Affective Computing: A Reverence for a Century of Research

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Abstract. To bring affective computing a leap forward, it is best to start with a step back. A century of research has been conducted on topics, which are crucial for affective computing. Understanding this vast amount of research will accelerate progress on affective computing. Therefore, this article provides an overview of the history of affective computing. The complexity of affect will be described by discussing i) the relation between body and mind, ii) cognitive processes (i.e., attention, memory, and decision making), and iii) affective computing's I/O. Subsequently, definitions are provided of affect and related constructs (i.e., emotion, mood, interpersonal stances, attitude, and personality traits) and of affective computing. Perhaps when these elements are embraced by the community of affective computing, it will us a step closer in bridging its semantic gap.

Keywords: affect, emotion, affective computing, biosignals, history, complexity, definitions, semantic gap.

"The increasing tendency to 'let's see what the computer shows' has dulled many investigators' sensitivity to the basic rules of research, sometimes to the point that the definition of the problem is unclear. The speed and ease of statistical computation, even of complex multivariate analysis involving N*s of 1000 or more, have tempted many investigators to submit all possible comparisons for analysis with little concern over the subtleties of multiple testing and the risk of type I errors. The computer cannot substitute for thoughtful planning or, as Medawar (1969, p. 29) put it,* 'We cannot browse over the field of nature like cows at pasture' " (Chapter 6, p. 333) [41]

1 Introduction

Almost half a century ago, the American psychologist Ulrich [47] described "*three fundamental and interrelated characteristics of human thought that are conspicuously absent from existing or contemplated computer programs*:

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1. *Human thinking always takes place in, and contributes to, a cumulative process of growth and development.*
2. *Human thinking begins in an intimate association with emotions and feelings which is never entirely lost.*
3. *Almost all human activity, including thinking, serves not one but a multiplicity of motives at the same time.*" (p. 194)

Ulrich [47] was not only one with this opinion, Nobel price winner and recipient of the ACM's Turing Award, Herbert A. Simon had similar ideas on this topic. He showed "*...how motivational and emotional controls over cognition can be incorporated into an information-processing system , so that thinking will take place in 'intimate association with emotions and feelings,' and will serve a 'multiplicity of motives at the same time.'*" (p. 29) [64]. Nonetheless, in the decades that followed Artificial Intelligence (AI) aimed at understanding human cognition *without* taking emotion into account [56].

Although emotions were sometimes denoted as important (e.g., [43, 44]), it took until the publication of Picard's book *Affective computing* [50] before they received center stage attention. Even though AI has made it possible that a computer can beat the world's best chess players [20] and can win quizzes such as Jeopardy! [28], the general opinion is that AI has failed [40] (cf. [23, 36]). This is likely to be (partly) because of a lack of focus on emotions. So, 50 years after Ulric Neisser's words, with the user more demanding than ever, perhaps now is the time to bring emotions to the front line of AI research and practice.

Affective computing includes signal processing and machine learning techniques [12, 14, 16], which can rely on a thorough foundation. Hence, this are not the aspects of *affective computing* that slow down its progress. I pose that the true complexity lies in i) the definition of constructs related to *affective computing*, ii) their operationalization, and, subsequently, iii) their mapping upon the biosignals (or other signals). Over a century of research has been conducted on these three issues, which are crucial for *affective computing*. Therefore, I pose that to bring *affective computing* a leap forward, it is best to start with a step back. Understanding this vast amount of research will accelerate progress on *affective computing*. Consequently, this article provides an overview of the history of *affective computing* (Section 2). Next, in Section 3, the complexity of affect will be discussed. Section 4 provides definitions for emotion, affect, affective computing, and related notions. In Section 5, I end this article with a discussion.

2 Historical Reflection[1]

Our knowledge on emotions has increased significantly over the last centuries [2]. However, often this knowledge is ignored to a great extent and the same (relatively) recent theories are adopted (e.g., the valence-arousal model). This phenomenon is in particular present in the field of *affective computing*, where

[1] This section is based on Section 2.1 of Part IV of [1].

an engineering is often valued more than a solid theoretical framework [1]. So comes that in practice most engineering approaches embrace the valence-arousal model as being the standard, without considering other models and/or theories. Nevertheless, an increase in awareness of other theories could heighten the understanding and, subsequently, contribute to the success of *affective computing*.

A vast number of handbooks and review papers on emotions, affective sciences, and affective neuroscience have appeared over the last 50 years. These include [25, 26, 39, 57, 59], which can all be considered as essential reading material. Regrettably. it is far beyond the scope of this chapter article to provide an exhaustive literature survey on *affective computing*. Therefore, this section will only touch upon some of the main works on emotion research, which originate from biology, medicine, physiology, and psychology.

In 1780, a book was published that presented the work of M. l'Abbé Bertholon with as its title *De l'Électricité du corps humain* [7]. This book is one of the earliest works that described human biosignals. In 1872, nearly a century later, *The expression of emotions in man and animals* of Darwin was published [25]. Next, independently of each other, William James and C.G. Lange coined their theories on emotions. These two theories showed to be remarkably similar and, hence, were merged and were baptized the James-Lange theory [25].

In sum, the James-Lange theory poses that the percept of our biosignals *are* what we denote as emotions. This implies that emotions cannot be experienced without these biosignals. This position was seriously challenged by both Cannon [21, 22] and Bard [3, 4]. Both Cannon and Bard denoted the important role of subcortical structures (e.g., the thalamus, the hypothalamus, and the amygdala) in our experience of emotions. Their theory was founded on five notions:

1. Emotions are experienced similar both with and without (e.g., as with the transection of the spinal cord and vagus nerve) biosignals.
2. Similar biosignals emerge with multiple emotions. Hence, these signals cannot cause these distinct emotions.
3. People's internal organs have fewer sensory nerves than other anatomical structures. This causes people to be unaware of their possible biosignals up to a high extent.
4. Most often, biosignals have a long latency compared to the duration of the emotional responses.
5. Drugs that set off biosignals do not inevitably set off emotions in simultaneously.

Next, I will discuss these five notions in light of *affective computing*. This is of importance for *affective computing* as will become apparent.

In 1966, Hohnmann [30] described a patient who reported: *"Sometimes I act angry when I see some injustice. I yell and cuss and raise hell, because if you don't do it sometimes, I learned people will take advantage of you, but it just doesn't have the heat to it that it used to. It's a mental kind of anger."* (p. 151) [30]. This patient's report appears to support the James-Lange theory. This patient suffered from a lesion, which influenced his patient biosignals and, simultaneously, his emotions have faded or are absent. However, the patient still reported emotions, although differently. If biosignals determine emotions (completely); then, how can this be explained? Can such effects be assigned solely to higher level cognition (i.e., reasoning)? If not, this can be considered as support for the first notion of the Cannon-Bard theory. More than anything else this case once more illustrates the complexity of affective processes as well as the need for user identification, in particular research on special cases.

The second notion of the Cannon-Bard theory touches upon the core of *affective computing*. It suggests that the hunt of *affective computing* is one without a future. Cannon-Bard can be interpreted as that *affective computing* is of little use since biosignals do not show a singular mapping on specific emotions. On the one hand, nowadays, this statement is depicted as crude [25]. On the other hand, awareness emerges on that *affective computing* is very hard to bring to practice successfully [9].

Modern science has indeed confirmed that the number of sensory nerves indeed differs in distinct structures in human bodies (Cannon's notion 3). This can explain their internal variance to emotional sensitivity. Moreover, research has shown that cross-cultural and ethnic differences underly differences in people's biosignals. This was already shown by Sternbach and Tursky [65, 69] and, more recently, confirmed [53, 60, 63].

The fourth notion concerns the latency period of biosignals, which Cannon denoted as being 'long'. Indeed a response time is present with biosignals, which one could denote as being long. Moreover, it varies considerably between the several biosignals used with *affective computing* [1, 70]. The former is a problem, although in most cases a work around is, to some extent, possible. The latter is possibly even more important to take into account, when conducting *affective computing*. Regrettably, this is seldom done.

The fifth notion of Cannon stretches beyond biosignals. It concerns emotion's neurochemical dimension. This aspect of human physiology has a significant influence on experienced emotions. However, this dimension is not yet embraced by *affective computing* and, hence, falls beyond the scope of this article.

In 1962, Schachter and Singer [58] were the first to suggest that neither the theory of James-Lange nor the theory of Cannon-Bard was complete but both contained valuable elements. Nowadays, this is general opinion among neuroscientists [25]. More than anything else, these samples from history illustrate the knowledge already available as well as its lagoons, which should be embraced both by *affective computing*.

3 On the Complexity of Affect

Affect is inherently complicated and not well understood by science and engineering. In this section, I will illustrate this by approaching affect from three distinct angles. Starting with philosophy and, subsequently, psychology, I will go to AI and Human-Computer Interaction (HCI) and, finally, to computer science's I/O in relation to affect.

3.1 The Relation between Body and Mind[2]

As the old Greek already noted that *"the body could not be cured without the mind"*. Both are indisputably related and, thus, in principle, measurement of emotions should be feasible. Currently, this perspective gains acceptance and more and more relations between body and mind are unveiled. Recent work confirmed this relation. For example, when chronic stress is experienced, similar physiological responses emerge as were present during the stressful events from which the stress originates. If such physiological responses persist, they can cause pervasive and structural chemical imbalances in people's physiological systems, including their autonomic and central nervous system, their neuroendocrine system, their immune system, and even in their brain [17].

Although the previous enumeration of people's physiological systems can give the impression that we are close to a holistic model, it should be noted that this is in sharp contrast with the current level of science. For example, with (chronic) stress, a thorough understanding is still missing. This can be explained by the complexity of human's physiological systems, the continuous interaction of all systems, and their integral dynamic nature. However, [17] considers emotions as if these can be isolated and attributed to bodily processes only. Moreover, in relation to computing entities, the interaction consists of much more than emotions; however, the same is true when no computing is involved at all.

3.2 Cognitive Processes

There is more than AI with cognitive behavioral systems, there is also the interaction with their users. So, a HCI perspective has to be taken as well. In the 90s of the previous century, Nass and colleagues [46, 52] touched upon a new level of HCI: a personal, intimate, and emotional level (cf. [12, 14, 16]). Together with the work of [49, 50] their work positioned affective processes firmly as an essential ingredient of HCI.

The importance of affect for HCI can be well explained by denoting its influence on three cognitive processes, which are important in HCI context:

1. **Attention:** Affective processes take hold on several aspects of our cognitive processing [24] and, hence, HCI [71]. One of the most prominent effects of affect lies in its ability to capture attention. Affective processes have a way of being completely absorbing. Functionally, they direct and focus our attention on those objects and situations that have been appraised as important to our needs and goals [71]. This attention-getting function can be used advantageously in HCI context [62].
2. **Memory:** It should be noted that affect also has implications for learning and memory [8, 11]. Events with an affective load are generally remembered better than events without such a load, with negative events being dominant

[2] This subsection is almost verbatim identical with part of an online commentary on [31]; see also `http://www.interaction-design.org/encyclopedia/affective_computing.html#egon+l.+van+den+broek`

over positive events [52]. Further, affect improves memory for core information, while undermining memory for background information [39].

3. **Decision making:** Affective processes influence our flexibility and efficiency of thinking and problem solving [39]. It has also been shown that affect can (heavily) influence judgment and decision making [6, 61]. Affective processes tend to bias thoughts by way of an affect-filter. Thoughts are directed to a affect-consistent position, which can also increase the risk of distractions.

This triplet of cognitive processes illustrates that a careful consideration of affect in HCI can be instrumental in creating interfaces that are both efficient and effective as well as enjoyable and satisfying [62]. Moreover, the experience of emotions alters our experience in general [5, 31].

3.3 Affective Computing's I/O: Impressions / Expressions

In the introduction, I already stated that emotions and computers have become entangled and, in time, will inevitably embrace each other. Computer science and practice employs *input/output (I/O)* operations to characterize its processes. This notion can also be fruitfully utilized for *affective computing*, as I will illustrate here.

Table 1 shows a matrix that provides a characterization of machinery using, what could be, standard *I/O*. Machinery without any *I/O* (i.e., –/–) at all is of no use. In contrast, machinery without either input (i.e., *I*) or output (i.e., *O*) are common practice. However, most of us will assume both input and output (i.e., *I/O*), at least to a certain extent, with most of our machinery. For example, take our standard (office) PC with its output (i.e., at least a video (the screen) and audio) and its input (i.e., at least a keyboard and a pointing device). Emerging branches of science and engineering such as AI, AmI, and *affective computing*, however, aim to redecorate this traditional landscape and provide intuitive *I/O* handling. In the case of *affective computing*, what does this imply?

Computer science's notion of *I/O* operations can also be utilized to divide *affective computing* into four categories. In terms of *affective computing*, the output (*O*) denotes the expression of affect (or emotions) and the input (*I*) denotes the perception, impression, or recognition of affect. This division is adapted from the four cases, as they were identified by Rosalind W. Picard's in her thought-paper, which presented her initial thinking on *affective computing* [49]. Entities without any affective *I/O* (i.e., –/–), such as traditional machinery, can be very useful in all situations where emotions hinder instead of help. Entities with only affective *O* could for example be avatars, consumer products (e.g., a sports car), toys for children, and our TV. However, such entities would not know what affective state its user is in and, hence, what affect to show as they would lack the affective *I* for it. So, as its name, emotion-aware systems, already gives away, a requirement for such systems is affective *I*.

Only affective *I* is possible. In such cases, the affective *I* alters other processes (e.g., scheduling breaks for pilots) and no affective *O* is given but another type of output closes the system. In case of affective *I/O*, the affective *O* can follow

		O: no	O: yes
I	no	–/–	I/–
	yes	–/O	I/O

Table 1. A description of the four categories of *affective computing* in terms of computer science's input/output (*I*/*O*) operations. In terms of *affective computing*, *I*/*O* denotes the expression (*O*) and the perception, impression, or recognition (*I*) of affect. This division is adapted from the four cases identified by Rosalind W. Picard [49].

the affective *I* immediately or with a (fixed or varying) delay. The affective *O* can also take various forms. Moreover, the person who provides the affective *I* is not necessarily the person who receives the affective *O*.

The theoretical framework concerning affective processes is a topic of continuous debate. Consequently, an accurate interpretation of affective *I* and, subsequently, an appropriate affective *O* is hard to establish. In particular in real-world settings, where several sources of noise will disturb the closed-loop, this will be a challenging endeavor. So, currently, it is best to apply simple and robust mechanisms to generate affective *O* (e.g., on reflex agent level [56]) or slightly more advanced. Moreover, it is not specific states of affect that need to be the target but rather the core affect of the user that needs to be smoothly (and unnoticeably) directed to a target core state [34]. The next section will elaborate on core affect and related concepts.

4 In Search for Definitions

In 1993, Robert C. Solomon noted in the *Handbook of Emotions* (Chapter 1, p. 3, 1st ed.) [39] that " *"What is an emotion?"* is the question that *"was asked in precisely that form by William James, as the title of an essay he wrote for* Mind *well over* 100 *years ago (James,* 1884*). ... But the question* "What is an emotion?" *has proved to be as difficult to resolve as the emotions have been to master. Just when it seems that an adequate definition is in place, some new theory rears its unwelcome head and challenges our understanding."* Regrettably, there is no reason to assume that this could not be the case for the concise theoretical framework that will be presented here (cf. [32]). Nevertheless, we need such a framework to bring emotion theory to *affective computing* practice.

4.1 Affect

In 2003, 10 years after Solomon's notion, in the journal *Psychological Review*, James A. Russell characterized the state-of-the-art of emotion (related) research as follows: *"Most major topics in psychology and every major problem faced by humanity involve emotion. Perhaps the same could be said of cognition. Yet, in the psychology of human beings, with passions as well as reasons, with feelings as well as thoughts, it is the emotional side that remains the more mysterious. Psychology and humanity can progress without considering emotion – about as fast as someone running on one leg."*)(p. 145) [55]. Where Solomon [39] (Chapter 1, p. 3, 1st ed.) stressed the complexity of affect and emotions, Russell [55] (p. 145) stressed the importance to take them into account. Indeed, affect and emotions are of importance for psychology and humanity but *also* for (some branches of) science and engineering, as we will argue in this article.

Solomon's [39] (Chapter 1, p. 3, 1st ed.) and Russell's [55] (p. 145) quotes perfectly points towards the complexity of the constructs at hand (i.e., affect and emotion, amongst other things). It is well beyond the scope of this article to provide an exhaustive overview of theory on affect, emotion, and related constructs. However, a basic understanding and stipulative definitions are needed, as they are the target state *affective computing* is aiming at. This section will provide the required definitions. Since this article aims at *affective computing*, I will focus on affect as the key construct, which is, from a taxonomic perspective, a convenient choice as well. Affect is an umbrella construct that, instead of emotions, incorporates all processes I am interested in, as we will see in the remaining section.

Core affect is a neurophysiological state that is consciously accessible as a primitive, universal, simple (i.e., irreducible on the mental plane), nonreflective feeling evident in moods and emotions [51, 55]. It can exist with or without being labeled, interpreted, or attributed to any cause [55]. People are always and continuously in a state of core affect, although it is suggested that it disappears altogether from consciousness when it is neutral and stable [55]. Affect influences our attitudes, emotions, and moods and as such our feelings, cognitive functioning, behavior, and physiology [29, 55]; see also Table 2. As such, affect is an umbrella construct, a superordinate category [29].

Affect is similar to Thayer's activation [67], Watson and Tellegen's affect [72], and Morris' mood [45] as well as what is often denoted as a feeling [55]. As such, core affect is an integral blend of hedonic (pleasure-displeasure) and arousal (sleepy-activated) values; in other words, it can be conveniently mapped onto the valence-arousal model [38, 54, 55, 67]. However, note that the term "affect" is used throughout the literature in many different ways [51]. Often it is either ill defined or not defined at all. However, affect has also been positioned on another level than that just sketched; for example, as referring to behavioral aspects of emotion [29].

With affect being defined, we are left with a variety of related constructs. To achieve a concise but proper introduction to these constructs, we adopt Scherer's table of psychological constructs related to affective phenomena [10]; see Table 2. It provides concise definitions, examples, and seven dimensions on which the constructs can be characterized. Together this provides more than rules of thumb, it demarcates the constructs up to a reasonable and workable level. Suitable usage of Table 2 and the theoretical frameworks it relies on opens affect's black box and makes it a gray box [35, 48], which should be conceived as a huge progress.

4.2 Affective Computing

In 1995, Rosalind W. Picard wrote a technical report , which was a thought-paper that presented her initial thinking on *affective computing*. In a nutshell, this report identifies a number of crucial notions, which are still relevant. Moreover, Picard provided an initial definition of *affective computing: "... a set of ideas*

Table 2. Design feature delimitation of psychological constructs related to affective phenomena, including their brief definitions, and some examples. This table is adopted from [10].

construct	brief definition and *examples*	intensity	duration	synchro-nization	event focus	appraisal elicitation	rapidity of change	behavioral impact
Emotion	Relatively brief episode of synchronized response of all or most organismic subsystems in response to the evaluation of an external or internal event as being of major significance *(e.g., angry, sad, joyful, fewful, ashamed, proud, elated. desperate).*	++ → +++	+	+++	+++	+++	+++	+++
Mood	Diffuse affect state, most pronounced as change in subjective feeling, of low intensity but relatively long duration, often without apparent cause *(e.g., cheerful, gloomy, irritable, listless, depressed, buoyant).*	+ → ++	++	+	+	+	++	+
Inter-personal stances	Affective stance taken toward another person in a specific interaction, coloring the interpersonal exchange in that situation *(e.g., distant, cold, warm, supportive, contemptuous).*	+ → ++	+ → ++	+	++	+	+++	++
Attitude	Relatively enduring, affectively colored beliefs, preferences, and predispositions towards objects or persons *(e.g., liking, loving, hating, valuing, desiring).*	0 → ++	++ → +++	0	0	+	0 → +	+
Personality traits	Emotionally laden, stable personality dispositions and behavior tendencies, typical for a person *(e.g., nervous, anxious, reckless, morose, hostile, envious, jealous).*	0 → +	+++	0	0	0	0	+

on what I call "affective computing," computing that relates to, arises from, or influences emotions." (p. 1) [49].

10 years later, Tao and Tan wrote a review on *affective computing* in which they defined it as: *"Affective computing is trying to assign computers the human-like capabilities of observation, interpretation and generation of affect features."* (cf. [66]). As such, they assured a one-on-one mapping of affect onto the traditional computer science / HCI triplet input (i.e., observation), processing (i.e., interpretation), and output (i.e., generation).

5 years later, Rafael A. Calvo and Sidney D'Mello [19] characterized the rationale of *affective computing* with: *"automatically recognizing and responding to a user's affective states during interactions with a computer can enhance the quality of the interaction, thereby making a computer interface more usable, enjoyable, and effective."*

I pose to adopt yet another definition, namely: *Affective computing is the scientific understanding and computation of the mechanisms underlying affect and their embodiment in machines.* This definition is inspired by the short definition of AI provided by the Association for the Advancement of Artificial Intelligence[3].

5 Discussion

Affective computing includes signal processing and machine learning techniques, which have a thorough mathematical foundation. Consequently, these elements are not those that slow down the progress of *affective computing*. In this article, I posed that *affective computing*'s true complexity lies in i) the definition of constructs related emotion, ii) their operationalization, and, subsequently, iii) their mapping on the signals available (e.g., audio, vision, or biosignals). To accelerate progress on *affective computing*, it is worth to become acquainted with the vast amount of work conducted in its related disciplines. Therefore, this article briefly touched on the history of *affective computing* (Section 2) and discussed the complexity of affect (Section 3). Subsequently, in Section 4 a concise set of definitions was provided on *affective computing*'s key concepts. In this section, I will identify lessons that can be learned from this endeavor and discuss some of challenges and limitations *affective computing* is facing.

The historical reflection in Section 2 was founded on the classical debate between the James-Lange theory and work of Cannon and Bard [25]. It is fair to pose that this debate is somewhat outdated and substantial progress has been made since the work of Cannon and Bard. Nevertheless, this debate still touches upon some key notions and identifies both knowledge and the gaps therein. Moreover, it provides a compact sketch of the true complexity underlying *affective computing*. As such, I hope that it can serve as an eye-opener and encourage readers to study the foundations of affective sciences in depth.

In Section 3, *affective computing* was approached from three independent angles: i) the relation between body and mind, ii) cognitive processes, and iii)

[3] Association for the Advancement of Artificial Intelligence (AAAI)'s URL: `http://www.aaai.org/` [Last accessed on April 14, 2012].

affective computing's I/O. The first angle can be perceived as an extension of the debate presented in Section 2. It takes a philosophical stance, starting with the old Greek and ending with state of the art neuroscience research [17]. In a nutshell, I conclude that, despite the tremendous progress made in science and engineering, we are far from a complete understanding of the relation between our body, mind, and context [13, 15]. The second angle concerns the awareness that emotions can not be studied in isolation, they interact with (other) cognitive processes. However, as with the body and mind issue, this interaction is complex and our knowledge on this is thin. The third angle takes a computing perspective instead of an philosophical or cognitive perspective. *Affective computing* is described in terms of computer science's I/O, which was adopted from Rosalind W. Picard [49]. Taking this perspective helps in making explicit what we denote as *affective computing*, which is often a source of confusion.

Section 4 is dedicated to providing definitions of affect-related constructs and affective computing. It includes Table 2 that provides definitions and examples of emotion, mood, interpersonal stances, attitude, and personality traits and characterizes these constructs on seven dimensions. Although it is advisable to start research with well grounded definitions, a contrasting position can be taken as well. Already in 1941, Elizabeth Duffy published her article *"An explanation of 'emotional' phenomena without the use of the concept 'emotion' "* in which she starts by stating that she considers *"... 'emotion', as a scientific concept, is worse than useless. ... 'Emotion' apparently did not represent a separate and distinguishable condition."* (p. 283) [27]. Similar concerns were expressed in 1990, John T. Cacioppo and Louis G. Tassinary [18]. So, although this statement is 60 years old it is still (or, again) up to date, perhaps even more than ever (cf. [37]).

To ensure sufficient advancement, it has also been proposed to develop computing entities that respond on their user(s) physiological response(s), *without* the use of any interpretation of them in terms of emotions or cognitive processes [68]. This approach has been shown to be feasible for several areas of application (e.g., [34]). It suggests that emotion research has to mature further before affective computing can be brought to practice. This is a crude but honest conclusion for the field of affective computing. It implies that affective computing should take a few steps back before making its leap forward. Gross [29] summarized in his article *"The future's so bright, I gotta wear shades"* a list of hot topics on emotion research, which would be a good starting point for this process (see also [70]). I pose that if anything, affective computing has to learn more about its roots; then, affective computing can and probably will have a bright future!

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