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The Oxford Handbook *of* AFFECTIVE COMPUTING

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Editor in Chief **PETER E. NATHAN**

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The *Oxford Library of Psychology,* a landmark series of handbooks, is published by Oxford University Press, one of the world's oldest and most highly respected publishers, with a tradition of publishing significant books in psychology. The ambitious goal of the *Oxford Library of Psychology* is nothing less than to span a vibrant, wide-ranging field and, in so doing, to fill a clear market need.

Encompassing a comprehensive set of handbooks, organized hierarchically, the *Library* incorporates volumes at different levels, each designed to meet a distinct need. At one level are a set of handbooks designed broadly to survey the major subfields of psychology; at another are numerous handbooks that cover important current focal research and scholarly areas of psychology in depth and detail. Planned as a reflection of the dynamism of psychology, the *Library* will grow and expand as psychology itself develops, thereby highlighting significant new research that will impact on the field. Adding to its accessibility and ease of use, the *Library* will be published in print and, later on, electronically.

The *Library* surveys psychology's principal subfields with a set of handbooks that capture the current status and future prospects of those major subdisciplines. This initial set includes handbooks of social and personality psychology, clinical psychology, counseling psychology, school psychology, educational psychology, industrial and organizational psychology, cognitive psychology, cognitive neuroscience, methods and measurements, history, neuropsychology, personality assessment, developmental psychology, and more. Each handbook undertakes to review one of psychology's major subdisciplines with breadth, comprehensiveness, and exemplary scholarship. In addition to these broadly conceived volumes, the *Library* also includes a large number of handbooks designed to explore in depth more specialized areas of scholarship and research, such as stress, health and coping, anxiety and related disorders, cognitive development, or child and adolescent assessment. In contrast to the broad coverage of the subfield handbooks, each of these latter volumes focuses on an especially productive, more highly focused line of scholarship and research. Whether at the broadest or most specific level, however, all of the *Library* handbooks offer synthetic coverage that reviews and evaluates the relevant past and present research and anticipates research in the future. Each handbook in the *Library* includes introductory and concluding chapters written by its editor to provide a roadmap to the handbook's table of contents and to offer informed anticipations of significant future developments in that field.

An undertaking of this scope calls for handbook editors and chapter authors who are established scholars in the areas about which they write. Many of the nation's and world's most productive and best-respected psychologists have agreed to edit *Library* handbooks or write authoritative chapters in their areas of expertise.

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In summary, the *Oxford Library of Psychology* will grow organically to provide a thoroughly informed perspective on the field of psychology, one that reflects both psychology's dynamism and its increasing interdisciplinarity. Once published electronically, the *Library* is also destined to become a uniquely valuable interactive tool, with extended search and browsing capabilities. As you begin to consult this handbook, we sincerely hope you will share our enthusiasm for the more than 500-year tradition of Oxford University Press for excellence, innovation, and quality, as exemplified by the *Oxford Library of Psychology.*

Peter E. Nathan
Editor-in-Chief
Oxford Library of Psychology

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Arvid Kappas is professor of psychology at Jacobs University Bremen in Bremen, Germany, and has conducted experimental research on affective processes for more than twenty-five years. He social psychology at Dartmouth College in 1989 and has since held university positions in Switzerland, Canada, the United Kingdom, Austria, Italy, and Germany. He is currently the president of the International Society for Research on Emotion. Arvid is particularly interested in emotions in interaction and how they influence expressive behavior, physiology, and subjective experience as well as how, in turn, emotions are regulated at intra- and interpersonal levels, including different levels of social organization and cultural context, within their biological constraints. His research is typically highly interdisciplinary, as exemplified by the recent projects CYBEREMOTIONS, eCUTE, and EMOTE.

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CHAPTER

1

Introduction to Affective Computing

Rafael A. Calvo, Sidney K. D'Mello, Jonathan Gratch, *and* Arvid Kappas

Abstract

The Oxford Handbook of Affective Computing aims to be the definite reference for research in the burgeoning field of affective computing—a field that turns 18 at the time of writing. This introductory chapter is intended to convey the motivations of the editors and content of the chapters in order to orient the readers to the handbook. It begins with a very high overview of the field of affective computing along with a bit of reminiscence about its formation, short history, and major accomplishments. The five main sections of the handbook—history and theory, detection, generation, methodologies, and applications—are then discussed, along with a bird's eye view of the 41 chapters covered in the book. This Introduction is devoted to short descriptions of the chapters featured in the handbook. A brief description of the Glossary concludes the Introduction.

Key Words: affective computing history, affective computing theory, emotion theories, affect detection, affect generation, methodologies, applications

As we write, affective computing (AC) is about to turn 18. Though relatively young but entering the age of maturity, AC is a blossoming multidisciplinary field encompassing computer science, engineering, psychology, education, neuroscience, and many other disciplines. AC research is diverse indeed. It ranges from theories on how affective factors influence interactions between humans and technology, how affect sensing and affect generation techniques can inform our understanding of human affect, and the design, implementation, and evaluation of systems that intricately involve affect at their core.

The 2010 launch of the *IEEE Transactions on Affective Computing* (IEEE TAC), the flagship journal of the field, is indicative of the burgeoning research and promise of AC. The recent release of a number of excellent books on AC, each focusing on one or more topics, is further evidence that AC research is gradually maturing. Furthermore, quite different from being solely an academic endeavor, AC is being manifested in new products, patent applications, start-up companies, university courses, and new funding programs from agencies around the world. Taken together, interest in and excitement about AC continues to flourish since its launch almost two decades ago.

Despite its recent progress and bright future, the field has been missing a comprehensive handbook that can serve as the go-to reference for AC research, teaching, and practice. This handbook aspires to achieve that goal. It was motivated by the realization that both new and veteran researchers needed a comprehensive reference that discusses the basic theoretical underpinnings of AC, its bread-and-butter research topics, methodologies to conduct AC research, and forward-looking applications of AC systems. In line with this, the *Handbook of Affective Computing* aims to help both new and experienced researchers identify trends, concepts, methodologies, and applications in this exciting research field. The handbook aims to be a coherent compendium, with chapters authored by world leaders in each area. In addition to being the definitive reference for AC, the handbook will also be suitable for use as a textbook for an undergraduate or graduate course in AC. In essence, our hope is that the handbook will serve as an invaluable resource for AC students, researchers, and practitioners worldwide.

The handbook features 41 chapters including this one, and is divided into five key main sections: history and theory, detection, generation, methodologies, and applications. Section 1 begins with a look at the makings of AC and a historical review of the science of emotion. This is followed by chapters discussing the *theoretical underpinnings* of AC from an interdisciplinary perspective encompassing the affective, cognitive, social, media, and brain sciences. Section 2 focuses on *affect detection* or affect recognition, which is among the most commonly investigated areas in AC. Chapters in this section discuss affect detection from facial features, speech (paralinguistics), language (linguistics), body language, physiology, posture, contextual features, and multimodal combinations of these. Chapters in Section 3 focus on aspects of *affect generation*, including the synthesis of emotion and its expression via facial features, speech, postures, and gestures. Cultural issues in affect generation are also discussed. Section 4 takes a different turn and features chapters that discuss *methodological issues* in AC research, including data collection techniques, multimodal affect databases, emotion representation formats, crowdsourcing techniques, machine learning approaches, affect elicitation techniques, useful AC tools, and ethical issues in AC. Finally, Section 5 completes the handbook by highlighting existing and future *applications* of AC in domains such as formal and informal learning, games, robotics, virtual reality, autism research, health care, cyberpsychology, music, deception, reflective writing, and cyberpsychology.

Section 1: History and Theory

AC is a scientific and engineering endeavor that is both inspired by and also inspires theories from a number of related areas, such as psychology, neuroscience, computer science, linguistics, and so on. In addition to providing a short history of the field, the aim of Section 1 is to describe the major theoretical foundations of AC and attempt to coherently connect these different perspectives.

This section begins with Chapter 2, by Rosalind Picard, the field's distinguished pioneer, who also coined its name. It is an adaptation of an introductory paper that was published in the inaugural issue of *IEEE Transactions on Affective Computing*. Picard's chapter, "The Promise of Affective Computing," provides an outline of AC's history and its major goals. Picard shares stories, sometimes personal, and offers historical perspectives and reflections on the birth and evolution of the AC community over the past 18 years.

The field's 18th birthday is a celebration of Picard's seminal book, *Affective Computing*, published in 1997, yet the study of emotions as a scientific endeavor dates back to the nineteenth century, with pioneers like Bell, Duchenne, and Darwin. Although it is daunting to provide a meaningful history of such an entrenched topic in a single chapter, Rainer Reisenzein does an excellent job in his contribution: "A Short History of Psychological Perspectives on Emotion" (Chapter 3). The chapter reviews various psychological perspectives on emotions that have emerged over the last century and beyond with respect to the following five key questions: (1) How are emotions generated? (2) How do they influence cognition and behavior? (3) What is the nature of emotions? (4) How has the emotion system evolved? (5) What are the brain structures and processes involved in emotions?

It is clear that neuroscience is strongly influencing the way we think about affective phenomena, a trend that is only likely to increase in the coming years. In Chapter 4, "Neuroscientific Perspectives of Emotion," Andrew Kemp, Jonathan Krygier, and Eddie Harmon-Jones summarize the exponentially growing affective neuroscientific literature in a way that is meaningful to the technically driven AC community. They discuss the neurobiological basis of fear, anger, disgust, happiness, and sadness—"the basic" emotions still used in much of AC research. Their chapter expands on the current debate as to whether these basic emotions are innate or whether more fundamental neuropsychobiological processes interact to produce these emotions. The "embodied cognition" perspective they adopt has received increased attention in cognitive psychology and human-computer interaction (HCI) literatures and might be beneficial to AC research as well.

Informed by all this science, engineers need concrete ways to represent emotions in computer systems, and appraisal theories provide one of the more promising representational structure to advance this goal. These are discussed in Chapter 5, entitled

"Appraisal Models," by Jonathan Gratch and Stacy Marsella. The appraisal theory of emotions has been the most widely adopted theory in AC. It is well suited for computing research because it provides a structured representation of relationships between a person and the environment, the different appraisal variables, and other components of the information processing ensemble, all of which are needed to model emotions.

Interpersonal information (information relevant to social interactions) plays a critical role in affective human-human interactions, but the dynamics of this information might change during human-computer interactions. An understanding of the complexity of pertinent issues, such as how new media can best communicate social cues, is essential in a world where a significant portion of interpersonal communication occurs through "emotionally challenged" media such as email and social networks. The design of such systems will often incur trade-offs, and these should be informed by a careful analysis of the advantages and disadvantages of different forms of mediated communication. These and other related issues are given a detailed treatment in Chapter 6, by Brian Parkinson, "Emotions in Interpersonal Life: Computer Mediation, Modeling, and Simulation."

Maja Pantic and Alessandro Vinciarelli introduce the wider field of social signal processing in Chapter 7. This area is closely related to AC in that it seeks to combine social science research (for understanding and modeling social interactions) with research in computer science and engineering, which is aimed at developing computers with similar abilities.

There are many reasons for building AC systems, some of which involve the basic scientific goal of understanding psychological phenomena while others are more practical, such as building better software systems. These motivations influence the type of architectures used. In Chapter 8, "Why and How to Build Emotion-Based Agent Architecture," Christine Lisetti and Eva Hudlicka review some of the emotion theories and discuss how they are used for creating artificial agents that can adapt to users' affect.

The motivations and the type of questions researchers ask is also, at least partially, linked to society's perceptions of what computers could and should do—perceptions often reflected in the popular media. In line with this, the first section of the handbook concludes with Chapter 9, by Despina Kakoudaki, titled "Affect and Machines in the Media"—that is, how artificial entities (e.g., computers) that have affective qualities have been portrayed in the media across time and how these portrayals have influenced AC research.

Section 2: Affect Detection

The development of an affect-aware system that senses and responds to an individual's affective states generally requires the system to first detect affect. Affect detection is an extremely challenging endeavor owing to the numerous complexities associated with the experience and expression of affect. Chapters in Section 2 describe several ingenious approaches to this problem.

Facial expressions are perhaps the most natural way in which humans express emotions, so it is fitting to begin Section 2 with a description of facial expression–based affect detection. In "Automated Face Analysis for Affective Computing" (Chapter 10), Jeff Cohn and Fernando De la Torre discuss how computer vision techniques can be informed by human approaches to measure and code facial behavior. Recent advances in face detection and tracking, registration, extraction (of geometric, appearance, and motion features), and supervised learning techniques are discussed. The chapter completes its introduction to the topic with a description of applications such as physical pain assessment and management, detection of psychological distress, depression, and deception, and studies on interpersonal coordination.

Technologies that capture both fine- and coarse-grained body movements are becoming ubiquitous owing to their low cost and easy integration in real-world applications. For example, Microsoft's Kinect camera has made it possible for nonexperts in computer vision to include the detection of gait or gestures (e.g., knocking, touching, and dancing) in applications ranging from games to learning technologies. In Chapter 11, "Automatic Recognition of Affective Body Expressions," Nadia Bianchi-Berthouze and Andrea Kleinsmith discuss the state of the art in this field, including devices to capture body movements, factors associated with perception of affect from these movements, automatic affect recognition systems, and current and potential applications of such systems.

Speech is perhaps the hallmark of human-human communication, and it is widely acknowledged that *how* something is said (i.e., paralinguistics) is as important as *what* is being said (linguistics).

The former is discussed by Chi-Chun Lee, Jangwon Kim, Angeliki Metallinou, Carlos Busso, Sungbok Lee, and Shrikanth S. Narayanan in

Chapter 12, "Speech in Affective Computing." This chapter starts with the fundamental issue of understanding how expressive speech is produced by the vocal organs, followed by the process of extracting acoustic-prosodic features from the speech signal, thereby leading to the development of speech-based affect detectors.

Affect detection from language, sometimes called sentiment analysis, is discussed in Chapter 13 by Carlo Strapparava and Rada Mihalcea entitled "Affect Detection in Texts." They begin with a description of lexical resources that can be leveraged in affective natural language processing tasks. Next, they introduce state-of-the-art knowledge-based and corpus-based methods for detecting affect from text. They conclude their chapter with two very intriguing applications: humor recognition and a study on how extralinguistic features (e.g., music) can be used for affect detection.

Since antiquity, eastern and western philosophers have speculated about how emotions are reflected in our bodies. At the end of the nineteenth century, William James and Charles Darwin studied the relationship between the autonomic nervous system and emotions. More recently, with the introduction of accurate small, portable, and low-cost sensors, physiologically based affect detection has dramatically exploded. Physiological researchers usually make a distinction between central and peripheral physiological signals (brain versus body). Affect detection from peripheral physiology is discussed by Jennifer Healey in Chapter 14, "Physiological Sensing of Affect." This chapter provides a brief history of the psychophysiology of affect, followed by a very accessible introduction to physiological sensors, measures, and features that can be exploited for affect detection.

Applications that monitor central physiology are discussed by Christian Mühl, Dirk Heylen, and Anton Nijholt in "Affective Brain-Computer Interfaces: Neuroscientific Approaches to Affect Detection" (Chapter 15). Their chapter reviews the theory underlying neuropyschological approaches for affect detection along with a discussion of some of the technical aspects of these approaches, with an emphasis on electrophysiological (EEG) signals. Major challenges and some imaginative potential applications are also discussed.

It is difficult to introduce sensors in the physical environment in some interaction contexts, such as classrooms. In these situations, researchers can infer affect from the unfolding interaction between the software and the user. In Chapter 16, "Interaction-Based Affect Detection in Educational Software," Ryan Baker and Jaclyn Ocumpaugh describe pioneering research in this field, particularly in the context of intelligent tutoring systems and educational games. In addition to reviewing the state of the art, their discussion on methodological considerations—such as ground truth measures, feature engineering, and detector validation—will be useful to researchers in other application domains as well.

The aforementioned chapters in this section describe research in one of the many modalities that can be used for affect detection. However, human communication is inherently multimodal, so it is informative to consider multimodal approaches to affect detection. A review of this literature with an emphasis on key issues, methods, and case studies is presented in Chapter 17, "Multimodal Affect Detection for Naturalistic Human-Computer and Human-Robot Interactions," by Ginevra Castellano, Hatice Gunes, Christopher Paters, and Björn Schuller.

Section 3: Affect Generation

Section 3 focuses on another important step toward building affect-aware systems—affect generation. More specifically, chapters in this section focus on embodied conversational agents (ECAs) (e.g., animated agents, virtual characters, avatars) that generate synthetic emotions and express them via nonverbal behaviors.

ECAs can have increasingly expressive faces in order to enhance the range of human-computer interaction. In Chapter 18, "Facial Expressions of Emotions for Virtual Characters," Magalie Ochs, Radoslaw Niewiadomski, and Catherine Pelachaud discuss how researchers are developing ECAs capable of generating a gamut of facial expressions that convey emotions. One of the key challenges in this field is the development of a lexicon linking morphological and dynamic facial features to emotions that need to be expressed. The chapter introduces the methodologies used to identify these morphological and dynamic features. It also discusses the methods that can be used measure the relationship between an ECA's emotional expressions and the user's perception of the interaction.

ECAs, just like humans, can be endowed with a complete body that moves and expresses emotions through its gestures. Margaux Lhommet and Stacy Marsella, in "Expressing Emotion Through Posture and Gesture" (Chapter 19), discuss many of the issues in this line of research. The bodily expressions can be produced via static displays or with movement. New techniques for emotional expressions in ECAs need to be represented in ways that can be used more widely. This is done using markup languages, some of which are briefly described in this chapter as well as in Chapter 18 by Ochs and colleagues. Markup languages require a more extensive coverage, so we have included a chapter on this topic in the next section.

Software agents are increasingly common in applications ranging from marketing to education. Possibly the most commonly used agents communicate over the phone with natural language processing capabilities. Consider Siri, Apple's virtual assistant, or the automated response units that preceded it by providing automated voice-based booking for taxis and other services over the phone. The future of these systems will require the agents to replace the current monotone speech synthesis with an emotional version, as described by Felix Burkhardt and Nick Campbell in Chapter 20, "Emotional Speech Synthesis." Here the authors provide a general architecture for emotional speech synthesis; they discuss basic modeling and technical approaches and offer both use cases and potential applications.

ECAs may have virtual faces and bodies, but they are still software instantiations and therefore implement a limited sense of "embodiment." One way of addressing this limitation is through the physicality of robots. Ana Paiva, Iolanda Leite, and Tiago Ribeiro describe this research in Chapter 20, titled "Emotion Modeling for Social Robots." They begin by describing the affective loop (Höök, 2009), where the user first expresses an emotion and then the system responds by expressing an appropriate emotional response. These responses convey the illusion of a robotic life and demonstrate how even simple behaviors can convey emotions.

The final chapter of Section 3, "Preparing Emotional Agents for Intercultural Communication" (Chapter 22), by Elisabeth André, addresses the challenge of how agents and robots can be designed to communicate with humans from different cultural and social backgrounds. It is already difficult to scaffold human-human communication when there are intercultural differences among communicators. The challenge is even more significant for human-computer communication. We need to understand how emotions are expressed across cultures and improve our emotion detection and generation techniques by either fine-tuning them to particular cultures or by generalizing across cultures (to the extent possible). This chapter provides an overview of some of the research in this area and touches on several critical topics such as culturally aware models of appraisal and coping and culture-specific variations of emotional behaviors.

Section 4: Affective Computing Methodologies

Although AC utilizes existing methods from standing fields including the affective sciences, machine learning, computer vision, psychophysiology, and so on, it adapts these techniques to its unique needs. This section presents many of these "new" methodologies that are being used by AC researchers to develop interfaces and techniques to make affect compute.

The problem of how to best collect and annotate affective data can be structured in a number of stages. Björn Schuller proposes 10 stages in Chapter 23, the opening chapter of this section, titled "Multimodal Affect Databases—Collection, Challenges, and Chances." The chapter discusses the challenges of collecting and annotating affective data, particularly when more than one sensor or modality is used. Schuller's 10 steps highlight the most important considerations and challenges, including (1) ethical issues, (2) recording and reusing, (3) metainformation, (4) synchronizing streams, (5) modeling, (6) labeling, (7) standardizing, (8) partitioning, (9) verifying perception and baseline results, and (10) releasing the data to the wider community. The chapter also provides a selection of representative audiovisual and other multimodal databases. We have covered these considerations with different depth across a number of chapters in the handbook. Some of these steps are encompassed in multiple chapters, while some chapters address multiple steps. For example, approaches to managing metainformation are discussed in Chapter 29, and Schuller himself discusses the challenges related to synchronizing multimodal data streams.

The first of Schuller's steps toward collecting affective data involves addressing ethical issues, a topic where formal training for engineers is sometimes scarce. In his chapter, "Ethical Issues in Affective Computing" (Chapter 24), Roddie Cowie brings together fundamental issues such as the formal and informal codes of ethics that provide the underpinning for ethical decisions. Practical issues have to do with the enforcement of the codes and ethical principles, which falls under the purview of human research ethics committees. This chapter will help clarify issues that these committees are concerned about, such as informed consent, privacy, and many more.

The second step to building an affective database, according to Schuller, is to make decisions about collecting new data or reusing existing affective databases. This involves deciding on the tools to be used, and some of these are discussed in "Research and Development Tools in Affective Computing" (Chapter 25), by Sazzad Md Hussain, Sidney K. D'Mello, and Rafael A. Calvo. The most common tools were identified by surveying current AC researchers, including several authors of this handbook, and therefore are a reflection of what researchers in the field find useful. Readers can find out about available databases in Schuller's chapter and at emotion-research.net.

Other issues to be taken into account include decisions on the affect representation model, or Schuller's fifth step (e.g., continuous or categorical) and temporal unit of analysis. Several chapters in this section briefly discuss issues that need to be considered in making these decisions, but the topic warranted its own chapter. In "Emotion Data Collection and Its Implications for Affective Computing" (Chapter 26), Shazia Afzal and Peter Robinson discuss naturalistic collection of affective data while people interact with technology, proposing new ways of studying affective phenomena in HCI. They emphasize issues that arise when researcher try to formalize their intuitive understanding of emotion into more formal computational models.

In a related chapter, "Affect Elicitation for Affective Computing" (Chapter 27), Jacqueline Kory and Sidney K. D'Mello discuss ways to reliably elicit emotions in the lab or "in the wild" (i.e., real-world situations). Kory and D'Mello discuss both passive methods—such as video clips, music, or other stimuli—and active methods that involve engaging participants in interactions with other people or where they are asked to enact certain behaviors, postures, or facial expressions. Examples of how these methods have been used by AC researchers are also discussed.

One of the most time-consuming and expensive stages of developing an affective database is affect labeling or annotation. Often this task can be outsourced to a large number of loosely coordinated individuals at a much lower cost and with a much faster turnaround time. This process, called crowdsourcing, is discussed in the context of AC by Robert R. Morris and Daniel McDuff in Chapter 28, "Crowdsourcing Techniques for Affective Computing." Crowdsourcing already has garnered impressive success stories, as when millions of images were labeled by people playing the ESP game while working for free and even having fun. Hence researchers planning to follow this approach will benefit from Morris and McDuff's account of the development and quality assurance processes involved in affective crowdsourcing.

Schuller's seventh consideration, standardizing, is about seeking compatibility in the data and the annotations, so that the data can be used across systems and research groups. In Chapter 29, "Emotion Markup Language," Marc Schröder, Paolo Baggia, Felix Burkhardt, Catherine Pelachaud, Christian Peter, and Enrico Zovato discuss EmotionML, the markup language for AC recommended by the World Wide Web Consortium (W3C). EmotionML is designed to represent and communicate affective representations across a series of use cases that cover several types of applications. It provides a coding language based on different emotion theories, so emotions can be represented by four types of data: categories, dimensions, appraisals, and action tendencies. Using these four types of data, emotion events can be coded as a data structure that can be implemented in software and shared.

Affect detection algorithms generally use supervised machine learning techniques that use annotated data for training. As Ashish Kapoor explains in Chapter 30, "Machine Learning Techniques in Affective Computing," when considered in tandem, labeling and training of algorithms can be optimized using active information acquisition approaches. Other approaches to annotation, feature extraction, and training that take into account how the data will be used in machine learning are also discussed by Kapoor.

Section 5: Affective Computing Applications

One of the key goals of AC is to develop concrete applications that expand the bandwidth of HCI via affective or emotional design. In line with this, this section highlights existing and emerging applications from a range of domains but with an emphasis on affect at their core.

Learning technologies abound in the digital and physical (e.g., school) spaces and have been among the first AC applications. A prolific research community, known as Intelligent Tutoring Systems and Artificial Intelligence in Education, has focused on developing next-generation learning technologies that model affect in addition to cognition, metacognition, and motivation. Sidney K. D'Mello and Art Graesser present a summary of these technologies in "Feeling, Thinking, and Computing with Affect-Aware Learning Technologies" (Chapter 31). They provide examples of two types of affect-aware educational technologies: reactive systems that respond when affective states are detected and proactive systems that promote or reduce the likelihood of occurrence of certain affective states.

The case studies described in D'Mello and Graesser's chapter focus on learning technologies that support school-related formal learning. However, learning is a lifelong endeavor. and much of learning occurs outside of formal educational settings, including museums, science centers, and zoos. These informal learning environments can also benefit from affect-aware technologies. In "Enhancing Informal Learning Experiences with Affect-Aware Technologies" (Chapter 32), Chad Lane describes how these technologies can be used to promote interest and attitudes in addition to knowledge when visitors engage in informal learning contexts.

Writing is perhaps the quintessential twenty-first-century skill, and both academic and professional work involves considerable writing. Changes in our writing environments brought about by the information age alter the writing process itself. On the positive side, we have access to endless resources and collaborative opportunities than ever before. Yet on the other hand, there are new problems and distractions, such as a continual barrage of email, social media, and countless other distractions of the digital age. In Chapter 33, titled "Affect-Aware Reflective Writing Studios," Rafael A. Calvo explores how new technologies can be used to produce tools that writers can use to reflect on the process they adopt, including circumstances in which they are most productive or enjoy writing the most.

Not everything in life can be learning and work. Georgios N. Yannakakis and Ana Paiva discuss how AC can improve gaming experiences (both for entertainment and learning) in "Emotion in Games" (Chapter 34). They review key studies on the intersection between affect, game design, and technology and discuss how to engineer effective affect-based gaming interactions.

Referring to another form of entertainment, music, Egon van den Broek, Joyce Westerink, and Joris Janssen discuss affect-focused music adaptation in Chapter 35, "Autonomous Closed-Loop Biofeedback: An Introduction and a Melodious Application." The chapter starts by considering some of the key issues involved in engineering closed-loop affective biofeedback systems and applies these insights to the development and real-world validation of an affective music player.

The two previous chapters discuss how education and entertainment could be improved with AC techniques. The following chapters focus on applications where the users interact and collaborate with robots or other humans. In "Affect in Human Robot Interaction" (Chapter 36), Ronald Arkin and Lilia Moshkina discuss various issues involved in this endeavor. They also pose some fundamental research questions, such as how affect-aware robotics can add value (or risks) to human-robot interactions. Other questions include whether such robots can become companions or friends, and issues regarding the role of embodiment in affective robotics (i.e., do the robots need to experience emotions to be able to express them, and what theories and methods can inform affective HRI research?).

The next two chapters focus on human-human interactions. First, in "Virtual Reality and Collaboration" (Chapter 37), Jakki Bailey and Jeremy Bailenson discuss how collaborative virtual environments can be built to support participants' expressions of affect via verbal and nonverbal behaviors. They contextualize their discussions within immersive virtual environment technologies (IVET), where people interact through avatars that act as proxies for their own identities. The chapter reviews the history and common architectures for these IVETs and concludes with a discussion of their ethical implications.

Chapter 38, "Unobtrusive Deception Detection," by Aaron Elkins, Stefanos Zafeiriou, Judee Burgoon, and Maja Pantic, focuses on an aspect of human-human communication that is of great importance in an era that is struggling to strike a balance between security and liberty. This chapter explores algorithms and technology that can be used to detect and classify deception using remote measures of behaviors and physiology. The authors provide a comprehensive treatment of the topic, encompassing its psychological foundations, physiological correlates, automated techniques, and potential applications.

As Cowie notes in his chapter "Ethical Issues in Affective Computing" (Chapter 24) on ethics, "its (AC's) most obvious function is to make technology better able to furnish people with positive experiences and/or less likely to impose negative ones." In line with this, the last three chapters explore how AC can support health and well-being. It is widely known that socioemotional intelligence is at the core of autism spectrum disorders (ASDs). In Chapter 39, “Affective Computing, Emotional Development, and Autism,” Daniel Messinger, Leticia Lobo Duvivier, Zachary Warren, Mohammad Mahoor, Jason Baker, Anne Warlaumount, and Paul Ruvolo discuss how AC can serve as the basis for new types of tools for helping children with ASDs. The tools can be used to study the dynamics of emotional expression in children developing normally, those with ASDs, and their high-risk siblings.

One approach to health care is to use avatars that simulate face-to-face doctor-patient interventions. In “Relational Agents in Health Applications: Leveraging Affective Computing to Promote Healing and Wellness” (Chapter 40), Timothy Bickmore surveys research on how affect-aware relational agents can build patient-agent rapport, trust, and the therapeutic alliance that is so important in health-care practices.

In principle, any technology that can help people change their mindsets and behavior can be used to improve psychological well-being. In the last chapter of the handbook (Chapter 41), titled “Cyberpsychology and Affective Computing,” Giuseppe Riva, Rafael A. Calvo, and Christine Lissetti propose using AC technologies in the wider context of personal development, an area being called positive technology/computing.

The Glossary

One of the biggest challenges in interdisciplinary collaborations, such as those required in AC, is the development of a language that researchers can share. The disparate terminology used in AC can be overwhelming to researchers new to the field. There is additional confusion when researchers redefine terms for which there are more or less agreed upon operational definitions. It is our hope that *The Oxford Handbook of Affective Computing* will help to develop this common understanding. To facilitate the process, we have included a glossary developed collaboratively by the contributors of each chapter. We asked all contributors to identify key terms in their contributions and to define them in a short paragraph. When more than one definition was provided, we left all versions, acknowledging that researchers from different backgrounds will have different terminologies. Hence, rather than forcing the common definition, the glossary might be a useful tool to minimize what is often “lost in translation.”

Concluding Remarks

It is prudent to end our brief tour of *The Oxford Handbook of Affective Computing* by briefly touching on its origin. The handbook emerged from brief conversations among the editors at the 2011 *Affective Computing and Intelligent Interaction (ACII 2011)* conference in Memphis, Tennessee. We subsequently sent a proposal to Oxford University Press, where it was subsequently approved; the rest is history. By touching on the history and theory of affective computing—its two major thrusts of affect detection and generation, methodological considerations, and existing and emerging applications—we hope that the first *Handbook of Affective Computing* will serve as a useful reference to researchers, students, and practitioners everywhere. Happy reading!

Acknowledgments

This handbook would not have been possible without the enthusiasm of the authors, who have volunteered their time to share their best ideas for this volume. We are very much indebted to them for their excellent work. We could not have compiled and prepared the handbook without the support of Oxford University Press, particularly Joan Bossert and Anne Dellinger, as well as Aishwarya Reddy at Newgen Knowledge Works. We are grateful to Jennifer Neale at the University of Notre Dame and Agnieszka Bachfischer at the Sciences and Technologies of Learning Research network at the University of Sydney for administrative and editing support.

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SECTION 1

Theories and Models

CHAPTER

2

The Promise of Affective Computing

Rosalind W. Picard

Abstract

This chapter is adapted from an invited introduction written for the first issue of the *IEEE Transactions on Affective Computing*, telling personal stories and sharing the viewpoints of a pioneer and visionary of the field of affective computing. This is not intended to be a thorough or a historical account of the development of the field because the author is not a historian and cannot begin to properly credit the extraordinary efforts of hundreds of people who helped bring this field into fruition. Instead, this chapter recounts experiences that contribute to this history, with an eye toward eliciting some of the pleasurable affective and cognitive responses that will be a part of the promise of affective computing.

Key Words: affective computing, agents, autism, psychophysiology, wearable computing

Introduction

Jodie is a young woman I am talking with at a fascinating annual retreat organized by autistic people for autistic people and their friends. Like most people on the autism spectrum (and many neurotypicals, a term for people who don't have a diagnosed developmental disorder), she struggles with stress when unpredictable things happen. Tonight, we are looking at what happened to her emotional arousal as measured by a wristband that gathers three signals—skin conductance, motion, and temperature (Figure 2.1).

Jodie was upset to learn that the event she was supposed to speak at was delayed from 8:00 to 8:30 PM. She started pacing until her friend told her "Stop pacing, that doesn't help you." Many people don't have an accurate read on what they are feeling (this is part of a condition known as alexithymia) and, although she thought pacing helped, she wasn't certain. So, she took his advice. She then started to make the repetitive movements often seen in autism called "stimming" and continued these until the event began at 8:30. In Figure 2.1, we see her skin conductance on the top graph, going down when she was pacing, up when she was stimming, and hitting its highest peaks while she presents. The level also stays high afterward, during other people's presentations, when she stayed up front to handle problems with the audiovisual technology, including loud audio feedback.

Collecting data related to emotional arousal is not new: for example, skin conductance has been studied for more than 100 years. What is new, however, is how technology can measure, communicate, adapt to, be adapted by, and transform emotion and how we think about it. Powerful new insights and changes can be achieved with these abilities. For example, Jodie collected her emotional arousal data wearing a stretchy wristband, clicked to upload it into a mobile viewer, and showed it to her friend (the one who had asked her to stop pacing). The first words spoken after checking the time stamps on the data display were his. He said, "I'm not going to tell you to stop pacing anymore." The next morning, I saw the two of them again. This time, she was pacing and he sat quietly nearby typing on his

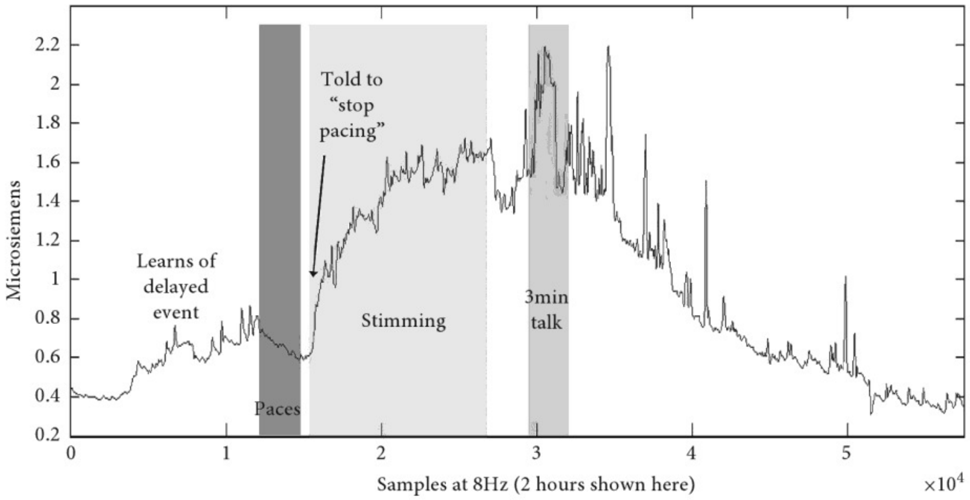

Fig. 2.1 Skin conductance level (top graph). Skin surface temperature (middle graph) and three-axis accelerometer values (lower graph). Skin conductance, which is associated with emotional arousal, was lowered during pacing, while it went up during "stimming," a presentation, and (afterward) while dealing with some audiovisual equipment problems. These data are from a young adult on the autism spectrum.

laptop, letting her pace. The ability to communicate objective data related to her emotional arousal and activity—specifically her sympathetic nervous system activation, of which skin conductance is a sensitive measure—prompted a change in his behavior. Mind you, she had told him in the moment of stress that she thought pacing was helping, but this did not change his behavior. Objective data about emotions carries much more power than self-reported subjective feelings.

The convenience of a new affective computing technology can lead to new self-understanding, as it did for Jodie. Objective data related to emotion is more believable than verbal reports about feelings. Shared affective data can improve communication between people and lead to better understanding and sometimes to beneficial changes in behavior: Jodie's friend could now accept that her pacing might be helpful, and he let Jodie pace.

Researchers inventing future products tend to put in features that marketing people can describe to customers. Features such as more memory, more pixels, and more processing power can all be quantified and designed into explicit goals. The saying "if you can't measure, it you can't manage it" drives progress in many businesses. Measure it, and you can improve it. What if technology enabled you to measure the frustration that a product reduces (or elicits) as easily as you measure processing speed increases (or decreases)? Measuring the frustration caused by a technology when it happens could enable engineers to pinpoint what caused the frustration and work to prevent or reduce it. With affect measurement, technology can be designed with the explicit goal of giving people significantly better affective experiences.

Technology can also be improved if it has an intelligent ability to respond to emotion. Intelligence about emotion is not easy. For example, you might think it would be intelligent to have a robot smile when it sees its collaborator exhibit the so-called true smile that involves both the lip corner pull and the cheek raise. Shared happiness is usually a positive experience and smart to elicit. However, we recently learned that whereas 90% of participants expressing delight made this facial expression, so too did 90% of participants in a frustration-eliciting scenario who reported feeling significant frustration. Although it might be intelligent to respond to a delighted smile with one of your own, it is probably not intelligent to appear delighted when your collaborator is frustrated if you want him to like you. Although recent progress is making it easier to do things like automatically discriminate smiles of delight and smiles of frustration, the effort to work out the situation, its interaction goals, and the personality differences of the participants is not simple. Affective computing has a lot of problems still to solve before machines will be able to intelligently handle human emotion.

Technology can also be improved by virtue of incorporating principles of emotion learned from biological systems. Emotions guide not only cognition but also other regulatory functions that affect healthy behaviors. Many extraordinarily difficult challenges in the modeling of and understanding of emotion remain to be solved in order to bring about its benefits.

Attitudes toward affective computing, which I defined in 1995 as "computing that relates to, arises from, and deliberately influences emotion," have changed so much in the past decade that it is now hard for some people to believe it used to be a ludicrous idea. In the early '90s, I had never heard of the shorthand "LOL" (Laugh out Loud) but it applied to this research. I beg the reader to let me indulge in some remembrances, starting in 1991, my first year on the MIT faculty.

In the Beginning, Laughter...

One morning, over breakfast cereal and the *Wall Street Journal* (the only nontechnical journal I read regularly), a front-page article about Manfred Clynes caught my eye. He was described as a brilliant inventor who, among better-known inventions that became commercially and scientifically successful, also invented a machine for measuring emotion. His "sentograph" (*sentire* is Latin for "to feel") measured slight changes in directional pressure applied to an immovable button that a person pushed. The finger push showed a characteristic pattern related to joy, sadness, anger, sex, reverence, and more. This is not a list approved by mainstream emotion theorists—who don't include sex or reverence—and Manfred is far from mainstream. Among his many distinctions, Manfred was a child prodigy who later received a fan letter from Einstein for his piano playing and who co-authored the 1960 paper that coined the word "Cyborg." But the *Wall Street Journal* described how he *measured* emotion, with objective physical signals. Later, others replicated the measures. I was amused, although not enough to do anything more than file the article, alongside other crazy ideas I liked such as refrigerators that were powered by the noise of nearby traffic. The article mentioned my friend, Marvin Minsky, who many years later introduced me to Manfred, and we became instant friends.

Manfred never claimed to be the first to build a machine to measure emotional categories. But Manfred may have been the first to get laughed at for his work in making affect computable. He told me about the time when he first tried to present his ideas about measuring emotion to other scientists: the audience laughed and laughed, and it was not the kind of laughter most speakers crave to elicit. He said he was literally laughed off the stage.

Discovering Real Importance for Emotion

When I first started thinking about emotion, it was the last thing I wanted to think about. I was up for tenure at MIT, working hard raising money, and conducting what people later praised as pioneering research in image and video pattern modeling. I liked my work to be rooted solidly in mathematics and machine learning. I was busy working six days and nights a week building the world's first content-based retrieval system, creating and mixing mathematical models from image compression, computer vision, texture modeling, statistical physics, and machine learning with ideas from film makers. I spent all my spare cycles advising students, building and teaching new classes, publishing, reading, reviewing, raising money, and serving on nonstop conference and lab committees. I worked hard to be taken as the serious researcher I was. I had raised more than a million dollars in funding for my group's work. The last thing I wanted was to wreck it all and be associated with emotion. Emotion was associated with being irrational and unreasonable. Heck, I was a *woman* coming from engineering. I did not want to be associated with "emotional," which also was used to stereotype women, typically with a derogatory tone of voice. If anybody needed to start work in this area, it needed to be a man.

However, I kept running into engineering problems that needed...well, something I did not want to address. For example, working on computer vision, I knew that we had a lot to learn from human vision. I collaborated with human vision scientists who focused on the cortex and visual perception. We labored to build computer vision systems that could see like people see, and we learned to build banks of filters, for example, that could detect high-contrast oriented regions and motions in ways that seemed to be similar to stages of the human visual cortex. Much engineering, whether for vision or earlier in my life for computer architectures, was focused on trying to replicate the amazing human cortex. We wanted to figure it out by building it. But nowhere did any of the findings about the human visual cortex address a problem I wanted to answer: How do you find what is *interesting* for a person? How do you find what *matters* to them? How do visual attention systems figure this out and shift automatically when they need to shift? Building a vision system is not just about detecting high-contrast oriented lines or telling a dog from a cat. Vision is affected by attention, and attention is affected by what matters to you. Vision—real seeing—is guided by feelings of importance.

Another problem arose from my years of work at AT&T Bell Labs and at MIT building new kinds of computer architectures for digital signal processing. We came up with many clever ways to parallelize, pipeline, optimize, and otherwise process sounds and sights and other signals humans usually interpret effortlessly. However, never did anyone figure out how to give a computer anything like motivation, drive, and a sense of how to evaluate shifting priorities in a way that acted genuinely intelligent. The machines did not genuinely *care* about anything. We could make it print, "Hello world, I care. Really, . . ." but we weren't fooled by that. We could give it functional programs that approximated some affective motivational components like "drive." Such programs worked under limited conditions that covered all the cases known up front—but always failed pathetically when encountering something new. And it didn't scale—the space of possibilities it needed to consider became intractable.

Today, we know that biological emotion systems operate to help human beings handle complex, unpredictable inputs in real time. Today, we know that emotions signal what matters, what you care about. Today, we know emotion is involved in rational decision making and action selection and that, to behave rationally in real life, you need to have a properly functioning emotion system. But at that time, this was not even on the radar. Emotion was irrational, and if you wanted respect then you didn't want to be associated with emotion.

Most surprising to me was when I learned that emotion interacts deeply in the brain with perception. From human vision research on perception, we all understood perception to be driven by the cortex—the visual cortex for vision, the auditory cortex for audition, and the like. But one Christmas break, while reading Richard Cytowic's "The Man Who Tasted Shapes," I was jolted out of my cortex-centric focus. In synesthesia, in which a person feels shapes in his palms when tasting soup or sees colors with letters involuntarily or experiences other crossed perceptual modalities, the cortex was observed to be showing less activity, not more.

Cytowic argued that multimodal perception was not only happening in the cortex, but also in the limbic structures of the brain, regions physically below the cortex, which were known to be important for three things: attention, memory, and emotion. I was interested in attention and memory. I started to read more neuroscience literature about these limbic regions. I was not interested in emotion. Alas, I found that the third role—emotion—kept coming up as essential to perception. Emotion biased what we saw and heard. Emotion played major roles not only in perception, but also in many other aspects of intelligence that artificial intelligence (AI) researchers had been trying to solve from a cortical-centric perspective. Emotion was vital in forming memory and attention and in rational decision making. And, of course, emotion communication was vital in human–machine interaction. Emotions influence action selection, language, and whether or not you decide to double-check your mathematical derivations, comment your computer code, initiate a conversation, or read some of the stories below.

Emotion being useful and even necessary was not what I was looking for. I became uneasy. I did not want to work on or be associated with emotion, yet emotion was starting to look vital for solving the difficult engineering problems we needed to solve.

I believe that a scientist has to commit to find what is true, not what is popular. I was becoming quietly convinced that engineers' dreams to build intelligent machines would never succeed without incorporating insights about emotion. I knew somebody had to educate people about the evidence I was collecting and act on it. But I did not want to risk my reputation, and I was too busy. I started looking around, trying to find somebody, ideally male and already tenured, whom I could convince to develop this topic, which clearly needed more attention.

Who Wants to Risk Ruining His Reputation?

I screwed up my courage and invited Jerry Wiesner, former president of MIT and scientific advisor to Presidents Eisenhower, Kennedy and Johnson, to lunch. Jerry was in a suit and always seemed very serious and authoritative. Over fish and bonbons at Legal Sea Foods, I filled him in on some of my work and sought his advice. I asked him what was the most important advice he had for junior faculty at MIT. I strained to hear him over the noise of that too-loud restaurant, but one line came out clear: "You should take risks! This is the time to take risks." As I walked back the one block to the lab, I took a detour and did some thinking about this. I was working in an exciting new research area at the time—content-based retrieval. I liked it and was seen as a pioneer in it. But it was already becoming popular. I didn't think it was really risky.

The Media Lab saw me as one of their more conventional players, as "the electrical engineer." Nicholas Negroponte, architect and founding director, spoke with pride and perfect French pronunciation, of how he formed the Media Lab as a "Sah-lon de ref-oos–say." The original Salon des Refusés was an exhibition by artists of work that was rejected by the authorities in charge. Nicholas was proud of establishing a lab that would do research that others might laugh at and reject. I didn't want to be labeled as a rejected misfit, but I didn't learn he saw our faculty in this way until after I was already a member of the lab. It was freeing to hear that if I were indeed ever viewed as a misfit, it would be valued. If I chose to work on emotion, the misfit title was going to happen. Maybe it would be okay here.

One of the brilliant visionaries Nicholas had recruited to the Media Lab was Seymour Papert, mathematician and leading thinker in education and technology, who told our faculty about researchers long ago who were all focused on trying to build a better wagon. They were making the wheels stronger so they stayed round and so they didn't break or fall off as easily. They worked hard to make wagons last longer, go faster, give smoother rides, and cover more distance. Meanwhile, Seymour said that while all the researchers of that day were improving the wagon wheel, these crazy engineers—the Wright brothers—went off and invented the airplane. He said we faculty in the Media Lab should be the crazies inventing the new way to fly. My maiden name is Wright. This story was inspiring.

Convinced that emotion was important and people should pay attention to it and that maybe my lab wouldn't mind if I detoured a few weeks to address this topic, I spent the holidays and some of the January "Independent Activities Period" writing a thought piece that I titled "Affective Computing" to collect my arguments. I circulated it as a tech note quietly among some open minds in the lab. A student from another group, who was more than a decade older than I, read it and showed up at my door with a stack of six psychology books on emotion. "You should read these," he said. I love how the students at MIT tell the faculty what to do. I needed to hear what he said, and I read the whole stack.

I then read every book on emotion I could get from Harvard, MIT, and the local library network only to learn that psychologists had more than a hundred definitions of emotion, nobody agreed on what emotion was, and almost everyone relied on questionnaires to measure emotion. As an engineer, it bugged me that psychologists and doctors relied on self-reports that they knew were unreliable and inaccurate.

I went to Jerry Kagan at the psychology department in Harvard. His office was high up in the William James building. I wanted to talk to him about my ideas about how to build accurate and systematic ways to measure and characterize affective information. He had been very discouraging to one of my students earlier, and I thought it was important to understand his perspective. He gave me a hard time at first, but after we argued, in the end, he was very nice and almost encouraging: he told me "You're shooting for the moon" when I proposed that my team could build wearable technology to measure and characterize aspects of emotion as it naturally occurred in daily life. I thought psychologists could benefit from the systematic approach engineers bring to difficult problems.

I attended neuroscience talks and read key findings on emotion in the neuroscience literature and found their methods to be more concrete—showing evidence for precise pathways through which aspects of emotional perception and learning appeared to be happening. Neuroscience studies were compelling, especially findings like Joe LeDoux's that showed perceptual learning (e.g., a rat learning to fear a tone) without involving the usual cortical components (e.g., after the audio cortex had been removed). Antonio Damasio's book *Descartes's Error* was also powerful in arguing for the role of emotion in rational decision making and behavior.

I spruced up my technical note envisioning affective computing as a broad area that I thought engineers, computer scientists, and many others should consider working on and submitted it as a manifesto to a non-Institute of Electrical and Electronics Engineers (IEEE) journal that had traditionally printed bold new ideas. It was rejected. Worse, one of the reviews indicated that the content was better suited to an "in-flight magazine." I could hear the laughter between the lines of rejection. I gave a talk on the ideas to our computer vision research group, and people were unusually silent. This was what I feared.

I gave a copy of the thought piece to Andy Lippman, a tall energetic man who always has bountiful words for sharing his opinions. Usually, we talked about signal processing or video processing. One day he showed up in my doorway, silent, with a peculiar look on his face, holding a document. He stabbed it with his finger, shook his head, pointed at it, shook his head some more and said nothing. This was not like him. Had he lost his voice? "Is something the matter?" I angled my head. Andy was never silent. Finally he blurted, "This is crazy! CRAZY!" He looked upset. I hesitated, "Uh, crazy is, good, in the Media Lab, right?" He nodded and then he smiled like a Bostonian being asked if he'd like free ice cream with mix-ins. Then I saw the document: it was my affective computing paper. He waved it, nodded and shook his head, and left with an odd smile. I never did resubmit that tech report, but it provided the only instance where I ever saw the voluble Lippman tongue-tied.

Visionary Supporters Trump Peer Review

I am a big fan of peer review, and I work hard to maintain the integrity of that process. But there are times in the life of new ideas when peer-reviewed papers don't stand a chance of getting published. Sometimes, years of acclimation are needed before an idea can make it through the process, even if the work is done solidly and with the best science and engineering. I realized the early ideas on affective computing were not going to make it into print until a lot more work had been done to prove them, and I only had a year before I was up for tenure. Emotion was just not an acceptable topic. How could I get a whole set of new ideas out when the average time from submission to publication of my computer vision papers was measured in years?

Nicholas Negroponte invited me to co-author his *Wired* column on affective computing. We published it and got a mix of responses. The most memorable responses were letters from people who said, "You are at MIT, you *can't* know *anything* about emotion." *Wired* was no substitute for peer review, but it started to get my ideas out, and the ideas shook some trees.

David Stork invited me to author the chapter on Hal's emotions for the book *Hal's Legacy*, commemorating the famous computer in Stanley Kubrick and Arthur C. Clarke's film, *2001 A Space Odyssey*. All of the other chapters addressed attributes of Hal, like his chess playing ability, his speech, his vision, and the like, and had "the most famous person in the field" to write them. David and I joked that I was the *only* person at the time who visibly represented the field of computers and emotions, and the word "field" was used with a stretch of a smile. I still enjoyed being in the book with a lot of impressive colleagues—Ray Kurzweil, Don Norman, Daniel Dennett, and others—and it was encouraging to be grouped with so many successful scientists. However, when I had dinner with Ray Kurzweil, his wife asked me if I was the "emotion woman," which only compounded my worries. But I had started digging deeper into affective computing research, and I knew the work was needed, even if it wrecked my image and my career.

The famous scientist Peter Hart, after coaxing me to ride bicycles with him up the "hill" (it felt more like a mountain) of Old La Honda on a 105 degree July day, told me he thought affective computing was going to become very important. He encouraged me to drop all the research I'd just raised more than a million dollars in funding for (content-based retrieval) and pursue affective computing wholeheartedly. I feverishly wondered how I could ever do that. Peter hosted, in July 1995, at Ricoh Silicon Valley, what was the first presentation outside of MIT on the ideas that would become my book *Affective Computing*. I saw Peter as an established outside authority in pattern recognition, not just a Media Lab crazy type, and his encouragement enabled me to believe that a book and more serious dedicated work on affect might be worthwhile. At least he would be one respected technical researcher who wouldn't write me off.

In August 1995, I emailed the director of the Media Lab that I was changing the name of my research group at MIT to "Affective Computing." He said it was a very nice name, "gets you thinking," and "is nicely confused with *effective*." I liked how easily he supported this new direction. I liked that my crazy new work would be confused with being effective.

I was asked to fax my unpublished tech report to Arthur C. Clarke (who didn't do email). I faxed it, and he mailed me a personal paper letter saying he liked it. Arthur added, "I sent your paper to Stanley—he is working on a movie about AI." I never got to meet "Stanley," but I understand he was the brilliant mind behind giving Hal emotions in the film *2001*. When I read Clarke's original screenplay, it had almost nothing on emotion in it, and Clarke's subsequent book on the story also downplayed emotion. But in the film, Hal showed more emotion than any of the human actors.

Through my Media Lab connections, I started to see that there were many mavericks who had recognized the power and importance of emotion, even though there were many more in engineering and computer science who did not think that emotion mattered. I felt encouraged to push ahead in this area, despite that I heard my technical colleagues at conferences whispering behind my back, "Did you hear what weird stuff she's working on?" and some of them blushed when I looked up at them and they realized I'd overheard. I did feel vindicated 5 years later at the same conference when one of them asked me if I would share my affect data with him because he was starting to do work in the field.

TV producer Graham Chedd for *Scientific American Frontiers* came by with one of my favorite actors, Alan Alda, and got interested in what my team was doing. Graham included our very early affective research in two of their shows. I am told that these episodes still air on very late night television, where you can see Alan Alda's emotional arousal going up as he thinks about hot red peppers and going down while he thinks about saltine crackers. I'm standing next to him, pregnant with my first child, trying to look like a serious scientist while I'm clanging a bell in his ear to elicit a startle response from him. Somehow it now seems fitting for late night television.

Dan Goleman called from the *New York Times* during a very busy week, and I asked him if we could talk at a different time. He said he was going to write about our work that week whether I would make time to speak with him or not. Later, his book on *Emotional Intelligence* sold more than 5 million copies. Putting "emotional" and "intelligence" together was a brilliant combination, originally conceived by Jack Mayer and Peter Salovey in their scholarly work under this name. Although the phrase is widely accepted today, at the time it was an oxymoron. Goleman's popular writing did a lot to interest the general public in the important roles emotions play in many areas of success in life—he argued it was more important than verbal and mathematical intelligences, which of course was what AI researchers had been focused on. The topic of emotion was starting to get more respect, although for some reason it was still very hard to get computer scientists to take it seriously.

Much later, William Shatner came by my office, dragged in by his ghostwriter who was creating a new book about the science of *Star Trek* and the role of emotion in their shows. It was kind of a stretch to find some science, given the booming sounds in the vacuum of outer space and more. But, I did confirm that the character of Spock had emotion. Spock was not emotionally expressive and kept emotion under control, but it was important to claim that he still had emotion, deep inside, in order for his intelligent functioning to be scientifically accurate. If he really didn't have emotion and behaved as intelligently as he behaved, then it would have been bad science in the show. The actor Leonard Nimoy, who had played Spock, later came to MIT and hosted a big event I chaired featuring new technology measuring and communicating emotional signals. He appeared remarkably unemotional, even when he was not playing Spock. I tried to convince him that he could show emotion and still be intelligent. He still showed almost no emotion, but his presence attracted more people to come and learn about why my group was developing affective technologies.

A famous high-priced speaker's bureau invited me to join their list of speakers, offering me lots of money if I would give talks about "more broadly interesting" technology topics than affect and computing. They thought emotion was not going to be of sufficiently broad interest to their well-heeled clients. I knew at this point I was going to spend all my spare cycles trying to get high-quality research done on affective computing and trying to get more engineers and computer scientists to consider working on emotion, so I declined their offer. I started giving more talks than ever on affective computing—dozens every year, mostly with zero or low pay to academic groups, trying to interest them in working on affect.

I remember one talk where the famous speech researcher Larry Rabiner came up to me afterward and asked why I was working on emotion. Larry said, "It's a very hard problem to tackle, and it just doesn't matter. Why are you wasting time on it?" I don't think he had paid much attention to my talk, or perhaps I had done a very bad job of explaining. I had always admired Larry's work, and this was tough to hear, but I tried to explain why I thought it was critical in early development for learning of language. I pointed out that dogs and small infants seem to respond to affect in speech. He seemed to think that was interesting. He did listen, but I never heard from him again.

After another talk, I remember a world-famous MIT computer scientist coming up to me, agitated, looking at my feet the whole time and complaining to me, "Why are you working on emotion? It's irrelevant!" I'm told this is how you tell if a CS professor is extroverted or introverted—if he looks at his feet, he's introverted, if he looks at yours, he's extroverted. He sounded angry that I would take emotion seriously. I tried, probably in vain, to convince him of its value, and he was soon joined by others who looked at each other's feet and changed the subject to help calm him down.

On multiple occasions, colleagues confided in me that they didn't know what emotion really was, other than extreme emotions like anger. Some of them even said, "I don't have feelings, and I don't believe they have a physical component you can measure." I think one of the attractions of computer science to many of them was that it was a world of logic largely devoid of emotional requirements, and they didn't want this threatened. I faced quite an uphill battle trying to convince my computer science colleagues of the value of emotion.

Through my talks to various groups, I became increasingly convinced that affective computing needed to be addressed, even if most computer scientists thought emotion was irrelevant. I wanted to make affective computing interesting and respectable so that progress would be made in advancing its science. I was always encouraged when people would go from looking scared of the topic, as if it was going to be an embarrassing talk to be seen at, to wanting to spend lots of time with me afterward talking deeply about the subject.

Somehow, in the midst of all of this, while up for tenure, trying to build and move into a new house, and getting ready to give birth to my first son, I signed a book contract in 1996, moved into the house, delivered the baby, delivered the book nine months later, and submitted my tenure case to MIT with a freshly minted copy of "Affective Computing." At the time, I had no peer-reviewed journal papers related to affective computing—those would come later. All my peer-reviewed scientific articles were on mathematical models for content-based retrieval or were conference papers on affective signal analysis. I was told that reviewers didn't know what to make of my schizophrenic tenure case: they wondered if the book was authored by somebody different from the person who wrote the papers, as if "Rosalind Picard" was a common name and maybe there were two of her.

Fortunately, I was in the Media Lab, probably the only place on the planet that loved you more the weirder you were. They were willing to take big risks. Jerry Wiesner's influence was huge, and our building was named after him. The director of our lab, Nicholas Negroponte, phoned me one day and said, "Roz, good news. Your tenure case went through like a hot knife through butter." The risk I had taken to start out in a totally new area, one that almost nobody wanted to be associated with, had not hurt my career. But I never did it for my career; I did it because I believed then, and I still believe, that affective computing is an extremely important area of research.

I was also amazed how, over time, the appeal of the topic became very broad—not just to researchers in computer science and human computer interaction, but also in medicine, literature, psychology, philosophy, marketing, and more. Peter Weinstock, a leading physician at Boston Children's Hospital, today calls emotion "the fourth vital sign." I had never known there were so many communities interested in affect, and I started to engage with researchers in a huge number of fields. I have learned a ton doing this, and it has been mind expanding.

I was delighted to see workshops on affective computing springing up around the world, led by visionary colleagues in computer science and psychology who were also bold in taking risks. I did not help much in terms of organizing meetings, and I admire greatly the huge efforts put in by so many talented technical colleagues who truly fostered the growth of this field. I cannot properly name them all here; however, Klaus Scherer, Paolo Petta, Robert Trappl, Lola Canamero, Eva Hudlicka, Jean-Marc Fellous, Christine Lisetti, Fiorella de Rosis, Ana Paiva, Jianhua Tao, Juan Velasquez, and Tienu Tan played especially important and memorable roles in instigating some of the early scientific gatherings. Aaron Sloman, Andrew Ortony, and I were frequent speakers at these gatherings, and I enjoyed their philosophical and cognitive perspectives and challenges.

The HUMAINE initiative became very influential in funding significant European research on emotion and computing, propelling them ahead of research efforts in the United States. The community involved a lot of top researchers under the warm leadership of Roddie Cowie, and, with the expert technical support of Marc Schroeder, was well organized and productive, funding dozens of groundbreaking projects.

The United States did not seem as willing as Europe to take bold risks in this new research area, and I always wondered why we lagged so far behind Europe in recognizing the importance of affect. I was lucky to have Media Lab corporate consortium funding with "no strings attached" or our MIT Affective Computing group would never have been able to get up and running. Meanwhile, a National Cancer Institute grant supported Stacy Marsella at the University of Southern California (USC) in developing a pedagogical system to teach emotion coping strategies to mothers of pediatric cancer patients, and an Army Research Institute grant recognized the importance of putting emotions into the cognitive architecture Soar (work by Paul Rosenbloom, also at USC, which not only included Jonathan Gratch, but also hooked him on emotion).

Much later, the National Science Foundation funded work by Art Graesser at Memphis that included my lab helping develop emotion recognition tools for an intelligent tutor, and then still later, work by Rana el Kaliouby and Matthew Goodwin and me building affective technology for autism. Although I remain very grateful for all sources of funding, I especially am grateful for those who find ways to give scientists the freedom to try things before the ordinary peer-review and proposal-review processes are ready to accept them. Emotion did not start out with respect, and if we had to wait for traditional sources of funding to get it to that point, this chapter would probably not be here.

. . . to IEEE and Beyond

I have a long history with the IEEE, from joining as a student to decades later being honored as a Fellow. I played a small role in helping found the IEEE International Symposium on Wearable Computing and the wearables special interest group. I have served on dozens of program committees, organized workshops, and served as guest editor and associate editor of *IEEE Transactions on Pattern Analysis and Machine Intelligence*. I've reviewed so many IEEE papers that, if combined into vertical stacks, they could bury a poor innocent bystander if they toppled. I know the high integrity and raise-the-bar standards of the IEEE research community.

However, when I submitted my first carefully written technical emotion recognition paper focusing on physiological pattern analysis to the IEEE conference on "computer vision and pattern analysis (CVPR)" the reviewers wrote "the topic does not fit into CVPR since it doesn't have any computer vision in it." Later, I strategically put "Digital processing of . . . " and "Signal processing for . . . " in the titles of papers submitted to the IEEE International Conference on Acoustics, Speech, and Signal Processing, and they got accepted. This same trick worked to get past the "it doesn't fit" excuses for our first *IEEE Transactions Pattern Analysis and Machine Intelligence* paper on affective computing as well: I put "machine intelligence" in the title. Of course, it was not that easy: the editor also insisted that five thorough reviewers iterate with me before approving the paper. Usually three will suffice. I had been an associate editor of PAMI and seen a lot of reviews, but I had never seen any set of such length as required for this first paper on emotion. I addressed every comment, and the paper got published.

By the way, it was not just the IEEE—the Association of Computing Machinery (ACM) also rejected my first affective computing submission as "not matching any of the topics or themes in the human–computer area." I wondered from the review if they had even read the paper or just rejected it when they saw it addressed emotion. Years later, I was delighted when several affective topics were added to their official themes. To this day, I still feel slightly amazed when I see conferences that openly solicit affective topics, even though affective computing has its own international conference now, and many other conferences also openly solicit affective computing work. It wasn't always that way—in the beginning, emotion was really fringe, unwelcome, and the few people working on it had to have an unusually large allocation of self-confidence.

In 2010, Jonathan Gratch led our community in launching its first journal, the *IEEE Transactions on Affective Computing*, which truly presents the field as respectable. Jaws dropped. The presence of an IEEE journal sent a message that serious engineering researchers could work on emotion and be respected.

Whether or not affective computing is an area in which you conduct research, you are using emotion when you choose to read this. You are involving your emotion system when you make a decision where to spend your time—when you act on what matters most to you. Affective computing researchers have a chance to elucidate how emotion works: how to build it, how to measure it, how to help people better communicate and understand it, how to use this knowledge to engineer smarter technology, and how to use it to create experiences that improve lives.

Affective computing is a powerful and deeply important area of research, full of extremely difficult technical, scientific, philosophical, and ethical challenges. I believe it contains the most complex real-time problems to be solved in human–computer interaction and in computer science models of human behavior and intelligence. At the same time, the field is not merely a subset of computer science. The complexity and challenge of giving computers real-time skills for understanding and responding intelligently to complex naturally occurring and naturally expressed human emotion spans many fields, including the human sciences of neuroscience, physiology, affective-cognitive science, and psychology. Affective computing is no longer a topic to be treated lightly, although laughter remains one of my favorite emotional expressions.

Acknowledgments

The author wishes to thank all her graduate and undergraduate student researchers over the years, especially those who helped build a solid base of research in affective computing, and those who politely tolerated and supported the group's transition to this topic back when they thought emotion was embarrassing and wished their advisor would go back to doing normal signal processing and machine learning. She also can not begin to properly credit the remarkable learning environment that MIT and the Media Lab have created supporting people who have different ideas, even laughable ones. MIT and the Media Lab are truly special places full of amazing colleagues. Picard would like to thank Drs. Ted Selker, Rich Fletcher, Rana el Kaliouby, and Matthew Goodwin for their significant collaborations, especially in creating new affective technologies that help people with disabilities and with needs for improved emotion communication.

CHAPTER

3

A Short History of Psychological Perspectives on Emotion

Rainer Reisenzein

Abstract

This chapter presents a short history of psychological theory and research on emotion since the beginnings of psychology as an academic discipline in the last third of the nineteenth century. Using William James's theory of emotion as the starting point and anchor, the history of research on five main questions of emotion psychology is charted. These concern, respectively, (1) the causal generation of emotions, (2) the effects of emotion on subsequent cognition and behavior, (3) the nature of emotion, (4) the evolutionary and learning origins of the emotion system, and (5) the neural structures and processes involved in emotions.

Key Words: emotion theory, history of emotion research, James's theory of emotion, cognitive emotion theories, basic emotions theory, neurophysiological basis of emotion

Psychology as an independent academic discipline emerged during the last third of the nineteenth century (see, e.g., Leahey, 2003). I have therefore chosen this period as the starting point of the present short history of psychological perspectives of emotion. However, readers should be aware that academic emotion psychology did not start from scratch. On the contrary, it build on a rich tradition of theorizing about emotions by philosophers, historians, and literary writers that dates back to the Ancient Greeks (see, e.g., Strongman, 2003) and has remained influential up to the present (e.g., Arnold, 1960; Nussbaum, 2001).

When psychology became an independent discipline, it defined itself initially as the science of consciousness (of conscious mental states; e.g., Brentano, 1873; Wundt, 1896). Given that emotions are salient exemplars of conscious mental states, it is not surprising that the psychologists of consciousness also had a keen interest in the emotions. In fact, most of the basic types of psychological emotion theory discussed today were already present, at least in the outlines, in the psychology of consciousness. During the subsequent, behaviorist phase of psychology (about 1915–1960), and due in large part to its restrictive research doctrines, research on emotions subsided again (see, e.g., Arnold, 1960), although behaviorists did make some important contributions to emotion psychology (e.g., research on the classical conditioning of fear; see Gray, 1975; LeDoux, 1998; Watson, 1919). Immediately after the so-called cognitive revolution of the early 1960s, when behaviorism was replaced by cognitivism—a modern version of mentalism guided by the metaphor of information processing in computers—emotion research took up speed again, until, in the 1990s, it became a boom that also began to affect other scientific disciplines. Today, emotion is an important topic in nearly every subfield of psychology, as well as in many other disciplines ranging from biology to neurophysiology to computer science, linguistics and literary studies. Some already see the emergence of a new interdisciplinary research field, analogous to cognitive science: *affective science*, the interdisciplinary study of emotions and related phenomena (Scherer, 2009).

One important reason for the recent surge of interest in emotions has been a re-evaluation of the adaptive utility of emotions. Traditionally, emotions have often been regarded as maladaptive (because, it was held, they interfere with rational thinking and decision-making; see, e.g., Roberts, 2013). In contrast, during the past 20 or so years, emotions have increasingly come to be seen as overall adaptive (e.g., Feldman-Barrett & Salovey, 2002; Frijda, 1994). Some theorists even regard emotions as indispensable for adaptive behavior (e.g., Damasio, 1994). This changed view of the usefulness of emotions has also been an important motive for launching of the field of affective computing (Picard, 1997).

Five Questions of Emotion Psychology

The task of emotion psychology can be defined as the reconstruction or "reverse engineering" of the structure and functioning of the human emotion system, including its relations to other subsystems of the mind (Reisenzein & Horstmann, 2006). The central subtasks of this task are to explain (Q1) how emotions are elicited or generated; (Q2) what effects (in particular what adaptive or functional effects) emotions have on subsequent cognitive processes and behavior, and, related to both questions, (Q3) what emotions themselves are—how they are to be theoretically defined, what kinds of mental and computational states they are (Reisenzein, 2012). Answering Q1–Q3 amounts to reconstructing the blueprint of the emotion system. However, as already argued by McDougall (1908/1960; see also, Tooby & Cosmides, 1990), to achieve this goal it is helpful, and even necessary, to address a further question that is also of independent interest, one that concerns the origins of the emotion system; namely (Q4), which parts of the emotion system are inherited and which are acquired through learning? Finally, to help answer questions Q1–Q4, it would be useful to know (Q5) how emotions are biologically realized or implemented (i.e., which neural structures and processes underlie them).

A generally accepted theory of emotions that gives detailed answers to all these questions, or even just to the central questions Q1–Q3, still does not exist. Nevertheless, progress has been made. In what follows, I trace the history of the most important proposed answers to the five main questions of emotion psychology. As the starting point and anchor of my report, I use a classical theory of emotion proposed by one of the founding fathers of psychology, the psychologist and philosopher William James (1884; 1890/1950; 1894). My reason for choosing James's theory of emotion for structuring this chapter is not that the theory has stood the test of time particularly well (see Reisenzein & Stephan, 2014), but that it has been highly influential, is widely known, and is possibly the first emotion theory that tries to give answers—if partly only very sketchy answers—to all of the five main questions of emotion psychology. I first describe James's answers to these questions and then discuss, in separate sections, what has been learned about them since James's time.

James's Theory of Emotion

The starting point of James's theory of emotion is the intuition, which I believe readers will confirm, that emotional experiences—for example experiences of joy, sorrow, anger, fear, pity or joy for another, pride, and guilt (see e.g., Ortony, Clore, & Collins, 1988)—have a special *phenomenal quality*; that is, it "is like" or "feels like" a special way to have them. James expressed this intuition with a metaphor that has since been adopted by many other emotion theorists: emotional experiences have "warmth"; they are "hot" experiences, in contrast to "cold" nonemotional mental states such as intellectual perceptions or thoughts, which James (1890/1950, p. 451) described as "purely cognitive in form, pale, colorless, destitute of emotional warmth." In addition, introspection suggests that the experiential quality of emotions is more or less different for different emotions (e.g., it feels different to be happy, angry, and afraid) and that each emotional quality can occur in different intensities (e.g., one can be a little, moderately, or extremely happy, angry, afraid).

James's main aim with his emotion theory was to explain this set of intuitions about emotional experience (Reisenzein & Döring, 2009). A central idea behind the explanation he offered was to notice that the description of emotions suggested by introspection—emotions are a unique group of related experiential qualities that can occur in different intensities—fitted the definition of *sensations* (e.g., of color, tone, or taste) (e.g., Wundt, 1896). Given the similarities between emotions and sensations, it seems natural to try to explain the phenomenal properties of emotions by assuming that they are a class of mental states analogous to sensations, or even that they are a subgroup of sensations. This is the basic idea of the so-called *feeling theory of emotion*, which until today has remained—at least in a "cognitively diluted" version (see the section on the nature of emotion)—the main approach to explaining the phenomenal character of emotions (Reisenzein, 2012; Reisenzein & Döring, 2009).

Q3: What Is an Emotion?

James himself opted for the radical version of feeling theory: he proposed that emotional feelings are not just *analogous to* sensations, but that they literally *are* a class of sensations on a par with sensations of color, taste, touch, and the like. Specifically, James argued, emotional feelings are the sensations of the bodily reactions that (he maintained) are always elicited by emotion-evoking events (see his answers to Q1 and Q4). Emotion-relevant bodily changes include facial and vocal expressions of emotion, as well as emotional actions (e.g., running away in fear), but most important are physiological reactions, such as heart pounding and sweating. In fact, in a response to critics of his theory, James (1894) argued that only physiological reactions are necessary for emotions.

Q1: How Are Emotions Elicited?

According to how James initially (James, 1884; 1890/1950) described the process of emotion generation, the bodily changes experienced as emotions are elicited by perceptions or ideas of suitable objects in a reflex-like (i.e., direct and involuntary) manner. To use James's most famous example, imagine a wanderer in the wilderness who suddenly sees a bear in front of him and feels terrified. According to James, the wanderer's feeling of fear is generated as follows: the perception of the bear elicits, in a reflex-like manner, a specific pattern of bodily reactions—that characteristic for fear (comprising among others an increase in heart rate, constriction of the peripheral blood vessels, sweating, and trembling; see James, 1890/1950, p. 446). The bodily changes are immediately registered by sense organs located in the viscera, skin, and muscles, and communicated back to the brain, where they are presumably integrated into a holistic bodily feeling (James, 1894). This feeling is the experience of fear.

Q2: What Are the Effects of Emotions on Subsequent Cognition and Behavior?

Given the evolutionary foundation of James's emotion theory (see Q4), it is interesting to learn that James was rather reserved about the adaptiveness of the bodily reactions elicited by emotional stimuli: although he believed that some of them are adaptive, he claimed that this is by no means the case for all. Furthermore, the emotion itself (e.g., the feeling of fear) does not seem to have any function of its own; indeed, the assumption of James's theory that emotions are the effects rather than the causes of emotional behaviors seems at first sight to *preclude* any useful function for emotions. However, as McDougall (1908/1960) has pointed out, feelings of bodily changes could still play a role in the control of ongoing emotional behavior (see also, Laird, 2007). Furthermore, if one assumes that emotional feelings are based on physiological changes only (James, 1884), they could at least in principle motivate emotional actions (e.g., fleeing in the case of fear) (see Reisenzein & Stephan, 2014).

Q4: Where Do the Emotion Mechanisms Come From; to Which Degree Are They Inherited Versus Learned?

According to James, the bodily reactions that constitute the basis of emotional feelings are produced by inherited emotion mechanisms that developed in evolution, although they can be substantially modified by learning. As said, James assumed that at least some of the evolutionary emotion mechanisms came into existence because they helped to solve a recurrent adaptive problem (see Q2). For example, the program that generates the fear pattern of physiological responses could be so explained: it developed because it helped our forebears to prepare for rapid flight or defense in dangerous situations (McDougall, 1908/1960). Furthermore, James assumed that the "instinctive" bodily reactions can be naturally elicited only by a small set of inborn releasers. However, as a result of associative learning experiences—essentially what later came to be known as classical conditioning (LeDoux, 1998; Watson, 1919)—all kinds of initially neutral stimuli can become learned elicitors of the inborn emotional reactions (James, 1884; see also McDougall, 1908/1860). Likewise, the reaction patterns can themselves become modified, within limits, as the result of learning (James, 1890/1950; see Reisenzein & Stephan, 2014).

Q5: What Are the Neural Structures and Processes Underlying Emotions?

To show that his psychological emotion theory was compatible with the then available neurophysiological knowledge, James (1884; 1890/1950) supplemented this theory with a sketch of the neural processes underlying the generation of emotions, resulting in what was perhaps the first neurophysiological model of emotion. According to James, at the neurophysiological level, the process of emotion generation can be described as follows: an object or event (e.g., an approaching bear) incites a sense organ (e.g., the eye). From there, afferent neural impulses travel to the sensory cortex, where they elicit a specific neural activation pattern that is the neurophysiological correlate of the perception of the object. Due to inherited or acquired neural connections, some sensory activation patterns (e.g., the pattern corresponding to the perception of a bear) activate one of several evolutionary bodily reaction programs located in the motor cortex (e.g., the "fear" reaction program). As a consequence, efferent impulses are sent to the inner organs and muscles of the body where they produce a complex, emotion-specific pattern of bodily changes (e.g., the fear pattern). These bodily changes are in turn registered by interoceptors in the viscera, skin, and muscles, whose signals are transmitted back to the sensory cortex, where they produce another neural activation pattern that is the neurophysiological correlate of an emotional feeling (e.g., fear). Hence, neurophysiologically speaking, emotions are simply special patterns of excitation in the sensory cortex caused by feedback from the bodily changes reflexively elicited by emotional stimuli.

Let us now look at what has been learned since James's times about the five questions of emotion psychology.

The Process of Emotion Generation

Worcester's Critique

Shortly after it had been proposed, James's theory of emotion came under heavy attack (see Gardiner, 1896). One of the objections raised concerned James's suggestion that emotions are elicited by sense perceptions in a reflex-like manner. Critics such as Worcester (1893) and Irons (1894) argued that this proposal conflicts with several well-known facts. Specifically, referring to James's example of a wanderer who feels fear upon encountering a bear, Worcester pointed out that a well-armed hunter might feel joy rather than fear when sighting a bear and that even an ordinary person might only feel curiosity if the bear were chained or caged. Worcester concluded from these cases that fear is not directly caused by sense perceptions but by certain thoughts to which these perceptions may give rise. Specifically, the wanderer feels afraid of the bear only if he believes that the bear may cause him bodily harm (Worcester, 1893, p. 287). In his response to Worcester's objection, James (1894) in effect conceded the point. Thereby, however, James accepted that, at least in the typical case, emotions are caused by cognitive processes, specifically by appraisals of objects as relevant to one's well-being (Arnold, 1960; see the next section). However, neither James nor Worcester clarified the cognitive processes involved in the generation of different emotions in more detail.

In fact, though, this issue had already been investigated in considerable detail in the cognitive tradition of emotion theorizing dating back to Aristotle (350 BC). In nineteenth-century introspective psychology, this tradition was represented by, among others, the cognitive emotion theories proposed by Alexius Meinong (1894) and Carl Stumpf (1899) (see Reisenzein, 2006; Reisenzein & Schönpflug, 1992). Unfortunately, however, these early cognitive emotion theories[1] became buried under the "behaviorist avalanche" (Leahey, 2003). It was only during the cognitive revolution of the early 1960s that the cognitive tradition of emotion theorizing was rediscovered (and partly reinvented) in psychology. The two theorists most responsible for this development were Magda B. Arnold (1960) and Richard S. Lazarus (1966), the pioneers of cognitive emotion theory in post-behaviorist psychology.

The Arnold-Lazarus Theory

Whereas James regarded the *phenomenal character* of emotions—the fact that it feels a particular way to have emotions—as their most salient feature and that most in need of explanation, Arnold (1960) focused on another property of emotions that had already been emphasized by James's contemporaries Meinong (1894) and Stumpf (1899; see also Irons, 1894): the *object-directedness of emotions* (the technical philosophical term is *intentionality*). Like some other mental states—the paradigmatic examples in this case are beliefs and desires—emotions are directed at objects: if one is happy, sad, or afraid, one is at least in the typical case (according to Arnold, even always) happy about something, sad about something, or afraid of something—or so emotions present themselves to the subject.

This *something* (which may not actually exist) is the intentional object of the emotion. For example, the object of fear of James's wanderer's—what he fears—is *that the bear might cause him bodily harm* (Worcester, 1893). As is the case for fear, the objects of most emotions are *states of affairs* (e.g., states, events, actions).

The object-directedness of emotions rather directly suggests that emotions presuppose cognitions of their objects (Arnold, 1960; Meinong, 1894). Arnold (1960) elaborated this idea by proposing that the cognitions required for an emotion directed at a state of affairs *p* are of two kinds: (a) *factual cognitions* about *p* (paradigmatically, these are beliefs concerning the existence and properties of *p*) and (b) an *evaluation* or *appraisal* of *p* as being good or bad for oneself. Paradigmatically, this appraisal is also a belief, namely, an evaluative belief, the belief that *p* is good or bad for oneself (in fact, appraisals were originally called "value judgments" by Arnold and Gasson, 1954).[2] Hence, for example, to feel joy about *p* (e.g., that Smith was elected as president), Mary must (at minimum) believe that *p* is the case (or, as Arnold [1960, p. 193] says, "is present") and evaluate *p* as good for oneself. Analogously, to experience sorrow about *p*, Mary must believe that *p* is the case and evaluate *p* as bad for herself. Furthermore, under normal circumstances (i.e., if Mary is awake, attentive, not under the influence of emotion-dampening drugs, etc.), the described cognitions are also sufficient for joy and sorrow to occur.

Although Arnold (1960) is not fully explicit on this point, it appears that she thought that the evaluation of an event as positive or negative is the outcome of a comparison of the event with one's goals or desires: events are positive if they are goal-congruent (fulfill a desire) and negative if they are goal-incongruent (frustrate a desire). This view of the appraisal process can be found in explicit form in Lazarus (1966) and has been adopted by most subsequent appraisal theorists (Reisenzein, 2006). However, this theory of the appraisal process implies that emotions presuppose not only beliefs (i.e., informational mental states) but also desires (i.e., motivational mental states), even though the latter are only indirect causes of the emotions: they are the standards to which facts are compared to determine whether they are good or bad.[3] The emotion itself, according to Arnold (and in contrast to James), is an experienced action tendency: a felt impulse to approach objects appraised as good or to avoid objects appraised as bad.

So far, I have only described Arnold's analysis of joy and sorrow. However, Arnold proposed that a parallel analysis is possible for all other emotions (at least all emotions having *states of affairs* [also called "propositions" by philosophers] as objects). Like joy and sorrow, these "propositional" emotions presuppose factual and evaluative beliefs about their objects; however, these beliefs differ more or less for the different emotions. Arnold elaborated this idea by proposing that the cognitions underlying the different emotions vary on (at least) three dimensions of appraisal,[4] two of which were already mentioned: *evaluation of the object* as good or bad for oneself (i.e., "appraisal" in the narrow meaning of the word), *presence-absence of the object*, and *the ease or difficulty to attain or avoid the object* or, as one can also say (with Lazarus, 1966), *coping potential*. As used by Arnold, *presence-absence* refers simultaneously to the subjective temporal location of a state of affairs and to the subjective certainty that it obtains; it contrasts subjectively present or past plus certain states of affairs with those that are subjectively future and still uncertain. *Coping potential* concerns the belief that the state of affairs in question (a) if still absent, is easy, difficult, or impossible to attain (positive state) or avoid (negative state); or (b) if already present, is easy, difficult, or impossible to keep (positive state) or to undo or adapt to (negative state). Note that this third appraisal dimension, like the second, refers to a factual belief. Different combinations of the possible values of the three appraisal dimensions give rise to different emotions. For example, according to Arnold (1960), joy is, precisely speaking, experienced if one believes that a positive state of affairs is present and can be easily maintained, whereas fear is experienced if one believes that a negative event might occur that one cannot prevent.

A very similar appraisal theory to that of Arnold was proposed by Lazarus (1966). As detailed in Reisenzein (2006), Lazarus essentially combined Arnold's first two appraisal dimensions into a single process that he called *primary appraisal* and renamed Arnold's third dimension *secondary appraisal*. However, even though Lazarus's (1966) original appraisal theory (for an expanded and revised version, see Lazarus, 1991) therefore did not go much beyond Arnold's, in contrast to Arnold, he supported his theory by a series of laboratory experiments (see Lazarus, 1966). These experimental studies did much to make appraisal theory scientifically respectable in psychology.

More Recent Appraisal Theories

Since the 1960s, the appraisal theory of emotion has become the dominant model of emotion generation in psychology. Over the years, however, the original version of the theory proposed by Arnold and Lazarus has been found wanting in various respects and, accordingly, improved appraisal theories have been proposed (e.g., Frijda, 1986; Ortony et al., 1988; Roseman, 1984; Scherer, 2001; Smith & Lazarus, 1990; for an overview, see Ellsworth & Scherer, 2003; and for a recent discussion, Moors, Ellsworth, Scherer, & Frijda, 2013). These newer appraisal theories share with the Arnold-Lazarus theory the basic assumption that emotions are products of factual and evaluative cognitions. However, unlike Arnold and Lazarus, they typically distinguish between different kinds of evaluations of the eliciting events (e.g., personally desirable/undesirable vs. morally good/bad) and postulate additional, as well as partly different, factual appraisals (e.g., probability of the event, unexpectedness of the event, and responsibility for the event). Perhaps the most elaborated, as well as the most systematic of the newer appraisal theories was proposed by Ortony et al. (1988). Ortony et al. specify the cognitions underlying 11 positive and 11 emotions and argue with some plausibility that other emotions are subspecies of these 22 emotions. The OCC model, as it is often referred to, has become the most widely used psychological template for computational models of emotion generation. Other more recent appraisal theories, such as those proposed by Smith and Lazarus (1990) and Scherer (2001), also seek to describe the computational processes of emotion generation in greater detail than Arnold and Lazarus did. A common assumption of these "process models" of appraisal is that appraisal processes can occur in several different *modes*, in particular as *nonautomatic* and as *automatic* processes. Whereas nonautomatic appraisal processes are akin to conscious inference strategies, automatic appraisals are assumed to be unconscious and to be triggered fairly directly by the perception of eliciting events. Like other cognitive processes, initially nonautomatic, conscious appraisals can become automatized as a result of their repeated execution (e.g., Reisenzein, 2001). Automatic appraisals can explain why emotions often rapidly follow their eliciting events.

Like the foundational appraisal theory of Lazarus (1966), the more recent appraisal theories have generated a sizable body of empirical research (e.g., Ellsworth & Scherer, 2003). Most of this research has been aimed at providing support for the assumption that different emotions are characterized by distinct patterns of appraisal composed from the values of a limited set of dimensions. This assumption has been reasonably well supported (Ellsworth & Scherer, 2003). However, in my view, the main reason for the success of appraisal theory has not been this and other empirical support for the theory but the fact that it agrees well with implicit common-sense psychology and has unmatched explanatory power (Reisenzein, 2006). Concerning the latter issue, it is simply hard to see *how else* than by assuming intervening cognitive processes of the kind assumed in appraisal theories (or in the belief desire theory of emotion; see Footnote 3), one could explain the following, basic facts of human emotions: (a) emotions are highly differentiated (there are many different emotions); (b) different individuals can react with entirely different emotions (e.g., joy vs. sorrow) to the same objective events (e.g., the victory of a soccer team); (c) the same emotion (e.g., joy) can be elicited by events that have objectively nothing in common (e.g., the victory of a soccer team and the arrival of a friend); (d) the same concrete emotional reaction (e.g., joy about the arrival of a friend) can be caused by information acquired in widely different ways (e.g., when seeing the friend approach, when hearing his voice, when being told by others that he has arrived); and (e) if a person's appraisals of an event changes, then in most cases her emotions about that event change as well.

Can Emotions Be "Noncognitively" Elicited?

Whereas the "cognitive path" to emotion described by cognitive emotion theories is generally acknowledged by today's emotion psychologists, the question of the existence or at least the practical importance of alternative "noncognitive" paths to emotion has given rise to a protracted debate (e.g., Lazarus, 1982; Leventhal & Scherer, 1987; Storbeck & Clore, 2007; Zajonc, 1980). This so-called cognition-emotion debate has suffered, among other things, from the failure to distinguish clearly between two different version of the hypothesis of "noncognitive" emotion generation: (a) the hypothesis that *certain kinds of emotion in the broad sense of the term*, such as sensory pleasures and displeasures or aesthetic feelings, are "noncognitively" caused; that is, they do not presuppose beliefs and desires but only nonpropositional and possibly even nonconceptual representations, such as certain visual patterns or sounds; and (b) the hypothesis that even *prototypical emotions* such as fear, anger, or joy can be (and perhaps even often are) noncognitively caused (e.g., that fear can be elicited by the sight of a dark moving form in the woods, without any mediating thoughts, as James [1890/1950] had claimed). Whereas the first hypothesis is plausible (Reisenzein, 2006), the second is more controversial: on closer inspection, the data that have been adduced to support this hypothesis turn out to be less convincing than is often claimed (see, e.g., Reisenzein, 2009*b*). Most of these data concern fear. For example, it has been argued that noncognitive fear elicitation is demonstrated by studies suggesting that physiological reactions can be elicited by subliminally presented emotional stimuli (e.g., Öhman & Mineka, 2001; see Storbeck & Clore, 2007, for a review). However, it is also possible that these physiological reactions are mediated by automatized and unconscious appraisal processes (e.g., Siemer & Reisenzein, 2007).

The Effects of Emotions

In contrast to James, common-sense psychology assumes that emotional feelings can have powerful effects on cognition and behavior. In fact, this belief is a main reason why emotions interest both lay people and scientists. As mentioned in the chapter's opening, psychologists have traditionally emphasized the negative, maladaptive effects of emotions; however, during the past 20 years or so, the view has increasingly gained acceptance that, notwithstanding their occasional negative consequences, emotions are overall (i.e., across all relevant situations) adaptive. The adaptive effects of emotions are their (evolutionary) *functions*—the reasons why the emotion mechanisms came into existence in the first place (e.g., Mitchell, 1995). However, although emotion psychologists today largely agree that emotions are functional, there is still only partial agreement on what the functional effects of emotions consist of (for overviews, see e.g., Frijda, 1994; Hudlicka, 2011). In what follows, I describe three main proposed functions of emotions concerning which there is reasonable consensus as well as empirical support: the attention-directing, informational, and motivational function of emotions.

The Attention-Directing Function of Emotions

According to this functional hypothesis, a primary function of emotions is to shift the focus of attention to their eliciting events; or, computationally speaking, to allocate central processing resources to the analysis of these events and give them priority in information processing (e.g., Simon, 1967; Sloman, 1992; see also, Reisenzein, Meyer, & Niepel, 2012).

The Informational Function of Emotions

The informational or epistemic function of emotions consists in providing adaptively useful information to other cognitive (sub-)systems, including other agents. This information presumably concerns (a) the results of (unconscious) appraisal processes (e.g., Schwarz & Clore, 2007) or the occurrence of changes in the person's belief-desire system (Reisenzein, 2009*a*) and/or (b) closely related to this, information about the value of objects and events, including actions and their consequences (e.g., Damasio, 1994; Meinong, 1894; Slovic, Peters, Finucane, & MacGregor, 2005). To illustrate, nervousness experienced when meeting a stranger might function to inform the decision-making system about the subconscious appraisal of the encounter as threatening. Similarly, a pleasant feeling experienced when considering a possible course of action could serve to signal the subconscious approval of the action and mark it as a good one to choose. Empirical evidence for these informational effects (and possibly functions) of emotions can be found in Schwarz and Clore (2007) and Slovic et al. (2005). Analogously, the nonverbal and verbal communication of emotions could serve to convey this information to other agents.

The Motivational Function of Emotions

The motivational function of emotions consists of their adaptive effects on action goals. It has been argued that emotions serve both to reprioritize existing goals or intentions and to generate to new ones (e.g., Frijda, 1986; Oatley & Johnson-Laird, 1987). With respect to the generation of new goals, two main mechanisms have been proposed (Reisenzein, 1996). First, it has been proposed that emotions or their anticipation generate hedonistic desires (e.g., Baumeister, Vohs, DeWall, & Zhang, 2007; Mellers, 2000). This path from emotion to motivation is central in *hedonistic theories of motivation* (e.g., Bentham, 1789/1970; Cox & Klinger, 2004), which assume that one ultimate goal or basic motive of humans, if not their only basic motive, is the desire to maximize pleasure and to minimize pain (displeasure). This hedonistic motive can be activated both by currently experienced emotions and by emotions that are merely anticipated: negative feelings generate a desire to reduce them (if they are present) or to avoid them (if they are anticipated); analogously, positive feelings generate a desire to maintain them or to bring them about. It is widely assumed that hedonistic desires can also influence cognitive processes including appraisals. For example, the unpleasant feeling of fear elicited by a threatening event may motivate the person to avoid thinking about the event or to try to reappraise it in more benign terms (e.g., Gross, 1998; Lazarus, 1991).

There can be little doubt that emotions influence motivation partly through the hedonistic route (see, e.g., Baumeister et al., 2007). However, several emotion and motivation theorists have argued that this is not the only path from emotion to motivation. Rather, according to these theorists, at least some emotions evoke adaptive goals or action tendencies (e.g., fear causes the desire to flee, anger to aggress, pity to help) *directly*, that is, without the mediation of hedonistic desires (e.g., Frijda, 1986; Lazarus, 1991; McDougall, 1908/1960; Weiner, 1995; for a discussion, see Reisenzein, 1996). Conceivably, this nonhedonistic effect of emotions on motivation is based on their attention-directing and informational functions. The nonhedonistic theory of the emotion–action link may be better able than the hedonistic theory to explain the motivational effects of some emotions, such as the effect of pity on helping and of anger on aggression (Rudolph, Roesch, Greitemeyer, & Weiner, 2004).

The three described functions of emotions—the attention-directing, informational, and motivational functions—can be seen as contributing, in different ways, to a single overarching function of emotions: to improve the generation of adaptive intentional actions (at least in the evolutionary environment). To achieve this effect, emotions need to influence the motivational machinery that proximately controls actions. According to the standard view of action generation in psychology and other disciplines, actions are proximately caused by a mechanism whose inputs are the agent's desires (goals) and means-ends beliefs, and whose basic decision principle is that *agents attempt to do what they believe will lead to what they desire* (e.g., Bratman, 1987; Pollock, 1989).[5] These considerations suggest that—contrary to the claims of some emotion theorists (e.g., Bentham, 1789/1970; Damasio, 1994; McDougall, 1908/1960)—emotions are *not* indispensable for the generation of adaptive actions, although "affect-free" actions may well be overall less adaptive than actions that are also informed by emotions.

The Nature of Emotion

Problems of Bodily Feeling Theory

The central assumption of James's theory concerns the nature of emotion: according to James, emotions are a class of sensations—the feelings of the bodily reactions generated by evolutionary emotion mechanisms. This assumption of James, too, immediately met with criticism (see Cannon, 1927; Gardiner, 1896; Stumpf, 1899). Two main objections were raised. The first was that this theory of the nature of emotion fails to account for other salient properties of emotion, in particular their object-directedness. This objection is considered later. The second objection was that James's theory even fails to account for the phenomenon it was primarily meant to explain, the phenomenal quality of emotions. The arguments that were advanced to support this second objection can be summarized in two main objections to James's explanation of emotional experience, one theoretical and the other empirical (see Reisenzein & Stephan, 2014). The *theoretical* objection was that James's theory is unable to explain in a noncircular way (i.e., without referring back to emotions) what distinguishes "emotional" bodily changes from nonemotional ones (e.g., a quickened pulse from running; Irons, 1894; Stumpf, 1899). The *empirical* objection was that, contrary to what James's theory implies, bodily feelings are neither necessary nor sufficient for emotion and do not match the subtle qualitative differences and intensity gradations of emotional experiences. A particularly convincing version of this objection—because it was supported by systematic experimental data—was published by Walter B. Cannon (1927). As a result, for many years, James's theory of emotion was widely regarded as having been refuted by Cannon.

However, in the wake of the renaissance of emotion research after the cognitive revolution of the 1960s, a number of emotion researchers argued that Cannon's criticisms were overdone and that a revised version of James's theory of the nature of emotion might, after all, be tenable. Accordingly, several more or less strongly modified versions of James's theory were proposed (e.g., Damasio, 1994; Laird, 1974; Schachter, 1964). In support of their views, the Neo-Jamesians refer to a variety of more recent empirical findings. The relatively most convincing of these are studies that suggest that experimentally induced physiological and expressive changes can, under certain circumstances, intensify emotional experiences (see Laird, 2007, for a summary). To illustrate, Strack, Martin, and Stepper (1988) found that when participants held a pen between their front teeth in a way that resulted in an expression resembling a smile, they judged cartoons to be funnier than in a no-smile control condition, suggesting that they felt more strongly amused. However, interesting as these findings are, they do not show that emotions are nothing but sensations of bodily (including facial) changes or even that bodily perceptions are necessary for emotions. In fact, other evidence suggests that this is not the case. In particular, studies of the emotional experiences of spinal cord-injured people, who have much reduced bodily feedback, suggest that their emotional life is largely intact (e.g., Cobos, Sánchez, Garcia, Vera, & Vila, 2002; see Reisenzein & Stephan, 2014). Similarly, studies on the effects of beta-adrenergic blocking agents (which specifically inhibit the reactivity of the cardiovascular system) on emotions typically failed to find reduced emotions in healthy subjects (e.g., Erdmann & van Lindern, 1980). Likewise, the experimental or natural reduction of facial feedback typically does not diminish emotional experience (see Reisenzein & Stephan, 2014).

Mental Feeling Theory

Although the available evidence suggests that emotional experiences are not (at very least not *only*) bodily sensations, James's more basic intuition, that the phenomenal quality of emotions is best explained by assuming that they are *sensation-like* mental states, remains forceful (Reisenzein, 2012). This intuition can be saved if one assumes that although emotions are indeed sensation-like feelings (or at least contain such feelings as components; see the next section), the emotional feelings are not created in the body but in the brain (e.g., Buck, 1985; Cannon, 1927; Oatley & Johnson-Laird, 1987; Wundt, 1896). The oldest and most prominent of these "mental" (as opposed to James's "bodily") feeling theories of emotion holds that emotions are feelings of pleasure and displeasure (e.g., Bentham, 1789/1970). Pleasure–displeasure theory was in fact the standard view of the phenomenal quality of emotional feelings in nineteenth-century psychology (e.g., Meinong, 1894; Wundt, 1896). Notwithstanding James's protest that this "hackneyed psychological doctrine . . . [is] one of the most artificial and scholastic of the untruths that disfigure our science" (James, 1894, p. 525), pleasure–displeasure theory is in fact much better established empirically than James's own theory of emotional experience (see, e.g., Mellers, 2000; Russell, 2003) and is today held, in some form, by many emotion researchers (e.g., Mellers, 2000; Ortony et al., 1998; Reisenzein, 2009*b*).

However, one must concede to James (1894) that, taken by itself, pleasure–displeasure theory cannot account for the qualitative distinctions among emotional experiences beyond positive–negative. As one attempt to overcome this problem of the theory, several theorists have postulated other mental feelings in addition to (or in place of; see Footnote 6) pleasure and displeasure. For example, Wundt (1896) proposed that (a) the centrally generated emotional feelings comprise not just pleasure–displeasure, but two more pairs of opposed (mutually exclusive) feeling qualities, excitement–quiescence and tension–relaxation, and that (b) emotions are different mixtures of these six "basic feelings" (e.g., anger is an unpleasant feeling also characterized, at least typically, by excitement and tension). In broad agreement with Wundt, contemporary "dimensional" theories of emotional experience (e.g., Russell, 2003; see also Reisenzein, 1994) assume that the feeling core of emotions consists of mixtures of pleasure or displeasure and (cortically produced) activation or deactivation (which corresponds approximately to Wundt's dimension of excitement–quiescence). Supportive evidence for this theory is summarized in Russell (2003).[6]

Cognition Feeling Theory

Although mental feeling theory is able to solve some problems of bodily feeling theory, it does not solve all. Two remaining problems are: (1) even if one assumes the existence of several different mental feeling qualities, this still does not explain the fine-grained distinctions among emotions, and (2), like the bodily feeling theory, the mental feeling theory has difficulties accounting for the object-directedness of emotions. To solve these problems, several feeling theorists proposed bringing in other mental elements into the emotion in addition to feelings. The most frequently proposed additional emotion components have been the cognitions (appraisals) by which the emotional feelings are caused (e.g., Lazarus, 1991; Oatley & Johnson-Laird, 1987; Schachter, 1964). According to the resulting "hybrid" cognition-feeling theory, emotional experiences are complex mental states that consist of feelings plus the appraisals that caused them. Because appraisals are undoubtedly finely differentiated, cognition feeling theory is able to solve the problem of emotion differentiation. It also seems to be able solve, at first sight at least, the problem of accounting for the object-directedness of emotions: According to cognition feeling theory, emotions have objects because they contain object-directed cognitions as components, and their objects are just the objects of these cognitions (but see Reisenzein, 2012, for objections to this idea).[7]

However, the "hybrid" cognition feeling theory is not the only option available to the feeling theorists. To solve the emotion differentiation problem, feeling theorists need not assume that cognitions are *components* of emotion; they can continue to regard them as the causes of emotions construed as sensation-like feelings but assume that emotions are partly distinguished by their causes (Reisenzein, 1994; 2012). For example, joy can be analyzed as a feeling of pleasure caused by the belief that a desire has been fulfilled, whereas pride can be analyzed as a feeling of pleasure caused by the belief that one has made an extraordinary achievement. With respect to the problem of accounting for the object-directedness of emotions, feeling theorists can argue that subjective impressions are misleading and that emotions do not really represent the objects at which they seem to be focused (e.g., Reisenzein, 2009*a*). For a discussion of these options, see Reisenzein (2012).

The Evolutionary Core of the Emotion System

In my discussion of the effects of emotion, I already referred to their adaptive effects or biological functions. The assumption that such functions exist implies that at least the core of the emotion system has been created by evolutionary processes, specifically through natural selection. This hypothesis is per se not very controversial among today's emotion psychologists; after all, presumably the cores of all mental subsystems (perception, cognition, motivation, emotion, etc.) were created by natural selection. Controversy starts, however, when it comes to specifying exactly what the evolutionary core of the emotion system consists of and, relatedly, to what degree and in which respects the emotion system is molded and moldable by learning. James's proposal was that the evolutionary core of the emotion system is a multimodular system consisting of a set of discrete emotion mechanisms, each of which generates a distinct, "basic" emotion (see James, 1890/1950). The set of basic emotion mechanisms was not precisely enumerated by James, but he suggested that they comprise at least anger, fear, joy, grief, love, hate, and pride (see Reisenzein & Stephan, 2014). These evolutionary assumptions have turned out to be even more influential than James's views about the nature of emotional experience. However, this part of James's emotion theory, too, remained a sketch. It was left to William McDougall (1908/1860) to explicate it in the first book-length account of the evolutionary theory of discrete basic emotions.

McDougall's Theory of Discrete Basic Emotions

McDougall claimed that the biological core of the emotion system consists of a small set of modular information processing mechanisms—McDougall called them *instincts*—that developed during evolution because each solved a specific, recurrent adaptive problem. McDougall initially proposed seven basic instincts or emotion modules, including the fear module (or flight instinct), the disgust module (or instinct of repulsion), and the anger module (or instinct of pugnacity). Formulated in information processing terminology, each basic emotion module consists of a *detector* that monitors incoming sensory information and a *reaction program*. When the detector receives appropriate input—namely, information that indicates the presence of the adaptive problem that the module was designed by evolution to solve—the associated reaction program is triggered, which causes the occurrence of a coordinated pattern of mental and bodily responses. According to McDougall, this emotional reaction pattern comprises an emotion-specific action impulse, a specific pattern of bodily (in particular peripheral-physiological) reactions, and a specific kind of emotional experience (see Reisenzein, 2006).

McDougall was much more certain than James that the emotional mechanisms are adaptive. The central biological function of the emotion modules, he claimed, is motivational; that is, they serve to generate impulses for adaptive actions—actions that regularly solved the pertinent adaptive problem in the ancestral environment (e.g., avoidance of bodily injury in the case of fear or protection against poisoning in the case of disgust). Accordingly, the central output of the emotion modules is the action impulse (e.g., the impulse to flee in the case of fear or the impulse to reject offensive substances in the case of disgust). The remaining outputs of the emotion modules, including emotional experience, only serve to support, in one way or other, this main biological function.

According to McDougall, the internal configuration of the emotion modules—the connection between the detector and the reaction program—is "hardwired" and cannot be modified by experience and learning. Nevertheless, during individual development, the emotional system as a whole is greatly modified by learning processes that affect the inputs and outputs of the emotion modules: only very few of the elicitors of the emotion modules are innate; most are acquired. Likewise, although the emotional action impulses are innate, whether they are expressed in action or not—and if they are, to which concrete actions they lead—depends mostly on learning.

Modern Theories of Basic Emotions

Post-behaviorist emotion psychology saw not only a renaissance of cognitive and feeling theories of emotion, but also of evolutionary emotion theories. Most of these theories are modern variants of McDougall's (and James's) theory of discrete basic emotions (e.g., Ekman, 1972; Izard, 1971; Plutchik, 1980; Tooby & Cosmides, 1990). The more recent basic emotions theorists differ from McDougall mainly in that they ascribe a more important role to cognitive processes in the elicitation of emotions as well as, in some cases (e.g., Ekman, 1972; Izard, 1971), to the facial expression of emotion. Perhaps the best-known modern basic emotions theory was proposed by Ekman (1972, 1992). According to Ekman, there are at least six (but possibly up to 15; Ekman, 1992) basic emotion modules: joy, sadness, anger, disgust, fear, and surprise. When activated by suitable perceptions or appraisals, these inherited "affect programs" generate emotion-specific feelings, physiological reaction patterns, and an involuntary tendency to show a particular facial expression (e.g., smiling in the case of joy). However, this "instinctive" tendency need not result in a facial expression because it can be, and often is, voluntarily controlled in an attempt to comply with social norms that regulate emotional expression (so-called *display rules*).

Actually, the influence of the James-McDougall theory of discrete, biologically basic emotions extends far beyond the mentioned, contemporary evolutionary emotion theories because central assumptions of this theory have also found their way into some contemporary appraisal theories (e.g., Arnold, 1960; Lazarus, 1991; Roseman, 1984; see Reisenzein, 2006, for a discussion).

Are There Discrete Basic Emotions?

Given the prominence of the basic emotions view, it is important to realize that it is not the only possibly theory of the evolutionary architecture of the emotion system. The main alternative that has been proposed is that, rather than consisting of multiple discrete emotion modules, the emotion system consists of a small number of more basic mechanisms that produce *all* emotions. This idea, which is already implicit in some classic emotion theories (e.g., Wundt, 1896), has been developed in different ways by different contemporary theorists (e.g., Lang, 1995; Reisenzein, 2009*a*; Russell, 2003). To illustrate, one proposal is that the emotion system consists of but two mechanisms, one of which compares newly acquired beliefs with existing beliefs and another that compares newly acquired beliefs with existing desires; these mechanisms are assumed to generate sensation-like feelings (e.g., of pleasure and displeasure and of surprise) that combine to form different emotions (Reisenzein, 2009*a*; 2009*b*).

Since the 1960s, a great deal of empirical research has been devoted to answering the question of whether the emotion system consist of a multimodular system of discrete "basic emotion" modules. A central testable implication of basic emotions theory is that presumed biologically basic emotions are associated with distinct patterns of physiological and expressive responses (see Barrett, 2006). The comparatively best support for this hypothesis stems from cross-cultural studies of facial expression (e.g., Ekman, Friesen et al., 1987; for summaries, see Elfenbein & Ambady, 2002; Nelson & Russell, 2013). In these studies, judges were presented with photographs of prototypical facial expressions of basic emotions (typically Ekman's six) together with a list of the names of the emotions, and they were asked to indicate which emotion is expressed by which facial expression. Using this method, very high "correct" emotion classifications have been obtained (e.g., Ekman et al., 1987). However, Russell (1994) has pointed out that observer agreement on the expressed emotions is artifactually inflated in these studies. Furthermore, observer agreement decreases significantly with increasing distance to Western cultures (Nelson & Russell, 2013). In addition, being studies of emotion recognition, these investigations do not directly speak to the question of the production of emotional facial expressions, which is the more important test case for basic emotions theory. Recent reviews of studies of spontaneous facial expressions of emotions in laboratory experiments (Reisenzein, Studtmann, & Horstmann, 2013) and naturalistic field studies (Fernández-Dols & Crivelli, 2013) suggest that (a) with the exception of amusement, experiences of basic emotions are accompanied by their presumably characteristic facial expressions only in a minority of cases, and (b) low emotion intensity and attempts to control facial expressions are insufficient to explain the observed emotion–face dissociations. Studies of peripheral-physiological changes in emotions have found even less coherence between emotional experience and behavior (e.g., Mauss & Robinson, 2009). However, it can be argued that the best place look for evidence for basic emotion modules is the brain (cf. James, 1884). This issue is addressed in the next section.

The Neurophysiological Basis of Emotions

James versus Cannon

According to James (1884), the neurophysiological processes that underlie emotions are, in their entirety, ordinary sensory and motor processes in the neocortex. This assumption, too, was rejected by Cannon (1927) in his critique of James's theory. Indeed, brain lesion studies in cats by Cannon's coworker Bard (e.g., Bard, 1934; see also, Cannon, 1931) suggested that the programs for bodily reactions are not located in the motor cortex, as James had thought, but in what Cannon called the "thalamic region," a subcortical brain region comprising the thalamus, hypothalamus, and adjoining structures. Based on these and other findings, Cannon and Bard proposed that emotional experience and expression are generated *simultaneously* when an "affect program" in the thalamic region is activated. However, because Cannon's affect programs were, like those of James, programs for bodily reactions, James need not have been too much disconcerted by Cannon's neurophysiological model and could even have welcomed it as an alternative implementation proposal for his own emotion theory, one that accounted for several problematic findings (Cannon, 1927; Reisenzein & Stephan, 2014). However, another assumption of the Cannon-Bard theory—that physiological reactions are essentially emotion-unspecific—is incompatible with James's theory (Cannon, 1927). In fact, the lack of physiological response differentiation speaks against any theory that assumes multiple discrete emotion mechanisms.

Limbic System Theory

This conclusion was incorporated in the next historically important neurophysiological emotion model, the limbic system theory proposed by Papez (1937) and MacLean (1952; 1973) (see Dalgleish, 2004, for a summary). The central assumption of this theory is that the neurophysiological basis of emotions, rather than consisting of a set of distinct emotion modules (as James and McDougall had assumed), is a single system—the *limbic system*. With this name, MacLean denoted a group of subcortical and cortical structures (including, among others, nuclei of the thalamus and hypothalamus, as well as the amygdala, on the subcortical side and the cingular cortex and hippocampus on the cortical side) that, he claimed, are tightly connected to each other but relatively isolated from the rest of the brain, in particular the neocortex, and hence form a neurophysiological module. In addition, MacLean proposed that the limbic system is a phylogenetically old part of the brain, whereas the neocortex is of comparatively recent origin.

The limbic system theory of emotion became highly influential; in fact, it dominated neurophysiological theorizing on emotions until the 1990s. Since then, however, the theory has been strongly criticized (e.g., Kotter & Meyer, 1992; LeDoux, 1998; 2012). The basic criticism is that, contrary to MacLean's claims, the structures subsumed under the name "limbic system" are neither neuroanatomically nor phylogenetically clearly distinct from the rest of the brain and hence do not really form a separate processing system. Furthermore, although some limbic system structures (e.g., the amygdala) certainly do play a role in emotions, others (e.g., the hippocampus) seem to have primarily cognitive functions (Dalgleish, 2004; LeDoux, 1998).

The demise of the limbic system theory has led some authors to conclude that some version of a multimodular, discrete basic emotions theory might after all be correct (e.g., LeDoux, 1998). But, of course, it is also possible that all emotions are produced by a single neural system that simply was not correctly described by limbic system theory (see also Arnold, 1960).

In Search of the Emotion Modules in the Brain

Since the 1980s, fostered by the development of new and improved methods of investigating brain structure and brain activity (such as neuroimaging methods like functional magnetic resonance imaging [fMRI] and positron emission tomography [PET]), neurophysiological emotion research has been growing at an exponential rate. Much of this research has been inspired, indirectly or indirectly, by the discrete basic emotions theory proposed by Ekman and others and has sought to provide evidence for or against the emotion modules assumed by this theory. An important boost to the search for emotion modules in the brain was provided by LeDoux (e.g., 1998). Based on research with animals, LeDoux argued that the amygdala—one of the subcortical structures of MacLean's limbic system—is in fact the "hub in the wheel of fear" (LeDoux, 1998, p. 168), that is, the central structure of a neurophysiological fear module of the kind proposed by the basic emotion theorists. LeDoux's neurophysiological model of fear has been supported by studies that suggest that the amygdala is necessary for the acquisition and display of most (but not all) conditioned fear reactions in animals. Parallel findings have been reported for the conditioning of physiological fear reactions in humans (LeDoux, 1998; 2012).

However, more recent brain imaging research has found that the amygdala is not only activated by fear-related stimuli, but can also be activated by unpleasant pictures and odors and the induction of a sad mood (see Murphy, Nimmo-Smith, & Lawrence, 2003). Even some positive stimuli have been found to activate the amygdala (see Murphy et al., 2003). In addition, the amygdala has been found to respond to novel, unexpected stimuli, to which it rapidly habituates when they have no relevant consequences (Armony, 2013). Furthermore, there is so far no firm evidence that the amygdala is necessary for the *experience* of fear or other emotions. On the contrary, a study by Anderson and Phelps (2002) of people with lesions of the amygdala found no evidence for reduced emotional experience. Taken together, these findings suggest that the function of amygdala activation is not primarily the generation of fear, nor of negative emotions, nor of emotions in general. Rather, as suggested by a number of authors, the function of amygdala activation may be to support the focusing of attention on stimuli that are potentially motivationally relevant.

The fear theory of the amygdala is representative for several other recent claims of having detected modules for discrete basic emotions in the brain. For example, it has been claimed that the disgust module is localized in the insula, the sadness module in the subgenual anterior cingulate cortex, and the anger module in the orbitofrontal cortex (see Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012). As in the case of LeDoux's fear theory, subsequent research has found these claims to be premature. A recent comprehensive meta-analysis of brain imaging studies of emotion concludes that there is little evidence that discrete basic emotions can be localized to distinct brain regions (Lindquist et al., 2012). These data reinforce the doubts about discrete basic emotions theory raised by research on the expression of emotions reported earlier. For further discussion of the conclusions that might be drawn from the neurophysiological data, readers are referred to Lindquist et al. (2012) and LeDoux (2012).

Emotion Psychology and Affective Computing

Many of the theories and findings of emotion psychology discussed in this chapter have been taken up by affective computing researchers. In particular, psychological emotion theories have been the main source of inspiration for the development of computational emotion models, that are implemented in artificial agents to make them more socially intelligent and believable (see Lisetti, Amini, & Hudlicka, 2014). As blueprints for modeling the *emotion elicitation process*, psychological appraisal theories have so far been used nearly exclusively (see Gratch & Marsella, 2014), most often the theory of Ortony et al. (1988) (e.g., Becker & Wachsmuth, 2008). However, other appraisal theories have also been computationally implemented: Gratch and Marsella (2004) used Lazarus's (1991) appraisal theory as the psychological basis of their computational emotion model; and Marinier, Laird, and Lewis (2009) used the appraisal theory proposed by Scherer (2001). In these models, the computed appraisal of a situation are either treated as causes of the emotion, which is for example conceptualized as a mixture of pleasure-displeasure and activation-deactivation (e.g., Becker-Asano & Wachsmuth 2008); or the appraisal pattern is implicitly identified with the emotion (e. g., Gratch and Marsella 2004).

Psychological emotion theories and empirical findings about emotions have also been a decisive source of information for modelling of the *effects of emotions* in artificial agents (see also, Lisetti et al., 2014). Most existing emotional software- and hardware agents model the effect of emotions on expressive behavior such as facial expressions (see Section 3 of this handbook). Here, Ekman's (1992) theory of basic emotions has had a particularly strong influence. However, the effects of emotions on actions proposed in some psychological emotion theories have been modeled as well. For example, Gratch and Marsella (2004)'s EMA model implements a hedonic regulation mechanism: Negative emotions initiate coping actions aimed at changing the environment in such a way that the negative emotions are reduced or mitigated. In addition, the effects of emotions on subsequent cognitions (appraisals) are modeled in EMA and some other emotional agents: They influence both the content of information processing and the way, or strategies of information processing (e g. the depth of future projection in the planning of actions), as well as on the cognitive content (e.g, wishful thinking and resignation).

Although the transfer of concepts has so far mainly been from emotion psychology to affective computing, a reverse influence is becoming increasingly apparent. Indeed, affective computing has much to offer to emotion psychology, both to theory and research methods. Regarding theory, computational emotion models constructed by affective computing researchers can help to clarify and concretize psychological emotion models. Regarding research methods, social simulations populated by artificial agents have the potential of becoming an important method for inducing emotions and studying their effects in social interactions; and automatic methods of affect detection from expression, speech and action (see Section 2 of this Handbook) are likely to become important tools of measuring emotions

Notes

1. In contemporary psychology, the term "cognitive emotion theory" is typically used to denote any emotion theory that assumes that cognitions—paradigmatically, beliefs, in particular evaluative beliefs—are necessary conditions for emotions, even if they are only regarded as causally rather than constitutionally necessary for emotions. In contrast, in contemporary philosophy, the term "cognitive emotion theory" is typically used in a narrower sense to denote emotion theories that claim that emotions *are* cognitions (of a certain kind; typically evaluative beliefs) or *contain* such cognitions as components, thus implying not only that emotions are intentional (object-directed, or representational) mental states, but also, that they are more specifically cognitive (information-providing) mental states (see Reisenzein & Döring, 2009).
2. However, Arnold (1960) subsequently argued that appraisals are a *special kind* of value judgments; in particular, she claimed that they are similar to sense-judgments in being "direct, immediate, nonreflexive, nonintellectual, instinctive, and intuitive"(p. 175). See also Kappas (2006).
3. An alternative version of cognitive emotion theory, the belief-desire theory of emotion, holds that emotions are directly caused by factual beliefs and desires, without intervening appraisals (evaluative beliefs). For example, according to this theory, Mary's joy about Smith's election as president is directly caused by the belief that Smith was elected and the desire that he should be elected. Arguments for the belief-desire theory are summarized in Reisenzein (2009*a*, 2009*b*; see also Castelfranchi & Miceli, 2009; Green, 1992). In this chapter, I follow the mainstream of cognitive emotion theory in psychology, i.e., appraisal theory. Those who find the belief-desire account more plausible should note that it is possible to reformulate (although with a corresponding change of meaning) most of appraisal theory in the belief-desire framework (see, e.g., Adam, Herzig, & Longin, 2009; Reisenzein, Hudlicka et al., 2013; Steunebrink, Dastani, & Meyer, 2012).
4. Note that "appraisal" is here used in a broad sense that includes all emotion-relevant factual and evaluative cognitions. In a narrow meaning, "appraisal" refers to evaluations only.
5. Psychological decision theories (e.g., Ajzen. 1991; Kahneman & Tversky, 1979) can be regarded as quantitatively refined versions of this qualitative belief-desire theory of action (see Reisenzein, 1996).
6. Another version of mental feeling theory postulates several distinct, unanalyzable mental feelings corresponding to presumed biologically basic emotions, such as joy, sadness, fear, anger, and disgust (e.g., Oatley & Johnson-Laird, 1987; see also Buck, 1985). On a broad understanding of "mental feelings," one can also subsume in the category of mental feeling theories the proposal that emotions are felt action tendencies (e.g., Arnold, 1960; Frijda, 1986). However, both of these versions of mental feeling theory have to cope with a number of problems (Reisenzein, 1995; 1996).
7. Impressed by the apparent ability of cognitions (appraisals) to explain the differentiation and object-directedness of emotions, several emotion theorists—mostly in philosophy—have proposed that emotional experiences are simply conscious evaluations (e.g., Nussbaum, 2001; Solomon, 1976). However, this "radically cognitive" theory of the nature of emotions has its own serious problems. In particular, it fails to provide a plausible explanation of the phenomenal quality of emotional experiences (see Reisenzein, 2012).

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CHAPTER

4

Neuroscientific Perspectives of Emotion

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Abstract

Emotion is often defined as a multicomponent response to a significant stimulus characterized by brain and body arousal and a subjective feeling state, eliciting a tendency toward motivated action. This chapter reviews the neuroscience of emotion, and the basis for the 'Great Emotion Debate' between the psychological constructionists and the basic emotion theorists. The authors adopt an embodied cognition perspective, highlighting the importance of the whole body—not just the brain—to better understand the biological basis of emotion and drawing on influential theories, including Polyvagal Theory and the Somatic Marker Hypothesis, which emphasize the importance of bidirectional communication between viscera and brain, and the impact of visceral responses on subjective feeling state and decision making, respectively. Embodied cognition has important implications for understanding emotion as well as the benefits of exercise, yoga, and meditation. The authors emphasise the need for research that draws on affective computing principles and focuses on objective measures of body and brain to further elucidate the specificity of different emotional states.

Key Words: basic emotions, natural kinds, psychological constructionism, emotion specificity, embodied cognition, psychophysiology, neuroimaging

Introduction

Bidirectional projections underpin emotional experience, such that the brain impacts on the body via visceral efferent pathways and the body impacts on the brain through afferent feedback. Take, for example, the case of laughter yoga, an activity that involves groups of people getting together to... laugh! Initially, the experience is awkward and forced, but very soon—with the help of yogic breathing techniques and physical movement—the forced laughter becomes spontaneous and contagious. Laughter is not unique to our species: Jaak Panksepp's work on rodent tickling indicates that 50-kHz chirping (laughter?) may be an evolutionary antecedent of human joy (Panksepp, 2005; Panksepp & Burgdorf, 2000; 2003). This research, along with that of others (Wild, Rodden, Grodd, & Ruch, 2003), suggests that laughter may depend on two partially independent neuronal pathways: an "involuntary," emotionally driven subcortical system and a cortical network that supports the human capacity for verbal joking. Laughter is an excellent example of the impact of the body on emotion experience, highlighting that laughter is possible without humor or cognitive thought. Although autonomic activation normally colors our subjective experience, in some cases, it is able to actually drive the emotions we experience.

Psychological research indicates that voluntary contraction of facial muscles contributes to emotional experience (Strack, Martin, & Stepper, 1988). Participants who hold a pencil with their lips, forcing their face to prevent or inhibit a smile, rate cartoons as less amusing than participants who hold a pencil in their teeth, mimicking a smile. Similarly, participants trained to produce typical emotional expressions muscle by muscle report subjective emotional experience and display specific physiological changes (Levenson, Ekman, & Friesen, 1990). More recent studies on botulinum toxin (or "botox") have shown that injection to the glabellar region—the space between the eyebrows and above the nose—to inhibit the activity of the corrugator and procerus muscles reduces the experience of fear and sadness in healthy females (Lewis & Bowler, 2009). Another study (Wollmer et al., 2012) on patients with major depressive disorder has even reported that glabellar botulinum toxin treatment is associated with a 47% reduction in depression severity over a 6-week treatment period (relative to only 9.2% in placebo-treated participants). These surprising findings are supported by current influential neuroscientific theories of emotion (Damasio, 1994; Porges, 1995; 2011; Reimann & Bechara, 2010; Thayer & Lane, 2000; 2009) that explicitly incorporate brain–body interactions into formal models.

Here, we emphasize the importance of an "embodied cognition" perspective in order to better understand the biological basis for emotion. Emotion is often defined as a multicomponent response to a significant stimulus characterized by brain and bodily arousal and a subjective feeling state that elicits a tendency toward motivated action. Note however, that there may be instances of emotion in which significant stimulus (cf., emotions without obvious causes), subjective feeling state (cf., unconscious emotions), and motivated action (cf., sadness) are not necessary. In this review, we first describe the role of several key brain regions in regards to emotion processing. These include the prefrontal cortex (PFC; involved in emotional experience and its regulation), amygdala (stimulus salience and motivational significance), anterior cingulate (selection of stimuli for further processing), and insula (feelings and consciousness). We then describe a major intellectual stalemate that has arisen with respect to understanding how different emotions arise. This is the debate over whether the basic emotions are "natural kinds" versus a product of "psychological construction." We suggest that one of the reasons for the difficulty in resolving this debate is the tendency to draw conclusions from different theoretical standpoints and experimental approaches. For example, recent efforts to understand human emotion may be characterized by a neurocentric approach arising from the wide use of functional magnetic resonance imaging (fMRI). This technique, however, has its limitations in regards to advancing our knowledge of emotion. Critically, it is often not clear whether emotional experiences are being evoked by the weak emotional stimuli that are often used in the scanner. Furthermore, fMRI studies require participants to remain in a supine body position during emotion elicitation, yet research has revealed that such a position reduces emotional responses (e.g., asymmetric frontal cortical activity as well as amygdala activity measured with other techniques) to appetitive emotional stimuli (Harmon-Jones, Gable, & Price, 2011; Price, Dieckman, & Harmon-Jones, 2012). (Readers interested in further details on neuroscientific approaches to affect detection are referred to Chapter 17).

There are many challenges to determining emotional specificity and correctly detecting the specificity of emotions. Interested readers are referred to excellent reviews by Calvo & D'Mello, 2010, and Fairclough, 2009. We conclude this review by highlighting the need for research that produce stronger manipulations of affective experiences, draws on affective computing principles, and employs multiple physiological and behavioral response systems under different conditions. We suggest that a multimodal approach to affective neuroscience may help to resolve the debate over whether the brain and body produce emotions as "natural kinds" or as "psychological constructions."

The Emotional Brain

Specific brain regions including the PFC, amygdala, anterior cingulate, and insula play a major role in the neurobiological basis of emotion. These regions and their interconnectivity are briefly described here.

The Prefrontal Cortex

The PFC is the most anterior part of the frontal lobes and is generally considered to play a primary role in higher order cognitive activity, judgment, and planning. However, contemporary neuroscientific views of emotion highlight a role of the PFC in emotional experience, motivation, and its regulation. The PFC is comprised of a number of discrete regions, including the orbitofrontal, dorsomedial, ventromedial, dorsolateral, and ventrolateral cortices, all of which may play specific roles in the generation of emotional processes. The orbitofrontal cortex integrates exteroceptive and interoceptive sensory information to guide behavior and plays a role in core affect, a psychological primitive that relates to the mental representation of bodily changes experienced as pleasure or displeasure with some degree of arousal (Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012). The dorsomedial and ventromedial prefrontal cortices play a role in realizing instances of emotion perception and experience by drawing on stored representations of prior experiences to make meaning of core affect. The dorsolateral PFC is involved in top-down, goal-directed selection of responses and plays a key role in executive function critical for directing other psychological operations involved in the generation of emotion. The ventrolateral PFC is implicated in selecting among competing response representations, response inhibition, and directing attention to salient stimuli in the environment (Lindquist et al., 2012).

Experimental research conducted in the 1950s and 1960s involving suppression of prefrontal cortical activity by injecting Amytal—a barbiturate derivative—into an internal carotid artery demonstrated a role of hemispheric asymmetry in emotion (Alema, Rosadini, & Rossi, 1961; Perria, Rosadini, & Rossi, 1961; Rossi & Rosadini, 1967; Terzian & Cecotto, 1959). Amytal injections in the left side—releasing the right hemisphere from contralateral inhibitory influences of the left—produced depression, whereas injections in the right side—releasing the left hemisphere—produced euphoria (see Harmon-Jones, Gable, & Peterson, 2010, for review). Research using the electroencephalogram (EEG) is consistent with these findings, demonstrating a role for the left PFC in positive affect and well-being and implicating right PFC in emotional vulnerability and affective disturbance, suggesting that activity in the left hemisphere region may provide a neurobiological marker of resilience (Begley & Davidson, 2012). Findings from normative and clinically depressed and anxious samples indicate that relative left-sided activation is decreased or that right-sided activation is increased in affective disturbance (Kemp, Griffiths et al., 2010*a*; Mathersul, Williams, Hopkinson, & Kemp, 2008; see also Kemp & Felmingham, 2008). Transcranial magnetic stimulation (TMS)—a technique applied to the scalp to either depolarize or hyperpolarize local neurons of the brain up to a depth of 2 cm—is an alternative nonpharmacological treatment for depression (Slotema, Blom, Hoek, & Sommer, 2010). Low-frequency (inhibitory) right-sided repetitive TMS (rTMS) or high-frequency (excitatory) left-sided rTMS is applied to the dorsolateral PFC of depressed patients to shift hemispheric asymmetry and ameliorate depressive symptoms. Other work (Harmon-Jones et al., 2010), however, demonstrates a role for left PFC in the emotion of anger—a basic emotion characterized by negative valence and approach-related motivation—highlighting a role for PFC in approach and withdrawal motivation, rather than positive and negative valence per se. Consistent with these electrophysiological findings, a meta-analysis of neuroimaging studies reported that the left ventrolateral PFC displays increased activity when participants perceive or experience instances of anger (Lindquist et al., 2012).

The Amygdala

The amygdala is an almond-shaped cluster of nuclei located in the anterior medial temporal lobe. Animal research has highlighted a central role for the amygdala in negative emotions such as fear and anxiety (Ledoux, 1998), and neuroimaging studies have confirmed its role in these emotions in humans (Murphy, Nimmo-Smith, & Lawrence, 2003; Phan, 2002). Amygdala activation is also observed in response to a variety of emotional states and stimuli including fear, disgust, sadness, anger, happiness, humor, sexually explicit images, and social emotions (Costafreda, Brammer, David, & Fu, 2008; Sergerie, Chochol, & Armony, 2008). A recent meta-analysis (Lindquist et al., 2012) concluded that the amygdala is part of a distributed network involved in core affect rather than fear per se and that it responds preferentially to salient exteroceptive sensations that are motivationally significant. Findings from several published meta-analyses of neuroimaging studies focusing on amygdala function in humans (Costafreda et al., 2008; Lindquist et al., 2012; Murphy et al., 2003; Phan, 2002; Sergerie et al., 2008; Vytal & Hamann, 2010) highlight a general role for the amygdala in processing stimulus salience, motivational significance, and arousal.

Although researchers (Costafreda et al., 2008) have emphasized that amygdala activation is more likely to respond to fear and disgust emotions, this may be due to the often weak evocative stimuli using in neuroimaging studies. Notably, a number of studies have examined amygdala activation during the experience of positive emotion, such as sexual arousal, and have produced findings highlighting an important distinction between motivated versus consummatory behavior. One study involving presentation of sexually explicit stimuli (Hamann, Herman, Nolan, & Wallen, 2004) reported strong activation in amygdala (and hypothalamus) and that this difference was greater in males than in females. The authors interpreted these gender differences in light of greater motivation in men to seek out and interact with such stimuli. An earlier positron emission tomography (PET) study (Holstege et al., 2003) on the brain activation during human male ejaculation reported decreases in amygdala activation. Together, these findings indicate that increased activity is associated with viewing appetitive sexual stimuli associated with approach-related motivation, whereas consummatory sexual behavior (or quiescence) is associated with decreased activity, reflecting conservation of amygdala function (Hamann et al., 2004).

Anterior Cingulate

The anterior cingulate cortex (ACC) forms a collar around the corpus callosum and is a key substrate for conscious emotion experience. The most ventral portion of this structure—known as the subgenual cingulate (sACC; Broadmann's area or BA 25)—is a localized target in deep brain stimulation studies of patients with "treatment resistant" depression. Acute stimulation of this region (up to 9 V at each of the eight electrode contacts; four per hemisphere) is associated with a variety of psychological experiences including "sudden calmness or lightness," "disappearance of the void," "sense of heightened awareness," "increased interest," and "connectedness." Although the rostral ventral region of ACC—including sACC and pregenual ACC (pACC; BAs 24,32)—was initially singled out as the ACC subregion involved in emotional processing (Bush, Luu, & Posner, 2000), a more recent review of the literature (Etkin, Egner, & Kalisch, 2011) focusing on fear conditioning and extinction in particular has characterized the caudal dorsal region as playing an important role in the appraisal and expression of emotion and the ventral rostral region in the regulation of regions such as the amygdala. It was noted (Etkin et al., 2011) that activity within dorsal ACC (and medial PFC [mPFC]) are observed during classical (Pavlovian) fear conditioning and instructed fear-based tasks and that this activity is positively correlated with sympathetic nervous system activity but negatively with ventral ACC (and mPFC regions). By contrast, recall of extinction 24 hours after conditioning—a process that is less confounded by residual expression of fear responses—yields activity in ventral ACC (and mPFC), thus providing support for the proposal that these regions are a neural correlate of fear inhibition that occurs during extinction (Etkin et al., 2011). Extending on this, a recent meta-analysis of functional neuroimaging studies (Lindquist et al., 2012) characterizes the sACC and pACC (Bas 24,32) (as well as adjacent posterior medial orbitofrontal cortex) as key sites for visceral regulation that helps to resolve which sensory input is selected for processing. By contrast, the more dorsal anterior midcingulate cortex is implicated in executive attention and motor engagement during response selection through connections to lateral PFC and the supplementary motor area.

Insula

The insula is located at the base of the lateral (Sylvian) fissure and plays a role in the experiential and expressive aspects of internally generated emotion. Early work highlighted a role for the insula cortex in gustatory function. Studies conducted in the 1950s demonstrated that electrically stimulating this region in conscious human patients produced nausea, the experience of smelling or tasting something bad, and unpleasant tastes or sensations (Penfield & Faulk, 1955). Consistent with these findings, one of the first meta-analyses of human neuroimaging studies (Murphy et al., 2003) reported that the insula was the most consistently activated brain region (along with the globus pallidus) for the emotion of disgust. This study reported insula activity in more than 70% of neuroimaging studies on disgust, whereas activity in this region was only observed in 40% of the studies on other discrete emotions. A more recent meta-analysis (Lindquist et al., 2012) indicated that the left anterior insula displays consistent increases in activation during instances of both disgust and anger, whereas the right anterior insula displays more consistent increases in activation during disgust, although activity in this region was not specific to this emotion.

The view of the insula's role in emotion has now expanded to a more general role for the awareness of bodily sensations, affective feeling, and consciousness (see Craig, 2009, for review). Work by Bud Craig and colleagues (Craig, 2002; 2003) indicates that ascending pathways originating from lamina I neurons in the spinal cord carry information about the physiological status of the body to the thalamus via the lateral spinothalamic tract. Thalamic nuclei then project to the mid/posterior dorsal insula, which then projects to the anterior insula. These pathways provide a neurophysiological basis for interoception (the physiological condition of the body) (Craig, 2002). The homeostatic afferent input received from the body is first represented in the dorsal insula—the primary sensory cortex of interoception—and this information is then re-represented in the anterior insula, providing a substrate for conscious awareness of the changes in internal physiological states and emotional feelings (Craig, 2002; 2003; 2009). The emotion of disgust involves a mental representation of how an object will affect the body (Lindquist et al., 2012), thus providing a potential explanation for neuroimaging findings that highlight a role for insula in this emotion.

The Great Emotion Debate

The fierce, ongoing debate over whether the emotions are discrete, innate human mental states has been likened to the Hundred Years' War between England and France (Lindquist, Siegel, Quigley, & Barrett, 2013). On the one hand, emotions may be considered as fundamental processes in the brain that exist across species (and human cultures); a phenomenon that is discovered, not created, by the human mind. In this regard, the basic emotions are characterized as "natural kinds," hardwired into the brain and associated with distinctive patterns of neural activation (Panksepp & Watt, 2011; Vytal & Hamann, 2010). On the other hand, those who favor a psychological constructionist approach (Barrett, 2006; 2012; Lindquist et al., 2012) argue that emotions are themselves constructed from activation relating to more basic building blocks, such as core dimensions like valence (positive vs. negative affect) and arousal (deactivation to activation). Ledoux (2012) recently observed that although neuroscientific research on emotion has increased exponentially over the past decade, "emotion" remains ill-defined and that this situation has led to an intellectual stalemate. One of the problems here is that the terms "emotion" and "feeling" are used interchangeably, and this has led to the use of common language "feeling" words such as fear, anger, love, and sadness to guide the scientific study of emotion, rather than focusing on specific phenomena of interest (such as the detection of and response to significant events) (LeDoux, 2012). Another explanation for different competing theories is that researchers have often tackled the same question from different theoretical standpoints and experimental approaches. In this regard, Panksepp (2011) distinguishes between behavioral neuroscientists who study "instinctual" primary processes that provide the foundation for understanding the biological basis of emotion versus cognitive psychologists who study the higher levels of emotion along with their associated "regulatory nuances."

Research on facial expressions—particularly the universally recognizable expressions of emotion—has been central to the ongoing debate about the nature of emotion. In the 1960s, Paul Ekman traveled to Papua New Guinea and conducted experiments on the isolated Fore tribesman who, at that time, had had little or no contact with the outside world. The ability of these tribesmen to reliably recognize certain facial expressions led to the proposal that there are certain "basic" emotions. These included fear, anger, disgust, surprise, happiness, and sadness; all of which are universally recognized, innate, and not reliant on social construction (Ekman, Sorenson, & Friesen, 1969). This work highlights that negative emotions are easily revealed in facial expressions of emotion. Research on vocalizations, however (Sauter & Scott, 2007), has revealed five putative positive emotions, including achievement/triumph, amusement, contentment, sensual pleasure, and relief. More recently, Ekman has expanded the basic emotions to include amusement, contempt, contentment, embarrassment, excitement, guilt, pride, relief, satisfaction, sensory pleasure, and shame (Ekman, 2012), emotions not associated with specific facial expressions. Ekman's work has led to extensive neuroscientific research on the neurobiology of emotion perception, and this research is being conducted more than 40 years after his findings were first reported.

In contrast to the work by Paul Ekman on human facial expressions, Jaak Panksepp has explored emotions through electrical stimulation of discrete subcortical brain structures in the rat. This approach has important methodological advantages over human neuroimaging in that localized electrical stimulation of the brain provides causal evidence for the role of certain subcortical regions in affective experience. Panksepp has employed a different experimental approach to that of Ekman, and his work has led to the identification of a different set of "basic" emotions (Panksepp, 2011) including seeking, rage, fear, lust, care, panic/grief, and play, which he labels as emotional instinctual behaviors. Panksepp employs special nomenclature—full captializations of common emotional words (e.g., RAGE, FEAR, etc.)—to distinguish these primary-process emotions as identified using electrical stimulation of discrete subcortical neural loci from their vernacular use in language. Although (some of) these behaviors are not typically thought of as emotions (i.e.SEEKING, CARE, and PLAY), Panksepp argues that these basic emotions provide "tools for living" that make up the "building blocks" for the higher emotions (Panksepp & Watt, 2011). Interestingly, and in contrast to Ekman, he specifically argues that disgust is not a basic emotion; rather, he categorizes disgust, like hunger, as a sensory and homeostatic affect. Panksepp argues that the higher emotional feelings experienced by humans are based on primitive emotional feelings emerging from the "ancient reaches of the mammalian brain, influencing the higher cognitive apparatus" (Panksepp, 2007). On the basis of findings obtained during electrical stimulation, Panksepp (2007) highlights the mesencephalon (or midbrain of the brainstem)—especially the periaqueductal gray—extending through the diencephalon (including the thalamus and hypothalamus) to the orbitofrontal cortex and then to the medial (anterior cingulate, medial frontal cortices) and lateral forebrain areas (including the temporal lobes and insula) as critical regions.

Although different experimental approaches have led to different conclusions over what the specific basic emotions may be, researchers have also drawn entirely different conclusions using the same technique in humans (Lindquist et al., 2012; Vytal & Hamann, 2010). An early meta-analysis of 106 neuroimaging studies using PET or fMRI found evidence for distinctive patterns of activity relating to the basic emotions (Murphy et al., 2003). Fear was associated with activation in the amygdala, disgust with activation in the insula and globus pallidus, and anger with activation in the lateral orbitofrontal cortex. Importantly, these regions are also associated with respective processing deficits when damaged. Extending on these findings, a more recent meta-analysis including 30 new studies also obtained results consistent with basic emotion theory (Vytal & Hamann, 2010). The authors reported that fear, happiness, sadness, anger, and disgust all elicited consistent, characteristic, and discriminable patterns of regional brain activity (Vytal & Hamann, 2010), albeit with somewhat different conclusions to the earlier meta-analysis by Murphy and colleagues. Fear was associated with greater activation in the amygdala and insula, happiness with activation in rostral ACC and right superior temporal gyrus, sadness in middle frontal gyrus and subgenual ACC, anger in inferior frontal gyrus (IFG) and parahippocampal gyrus, and disgust in IFG and anterior insula. It is worth noting here that facial emotion stimuli are the most frequently used stimuli in studies of human emotion and that it is important to distinguish between emotion perception (as is assessed most often in studies using facial emotion) and emotion experience. However, the authors of this meta-analytic study (Vytal & Hamann, 2010) noted that—although preliminary—their results provided evidence to suggest that findings are not unique to studies of facial emotion stimuli.

In direct contrast to these prior studies (Murphy et al., 2003; Vytal & Hamann, 2010), another meta-analysis (Lindquist et al., 2012) on 234 PET or fMRI studies reported that discrete emotion categories are neither consistently nor specifically localized to distinct brain areas. Instead, these authors concluded that their findings provide support for a psychological constructionist model of emotion in which emotions emerge from a more basic set of psychological operations that are not specific to emotion. This model has a number of features; these include core affect underpinned by processing in a host of regions including the amygdala, insula, medial orbitofrontal cortex (mOFC), lateral orbitofrontal cortex (lOFC), ACC, thalamus, hypothalamus, bed nucleus of the stria terminalis, basal forebrain, and the periaqueductal gray. The authors clearly distinguish core affect from the more general term, *affect*, which is often used to mean anything emotional. Although the authors highlight the dimensional constructs of valence and arousal, other dimensional constructs—such as approach and withdrawal (Davidson & Irwin, 1999)—have been proposed. Approach and withdrawal motivations are considered to be fundamental motivational states on which emotional reactions are based and may actually provide a superior explanation for the way some brain regions process emotional stimuli (Barrett & Wager, 2006; Harmon-Jones, 2003).

Systematic reviews using meta-analytic statistical procedures generally provide a more objective review of the literature, allow for generalizations to be made on a body of literature, and avoid low study power. One of the problems associated with individual neuroimaging studies on emotion in humans is the multiple comparisons problem, making it more likely to identify an effect when there is none (otherwise known as a type 1 error). A case in point is a recent fMRI study using a "social perspective-taking task" in a postmortem Atlantic salmon (Bennett & Miller, 2010; Bennett, Baird, Miller, & Wolford, 2011). When statistical analysis did not correct for multiple comparisons, this study observed evidence of activity in the tiny dead salmon's brain. Although farcical, this study has a serious message: that inadequate control for type 1 error risks drawing conclusions on the basis of random noise, in part highlighting an important role for meta-analysis (Radua & Mataix-Cols, 2012). However, the observation that different meta-analyses have led to contradictory findings and entirely opposite conclusions on a body of literature could leave one feeling rather perplexed. Surely, meta-analyses should aid in resolving the many reported inconsistencies rather than making them more explicit and further contributing to contradictory findings!

There are actually a number of explanations to this conundrum and a number of considerations to bear in mind when reviewing the neuroimaging literature. Hamann (2012) suggests that rather than presenting these different proposals as competing theories, an alternative hybrid view could combine the key advantages of both. A major limitation of the work by Lindquist and colleagues (2012) is the focus on single brain regions rather than on networks of two or more regions. Hamann (2012) argues that once the neural correlates of basic emotions are identified—which could relate to brain connectivity rather than discrete brain regions—these correlates could then be encompassed within the psychological constructionist framework as part of core affect. Indeed, recent preliminary work (Tettamanti et al., 2012) has reported that whereas functional integration of visual cortex and amygdala underpins the processing of all emotions (elicited using video clips), distinct pathways of neural coupling were identified (in females) for the emotions of fear, disgust, and happiness. The authors noted that these emotions were associated with cortical networks involved in the processing of sensorimotor (for fear), somatosensory (for disgust), and cognitive aspects (happiness) of basic emotions. We now review various influential neuroscientific models relating to the neural circuitry of emotion.

The "Emotional" Circuitry

Regional brain interconnectivity, rather than the activity in specific regions per se, is critical to further understanding the brain basis of emotion. An early model of brain connectivity relating to emotion experience and the cortical control of emotion was proposed by Papez in 1937 a specific circuit of neural structures lying on the medial wall of the brain. These structures included the hypothalamus, anterior thalamus, cingulate, and hippocampus. Two emotional pathways were proposed, including the "stream of thinking" (involving the cingulate cortex) and the "stream of feeling" (hypothalamus). Extending on earlier work by Papez and others, LeDoux (1998) highlighted an important role of the amygdala, proposing two pathways associated with the processing of emotional stimuli, the "low road" (thalamo-amygdala) and "high road" (thalamo-cortico-amygdala). The "low road" or direct pathway reflects a preconscious emotional processing route that is fast acting and allows for rapid responsiveness and survival. This pathway transmits sensory messages from the thalamus to the lateral nucleus of the amygdala, which then elicits the fear response. Information from other areas, including the hippocampus, hypothalamus, and cortex, is integrated in the basal and accessory basal nuclei of the amygdala. The signal is then transmitted to the central nucleus of the amygdala (amygdaloid output nuclei), which projects to anatomical targets that elicit a variety of responses characteristic of the fear response (e.g., tachycardia, increased sweating, panting, startle response, facial expressions of fear, and corticosteroid release). By contrast, the "high road" or indirect pathway facilitates conscious and cognitive "emotional processing" that is slow acting and allows for situational assessment. Overprocessing of stimuli by the subcortical emotional processing pathway and ineffective cortical regulation has provided useful insights to understanding affective disturbance displayed by various psychiatric disorders, including posttraumatic stress and panic disorders. Although this theory has been tremendously influential, it has also been criticized for ignoring the "royal road" (Panksepp & Watt, 2011)—involving the central amygdala, ventrolateral hypothalamus and periaqueductal gray (located around the cerebral aqueduct within the tegmentum of the midbrain)—which governs instinctual actions such as freezing and flight that help animals avoid danger.

This low- versus high-road distinction has also been called into question (Pessoa & Adolphs, 2010) with respect to the processing of affective visual stimuli in humans. The work by LeDoux and others is based on rodent studies that identified the subcortical pathway using auditory fear conditioning paradigms. Fear conditioning is a behavioral paradigm in which the relationship between an environmental stimulus and aversive event is learned (Maren, 2001). The assumption that this same subcortical route exists for visual information processing in humans has been questioned (Pessoa & Adolphs, 2010) on the basis of findings indicating that visual processing of emotional stimuli in the subcortical pathway is no faster than in the cortical pathway.

For instance, visual response latencies in some frontal sites including the frontal eye fields may be as short as 40–70 ms, highlighting that subcortical visual processing is not discernably faster than cortical processing (Pessoa & Adolphs, 2010). These findings led to the proposal of a "multiple-waves" model (Pessoa & Adolphs, 2010) that highlights that the amygdala and the pulvinar nucleus of the thalamus coordinate the function of cortical networks during evaluation of biological significance in humans. According to this view, the amygdala is part of a core brain circuit that aggregates and distributes information, whereas the pulvinar—which does not exist in the brains of rodents or other small mammals—acts as an important control site for attentional mechanisms.

Brain–Body Interaction and Embodied Cognition

Here, we consider emotion as an embodied cognition, the idea that the body plays a crucial role in emotion, motivation, and cognition (see Price, Peterson, & Harmon-Jones, 2011, for review). Although regional brain connectivity is a necessary development in neuroscientific understanding of the emotions (discussed in the preceding section), current influential neuroscientific theories of emotion (Damasio, 1994; Porges, 1995; 2011; Reimann & Bechara, 2010; Thayer & Lane, 2000; 2009) incorporate brain–body interactions into formal models. These include the neurovisceral integration model (Thayer & Lane, 2000; 2009; Thayer, Hansen, Saus-Rose, & Johnsen, 2009), the polyvagal theory (Porges, 1995; 2001; 2003; 2007; 2009; 2011), the somatic marker hypothesis (Damasio, 1994; Reimann & Bechara, 2010), and the homeostatic model for awareness (Craig, 2002; 2003; 2005). These complementary models provide mechanisms for better understanding the impact of interventions such as exercise, yoga, and meditation and how they might impact on emotion and mood.

The neurovisceral integration model (Thayer & Lane, 2000; 2009; Thayer et al., 2009) describes a network of brain structures including the PFC, cingulate cortex, insula, amygdala, and brainstem regions in the control of visceral response to stimuli. This *central autonomic network* (CAN) is responsible for the inhibition of medullary cardioacceleratory circuits, for controlling psychophysiological resources during emotion, for goal-directed behavior, and for flexibility to environmental change. The primary output of the CAN is heart rate variability (HRV), mediated primarily by parasympathetic nervous system innervation—vagal inhibition—of the heart. Increased HRV—reflecting increased parasympathetic nervous system function—is associated with trait positive emotionality (Geisler, Vennewald, Kubiak, & Weber, 2010; Oveis et al., 2009). By contrast, decreased HRV—reflecting decreased parasympathetic nervous system function—is associated with depression and anxiety (Kemp, Quintana, Felmingham, Matthews, & Jelinek, 2012*a*; Kemp, Quintana, Gray, Felmingham, Brown, & Gatt, 2010*b*). Polyvagal theory (Porges, 2011) is consistent with the neurovisceral integration model, but further emphasizes vagal afferent feedback from the viscera and internal milieu to the nucleus of solitary tract (NST) and cortex, allowing for subsequent regulation of initial emotional responses. This theory also distinguishes between the myelinated and unmyelinated vagus nerves (hence "polyvagal"), such that the myelinated vagus underpins changes in HRV and approach-related behaviors including social engagement, whereas the phylogenetically older unmyelinated vagus—in combination with the sympathetic nervous system—supports the organism during dangerous or life-threatening events. According to this model, social engagement is associated with cortical inhibition of amygdala; activation of the vagus nerve—increasing vagal tone—and connected cranial nerves then allow socially engaging facial expressions to be elicited, leading to positive interactions with the environment. The NST receives vagal afferent feedback from the viscera and internal milieu, and this information is then directed to cortical structures responsible for the top-down regulation of emotion. Increased activation of the vagus nerve—indexed by increased HRV—therefore provides a psychophysiological framework compatible for social engagement facilitating positive emotion. By contrast, social withdrawal is associated with perception of threat underpinned by increased amygdala activity and vagal withdrawal—decreasing vagal tone—triggering fight-or-flight responses leading to negative social interactions with the environment. Again, information relating to the status of the viscera and internal milieu are fed back to the nucleus of solitary tract and the cortex, allowing for subsequent regulation of the emotion response. Decreased activation of the vagus nerve—indexed by decreased HRV—therefore provides the framework compatible for fight-or-fight responses facilitating negative emotion.

The vagus nerve, which has been termed the single most important nerve in the body (Tracey, 2007), not only supports the capacity for social engagement (Porges, 2011) and mental well-being (Kemp & Quintana, 2013), but also plays an important role in longer term physical health (Kemp & Quintana, 2013). The vagus nerve plays an important regulatory role over a variety of allostatic systems including inflammatory processes, glucose regulation, and hypothalamic-pituitary-adrenal (HPA) function (Thayer, Yamamoto, & Brosschot, 2010). A proper functioning vagus nerve helps to contain acute inflammation and prevent the spread of inflammation to the bloodstream. Intriguingly, increased HRV is not only associated with various indices of psychological well-being including, cheerfulness and calmness (Geisler et al., 2010), trait positive emotionality (Oveis et al., 2009), motivation for social engagement (Porges, 2011), and psychological flexibility (Kashdan & Rottenberg, 2010), but it also appears to be fundamental for resilience and long-term health (Kashdan & Rottenberg, 2010). These observations are also consistent with research findings on the association between positive psychological well-being and cardiovascular health, highlighting a key role for attributes such as mindfulness, optimism, and gratitude in reducing the risk of cardiovascular disease (Boehm & Kubzansky, 2012; DuBois et al., 2012). By contrast, chronic decreases in vagal inhibition—indexed by reductions in HRV—will lead to premature aging, cardiovascular disease, and mortality (Thayer, Yamamoto, & Brosschot, 2010). The process by which vagal activity regulates these allostatic systems relates to the "inflammatory reflex" (Pavlov & Tracey, 2012; Tracey, 2002; 2007): the afferent (sensory) vagus nerve detects cytokines and pathogen-derived products, whereas the efferent (motor) vagus nerve regulates and controls their release.

In addition to parasympathetic (vagal) afferent feedback, afferents from sympathetic and somatic nerves further contribute to interoception and the homeostatic emotions involving distinct sensations such as pain, temperature and itch in particular (Craig, 2002; 2003; 2005). The functional anatomy of the lamina I spinothalamocortical system has only recently been elucidated. This system conveys signals from small-diameter primary afferents that represent the physiological condition of the entire body (the "material me"). It first projects to the spinal cord and brainstem and then generates a direct thalamocortical representation of the state of the body involving the insula and ACC. Consistent with electrophysiological work highlighting a role for prefrontal cortical structures in approach and withdrawal motivation (Harmon-Jones, Gable, & Peterson, 2010), Craig's homeostatic model for awareness (Craig, 2002; 2005; 2009) links approach (appetitive) behaviors, parasympathetic activity, and affiliative emotions to activity in the left anterior insula and ACC and withdrawal (aversive) behaviors, sympathetic activity, and arousal to activity in the right anterior insula and ACC. Stimulation of left insula cortex produces parasympathetic effects including heart rate slowing and blood pressure suppression, whereas stimulation of right insula produces sympathetic effects including tachycardia and pressor response (increased blood pressure) (Oppenheimer, Gelb, Girvin, & Hachinski, 1992). Research, for example, indicates that although left anterior insula (and ACC) are strongly activated during parasympathetic or enrichment emotions such as romantic love and maternal attachment (Bartels & Zeki, 2004; Leibenluft, Gobbini, Harrison, & Haxby, 2004), right-sided activity is observed during aroused or sympathetic emotions elicited through experimental challenge (see Craig, 2005, for review). We note, however, that directly linking positive emotions to parasympathetic activity and negative emotions to sympathetic activity is somewhat problematic on the basis of findings from psychophysiological research. For instance, emotion images containing threat, violent death, and erotica elicit the strongest emotional arousal and the largest skin conductance responses, thus highlighting a role for sympathetic activation in both defensive and appetitive responses (Bradley, Codispoti, Cuthbert, & Lang, 2001). These findings were argued to reflect a motivational system that is engaged and ready for action.

Finally, the somatic marker hypothesis highlights a key role for the ventromedial PFC in translating the sensory properties of external stimuli into "somatic markers" that reflect their biological relevance and guide subsequent decision-making (Damasio, 1994; Reimann & Bechara, 2010). Based on a body of research inspired by Phineas Gage—a nineteenth-century railroad worker who survived an accident involving serious damage to the prefrontal cortices—patients with damage to the ventromedial PFC display major difficulties in decision making that may have negative consequences, such as poor judgment and financial loss, despite having normal intellect (Reimann & Bechara, 2010). According to this model, the ventromedial PFC indexes changes in heart rate, blood pressure, gut motility, and glandular secretion, which then contribute to decision making and affective experience (Reimann & Bechara, 2010). Visceral responses contribute to the subjective feeling state, which subsequently "marks" potential choices of future behavior as advantageous or disadvantageous.

A simplified model of emotion processing is presented in Figure 4.1, drawing on current state of the literature and major theories described earlier. The model highlights the role of hemispheric effects in emotion experience (Craig, 2005; Davidson & Irwin, 1999; Harmon-Jones, 2003), the regulatory role of the central autonomic network (Thayer & Lane, 2009; Thayer et al., 2009), and vagal nerve inhibition over sympathetic nervous system contribution to the heart (Huston & Tracey, 2010; Pavlov & Tracey, 2012; Thayer et al., 2009). An adequately functioning vagal nerve will serve to facilitate positive emotions and social engagement (Porges, 2011), whereas a poorly functioning vagal nerve will lead to negative emotion and, over the longer term, mood and anxiety disorders (Kemp et al., 2012a; Kemp, Quintana, Gray, Felmingham, Brown, & Gatt, 2010b) and poor physical health (Thayer & Brosschot, 2005; Thayer & Lane, 2007; Thayer et al., 2010). The model further highlights an important role of vagal afferent feedback, which makes an important contribution to emotion experience and subsequent social behavior (i.e., "embodied cognition"). Also highlighted are the many observable outcome measures needed to help move affective neuroscience beyond the current debate over whether the brain and body respects the "natural kind" versus the "psychological constructionist" view of emotion (see also Lindquist et al., 2013, for recent commentary on this debate).

Specificity of the Emotions

There is significant interest (and debate) over the ability to discriminate the emotions using a variety of affect detection methods. Although the basic emotions are characterized by specific facial expressions (Ekman & Friesen, 1975), a single set of facial actions can become different emotional expressions in different contexts (Barrett, 2012). For example, the same face posing the same facial actions appears to become a different facial expression when paired with the words "surprise," "fear," and "anger" (Barrett, 2012). Despite the many challenges to correctly detecting specific emotions—interested readers are referred to reviews by Calvo and D'Mello (2010) and Fairclough (2009)—we are confident that the reliability and validity of detection will be improved in research that draws on affective computing principles, focuses on multiple objective measures of emotion (see Figure 4.1), and utilizes stronger manipulations of emotion. Studies on emotion specificity have employed a variety of detection measures ranging from facial expressions

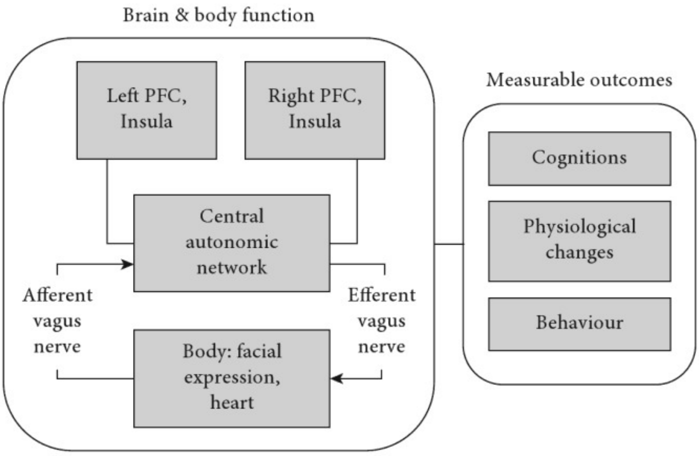

Fig. 4.1 Model of brain and body function with regards to emotion processing highlighting role of hemispheric asymmetry (Davidson, Harmon-Jones), the central autonomic network (Thayer), and inhibition of sympathetic nervous system contribution to the heart (Thayer, Porges, Kemp) via the efferent vagus nerve and afferent feedback. The role of brain and body in emotion is bidirectional, and visceral afferent feedback to the brain makes an important contribution to emotion experience and subsequent social behavior (i.e., "embodied cognition"). Also highlighted are broad categories of measures needed to distinguish between "natural kinds" and "psychological construction" (Lindquist, Barrett).

to psychophysiological measures and neuroimaging. We now provide a brief review of this literature.

Unlike the disagreement over the neural specificity of different emotions (Lindquist et al., 2012; Vytal & Hamann, 2010) discussed earlier, recent reviews of autonomic nervous system (ANS) activity (Harrison, Kreibig, & Critchley, 2013; Kreibig, 2010) highlight considerable specificity in the presentation of emotion. However, it is important to note that these specific patterns are often only revealed by inspection of data from a broad range of autonomic measures, a key point with regards to emotion detection more generally. This specificity of discrete emotions may be understood in the context of the *component model of somatovisceral response organization* (Stemmler, Heldmann, Pauls, & Scherer, 2001). According to this model, state-driven psychophysiological responses are associated with three components. The first relates to demands by processes not in the service of emotions (e.g., ongoing motor activity); the second relates to the effects of organismic, behavioral, and mental demands determined by a certain context (e.g., motivation to approach vs. withdraw); the third relates to the "emotion signature proper," characterized by emotion-specific responses. This model therefore allows for considerable overlap of activity associated with emotion responses but also emotion specificity. Emotion-specific features of fear, anger, disgust, sadness, and happiness detected using a variety of techniques are now briefly reviewed.

The emotion of fear is characterized by eyebrows raised and drawn together, wide-open eyes, tense lowered eyelids, and stretched lips (Ekman & Friesen, 1975). It is associated with activation within frontoparietal brain regions (Tettamanti et al., 2012) and a broad pattern of sympathetic activation (Harrison et al., 2013; Kreibig, 2010), allowing for the preparation of adaptive motor responses. Autonomic nervous system function reflects a general activation response and vagal withdrawal (reduced HRV), but may be distinguishable from anger (associated with harassment or personalized recall) by reduction in peripheral vascular resistance (Harrison et al., 2013; Kreibig, 2010), a measure of resistance to flow that must be overcome to push blood through the circulatory system. Fear is also associated with more numerous skin conductance responses and larger electromyographic corrugator activity than is anger (Stemmler et al., 2001), a finding that was interpreted in line with the adrenaline hypothesis of fear (Funkenstein, 1955). By contrast, the emotion of anger is characterized by lowered eyebrows drawn together, tensed lowered eyelids and pressed lips. A body of literature highlights a role for left frontal PFC in approach-related emotions including positive affect (Begley & Davidson, 2012), as well as the emotion of anger (Harmon-Jones et al., 2010). By contrast, the right PFC is implicated in withdrawal-related behaviors (such as fear), although the EEG literature in this regard has been contradictory (Wacker, Chavanon, Leue, & Stemmler, 2008). Contradictory findings highlight the need for better manipulations of affective experience. It is also important to note that anger may elicit either an anger-mirroring or a reciprocating fear response (Harrison et al., 2013), and that psychophysiological responses will be dependent on the response elicited.

The physiological differentiation between fear and anger in humans has been a topic of great interest for decades (see, e.g., Ax, 1953). Walter Cannon (1929) introduced the concept of the "fight-or-flight" response arguing for similar underlying visceral patterns in the two responses. By contrast, Magda Arnold (1950) highlighted a key role for the sympathetic branch of the ANS in fear and a role for both the sympathetic and parasympathetic branches in anger. Although an interesting proposal in light of an important role of parasympathetic activity in approach-related motivation (Kemp et al., 2012*b*; Porges, 2011)—an important characteristic of anger—research findings have generally reported no change in HRV (e.g., Rainville, Bechara, Naqvi, & Damasio, 2006), a psychophysiological variable primarily driven by the parasympathetic nervous system. Critically, research has highlighted the importance of context and individual differences in order to understand emotion-specific responses and their discriminability (e.g., Stemmler et al., 2001). For instance, whereas fear is generally associated with an active coping response reflected in sympathetic activation, such as increases in heart rate, imminence of threat may shift responses toward more of an immobilization response and sympathetic inhibition (heart rate decreases). These differential responses to fear-inducing stimuli may be understood in the context of polyvagal theory (Porges, 2011), which distinguishes between immobilization and mobilization responses. Although immobilization is the most phylogenetically primitive behavioral response to threat involving the unmyelinated vagus nerve (associated with fear-related bradycardia), mobilization involves the sympathetic nervous system, which prepares the organism for flight or fight.