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To feel or not to feel: The role of affect in human–computer interaction

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Abstract

The past decade has witnessed an unprecedented growth in user interface and human–computer interaction (HCI) technologies and methods. The synergy of technological and methodological progress on the one hand, and changing user expectations on the other, are contributing to a redefinition of the requirements for effective and desirable human–computer interaction. A key component of these emerging requirements, and of effective HCI in general, is the ability of these emerging systems to address *user affect*. The objective of this special issue is to provide an introduction to the emerging research area of affective HCI, some of the available methods and techniques, and representative systems and applications.

Keywords: Affective HCI; Affective computing; Affect recognition; Affect expression; Affective user modeling

1. Introduction

The past decade has witnessed an unprecedented growth in user interface and human–computer interaction (HCI) technologies and methods. Ideas and techniques that seemed outlandish and even fantastic just a few years ago are now firmly established in the research community and even beginning to enter the mainstream user community. These range from *techniques and devices for assessing user state* (e.g. eye tracking, facial expression recognition, wearable computers such as earrings collecting physiological data (Picard and Healey, 1997), 'expression glasses' detecting interest or confusion (Picard, 2000), through *integrated systems functioning as socially intelligent agents* (e.g. robots and avatars interacting with autistic children to

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facilitate social skill acquisition (Blocher and Picard, 2002; Dautenhahn et al., 2002a, b; Michaud and Theberge-Turmel, 2002), experimental avatars and synthetic agents populating virtual environments (e.g. Marsella and Gratch, 2002), to high-level '*paradigm shifts*' *in thinking about HCI* (e.g. cognitive systems engineering and collaborative systems) (e.g. Hollnagel, 2003).

New developments in human–computer interaction technology are making a range of novel HCIs possible, and are narrowing the gap between the human and the machine at the human–machine interface. Machines are increasingly able to sense, or infer, user attributes, and use increasing numbers of available 'modalities' to interact with the user (e.g. virtual reality (VR) technologies used in neuropsychological assessment (Rizzo et al., 2003) and as adjuncts to behavioral treatment of a variety of phobias (e.g. http://www.virtuallybetter.com/) (Zimand et al., 2003)).

Traditionally 'hardcore' computing journals publish overviews of techniques and applications that only a few years ago were explored by a handful of graduate students in the corner of some of the more lavishly funded research institutions (e.g. physiological interfaces (Allonson, 2002) and wearable computers (Ditlea, 2000)).

1.1. Focusing on the user

What characterizes these developments is the increased focus on the users: their often idiosyncratic characteristics and reactions, and their changing needs. Long gone are the days when computer system users had to 'put up or shut up', and accommodate the *designers*' preferences and idiosyncracies. The burden of adaptation has gradually been shifting from the human user to the computer. More often than not, the user is now the central component of system design and user needs drive both the nature of the user interface, and the function allocation of tasks between the user and the machine.

In some research communities we no longer even speak of users and machines as separate entities, but rather of collaborative systems, integrated human–machine systems, and joint cognitive systems (Hollnagel, 2003). These subtle concatenations reflect a deep and significant shift in underlying design philosophy and objectives, and indeed in the expectations we now have of computer systems.

To be sure, there continue to be examples of frustrating applications and systems, and the good intentions do not guarantee corresponding results (Hoffman et al., 2002). But such systems will be unable to survive in the increasingly competitive, user focused, environment, much as we no longer see boxes of punched cards.

As the range of computer applications broadens, and as we approach the predicted ubiquitous computing environment (Lyytinen and Yoo, 2002), a new set of requirements begins to evolve for the human–machine interface. These requirements are driven not only by the diversity of the tasks themselves, but also by the increasingly heterogeneous user population, and the decreasing tolerance of user frustration.

In short, the synergy of technological and methodological progress on the one hand, and changing user expectations on the other, are contributing to a redefining of the requirements for what constitutes effective and desirable HCI. A key component of these emerging requirements, and of effective HCI in general, is the ability of these emerging systems to address *user affect*.

1.2. Addressing user affect

Why the vague term '*address*'? Because 'addressing affect' encompasses various interpretations, corresponding to the variety of possible roles and functions that affective considerations introduce into HCI. It can mean *recognizing user affect*, *adapting to the user's affective state*, *generating 'affective' behavior by the machine*, *modeling user's affective states*, or *generating affective states* within an agent's cognitive architecture. Fig. 1 highlights these roles and functions in the context of a human–machine collaborative system, and the remainder of this section describes them in more detail below. (These distinct roles and functions can also form the basis for a framework for organizing affective HCI research, as discussed in Section 3.)

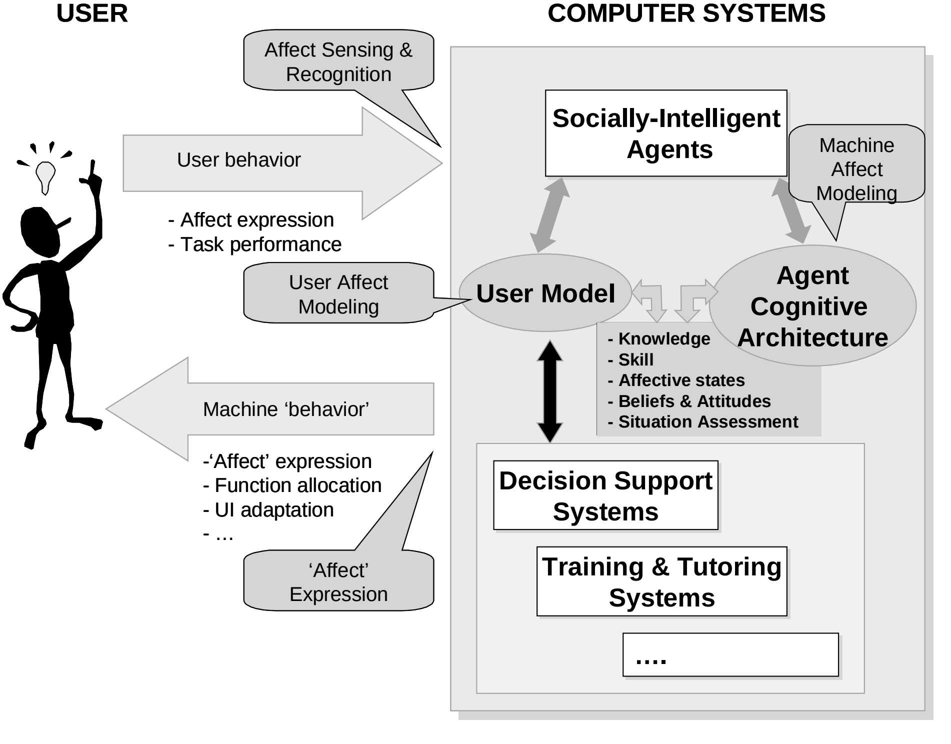

Fig. 1. Framework for organizing affective HCI research. The figure depicts a human-machine system, explicitly indicating a range of possible system types on the right. This includes autonomous, socially intelligent agents (with their own cognitive architectures controlling their behavior), as well as a range of decision-aids and tutoring systems. Both the agents and the more traditional systems may explicitly model the user. Both the user model, and the agent cognitive architecture, may include explicit models of affect. The research areas of affective HCI are highlighted in the 'stickies': 'Affect Sensing and Recognition', 'User Affect Modeling', 'Machine Affect Modeling', and 'Machine Affect Expression'.

1.2.1. Affect sensing and recognition

Addressing affect can mean *sensing and recognizing the user's affective state or affective style*, in order to adapt the machine's responsiveness accordingly, as necessary. Indeed, this is a core aspect of affective computing in general (Picard, 2000), and is being addressed by a number of researchers. A variety of options exist for affect recognition, including the use of psychophysiological measures (e.g. heart rate); diagnostic tasks; self-reports; facial expressions; and knowledge-based methods to derive likely affective state based on factors from current task context (e.g. type, complexity, time of day, length of task), personality (extraversion, aggressiveness, obsessiveness, etc.) and individual history (past failures and successes, affective state associated with current task, etc.) (Hudlicka, 2002b). While much progress has been made in affective assessment using a single particular measure type (e.g. see Picard et al., 2001), reliable assessment typically requires the concurrent use of multiple methods. Which combinations of these are used within a given context depends on a number of factors, including: the *types of emotions* to be detected (some emotions are more readily detected via physiological signals whereas for others facial expressions or self-reports may be more appropriate); the *instrumentation necessary* to collect the required data (in some cases psychophysiological measures and facial expression data may be collected easily, whereas in other contexts the required sensing apparatus would be too invasive or otherwise inappropriate; e.g. in children, causing interference with task, etc.); the *real-time requirements* (in some cases real-time detection may not possible due to the computational requirements of the necessary data analysis), or *data availability* (e.g. speech is a good source of affective information, but a noisy working environment may preclude its use). All of the papers in this issue address some aspect of affect sensing and recognition.

1.2.2. Adapting to user affect

Once the user affective state is identified, a decision needs to be made as to how, and whether, to *adapt the system functionality to this state*. The first question that arises concerns who should be making this decision. Should the user be involved? Always? Depending on the context? For example, in real-time high-automation contexts, such as the modern aircraft, there may not be adequate time to allow the user to be involved. (On the other hand, if the user is not involved, user acceptance and trust will be affected.) Thus, a range of issues arises in deciding who should control the level and type of adaptation.

The next question concerns the aim of the system adaptation with respect to the user affective state: should the identified state be reduced, augmented, transformed into another state, or ignored altogether? Again, the choice here depends on the specific context and objectives for the human–machine system. Is the objective to *prevent errors*, as it might be in designing an air traffic control decision-support system? Then an optimal stress level must be maintained and the system may need to adjust its user interface or function allocation to reduce user stress in certain situations. Some of these alternatives are being explored in research settings (e.g. adapting user interface layout in response to detected stress (Hudlicka, 2002b);

providing tailored feedback in response to user frustration (Klein, 1999). In some instances optimal performance may, paradoxically, require an increase in stress levels, or, more precisely, arousal levels (Yerkes and Dodson, 1908). For example, in situations where the user enters a state of boredom and associated lack of vigilance, which may occur in pilots on long-haul flights with high levels of automation (e.g. Matthews et al., 2000b).

Is the objective to *maintain a particular user state for particular task*, as it might be during training and tutoring, or during long-term repetitive tasks such as customer support call centers? Then the level of negative emotions such as anxiety and frustration must be kept relatively low, otherwise performance suffers (e.g. learning is impeded, customer support does not provide necessary assistance, etc.). In educational settings in particular, more subtle user affective states need to be considered to promote effectiveness of the interaction (e.g. capitalize on detected positive affect, curiosity or surprise) (e.g. Conati, 2002).

Is the objective to *induce a particular state* as it might be during team training or during virtual neuropsychological assessment and treatment? Some of these applications might warrant an enhancement or amplification of a particular state, even a negative state (e.g. flooding or systematic desensitization approaches to phobia treatment). Then specific induction strategies must be initiated, which may be highly idiosyncratic and context dependent, and require the use of appropriate monitoring procedures to prevent undesirable or dangerous extremes.

Or is the objective simply to *make the user's experience enjoyable*, exciting and fun, as it might be in a variety of gaming and entertainment applications? In fact, some researchers are suggesting that the next leap in design philosophy will be precisely the attention to affect (see forthcoming book on the role of emotion in design by Norman (2003)).

1.2.3. Machine 'affect expression'

Whatever type of adaptation is selected as the most appropriate, it may (or may not!) involve a degree of *affective expression* by the machine itself.[1] Machine affect, in turn, may not be expressed solely as a means of adapting to the user, but also in cases where synthetic avatars and robots have their own goals and agendas, which involve inducing a particular affective state in a human (or perhaps another synthetic) partner.

While it is justifiably a topic of some controversy as to whether or not machines can have emotions (see Picard and Hollnagel, in this issue), there is no doubt that machines can behave in a way that *appears to reflect* a particular affective state. This behavior may then be interpreted as a particular emotion, or may induce affective reactions in the human user or partner. Picard points out how even the simple familiar Macintosh smiley face generates an affective response, and there are numerous examples of unintended conditioned affective responses (e.g. the sadly

[1] 'Affective' is in quotes to emphasize the distinction between expression of real affect, as encountered in animals (including, of course, humans) and 'simulated' expressions of affect by machines. (This distinction is also discussed by Hollnagel and Picard in this issue.)

familiar sound of a Windows machine rebooting). The range of possibilities for machine affect-like or affect-influencing expression has grown tremendously over the past 5 years, and includes a number of modalities (e.g. avatar or robot facial expression, gesture, body movement, voice quality, specific utterances selected, etc.). Number of papers in this issue address machine affect expression (deRosis et al., Breazeal, Lisetti et al., Oudryer, and McKenzie et al.).

1.2.4. Modeling affect in user and machine

The ability to recognize the user's affective state, and to decide how, or whether, to respond to it, may involve some degree of *user affective modeling*; that is, the modeling of a relevant subset of the user's motivational-behavioral repertoire across multiple contexts (e.g. training scenarios or treatment protocols), to determine the most likely user affective state, or to predict a likely reaction to a hypothetical situation. Such models can also help disambiguate available sensor data (e.g. fast heart rate signaling excitement and positive emotion vs. fast heart rate signaling fear or anger), or make up for lack of some data, and help determine the best means of responding to a particular affective state.

The ability to generate an affective state is also critical for autonomous agents, whether robots or avatars, both to increase realism and believability, and to improve adaptability and survival in a synthetic or virtual world. In these cases we speak of *agent cognitive architectures* (*affective–cognitive architectures*) *and emotion models*, capable of producing a cognitive–affective appraisal of the current internal and external context, much as humans do in day-to-day functioning. To accomplish this, the agent's architecture must combine current stimuli with existing schemas stored it its memory, representing a variety of information, including past experiences, current goals and needs, and knowledge of the world, to derive the most likely affective state, which then guides subsequent behavior. Section 2.3 discusses these issues in more detail and several papers in this issue focus on some aspect of this process (deRosis et al., and Breazeal).

1.3. Do we really need to bother with affect?

The skeptical observer (or user)—and there are many—may ask: Why should consideration of the user's affective factors be necessary? In fact, it may not *always* be necessary, and the degree and form of adapting to the user's affective state, or generating an affective state for an autonomous agent, are likely to vary greatly, depending on the context, as outlined above. There are certainly many situations where user affect is irrelevant, and where it may, and should, be disregarded. Much as consumers did not take to talking cars and elevators, we are unlikely to prefer affective bank machines. In fact, as Picard points out, some recent instances of 'simulated affect', such as the notorious animated paperclip, can be very irritating (Picard, 2000).

However, there are equally many cases where user affect is critical for the successful completion of a task, for avoiding (often disastrous) errors, for achieving optimal performance, or for maintaining reasonable user stress levels. While progress is being made in user-modeling (e.g. Bauer et al., 2001) and adaptive user interfaces (Haas and Hettinger, 2001), the majority of existing systems continue to assume normative performance, and fail to adapt to the individual characteristics of particular users, let alone user affect.

This existing lack of detection, assessment, and modeling of affective states on the one hand, and adaptation to these states on the other, can lead to non-optimal behavior at best, and contribute to errors with disastrous consequences. In fact, the situations where affective considerations are most critical are precisely the types of situations where the consequences of the human–machine interaction failures are most severe. For example, in the increasing numbers of decision-support systems in critical, typically high-stress, applications such as air traffic control, process control in nuclear power plants and chemical plants, emergency vehicle dispatchers, healthcare, pilots and drivers, computer network managers, and a variety of military operational contexts. There are numerous examples where affective considerations in system design may have prevented disasters (e.g. Three mile island, USS Vincennes, numerous commercial aviation incidents, etc.) (e.g. Collyer and Malecki, 1998). The increasing frequency of accidents and incidents attributed to the broad area of 'human error' in a variety of settings could be reduced by considering the user affect in system design, particularly stress and anxiety, frustration, and boredom.

But affective considerations are not just relevant in 'extreme' and dangerous situations. As already outlined above, there are increasing numbers of situations where a variety of more subtle affective states need to be considered to prevent burnout and maintain positive affect, to enhance the user's experience, or to induce a particular affect for treatment or assessment purposes.

Regardless of whether or not affective factors will ultimately be considered in a particular human–machine context, it is critical that the system designers accurately assess the range of possible affective states the users may, or should, experience during interactions with the system, and that they understand their effects on the user, and thus on task performance. Such understanding then allows informed decisions regarding which affective considerations must be addressed, when and how. This, in a nutshell, is the broad aim of affective HCI.

1.4. How should we address affect in HCI?

How should the HCI research community approach this ambitious undertaking? We must, first of all, *understand the range of user affective states and their effects*, both the generic effects, and their specific effects within the context of the task at hand. Most researchers would agree that emotion effects fall into four categories: somatic–physiological; cognitive–interpretive; motivational–behavioral and experiential–subjective (Clore and Ortony, 2002). Different affective states have distinct, and often highly idiosyncratic, 'signatures' across these categories. By 'affective states' we mean a range of conditions, including simple bi-polar 'reactions' such as like and dislike, boredom and excitement, or approach and avoid; basic emotions such as joy, sadness, frustration, anger, fear and anxiety; complex emotions such as shame, guilt, jealousy; and long-term moods (see Ekman and Davidson, 1994). These signatures depend both on the individual (his temperament, individual history, current physiological state and psychological context) and on the situational context (e.g. situations differ in the degree to which they promote or inhibit the expression of particular emotions).

Depending on the exact nature of these factors and their interactions, the user's affective reaction may be subtle or none, it may be adaptive (e.g. approach in response to pleasant stimuli, focus on threat in dangerous situations), it may be maladaptive (e.g. persistent interpretations of ambiguous situations as threatening and resulting state of anxiety), it may be pathological and even dangerous (e.g. reacting in violent rage to a minor frustration). Indeed, there are many examples of the misapplication of the fundamentally adaptive affective reactions such as attentional narrowing, working memory capacity reduction, or threat focus (e.g. USS Vincennes incident, Collyer and Malecki, 1998), not to mention the variety of extreme affective reactions, without which entire musical genres would not even exist. In fact, it is precisely these types of extreme phenomena that have resulted in the various negative connotations associated with affect. Adaptive or not, understanding the range of user affective states and the spectrum of their individual signatures and effects, is the essential basis for any subsequent considerations of affect in HCI. The wealth of emotion research in psychology and neuroscience over the past decade provides a rich source of empirical data for HCI researchers and practitioners; (e.g. Lewis and Haviland, 1993; Ekman and Davidson, 1994; Williams et al., 1997; Forgas, 2000; Matthews et al., 2000a, b; Lane and Nadel, 2000; Scherer et al., 2001).

We must next *accurately recognize the user's affective state*, often in real time. This is particularly challenging, given the complexity of emotions, their essentially personal and subjective nature, the variability of their expression across, and even within, individuals, and, frequently, lack of sufficient differentiation among associated visible and measurable signals. The range of factors that must be considered, the vagaries of the sensing equipment and the amount of data and complexity of analysis, all contribute to making this a challenging task. However, much progress has been made in this area over the past 5 years, with researchers reporting machine forced-choice recognition of basic emotions at success rates matching those of humans (e.g. 60% in speech (Oudryer, this issue), 80% using psychophysiological measures (Picard et al., 2001) and in the mid to high 80% using facial expression (Cohen et al., 2003)).

Finally, given the knowledge of the user's affective state and its likely effects, and the user's desired state for the objectives of the HCI, we must *decide whether or not the system should respond to this state, and how*, or what affective behavior, if any, the system should display to induce a desired user state or behavior. Here we must consider the broad range of available modalities, whose exact configuration depends on the specific context and available means. Thus at the more traditional end of the HCI spectrum (refer to Fig. 1), a decision-aiding system with a traditional 2-D user interface may respond to user affect by simply modifying the interface or the task-allocation strategy (Hudlicka, 2002b; Hudlicka and McNeese, 2002). We can even envision future automation systems taking over, or re-assigning, a user's task when the user stress level reaches unacceptable or dangerous levels. (Of course, there are numerous ethical and user acceptance issues, which have yet to be resolved.) At the more futuristic end of the spectrum, we can envision autonomous agents attempting to address the user's affective state directly, to reduce, amplify, or induce a different state, depending on the objective of the interaction. A broad range of modalities is available here, including speech and language, gesture and head movement, body movement and posture, as well as facial expression. These types of interactions are already being explored in a number of research laboratories (see Paiva, 2001; Picard et al., 2001; Dautenhahn et al., 2002a, b).

In 1997, Rosalind Picard defined *affective computing* as 'computing that relates to, arises from and deliberately influences emotion' and published the first book in this area (Picard, 1997). Since then, interest in exploring the role of affect across a number of subdisciplines within computer science has burgeoned. There are now numerous workshops, conferences and special issues addressing the variety of topics relevant to the broad area of affective computing.

The objective of this special issue is to provide an introduction to the emerging research area of affective HCI, some of the available methods and techniques, and representative systems and applications. The papers address a broad range of problems, use a variety of methods and techniques, and apply them in diverse application domains. It is our hope that this broad range of topics will serve several functions for the reader, whether an experienced researcher, a novice, or just a curious on-looker. *First*, that it will motivate the need to better *understand affective factors within HCI*. *Second*, that it will serve to provide an *introduction to the various methods and techniques* applicable to the variety of problems encountered in affective HCI, ranging from sensing user affective signals, interpreting them to recognize the user state, selecting the most appropriate system reaction to this state or generating an appropriate affective state within an agent, as required, and selecting the most appropriate mode and means for its expression. *Third*, that it will help provide a *framework for organizing the diverse endeavors* in this emerging research area. *Fourth*, that it will provide concrete examples of specific applications where affective HCI can play an important role. And *finally*, that it will help *dispel a number of persisting misconceptions* about affect and affective computing and help provide a philosophical grounding for assessing the feasibility and utility of particular efforts.

In the remainder of this paper I first highlight some of the significant recent findings in emotion research relevant to affective HCI (Section 2), briefly introduce the papers in this special issue, in the context of an organizing framework (Section 3) and conclude with a set of questions that affective HCI researchers should be asking (and answering).

2. Emotion research and affective HCI

Emotion has been a topic of wonder, research and polemics since antiquity, (see Fellous (1996) for an overview of emotion theories through the ages); fascinating, frightening and generally puzzling the 'common man', the researcher, and the philosopher alike. In large part, this may be due to one of the more intriguing aspects of emotions: the apparent ability to 'take over', to 'control' us, to completely alter our perspectives and our standard modus operandi. It is undoubtedly these more extreme manifestations of emotions that have also led us to fear and suspect affect, earning epitomes such as the Kantian 'diseases of the rational mind'. These extreme manifestations have also contributed to the various forms of emotional vs. rational dichotomies that have, until very recently, characterized Western thought about these complex phenomena. This apprehensive attitude, due to the more readily visible and extreme manifestations of affect, coupled with the difficulties of studying these complex and difficult to measure phenomena, have contributed to the frequently marginal status that emotion research has had until recently. This is exemplified, for example, by the almost complete denial of affective influence on cognition during the 'cognitivist revolution' that began in the 1960s. (Although notable dissenting opinions existed even then, e.g. Simon, 1967.) This perspective was in turn influenced by the preceding 'out of sight, out of mind' attitude of the classical behaviorists, who regarded emotions as epiphenomena, not involved in motivation or mediation of behavior, and in any case impossible to study, being considered largely unmeasurable.

Thus although central to individual and social development, and to effective intrapsychic and interpersonal functioning, emotions have, until recently, been largely ignored by cognitive science and neuroscience researchers, not to mention AI and HCI. Over the past 15 years, however, important discoveries in neuroscience and psychology have contributed to a growing interest in the scientific study of emotion and have in effect 'legitimized' emotion research. In part, this has been due to the discovery that emotions play a critical role in what have traditionally been considered 'rational' aspects of behavior: perception, decision-making, learning, planning and action selection. These effects exist not just at the extremes, but also in the myriad of apparently insignificant decisions and adaptations that make up daily life; insignificant, that is, until something goes wrong with the decision-making apparatus, and, in particular, with its affective component. At that point, even minor decisions such as dressing and chore planning can become impossible to negotiate (Damasio, 1994). Emotion has thus been 'legitimized' to the point where the past 10 years have witnessed a unprecedented growth in emotion research (Forgas, 2001a), both in disciplines which have traditionally addressed this area (e.g. psychology, sociology), but also in a variety of interdisciplinary settings, and in computational disciplines such as cognitive science and HCI.

It is of course not possible to do justice to the vast body of emotion research in a few pages. The aim of this section is to provide a high-level introduction to several representative perspectives on emotion, some of the research methodologies involved, and highlight a few critical recent findings; both to whet the reader's appetite, and to point out their relevance for affective HCI. I have selected to highlight neuroscience, cognitive and experimental psychology and recent cognitive science models of appraisal and emotion effects. The omission of social and clinical psychology (as well as a number of other disciplines addressing emotion) does not reflect their lack of relevance but rather a lack of space.

2.1. Neuroscience

Neuroscientists and physiologists have focused on identifying the neural and hormonal circuitry, and associated complex feedback mechanisms, that mediate affective processing and expression. Neuroscience research has identified circuitry dedicated to the processing of emotionally relevant stimuli; that is, stimuli that threaten or benefit the survival of the organism or the species (LeDoux, 1989). LeDoux and colleagues, studied fear conditioning in rats and produced a number of key findings: (1) existence of dedicated circuitry processing fearful stimuli, with the amygdala playing a critical role; (2) evidence that this emotional circuitry by-passes the cortex and performs fast, less differentiated processing and rapid behavior selection (e.g. freezing behavior in rats); and (3) evidence that this processing is mediated by connections linking sensory organs directly to emotional circuitry in the brain, specifically, the amygdala (LeDoux, 1992, 1996, 2002). Affective processing thus achieves this fast responsiveness in part by bypassing the high-level, cortical circuitry and mediates a parallel, direct response to critical stimuli. The projections from the amygdala to a number of arousal systems further facilitate a coordinated, efficient behavioral response. Recent non-invasive neuroimaging studies appear to suggest that similar circuitry also functions in humans (e.g. Davidson, 2000).

Damasio and colleagues have focused on explorations of information processing and decision-making in humans with lesions in the cortical areas integrating emotional stimuli and identified the critical role of emotion in these processes (Damasio, 1994). Damasio's findings suggest that emotions, and associated affectively motivated considerations, help 'prune' the search spaces generated through cognitive processing, and are in fact necessary for what has traditionally been referred to a rational decision-making. In fact, some researchers suggest that we distinguish between rational behavior aimed at satisfying goals, and rational reasoning that reflects a particular formal means of manipulating information. Lisetti has suggested that we term these rationality_1 and rationality_2, respectively (Lisetti and Gmytrasiewicz, 2002).

Gray presents evidence supporting the existence of neuroanatomical components that mediate three fundamental behavior-coordinating systems: approach, avoidance and, to some extent, fight or flight (Gray, 1994). These systems reflect corresponding categories of affective reactions: positive affect and approach behavior; negative affect and avoidance, and anger/aggression and fear. Davidson presents evidence about the location of some of these systems in the brain: the behavioral approach system in the left anterior cortex, and the behavioral inhibition system in the right anterior cortex. He postulates the role these systems play in emotional reactivity and pathology; for example, correlation of understimulation of the left anterior cortex, associated lack of positive affect, and predisposition to depression (Davidson, 1994; Davidson, 2000).

Perhaps one of the more critical contributions of these findings has been the long-overdue debunking of the outdated emotion vs. reason dichotomy,[2] and its later incarnation within the appraisal theories: primacy-of-affect vs. primacy-of-cognition (Zajonc, 1980; Lazarus, 1991a, b). Current discussions of the role of emotion in decision-making, and of cognition–emotion interactions in general, typically adopt a more encompassing view of a variety of parallel, distributed circuits and sub-systems processing a corresponding variety of information relevant to the organism's survival (LeDoux, 2000). Some of these systems falling within what has traditionally been referred to as the 'cognitive' realm, while others fall within what has traditionally been considered 'emotive'.

In short, neuroscience research demonstrates that emotional processing is an integral part of adaptive behavior across species. Emotions represent phylogenetically older, less differentiated but robust information processing mechanisms. They mediate behavior which is particularly adaptive for the organism, by facilitating simple reflexive responses, as well as coordinating complex cognitive processing (LeDoux, 1987). Extensive recent studies provide strong evidence that emotional information processing is intimately linked with all functions we currently understand to comprise cognition: attention, perception, learning, reasoning, and memory storage and retrieval.

Neuroscience findings thus both motivate and constrain specific hypotheses regarding the mechanisms through which emotions influence our decision-making processes and behavior. The identification of specific circuitry by neuroscientists provides concrete examples of structures and processes that should be included in computational models of emotion (e.g. identification of multiple working memory and goal-state processing structures (Goldman-Rakic, 2000; Davidson, 2000)) and contributes to the construction of more realistic models of these complex phenomena. The disproving of a variety of hypothesized structures (e.g. grandmother cells), similarly helps direct the modeling efforts, by helping us avoid futile searches for grandmother cells, homunculi, and such, much as we no longer search for phlogiston or attempt to develop more precise phrenological instruments.

2.2. *Psychology: cognitive and experimental*

Emotion research in psychology reflects the diversity of the discipline itself. Like the proverbial elephant, the complex phenomenon of emotions is addressed from different perspectives, at different levels of abstraction, using different methods, and asking different questions, depending on the subdiscipline.

Psychologists have studied all aspects of affect extensively. In 1872, Darwin published the seminal 'The Expression of the Emotions in Man and Animals' (Darwin, 1872 [1998]), which lay the groundwork for the rich tradition of descriptive and experimental approaches that predominated in emotion research until recently. This research focused on the development of a variety of taxonomies and

[2] In spite of this, there are still a number of researchers, even emotion researchers, who use the affective vs. rational terminology.

dimensional structures of emotion (Ekman and Davidson, 1994), on identifying the variety of visible and measurable correlates and signs of emotion across multiple modalities (e.g. Ekman and Friesen (1978) for facial expressions), as well as on the identification of specific measurable effects of a variety of affective states on perception, cognition and performance (Persons and Foa, 1984; Isen, 1993; Williams et al., 1997) (see Section 2.2.3 below). Much work has also been devoted to affective development, the subjective components of emotion—the 'feeling states', cultural differences and personality effects (Lewis and Haviland, 1993; Ekman and Davidson, 1994).

Social psychologists focus on the *interpersonal* role of emotion within the larger social context; its role in constructing, maintaining, and coordinating social interactions, structures and processes (e.g. Forgas, 2001a, b). *Cognitive and experimental psychologists* focus the *intrapsychic* functions of emotion; its role in regulating individual behavior and managing goal priorities to assure adaptive behavior and homeostasis. A critical component of the intrapsychic role of emotions is the interaction of cognition and emotion—adaptive under optimal circumstances (e.g. anxiety causing attentional narrowing to focus on impending threat), but also causing undesirable consequences when emotion-induced biases are extreme or not warranted by the situation. It is these phenomena that are then addressed by *clinical psychologists*, who typically focus on the maladapative or pathological manifestations of emotions and the means of correcting them (e.g. Safran and Greenberg, 1991).

More recent research efforts, perhaps inspired, and certainly aided, by computational modeling, tend to focus on identifying the mechanisms involved both in emotion generation during appraisal processes, and those that mediate the known effects of emotions on cognition. These attempts range from the identification of specific structures and processes, at a sufficiently concrete level to allow computational models (e.g. Ortony, Clore and Collins, 1998; Smith and Kirby, 2000), to implementation of computational cognitive architectures, at which point they begin to merge with cognitive science and AI (see Section 2.3. below).

Here I focus on cognitive and experimental psychology as the most immediately relevant, to provide minimal background information for the papers in this issue. Specifically, I highlight representative research findings and approaches for several key areas relevant for affective HCI: typologies and taxonomies of affective states (2.2.1), roles of emotion (2.2.2), and effects of emotion on cognition (2.2.3).

2.2.1. Descriptive typologies of affective states, emotions and moods

Several options exist for describing and categorizing the range of affective and feeling states. They can be categorized by their duration (transient *emotions* vs. long-lasting *moods*); by their degree of differentiation and behavioral specificity (*affective states* such as like/dislike or approach/avoid reactions vs. more specific *emotions* such as joy, pride, sadness, fear, shame, anger, etc.); by the degree of cognitive involvement and consequent individual behavioral variations possible (*basic emotions* such as fear, sadness, happiness, anger typically show fewer variations than *complex emotions* such as pride, shame, jealousy, guilt);[3] and by a number of additional factors such as triggers, manifestations, and degree of voluntary control. For extensive discussions of these issues see Ekman and Davidson (1994), Lewis and Haviland (1993) and Forgas (2000, 2001a).

An alternative method of characterizing affective states and emotions, most often applied to moods and basic emotions, is to focus on the underlying, often physiologically correlated factors (e.g. arousal) and map these onto distinct dimensions. Several such two- or three-dimensional sets have been proposed, including positive and negative affect (Watson and Clark, 1992), energetic and tense arousal (Thayer, 1996), hedonic tone, energy and tension (Matthews et al., 1990), and valence and arousal (Watson and Tellegen, 1985; Russell, 1979). The dimensional models are helpful in both recognition and expression, as well as in models of emotion generation, in situations where sufficient data may not be available for more highly differentiated responses, or to assure that realistic continuous transitions among agent's emotions are achieved (see, for example, Breazeal, this issue).

In describing emotions relevant for a particular HCI context, we may choose existing, familiar high-level terms (e.g. pride, joy, sadness, jealousy, etc.), and many studies have focused on machine recognition and generation of these emotions, often in cross-cultural settings. On the other hand, we may also choose to 'invent' new emotions, or rather specific combinations of emotions relevant for a particular context, such as user state when 'all is going well with the computer' or 'when encountering annoying usability problems' (e.g. Picard, 1997, p. 53 and this issue).

2.2.2. *Characteristics and roles of emotion*

Neuroscience and experimental psychology research has identified a number of characteristics of emotions, including:

- Rapid identification and response to environmental stimuli which are dangerous or beneficial to the organism's survival.
- Mediation by hardwired and highly species- and situation-specific responses (e.g. rats responding to squeaks of certain frequencies emitted by pups in danger).
- Reliance on pre-wired circuitry to accomplish fast and long-lasting learning, when necessary.
- Capability to induce processing states which bias the organism towards specific types of behavior over long periods of time.
- Capability to quickly allocate appropriate resources in critical situations and thereby focus attention and delay less critical processing.
- 'Automatic appraisal, commonalities in antecedent events, presence in other primates, quick onset, brief duration, and unbidden occurrence and distinctive physiology' (Ekman and Davidson, 1994, p. 18).

[3] It should be noted that not everyone subscribes to the notion of basic emotion (e.g. Ekman, 1994). The notion of basic emotions remains somewhat controversial, with a number of researchers disputing its terminological usefulness or idea that a small set of basic emotions can be identified.

- Continuity of emotional expression across species, cultures and across the lifespan.

How do these capabilities and characteristics translate to hypothesized or actual roles of emotion? Emotion researchers have proposed several answers to this question, both within the intrapsychic (individual) and the interpersonal (social) realms. We briefly describe three of the primary hypothesized roles below.

2.2.2.1. Emotions as interpersonal communication mechanisms. In the *interpersonal* realm, behavioral manifestations of emotions serve to communicate intentions and behavioral tendencies (e.g. imminent attack or withdrawal, pleasure vs. displeasure, etc.) among individuals across a number of species and thereby help coordinate group behavior and social interaction, and assure appropriate response (e.g. withdrawal in response to growling).

2.2.2.2. Emotions as internal goal management mechanisms. In the *intrapsychic* realm, emotions are thought to be associated with processing required to coordinate activities aimed at satisfying multiple-goals in an uncertain and unpredictable environment, and in general monitoring and regulation of goal-directed behavior (Frijda, 1986; Oatley and Johnson-Laird, 1987; Sloman, 2000). This includes the changing of motivations and goals when necessary (Clore, 1994), that is, when expectations are violated, or individual or environmental circumstances prevent the satisfaction of current goals. This role has also been termed the interruption theory (Mandler, 1984) or global interrupt signal theory (Oatley and Johnson-Laird, 1987).

2.2.2.3. Emotions as behavior preparation mechanisms. Distinct emotions are linked to distinct desired behavior. They function to improve the organism's chances for survival (Levenson, 1994; Plutchik, 1980), by rapidly preparing the organism for a coordinated execution of specific behavior patterns. This includes optimal resource allocation (Simon, 1967) that involves autonomic nervous system (ANS) components controlling arousal and metabolism (e.g. adrenaline prepares for quick response), and high-level cognitive re-directing (e.g. attention and perceptual interpretive processes). This also involves the broad range of effects of emotion on a variety of perceptual and cognitive processes. These are discussed in more detail below.

2.2.3. Effects of emotion on attention and cognitive processes

The specific effects on attention and cognition of a number of affective states have been studied extensively (e.g. anxiety and fear, anger and frustration, positive and negative affect, etc.). These effects include altering the nature of attentional processing (e.g. changes in attention capacity, speed and bias); helping to activate (or inhibit) particular perceptual and cognitive schemas that enhance (or limit) the perception and processing of specific stimuli. These include the following: *perceptual categorization biases* towards threats; *memory encoding and recall* effectiveness and biases; and a variety of additional *influences on reasoning*, *judgment*, *and*

Table 1
Effect of emotions on cognition: examples of empirical findings

Anxiety and attention (Williams et al., 1997; Mineka and Sutton, 1992)
Narrowing of attentional focus
Predisposing towards detection of threatening stimuli
Affective state and memory (Bower, 1981; Blaney 1986)
Mood-congruent memory recall—positive or negative affective state induces recall of similarly valenced material
Obsessiveness and performance (Persons and Foa, 1984)
Delayed decision-making
Reduced ability to recall recent activities
Reduced confidence in ability to distinguish among actual and imagined actions and events
Narrow conceptual categories
Affect and judgment and perception (Isen, 1993; Williams et al., 1997)
Depression lowers estimates of degree of control
Anxiety predisposes towards interpretation of ambiguous stimuli as threatening
Positive affect promotes heuristic processing (Clore, 1994)
Positive affect increases estimates of degree of control (Isen, 1993)

decision-making (LeDoux, 1992; Mineka and Sutton, 1992; Isen, 1993; Eysenck, 1997; Williams et al., 1997). These emotion effects exist at both low-level (e.g. attention and working memory speed and capacity), and at higher-levels (situation assessment, decision-making, planning, learning and judgment). Examples of specific findings are shown in Table 1.

In short, recent research confirms what folk psychology has known all along: that emotion influences cognitive processing and plays a central role in the control of behavior. The emerging findings also begin to blur the distinction between what has traditionally been thought of as the separate realms of cognition and emotion. Minsky has recently summarized this perspective as follows: '*Each of our so-called emotional states is, in effect, a somewhat different way to think*' (Minsky, 2003).[4]

2.3. Cognitive science and AI: emotion architectures and models of appraisal

Cognitive science and AI computational modeling approaches provide a recent addition to the methodological repertoire available for emotion research. The development of a computational model implementing a particular theory, or attempting to account for particular data, provides an opportunity for validation and for the generation of alternative hypotheses explaining specific affective data or phenomena.

[4] Minsky goes on to suggest the role of affect, in human and machine: 'But no single, particular way to think will work well on every kind of problem. Therefore, a truly intelligent computer will need to have what will seem like emotions'.

A number of models addressing emotion have been developed in cognitive science and AI. These models range from individual processes to integrated architectures, and explore several of the emotion roles outlined above. The most frequently modeled process has been *cognitive appraisal*, whereby external and internal stimuli (emotion elicitors) are mapped onto a particular emotion. Several alternatives have been hypothesized for these processes in the psychological literature (Frijda, 1986; Lazarus, 1991b; Scherer, 1993; Ortony, Clore and Collins, 1998; Smith and Kirby, 2000). A number of these models have been implemented, both as stand-alone versions, and integrated within larger agent architectures (e.g. Scherer, 1993; Velasquez, 1997; Canamero, 1998; Castelfranchi, 2000; deRosis et al., this issue; Breazeal, this issue). The most frequently implemented theory is the OCC appraisal model (Ortony, Clore and Collins, 1998), implemented in a number of systems and agents (Bates et al., 1992; Andre et al., 2000; Elliot et al., 1999; Martinho et al., 2000). Other emotion model implementations include models of emotions as goal management mechanisms (Frijda and Swagerman, 1987), models of interaction of emotion and cognition (Araujo, 1993), explicit models of the effects of emotion on cognitive processes (Hudlicka, 2002b), and effects of emotions on agent's belief generation (Marsella and Gratch, 2002). Examples of *integrated architectures* focusing on emotion include most notably the work of Sloman and colleagues (Sloman, 2000), but also more recent efforts to integrate emotion effects in Soar (Jones et al., 2002), and to develop an emotion-augmented cognitive architecture (Hudlicka, 2002a).

2.4. Relevance of emotion research for affective HCI (and vice versa)

The vast amount of existing empirical findings provides a rich foundation for researchers wishing to address the various challenges of affective HCI. There is much opportunity, and *necessity*, for interdisciplinary collaboration. Research in psychology and neuroscience helps provide *conceptual frameworks*, *vocabularies and descriptive features* for these complex phenomena, and, of course, a wealth of specific *empirical data*. These data range from knowledge of the physiological signatures of particular emotions, theories and data triggers for specific emotions and the processes that derive them, and generic effects of emotional states on different processes involved in attention, perception, cognition, and motor performance. These generic effects can be used in the absence of task specific information, and also serve as guiding principles for the affective/cognitive task analysis (Hudlicka, 2001a, b) required to identify specific performance effects in particular task contexts.

The findings can help us address the various open questions in affective HCI such as which emotions should be considered within particular contexts, what causes these emotions to be triggered, and how they influence perceptual and cognitive processes.

While we should build on the existing findings, we should also not hesitate to challenge the existing theories. Computational modeling can serve the role of hypothesis testing that may not otherwise be feasible, particularly with the more 'internal' and difficult to measure cognitive processes such as situation assessment, goal management and planning. The exercise of constructing a computational model of hypothesized processes and structures requires a degree of operationalization, which often reveals gaps in knowledge or theoretical contradictions. The ability to construct computational models of specific hypothesized mechanisms of emotion thus greatly enhances our ability to validate these hypotheses on the one hand, and to generate additional or alternative hypotheses regarding the nature of these mechanisms on the other.

In summary, the current symbiosis of empirical and computational methodologies offers an unprecedented opportunity for mutually constructive and mutually constraining feedback among various research methods, and promises to further advance the already rapid progress in emotion research.

3. Framework for organizing affective HCI research and issue outline

As outlined in Section 1 above, affective HCI covers a broad range of issues, methods, techniques, and application domains, in addition to philosophical considerations of feasibility, utility, and ethics. In this issue, we attempt to provide representative samples of research along this spectrum. To accomplish this, we have selected a non-traditional format. We first present two invited papers addressing both philosophical considerations, and issues of feasibility, utility and ethics, and providing a high-level overview of the state of the art in several areas of affective computing relevant to HCI (section II). The Picard commentary, representing an affect-proponent viewpoint, is structured around a series of challenges or skeptical statements, regarding the feasibility and utility of affective computing in HCI, and focuses on affect recognition, modeling, expression, and briefly touches on the issue of ethics. The Hollnagel commentary, representing an affect-skeptic viewpoint, focuses in part of terminological issues, which have often led to unjustified skepticism regarding the aims and possibilities of affective HCI, and in part on the ultimate utility of affect within HCI. Perhaps its most controversial point is the often implicit assumption made by affective researchers that affect enhances human–human communication and should therefore be incorporated into human–computer interaction.

The rationale for including these 'opposing' views is three fold: *first*, to identify, and hopefully clarify, some of the controversies that have plagued emotion research (e.g. terminological arguments); *second*, to provide the reader with a spectrum of possible 'attitudes' towards affective HCI, along with reasoned justifications; and *third*, to provide some basic information regarding the state-of-the-art in several key areas relevant to affective HCI. By providing this material, in a point-counterpoint dialogue format, we hope to both alert the reader to the possible reasons for (justified) skepticism, and to identify cases where the skepticism is due to inexact terminology or unspecified objectives. It is our hope that the perspectives provided here will then help the reader in critical evaluations of the research papers in subsequent sections describing specific methods and systems.

The rest of the issue is devoted to papers describing integrated systems functioning as *socially intelligent agents* (robots or avatars), and *methods and techniques* that form the building blocks of affective HCI. This latter category includes algorithms for affect recognition using a variety of signals (psychophysiological measures, body movements and gestures, speech), methods for affect expression via several modalities (language and speech, posture and movement, facial expressions), and empirical studies relevant for affective HCI (e.g. effectiveness of particular psychophysiological measures in affect recognition).

The five papers comprising section III focus on completed projects or studies. The papers in section IV provide summaries of research in progress, aimed at providing the reader with an appreciation of the breadth of domains where affective considerations are relevant, and the variety of possible future applications.

3.1. Framework for organizing affective HCI research

How do we make sense of the diversity of methods, techniques and applications that comprise affective HCI? One way to navigate this intricate landscape, is to organize the topics and systems along the sequence of events that comprise the stages in affect processing (refer to Fig. 1): sense (external and internal affect-relevant signals); recognize (an affective state in self or other);[5] interpret and appraise (current situation to derive candidate affective states); select or generate (an affective state); express (the affective state via one or more established behavior scripts). This sequence is analogous to the familiar see-think-do processing structure that characterizes a number of cognitive architectures (Pew and Mavor, 1998).

Each of these stages can be further divided into the specific signals being sensed (psychophysiological measures, facial expressions, body movements, gestures, voice, etc.), the emotions being recognized or generated by the machine (e.g. generalized affective states such as approach/avoid, basic emotions, complex emotions, affective dimensions of valence and arousal, etc.), and the channels and modalities available for their expression (e.g. speech tone, word choice, facial expression, gesture and movement, etc.).

To organize existing research efforts, we can construct a matrix, with the *rows* corresponding to the distinct affective processing stages outlined above and shown in Fig. 1, the *columns* corresponding to particular systems, empirical studies, or, in this case, the papers in this issue, and the *cells* listing the specific signals used for sensing, and the emotions recognized, generated and expressed, and the associated expression modalities and channels (refer to Table 2). This organization then provides a means of rapidly determining the scope and functionality of particular system or particular empirical study. It thus provides both an orienting tool and a means of rapidly determining both the scope of each effort, and the identification of any gaps (e.g. the fact that few systems address the recognition of complex emotions).

[5] We focus here only on affective states. The generic process of situation assessment that forms a core component of many agents and cognitive architectures is not addressed here.

Table 2
Organizing framework for affective HCI research and summary of special issue papers

	Breazeal	DeRosis et al.	Oudryer	Partala and Surakka	Ward and Marsden	Camurri et al.	Paiva et al.	Lisetti et al.	McKenzie et al.
Affect Sensing	Speech tone		Pitch Intensity	Pupil size	Skin conductance, blood volume pressure, HR	Body movement	Gestures head movement (via doll)	GSR, body temp., HR	
Affect Recognition	Approval Prohibition Attention Comfort					Anger Fear Grief Joy	Happiness Sadness Surprise Fear Gloating anger	Anger Fear Frustration Sadness Neutral	
Affect Appraisal and Generation *Emotions*	Anger Fear Disgust Joy Sorrow Surprise	Anger Fear Disgust Happiness Sadness Surprise							Anger Nervousness Deception
Dimensions	Arousal			Negative Positive	Negative Positive				
Affect Expression	Head position, facial expression, posture	Head position, gaze, facial expression, gestures, speech tone, NLP	Speech pitch, phoneme duration					Facial expression	Body movement

Those papers representing integrated systems, whether robots (Breazeal), synthetic agents (deRosis et al.), or decision-aiding systems (Lisetti et al.), span larger segments of this matrix, representing multiple stages within the affect-processing spectrum. Those papers focusing in depth on a particular method or technique, occupy one or two cells within the matrix (e.g. Partala and Surakka, and Ward and Marsden focus on a specific psychophysiological measures as a means of affect assessment; Oudryer focuses on speech tone in both recognition and synthesis; Camurri and colleagues focus on body movement analysis as a means of affect recognition; Paiva and colleagues focus on gesture recognition; McKenzie and colleagues describe a possible approach to movement synthesis).

The rest of this section first introduces each of the papers, and places them within the organizing framework. To reflect the integrated systems vs. methods and techniques focus of the papers, we group the introductions into two sections: 'Computers as socially intelligent agents: integrated systems demonstrating affective HCI', introducing the deRosis et al., Breazeal, and Lisetti et al. papers, and 'Methods and techniques: the building blocks of affective HCI', introducing the remainder of the papers.

3.2. *Socially intelligent agent: integrated systems demonstrating affective HCI*

Three papers reflect the recent shift from computers as tools to computers as partners and socially intelligent agents, and intelligent decision-aids. Since affect is a critical component of effective social interaction, these papers focus on affective considerations, within the broader context of creating 'believable' agents capable of socially effective interaction, and on embodied agents. (Embodied agents reflect a recent trend in the development of intelligent autonomous entities, which have both a 'brain' and some type of a 'body' that both constrains and enables a variety of movements and behaviors. Embodied agents can be either animated (e.g. Greta (de Rosis et al. paper)) or robotic (e.g. Kismet (Breazeal paper)).

de Rosis and colleagues, focusing on creating an embodied, expressive and believable agent, address the elements of social interaction that contribute to believability. They identify several characteristics of believability, including behavioral consistency (over time and across modes of expression), moderation and natural variation of affective expression, and, most critically, the necessity of a 'mind' to drive any type of adaptive interaction (in contrast to scripted dialog). To that end, they construct a 3-D animated agent face, Greta, functioning in real time. Greta generates her own affective state as a function of the situation and her current goals, using the belief–desire–intention (BDI) model as a basis for emotion generation, and expresses this state (or not! depending on her goals and the needs of the dialogue) via speech tone, word choice, facial expressions, and head movement and gaze direction. Greta is also able to express other mental states in addition to affect, such as intentions, beliefs, and metacognitive information. Both her affect appraisal and affect expression are further modulated by her personality, providing her with additional realism. Within the specific context explored, Greta functions as a counselor, providing health-related advice. In terms of the organizing framework, Greta covers the complete range of the sense-recognize-appraise-express spectrum.

The focus of Breazeal's paper is on the role of emotion in regulating social interaction between a human and a robot, in two learning contexts: free form communication and didactic dialogue. To explore these issues, Breazeal developed an anthropomorphic robot, Kismet, whose objective is to 'engage with humans and learn from them'. To regulate the degree of engagement, Kismet senses a human's interlocutor affective state via their tone of voice, as well as a range of additional affect-relevant stimuli (e.g. distance, size), generating its own affective state in response to both the external stimuli and internal needs (e.g. need for stimulation vs. distance), and expressing its affective state via facial expressions involving the movement and position of its eyelids and eyebrows, lips, ears, as well as gaze and head direction. Thus Kismet, like Greta, has a mind associated with the robot body. Like Greta, Kismet covers the full range of the sense-recognize-appraise-express spectrum within the context of human–robot interaction.

The work by Lisetti and colleagues provides yet another example of an integrated system, functioning as a decision-aid, involving elements of affect recognition, appraisal, and expression, and applied within the context of tele-home health care. The aim is to help overcome what has been termed the computer mediated communication paradox; that is, the lack of critical non-verbal cues, including affective cues, in existing computer-mediated communication. The specific aim of this research is to enhance remote patient monitoring and care by augmenting the remotely collected data to include information about the patient's affective state, and communicating this to the health care provider via an appropriate integrated display. To this end, Lisetti describes an application of an emotion-recognition system under development, MOUE, which integrates a number of multimodal user expressions to derive the most likely user state. The most challenging issue here is the need for real-time, accurate, non-invasive patient affect assessment. This is approached via the use of a series of wearable sensing devices, collecting several psychophysiolgoical measures (galvanic skin response, heart rate, body temperature), and mapping them onto one of several possible affective states. The detected state is then expressed in terms of a commercially available synthetic avatar's facial expression, and presented to the user (in this case the patient) as part of a confirmation process, allowing the user to correct the system's assessment. The tele-health care setting presents a number of challenges, in addition to the already difficult problems of accurate real-time affect recognition. These include user acceptance (e.g. How will senior citizens with serious health conditions react to synthetic avatars?) and the fact that many patients may have conditions that influence the psychophysiological measures used to assess affect. The MOUE design also spans the full range of sense-recognize-appraise-express spectrum, within the context of decision-aiding in healthcare.

All three systems thus provide examples of the enriched set of interactions with computers, whether embodied agents or not, made possible with the consideration of affect. The eventual objective is to improve the effectiveness of HCI, both by making the computer more 'sensitive' to the human user's affective state, and by enabling it to produce a variety of appropriate affective states in response, both directly (via facial expressions), and indirectly (by modifying its interaction—e.g. sounding more empathetic, etc.).

3.3. Methods and techniques: the building blocks of affective HCI

In contrast to the integrated systems above, the remainder of the papers focus on the development and evaluation of particular methods and techniques that form the building blocks of affective HCI systems and components. These include the evaluation of particular psychophysiological measures to detect an affective state (Partala and Surakka, Ward and Marsden), development of speech analysis and synthesis methods capable of recognizing and expressing affect using acoustic properties of speech (Oudryer—also addressed by Breazeal), recognizing affect from gestures (Paiva et al.) and larger body movements (Camurri et al.), and initial work exploring affect integration within 3-D synthetic avatar movements (McKenzie et al.). The introductions are grouped into these categories below.

3.3.1. Psychophysiological measures

Psychophysiological measures (e.g. skin conductance, heart rate, pupil size, respiration, blood volume pressure) reflect involuntary ANS reactions, controlling, among others, the arousal level. To the extent that distinct emotions prepare the organism for distinct behavior (e.g. approach vs. avoid, and fight vs. flee at the most fundamental level), they ought to be reflected in distinct physiological signatures. This is the basis for using specific signatures along these measures to recognize a particular affective state. While debate continues regarding the specificity of these signatures for particular emotions, and the degree of affective differentiation possible, particularly when only ANS signals are considered (Davidson and Ekman, 1994), recent work by Picard et al. (2001) suggests that with sufficient data, appropriate baseline and normalizing procedures, and subsequent pattern recognition algorithms, it is possible to differentiate among a number of emotions with accuracy that begins to match human assessments (81% by machine vs. 80–98% in humans). (Interestingly, Picard and colleagues even departed from the traditional basic emotions typically used in these studies and include differentiation among emotions such as platonic and romantic love, and reverence.) There are of course a number of 'pros' and 'cons' associated with the use of these measures, which are discussed by Picard, and also outlined in the Lisetti et al. paper in this issue.

Three papers in this issue focus on the application of these methods. Partala and Surakka present an empirical study relevant for the 'front-end' component of the affective processing spectrum, that is, for the recognition of affect, via a specific psychophysiological measure, pupil size. Their study demonstrates that pupil size in human subjects increases following emotionally significant auditory stimuli, and that variations exist both in gender-responsiveness, and in the time-course of the response. These findings, coupled with the increasing effectiveness of eye-tracking systems, show promise for the development of real-time user affect assessment methods. As the authors point out, an additional application of their findings is also in identifying particular affect-induction protocols (e.g. inducing a positive affect to improve learning).

Ward and Marsden use several psychophysiological measures (heart rate, blood volume pulse, and skin conductance) to assess user's responses within a particular HCI context: Web page interaction. The specific experimental context focuses on interactions with 'poorly designed' software. Their study provides an example of integrating psychophysiological assessment into the usability evaluation process. By describing the experimental setup necessary, the specific sensing equipment needed, and the difficulties associated with accurate psychophysiological measurement and data processing, they provide an illustrative example of the types of issues that must be addressed in using user affect as a means of assessing UI effectiveness. Their study demonstrates an important application of affect in HCI—its use as a measure of user satisfaction and thus of interface or product usability.

An advantage of psychophysiological measures is that they reflect ANS reactions and are thus difficult to 'fake'. They also provide a real-time window into the user's current state. The disadvantage is the difficulty associated with accurate signal detection, and considerable expertise required both for the appropriate use of the sensing apparatus, and the subsequent signal analysis, including collection of baseline data and normalizing procedures. However, with recent improvements in wearable and remote sensors, and promising results indicating the ability to differentiate among basic emotions via complex pattern recognition algorithms, these methods show a real promise for both usability evaluation, and real-time user affective state assessment during human–machine collaboration, across a variety of tasks and domains, in both training and applied settings.

3.3.2. Speech: affect expression and recognition

Speech is one of the many modalities available for affect expression, and a number of acoustic properties of speech have been used to recognize and express affect (Petrushin, 2002; also Breaezel and DeRosis, this issue). With success rates in averaging around 63%, speech is not the most diagnostic modality with respect to emotion (this is in contrast to 80% range for psychophysiological measures and 85th percentile for facial recognition). Speech does however provide one of several options for affect recognition and, coupled with other measures, is an important source of affect recognition data, and an important channel for affect expression.

The Oudryer paper addresses both of these areas. In *affect recognition*, he explores a series of algorithms to analyse pitch and intensity across 2000 samples of short utterances representing multiple speakers and three of the basic emotions (joy, sorrow, anger (and neutral)). He also explores several methods for reducing the set of analysed features, which could lead to important time savings in the computationally intensive pattern recognition algorithms required to analyse these measures. He reports high rates of emotion recognition (up to 97%). What is striking here is also the difference in performance among specific algorithms, indicating the need for careful evaluation of alternative algorithms, whose effectiveness may vary with the type of data being analysed. In *affect synthesis*, he reports work focused on generating distinct expressions for five affective states (anger, sadness, happiness, and comfort (and calmness)), in terms of acoustic speech attributes (pitch and phoneme duration) associated with a variety of nonsense (pre-verbal) utterances. The effectiveness of these algorithms was evaluated using human subjects to recognize the expressed affect. Success rates of 57% were obtained, which compare favorably with mean human success rates of 63%.

Both findings show promise for speech as a modality for both affect recognition and affect expression. The fact that many speech qualities are independent of semantics and culture, as exemplified by both the Oudryer and Breaezel work in this issue, is particularly encouraging.

3.3.3. Body movement and gestures

Body movement and gestures represent powerful means of both affect recognition and expression, yet these indicators have only recently begun to be explored in affective HCI settings. This is understandable, since their use is limited in traditional desktop computer settings, both in terms of feasibility and utility. However, once we leave the desktop setting and enter the world of wearable sensing devices (possibly sewn into our clothing (e.g. the conductor's jacket (Picard, 2000)), remote sensors for drivers or pilots, and virtual environments and synthetic avatars, these modalities become more relevant. Several papers in this issue focus on movement and gestures as a means of expressing and recognizing emotions.

The Camurri paper addresses affect recognition via body movements and gestures. Drawing on the fact that distinct emotions are often associated with distinct qualities of body movements, Camurri and colleagues develop a system for capturing human body movement data, analysing these data via a layered series of signal and feature processing algorithms, and mapping the raw movement data onto one of four basic emotions (anger, fear, grief and joy) via a series of increasingly abstract feature sets. A particularly interesting aspect of this work is the use of non-propositional movement qualities (e.g. tempo and force of the movement), rather than specific gestures expressing particular emotions, which are often culture specific. The application context for this research is analysis of dance movement data. One can envision numerous applications of this work in entertainment and the arts, with avatars and robots recognizing affect from movement, as well as using movement as an affect expression channel. For the more practically minded among us, it is also intriguing to imagine applications in settings such as medicine, where sensing devices could detect heightened states of a surgeon's stress level from the quality of hand movements and display a warning to prevent potential errors.

Working with gestures and head movements, Paiva and colleagues focus on the expression end of the spectrum, but in the process also address affect recognition. They introduce a novel input device, the doll SenToy, which allows users (typically children) to express a particular emotion by manipulating the doll's hands, legs and head. The doll movements are then mapped onto one of 6 basic emotions, which influence the behavior of a synthetic character in a game. As was the case in Camurri's work above, the challenge in SenToy is to map the doll movements onto specific emotions. Unlike Camurri, who focused on non-propositional movements, Paiva and colleagues focus more on established symbols for particular emotions (e.g. hands covering the eyes to communicate fear). One can imagine a number of applications, including entertainment, but also therapeutic environments where use of speech may not be an option (e.g. pre-verbal children or stroke patients). The combination of non-propositional movement qualities, such as those analysed by Camurri, with symbols reflecting specific emotions, used by Paiva, appears particularly promising.

Finally, McKenzie and colleagues take on the ambitious task of communicating emotion in terms of body movements of a synthetic character (using the Jack 3-D model) within a VR training environment. A number of efforts are underway in this area (e.g. Marsella and Gratch, 2002), and represent an important synthesis of affect-generation and affect-expression within VR environments, moving in the direction of building realistic and believable synthetic avatars with a broad range of applications.

4. Looking ahead: questions and parting thoughts

4.1. Questions we should be asking

It is difficult to identify 'key issues' in an endeavor as diverse and complex as affective HCI. Nevertheless, I attempt to list some critical questions that we should be addressing, to help lay a solid foundation for empirically based affective HCI and to help coordinate the diverse research efforts. (See also lists of 'affect-related' questions by Canamero (1998), and by a panel at a recent workshop addressing affective user modeling (Carberry et al., 2002)).

- *Importance of affect*
  What are the HCI contexts where affect is critical and must be addressed, when can it safely be ignored, and when might affective considerations interfere with performance? Can we identify features of the situations, and the users, that warrant the investment required to assess, adapt to, model, and express affect? How can we rapidly evaluate the tradeoffs involved?
- *Selecting emotions*
  Which emotions must be considered, in which contexts and for which types of users? Are the existing taxonomies of emotions adequate? Or do we need to define more complex cross-products of person–emotion–task features to help answer this question? And what are those features?
- *Assessing emotions*
  What are the most appropriate methods for affect assessment, for different users and contexts? What are the limits of these methods? How accurate must these assessments be to be of use in HCI, and how does this accuracy requirement vary across the user–emotion–task space? When is it better to focus on refining a single modality vs. using multiple, concurrent assessments?

- *Adapting: who and when*
  Under what circumstances should computers adapt to user affect and when should users be trained so that affect does not play a role? Can we construct tasks and task allocations to eliminate the possibility of affective interference, and thus the need for affective adaptation?
- *Modeling emotions in synthetic agents*
  Do synthetic agents really require 'emotions' to exhibit adaptive behavior, manage goals, and maintain homeostasis? Through what information processing mechanisms and structures do emotions accomplish these functions and how can their understanding help design synthetic adaptive systems? How can these findings be applied in clinical settings?
- *Expressing emotions*
  What is degree of fidelity required to generate 'convincing' affective behavior in synthetic agents? To generate behavior that will induce an affective response in the user? How does this fidelity vary across the user–emotion–task space?
- *Measuring effectiveness*
  How must existing usability criteria be augmented to include affective considerations? How can developments in cognitive systems engineering be used to help design evaluation protocols and metrics?
- *Benchmark problem sets*
  Much of the spectacular developments in speech recognition and synthesis in the 1980s occurred as a result of DARPA-sponsored 'bakeoffs', where a number of algorithms developed by different researchers competed against benchmark problems. Can the affective HCI community help establish similar benchmark problem sets to help focus and compare on-going research efforts, and share results and system components?
- *Plug-and-play and emerging standards*
  How can the affective research community facilitate the development of, and adherence to, standards (e.g. MPEG-4, markup languages, facial expression coding systems and body movement vocabularies). Can these standards be extended to the often confusing and redundant terminology, which is particularly prevalent in models of affect appraisal and emotion architectures? What is the best way to establish web-based libraries of components to facilitate component exchange and system development?

4.2. Parting thoughts

Recent advancements in agent technologies aim to provide 'believable' and effective agents, whether robots and synthetic avatars, or decision-aids and educational systems, capable of interacting with human users in an adaptive, 'seamless' manner. To accomplish this type of interaction will require that the agents recognize and respond to user affect. Skeptics will argue, as do a number of affective computing researchers, that such affective considerations are not always necessary, and this is certainly true. In claiming the need for affective agents, I therefore limit myself to cases where affect influences the task performance, or where human-like agents are necessary for effective human–machine interaction.

At this point in time, we are nowhere near this state of affairs. But the on-going research in this area is beginning to identify the critical factors that must be addressed to make such a symbiotic relationship possible. Much as CRTs were a luxury in the days of punched cards, and wireless PDAs unthinkable, so may the types of affective considerations discussed in this issue become a required standard in the near future, as Norman argues in his forthcoming book on design (Norman, 2003).

A challenge in pursuing affective research in a computational setting is to strike a balance between the 'easy' extremes. We must address justified (and even unjustified) skepticism and criticism, but must also guard against a type of born-again 'affectiveness', and its uncritical assumption that since affect is essential for people, it is therefore essential for synthetic agents and HCI.

A frequent argument for affect-inclusion in autonomous agents is the critical role of emotion in goal management necessary for homeostasis, adaptation and autonomy. Of course that is one role that emotions play in animals, and while our silicon-based autonomous artifacts may or may not need emotions, they certainly need some mechanism for goal management and homeostasis. And these considerations bring us back full-circle to the recognition that emotions are primarily another means of information processing.

Recently, I left a workshop on affective computing with a sinking feeling that emotions are nothing but glorified servomechanisms, which, in our carbon-based life forms, happen to occasionally, and for largely unknown reasons, be associated with mysterious passions and ineffable, well, *feelings*, that we cherish and find equally a source of pleasure, frustration and general wonder. I experienced a few days of sobering disillusionment that this phenomenon I have found so intriguing could be so mundane and pedestrian.

The danger with the reductionism inherent in any empirically based scientific enterprise is of course a possible disillusionment or loss of wonder, as Whitman expressed so eloquently nearly 150 years ago in the poem *When I Heard the Learn'd Astronomer.* But engaging in affective computing research need not imply a forced choice between Whitman's options. We do not need to forsake the 'charts and diagrams' to maintain our sense of wonder with something that we consider so quintessentially human, at times frustrating, but always awe inspiring: the power and mystery of our emotional experience.

Twenty years ago, this journal published a paper that coined[6] the term cognitive systems engineering (Hollnagel and Woods, 1983). Perhaps it may be going too far to suggest that now is the time to update this term to affective–cognitive systems engineering—but maybe not.

[6] The term 'cognitive engineering' was coined by Norman somewhat prior to this publication (Norman, 1981).

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References

Allonson, J., 2002. Electrophysiologically-interactive computer systems. IEEE Computers 35 (3), 60–65.

Andre, E., Klesen, M., Gebhard, P., Allen, S., Rist, T., 2000. Integrating models of personality and emotions in lifelike characters. In: Proceedings of IWAI, Siena, Italy.

Araujo, A.F.R., 1993. Emotions influencing cognition. In: WAUME '93: Workshop on Architectures Underlying Motivation and Emotion, The University of Birmingham, Birmingham, UK.

Bates, J., Loyall, A.B., Reilly, W.S., 1992. Integrating reactivity, goals, and emotion in a broad agent. In: Proceedings of the 14th Meeting of the Cognitive Science Society, Boulder, CO.

Bauer, M., Gymtrasiewicz, P., Vassileva, J., 2001. User Modeling 2001. Springer, New York.

Blaney, P.H., 1986. Affect and memory. Psychological Bulletin 99 (2), 229–246.

Blocher, K., Picard, R.W., 2002. Affective social quest: emotion recognition therapy for autistic children. In: Dautenhahn, K., Bond, A.H., Canamero, L., Edmonds, B. (Eds.), Socially Intelligent Agents: Creating Relationships with Computers and Robots. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Bower, G.H., 1981. Mood and memory. American Psychologist 36, 129–148.

Canamero, D., 1998. Issues in the design of emotional agents. In: Proceedings of Emotional and Intelligent: The Tangled Knot of Cognition. AAAI Fall Symposium, TR FS-98-03. AAAI Press, Menlo Park, CA, pp. 49–54.

Carberry, S., Conati, C., de Rosis, F., Gmytrasiewicz, P., Hudlicka, E., Ishizuka, M., Lisetti, C., Ortony, A., Prendinger, H., Ortony, A., 2002. Panel discussion. Applied Artificial Intelligence 16 (7–8), 643–670.

Castelfranchi, C., 2000. Affective appraisal versus cognitive evaluations in social emotions and interactions. In: Paiva, A. (Ed.), Affective Interactions: Towards a New Generation of Affective Interfaces. Springer, New York.

Clore, G.L., 1994. Why emotions require cognition. In: Ekman, P., Davidson, R.J. (Eds.), The Nature of Emotion. Oxford University Press, Oxford.

Clore, G.L., Ortony, A., 2002. Cognition in emotion: always, sometimes, or never? In: R.D. Lane, L. Nadel (Eds.), Cognitive Neuroscience of Emotion. Oxford University Press, Oxford.

Cohen, I., Sebe, N., Chen, L., Garg, A., Huang, T.S., 2003. Facial expression recognition from video sequences: temporal and static modeling, computer vision and image understanding (CVIU), in press.

Collyer, S.C., Malecki, G.S., 1998. Tactical decision making under Stress: history and overview. In: Cannon-Bowers, J.A., Salas, E. (Eds.), Making Decisions Under Stress: Implications for Individual and Team Training. American Psychological Association, Washington, DC.

Conati, C., 2002. Probabilistic assessment of user's emotions in educational games. Applied AI 16 (7–8), 555–576.

Damasio, A.R., 1994. Descartes' Error: Emotion, Reason, and the Human Brain. Putnam, New York.

Darwin, C., 1872. The Expression of the Emotions in Man and Animals. 3rd Edition, Oxford University Press, Oxford, 1998.

Dautenhahn, K., Werry, I., Rae, J., Dickerson, P., Stribling, P., Ogden, B., 2002a. Robotic Playmates: analysing interactive competencies of children with autism playing with a mobile robot. In: Dautenhahn, K., Bond, A.H., Canamero, L., Edmonds, B. (Eds.), Socially intelligent agents: creating relationships with computers and robots. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Dautenhahn, K., Bond, A.H., Canamero, L., Edmonds, B., 2002b. Socially Intelligent Agents: Creating Relationships with Computers and Robots. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Davidson, R.J., 1994. Honoring biology in the study of affective style. In: Ekman, P., Davidson, R.J. (Eds.), The Nature of Emotion. Oxford University Press, Oxford.
Davidson, R.J., 2000. In: Lane, R.D., Nadel, L. (Eds.), Cognitive Neuroscience of Emotion. Oxford, New York.
Davidson, R.J., Ekman, P., 1994. Afterward: is there emotion specific physiology. In: Ekman, P., Davidson, R.J. (Eds.), The Nature of Emotion. Oxford University Press, Oxford.
Ditlea, S., 2000. The PC goes ready-to-wear. IEEE Spectrum 37 (10), 34–39.
Ekman, P., Davidson, R.J., 1994. The Nature of Emotion. Oxford University Press, Oxford.
Ekman, P., 1994. All Emotions Are Basic. In: Ekman, P., Davidson, R.J. (Eds.), The Nature of Emotion. Oxford University Press, Oxford.
Ekman, P., Friesen, W., 1978. Unmasking the Face: A Guide to Recognizing Emotions from Facial Clues. Prentice-Hall, Englewood Cliffs, NJ.
Elliot, C., Lester, J., Rickel, J., 1999. Lifelike pedagogical agents and affective computing: an exploratory synthesis. In: Wooldridge, M., Veloso, M. (Eds.), AI Today. Lecture Notes in AI. Springer, New York.
Eysenck, M.W., 1997. Anxiety and Cognition: A Unified Theory. Psychology Press, Hove, East Sussex.
Fellous, J.-M., 1996. A historical perspective on emotion, http://emotion.salk.edu/Emotion/history/Hgeneral.html
Forgas, J.P., 2000. Feeling and Thinking: The Role of Affect in Social Cognition. Cambridge University Press, Cambridge, UK.
Forgas, J.P., 2001a. Introduction: affect and social cognition. In: Forgas, J.P. (Eds.), Handbook of Affect and Social Cognition. LEA, Mahwah, NJ.
Forgas, J.P., 2001b. Handbook of Affect and Social Cognition. LEA, Mahwah, NJ.
Frijda, N.H., 1986. The Emotions. Studies in Emotion and Social Interaction. Cambridge University Press, New York.
Frijda, N.H., Swagerman, J., 1987. Can computers feel? Theory and design of an emotional system. Cognition and Emotion 1 (3), 235–257.
Goldman-Rakic, P.S., 2000. Architecture of the prefrontal cortex and the central executive. In: Gazzaniga, M.S. (Ed.), Cognitive Neuroscience: A Reader. Blackwell Publishers Inc., Malden, MA.
Gray, J.A., 1994. Three fundamental emotion systems. In: Ekman, P., Davidson, R.J. (Eds.), The Nature of Emotion. Oxford University Press, Oxford.
Hass, M.W., Hettinger, L., 2001. Adaptive User Interfaces. LEA, Mahwah, NJ.
Hoffman, R.R., Klein, G., Laughery, K.R., 2002. The state of cognitive systems engineering. Human-Centered Computing, Jan/Feb.
Hollnagel, E., 2003. From human factors to cognitive systems engineering: human machine interactions in the 21st century. In: Kitamura, M., Kimura, I. (Eds.), Anzen-no-Tankyu (Researches on Safety). ERC Publishing, Tokyo.
Hollnagel, E., Woods, D.D., 1983. Cognitive systems engineering: new wine in new bottles. International Journal of Man–Machine Studies 18, 583–600.
Hudlicka, E., 2001a. Modeling affect regulation and induction. In: Proceedings of the AAAI Fall Symposium, Emotional and Intelligent II: The Tangled Knot of Social Cognition, TR FS-01-02. Falmouth, MA, November.
Hudlicka, E., 2001b. CAPTA: Cognitive affective personality task analysis. In: Proceedings of the 45th Annual Meeting of the Human Factors and Ergonomic Society. Minneapolis, MN, October.
Hudlicka, E., 2002a. This time with feeling: integrated model of trait and state effects on cognition and behavior. Applied Artificial Intelligence 16 (7–8), 1–31.
Hudlicka, E., 2002b. Increasing SIA architecture realism by modeling and adapting to affect and personality. In: Dautenhahn, K., Bond, A.H., Canamero, L., Edmonds, B. (Eds.), Multiagent Systems, Artificial Societies, and Simulated Organizations. Kluwer Academic Publishers, Dordrecht, The Netherlands.
Hudlicka, E., McNeese, M., 2002. User's affective & belief state: assessment and GUI adaptation. International Journal of User Modeling and User Adapted Interaction 12 (1), 1–47.
Isen, A.M., 1993. Positive affect and decision making. In: Haviland, J.M., Lewis, M. (Eds.), Handbook of Emotions. The Guilford Press, New York, NY, pp. 261–277.

Jones, R., Henninger, A., Chown, E., 2002. Interfacing emotional behavior moderators with intelligent synthetic forces. In: Proceedings of the 11th Conference on Computer Generated Forces and Behavior Representation, Orlando, FL.

Klein, J., 1999. Computer response to user frustration. MS Thesis, MIT Media Lab, MIT, Cambridge, MA.

Lane, R.D., Nadel, L., 2000. Cognitive Neuroscience of Emotion. Oxford, Oxford.

Lazarus, R.S., 1991a. Cognition and Motivation in Emotion. American Psychologist 42, 352–367.

Lazarus, R.S., 1991b. Emotion and Adaptation. Oxford University Press, New York, NY.

LeDoux, J.E., 1987. Emotion. In: Plum, F. (Ed.), Handbook of Physiology, 1: The Nervous System. American Physiological Society, Bethesda, MD, pp. 419–460.

LeDoux, J.E., 1989. Cognitive–Emotional Interactions in the Brain. Cognition and Emotion 3 (4), 267–289.

LeDoux, J., 1996. The Emotional Brain. Simon and Schuster, New York.

LeDoux, J., 2000. Cognitive–emotional interactions: listen to the brain. In: Lane, R.D., Nadel, L. (Eds.), Cognitive Neuroscience of Emotion, Oxford.

LeDoux, J.E., 1992. Brain Mechanisms of Emotion and Emotional Learning. Current Opinion in Neurobiology 2 (2), 191–197.

Levenson, R.W., 1994. Human emotion: a functional view. In: Ekman, P., Davidson, R.J. (Eds.), The Nature of Emotion. Oxford University Press, Oxford.

Lewis, M., Haviland, J.M., 1993. Handbook of Emotions. The Guilford Press, New York.

Lisetti, C.L., Gmytrasiewicz, P., 2002. Can a rational agent afford to be affectless? Applied Artificial Intelligence 16 (7–8), 577–609.

Lyytinen, K., Yoo, Y., 2002. Issues and challenges in ubiquitous computing. Communications of the ACM 45 (12), 62–65.

Mandler, G., 1984. Mind and body: The psychology of emotion and stress. Norton, New York.

Marsella, S., Gratch, J., 2002. A step toward irrationality: using emotion to change belief. In: Proceedings of the First International Joint Conference on Agents and Multiagent Systems, Bologna, Italy.

Martinho, C., Machado, I., Paiva, A., 2000. A Cognitive Approach to Affective User Modeling. In: Paiva, A. (Ed.), Affective Interactions: Towards a New Generation of Affective Interfaces. Springer, New York.

Matthews, G., Jones, D.M., Chamberlain, A.G., 1990. Refining the measurement of mood: the UWIST mood adjective checklist. British Journal of Psychology 81, 17–42.

Matthews, G., Derryberry, D., Siegle, G.J., 2000a. Personality and emotion: cognitive science perspectives. In: Hampson, S.E. (Ed.), Advances in Personality Psychology, Vol. 1. Routledge, London.

Matthews, G., Davies, R.D., Westerman, S.J., Stammers, R.B., 2000b. Human Performance: Cognition, Stress and Individual Differences. Taylor and Francis, Philadelphia, PA.

Michaud, F., Theberge-Turmel, C., 2002. Mobile robotic toys and autism: observations of interaction. In: Dautenhahn, K., Bond, A.H., Canamero, L., Edmonds, B. (Eds.), Socially Intelligent Agents: Creating Relationships with Computers and Robots. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Mineka, S., Sutton, S.K., 1992. Cognitive biases and the emotional disorders. Psychological Science 3 (1), 65–69.

Minsky, M., 2003. The emotion machine, forthcoming.

Norman, D.A., 1981. Steps towards a cognitive engineering: system images, system friendliness, mental models. Department of Psychology and Program in Cognitive Science (Draft.), University of California, San Diego, California.

Norman, D.A., 2003. Emotion & Design. Basic Books, New York, in press.

Oatley, K., Johnson-Laird, P., 1987. Towards a cognitive theory of emotion. Cognition and Emotion 1, 51–58.

Ortony, A., Clore, G.L., Collins, A., 1988. The Cognitive Structure of Emotions. NY: Cambridge University Press.

Paiva, A., 2000. Affective Interactions: Towards a New Generation of Affective Interfaces. Springer, New York.

Persons, J.B., Foa, E.B., 1984. Processing of fearful and neutral information by obsessive-compulsives. Behavior Research Therapy 22, 260–265.

Petrushin, V., 2002. Creating emotion recognition agents for speech signal. In: Dautenhahn, K., Bond, A.H., Canamero, L., Edmonds, B. (Eds.), Socially Intelligent Agents: Creating Relationships with Computers and Robots. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Pew, R., Mavor, A., 1998. Representing Human Behavior in Military Simulations. National Academy Press, Washington, DC.

Picard, R., 1997. Affective Computing. The MIT Press, Cambridge.

Picard, R., 2000. Towards computers that recognize and respond to user emotion. IBM Systems Journal 39 (3–4), 705–719.

Picard, R., Healey, J., 1997. Affective wearables. Personal Technologies 1 (4), 231–240.

Picard, R.W., Vyzas, E., Healey, J., 2001. Toward Machine Emotional Intelligence: Analysis of Affective Physiological State. IEEE PAMI 23 (10), 1165–1174.

Plutchik, P., 1980. Emotion: A psychobioevolutionary synthesis. Harper & Row, New York.

Rizzo, A.A., Schultheis, M., Kerns, K.A., Mateer, C., 2003. Analysis of assets for virtual reality applications in neuropsychology. Neuropsychological Rehabilitation, in press.

Russell, J.A., 1979. Affective space is bipolar. Journal of Personality and Social Psychology 37, 345–356.

Safran, J., Greenberg, L., 1991. Emotion, Psychotherapy, and Change. The Guilford Press, New York.

Scherer, I.R., Schorr, A., Johnstone, T., 2001. Appraisal Processes in Emotion: Theory, Methods, Research. Oxford University Press, Oxford.

Scherer, K., 1993. Studying the emotion-antecedent appraisal process: the expert system approach. Cognition and Emotion 7, 325–355.

Simon, H.A., 1967. Motivational and Emotional Controls of Cognition. Psychological Review 74, 29–39.

Smith, C., Kirby, L., 2000. Consequences require antecedents: toward a process model of emotion elicitation. In: Forgas, J.P. (Ed.), Feeling and Thinking: The Role of Affect in Social Cognition. Cambridge University Press, Cambridge, UK.

Sloman, A., 2000. Architectural requirements for human-like agents both natural and artificial. In: Dautenhand, K. (Ed.), Human Cognition and Social Agent Technology. John Benjamins, Amsterdam/Philadelphia.

Thayer, R.E., 1996. The Origin of Everyday Moods. Oxford University Press, New York.

Velasquez, J.D., 1997. Modeling emotions and other motivations in synthetic agents. In: Proceedings of the AAAI, Providence, RI, pp. 10–15.

Watson, D., Tellegen, A., 1985. Toward a consensual structure of mood. Psychological Bulletin 98, 219–235.

Watson, D., Clark, L.A., 1992. On traits and temperament: general and specific factors of emotional experience and their relation to the five-factor model. Journal of Personality 60, 441–446.

Williams, J.M.G., Watts, F.N., MacLeod, C., Mathews, A., 1997. Cognitive Psychology and Emotional Disorders. Wiley, New York.

Yerkes, R.M., Dodson, J.D., 1908. The relation of strength of stimulus to rapidity of habit formation. Journal of Comparative Neurology and Psychology 18, 459–482.

Zajonc, R.B., 1980. Feeling and Thinking: Preferences Need no Inferences. American Psychologist 35, 151–175.

Zimand, E., Anderson, P., Gershon, G., Graap, K., Hodges, L., Rothbaum, B., 2003. Virtual reality therapy: innovative treatment for anxiety disorders. Primary Psychiatry 9 (7), 51–54.