential concerns that arise with affective computing. Chapter 1 overviews relevant concepts from emotion theory, since most readers will not be specialists in that area. Chapter 2 takes what is known about human emotions, and constructs requirements for computers that would have the ability to recognize, express, and "have" emotions. It also discusses emotional intelligence, which will likely have to accompany the other affective abilities if affective computing is to become successful. Chapter 3 describes potential applications of affective computing, including both some that are practical now, and some that are in the indeterminate future, but which allow us to think differently about how computers and our relationships with them might advance. Affective computers, especially those that "have" emotion, raise moral and ethical dilemmas, as well as a number of social and philosophical questions, which are broached in Chapter 4.

Part II provides more depth for those who wish to help realize the ideas and applications in Chapters 2 and 3. Low-level representations of emotions, moods, and human physiological signals are addressed in Chapter 5. Chapter 6 poses human affect recognition as a pattern recognition and learning problem, proposes some models for its solution, and highlights results in affect recognition and expression. Chapter 7 describes models for synthesizing emotions and their influences in computers, particularly in software agents. Finally, Chapter 8 describes the development of affective wearable computers, devices that not only have many exciting future applications, but that also can potentially help advance fundamental understanding of human emotions.