DYNAMIC FACES

INSIGHTS FROM EXPERIMENTS AND COMPUTATION

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Insights from Experiments and Computation

edited by Cristóbal Curio, Heinrich H. Bülthoff, and Martin A. Giese

Foreword by Tomaso Poggio

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Foreword

An area of research that has been greatly promoted for a long time is the interface between artificial and biological vision. However, it is only in the past few years that this area is finally looking promising. Even more interesting, it is neuroscience that seems to be providing new ideas and approaches to computer vision—perhaps in a first sign that the explosion of research and discoveries about the brain may actually lead the development of several areas of computer science and in particular artificial intelligence. Thus the science of intelligence will eventually play a key role in the engineering of intelligence. Vision—which is the general topic of this book—may well be at the forefront of this new development.

The specific topic of this collection of papers is faces, particularly when the time dimension is considered. Even just two decades ago it would have been surprising to state that faces are possibly the key to understanding visual recognition and that recognition of faces should be a key problem in vision research. In the meantime, the number of papers on face perception and recognition that have appeared in the neuroscience of vision as well as in computer vision is enormous and growing. At the same time there is a clear trend, driven by advances in communication and computer technology, to consider recognition of videos and not just of images. The trend is most obvious in computer vision but is also growing in visual physiology and psychophysics.

For all these reasons, this state-of-the-art collection will contribute to leading a very active field of scientific and engineering research in an interesting and natural direction. The book is edited by an interdisciplinary team who assembled a set of experts in the psychophysical, physiological, and computational aspects of the perception and recognition of dynamic faces. It provides an overview of the field and a snapshot of some of the most interesting recent advances.

Tomaso Poggio

Introduction

The recognition of faces is a highly important visual function that has central importance for social interaction and communication. Impairments of face perception, such as prosopagnosia (face blindness), can create serious social problems since the recognition of facial identity and emotional and communicative facial expressions is crucial for social interaction in human and nonhuman primates. Correspondingly, the recognition of faces and facial expressions has been a fundamental topic in neuroscience for almost two centuries (Darwin, 1872) The scientific interest in the processing of faces has vastly increased over the past decade. However, a major part of the existing studies has focused on the processing of static pictures of faces. This is reflected by the fact that over the past ten years more than 8,000 studies on the perception of faces have been listed in the PubMed library of the U.S. National Library of Medicine and the National Institutes of Health but only 300 listed studies treat the recognition of dynamic faces or the perception of faces from movies.

The neural mechanisms involved in processing pictures of faces have been the topic of intense debates in psychology, neurophysiology, and functional imaging. Relevant topics have been whether faces form a "special" class of stimuli that are processed by specifically dedicated neural structures, and whether the process exploits computational principles that differ substantially from those underlying the recognition of other shapes. Most of these debates are still ongoing and no final conclusions have been drawn on many of these topics. Even less is known about the mechanisms underlying the processing of dynamic faces, and systematic research on this topic has just begun. Are there special mechanisms dedicated to processing dynamic as opposed to static aspects of faces? Are these mechanisms anatomically strictly separate? To what extent does the processing of dynamic faces exploit the same principles as the processing of static pictures of faces? Finally, what are the general computational principles of the processing of complex spatiotemporal patterns, such as facial movements, in the brain?

The enormous biological relevance of faces makes their analysis and modeling also an important problem for technology. The recognition of static and dynamic faces has become a quite mature topic in computer vision (Li & Jain, 2005), and since the proposal of the first face recognition systems in the 1960s, a large number of technical solutions for this problem have been proposed. Modern computer vision distinguishes different problems related to the processing of faces, such as identity and expression recognition, face detection in images, the tracking of faces, or the three-dimensional geometry of a face in video sequences. The recognition of faces and facial expressions has important applications, such as surveillance, biometrics, and human–computer interfaces.

Not only the analysis but also the synthesis of pictures and movies of faces have become important technical problems in computer graphics. Starting from very simple systems in the 1970s (Brennan, 1985) that generated line drawings of faces, the development has progressed substantially, and today's systems are capable of the simulation of photorealistic pictures of faces. Modern systems of this type exploit data on the texture and three-dimensional structure of faces, which are obtained by special hardware systems, such as laser scanners. Highly realistic simulations have been obtained for static pictures of faces (e.g., Blanz & Vetter, 1999) and recently also for movies of faces (e.g., Blanz, Basso, Poggio, & Vetter, 2003). The simulation of realistic dynamic facial expressions by computer graphics has been fundamental for the realization of many recent movies, such as *The Final Fantasy, The Polar Express, Beowulf*, or the most recent production of *Benjamin Button*. Other application domains for the simulation of faces and facial expressions encompass facial surgery and forensic applications. Finally, a challenging problem, with high potential future relevance, which scientists have started to address only recently is the simulation of facial movements for humanoid robots (Kobayashi & Hara, 1995).

Thus, recognition and modeling of dynamic faces are interesting and largely unexplored topics in neuroscience that have substantial importance for technical applications. Our goal here is to provide an overview of recent developments in the field of dynamic faces within an interdisciplinary framework. This book is an outgrowth of a workshop we organized in March 2008 at the COSYNE conference in Snowbird, Utah. The chapters are written by experts in different fields, including neuroscience, psychology, neurology, computational theory, and computer science. We have tried to cover a broad range of relevant topics, including the psychophysics of dynamic face perception, results from electrophysiology and imaging, clinical deficits in patients with impairments of dynamic face processing, and computational models that provide interesting insights about the mechanisms of processing dynamic faces in the brain. This book tries to address equally researchers in biological science and neuroscience and in computer science. In neuroscience, we hope that an overview of the state of the art of knowledge about how dynamic faces are processed might be suitable as a basis for designing new experiments in psychology, psychophysics, neurophysiology, social and communication sciences, imaging, and clinical neuroscience.

At the same time, increasing our knowledge about the mechanisms that underlie the processing of dynamic faces by the nervous system seems highly relevant for computer science. Such knowledge seems suitable for improving technical systems for the recognition and animation of dynamic faces by taking into account the constraints and critical properties that are central for processing such faces in biological systems. Second, the principles the brain uses to recognize dynamic faces might inspire novel solutions for technical systems that can recognize and process dynamic faces—similar to the inspiration that the principles of biological vision provided for a variety of other technical solutions in computer vision. Finally, the experimental methods for quantitative characterization of the perception of dynamic faces that are discussed here provide a basis for the validation of technical systems that analyze or synthesize dynamic facial expressions. This makes biological methods interesting for the development and optimization of technical systems in computer science.

The book is divided into three major parts that cover different interdisciplinary aspects of the recognition and modeling of dynamic faces: psychophysics, physiology, and computational approaches. Each part starts with an overview by a recognized expert in the field. The subsequent chapters discuss a spectrum of relevant approaches in more detail.

In part I, Alan Johnston introduces the general topic of the psychophysics of the human perception of dynamic faces (chapter 1). He discusses methodological and technical issues that are important for experimentalists and modelers.

In chapter 2, Alice O'Toole and Dana Roark present novel insights on the role of dynamic information in face recognition. They discuss the findings in the context of what so far has defined the supplemental information and the representation enhancement hypotheses. This chapter also serves as a good introduction to these two theories.

In chapter 3, Natalie Butcher and Karen Lander present in detail a series of studies, including their own new experimental data revealing the dynamic characteristics that are important for face recognition.

In chapter 4, Cristóbal Curio and his colleagues present work that exploited 3D computer graphics methods to generate close-to-reality facial expressions in a study of high-level aftereffects in the perception of dynamic faces. The generation of the dynamic facial expressions was based on an algorithm that provides low-dimensional parameterizations of facial movements by approximating them through the superposition of facial action units. The study shows in particular that dynamic faces produce high-level aftereffects similar to those shown earlier for static pictures of faces.

In chapter 5, Barbara Knappmeyer has particularly investigated the interaction between facial motion and facial form. A cluster-based animation approach allowed the exchange of characteristic motion signatures between different identities. This study shows that the perception of facial identity is modulated by the perception of individual specific motions.

In chapter 6, Harold Hill presents a detailed overview of studies that focus on facial speech perception. His thorough discussion provides insights on spatiotemporal aspects of the interplay of auditory and facial speech signals that are supported by novel data.

Part II is devoted to physiology and is introduced by David Leopold (chapter 7). Besides providing a brief overview of this section, he lays out his view on outstanding neural challenges. Given that facial expressions play a central role in social communication, he suggests that the neurophysiological basis of the perception and production of facial expressions, including vocalization and gaze, should be studied by taking into account interactive contexts.

In chapter 8, Stephen Shepherd and Asif Ghazanfar cover neurophysiological aspects of gaze, attention, and vocal signals during the perception of expressions. They review behavioral and electrophysiological evidence that perception of facial dynamics and vocalization is linked.

In chapter 9, Aina Puce and Charles Schroeder review human electrophysiological event-related potential (ERP) experiments related to facial movement. Using a novel methodological approach, they provide evidence that socially relevant signals, such as a gaze toward or away from an observer, modulates the amplitude of ERP responses.

In chapter 10, Patrik Vuilleumier and Ruthger Righart provide a more detailed review of factors that influence the ERP signal (N170) during the perception of dynamic faces. They discuss in detail evidence from their own and others' work for the coupling of the perception and production of dynamic faces.

In chapter 11, Beatrice de Gelder and J. Van den Stock review clinical observations relating to the dynamic information in faces. They complement the discussion on the processing of static and dynamic faces in normal subjects with insights from studies on how movement affects the perception of faces in patients with various cognitive deficits that range from developmental prosopagnosia to brain lesions and autism spectrum disorder.

The computational aspects of dynamic faces are introduced in part III in the overview chapter by Pawan Sinha (chapter 12). He formulates a number of computational challenges that are associated with the processing of dynamic faces. The computational chapters of this section cover rather diverse topics that range from neural modeling (chapter 13), automatic behavior classification with applications (chapter 14), and a real-time interactive avatar system for closed-loop behavior research (chapter 15) to state-of-the-art 3D computer graphics that provide novel 3D stimuli for challenging experiments on dynamic faces (chapter 16).

In chapter 13, Thomas Serre and Martin Giese present elements of neural theories for object, face, and action recognition that might be central for the development of physiologically inspired models for recognition of dynamic faces.

In chapter 14, Marian Bartlett and her colleagues give an overview of their work on automatic expression measurements. They present a computer vision-based system for recognizing facial expression that uses detectors of facial action units. They review the usefulness of their tool in various interactive applications that require automatic analysis and validat their system by comparison with human performance.

Chapter 15, by Steven Boker and Jeffrey Cohn, presents a computational approach that permits the real-time dissociation of facial appearance and dynamics during natural conversation. Their analysis and animation system is one of the first approaches in behavior research that allows the study of facial expressions with realistic-looking avatars that can reproduce and manipulate participants' facial actions and vocal sounds during interactive conversation.

Part III concludes with a novel computer graphics approach suitable for constructing 3D facial animations (chapter 16). Christian Walder and his colleagues present a kernel-based approach for dense three-dimensional tracking of facial movements, providing essential data that are required for realistic and controllable face animation and dynamic analyses of face space.

We wish to thank the many colleagues without whom the successful completion of this book would not have been possible. We thank Andreas Bartels, Martin Breidt, Isabelle Bülthoff, Christoph D. Dahl, and Johannes Schultz for reviewing and providing comments on individual chapters of the draft.

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