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COMPUTATIONAL AND NEURAL NETWORK MODELS OF FACE PROCESSING

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In this special issue, we present some recent developments in modeling how the human visual system processes facial stimuli to enable the recognition and categorization of faces. Biologically speaking, face recognition is a highly specialized form of pattern recognition. One for which members of the human species demonstrate an amazing expertise. Despite the high similarity between faces, we are all able to recognize and identify, at a glance, an almost unlimited number of faces. As an illustration of this incredible ability, Bahrick, Bahrick, and Wittlinger [1] demonstrated that human observers were able to recognize 75% of the faces of former school mates 50 years later.

The human face represents a unique visual stimulus: Not only does it provide identification information, but also it is an important source of social information useful for human interactions. Indeed, it is very important to know whether the person standing before you is young or old, whether it is a man or a woman, or whether the person is sad, happy, or angry. In fact, face recognition seems to be so biologically important that some researchers have argued that the human face expertise could, at least to some extent, be innate (see e.g., [7]). Such a hard wiring hypothesis could explain the remarkable interest in faces demonstrated by newborn human infants [5, 9] as well as the fact that the visual human system is prone to interpret ambiguous configurations, such as those found in clouds and flames, as faces. Though the idea that we are innately equipped to recognize faces is an appealing one, it is still far from eliciting a consensus among face processing researchers.

More popular is the idea that, because of its biological relevance, face processing has evolved through experience as a special process, qualitatively different from those involved in perceiving and remembering other objects. Among the numerous

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arguments supporting the idea of a face specific system, the most compelling one is the double dissociation described in the face neuropsychological literature (see [15] for a review). Some patients, referred to as "prosopagnosics" can distinguish faces as a category as opposed to other visual objects, but are unable to identify any familiar faces (famous persons, friends, family or even their own face). These patients have no problems identifying other visual stimuli. Other patients, on the contrary, are able to identify faces but experience problems with other objects [4].

Some additional evidence for the contention that faces are indeed special comes from single cell recordings in the temporal lobe of monkeys. For example, Perret, Rolls, and Caan [11] recorded a population of cells in the fundus of the superior temporal sulcus of three rhesus monkeys that were selectively responsive to human and monkey faces. Some of these face selective cells responded to many different faces but were able to cope only with limited depth rotations. Conversely, other cells or groups of cells responded selectively to specific faces across different view orientations (see [12] for a review). None of these face selective cells responded to other objects. Of course, the results of these studies cannot be used as direct evidence for the existence of a face module for human subjects, however, they support the idea that some brain areas might be dedicated to the processing of faces. In agreement with this idea, PET scans of human brains have revealed that some specific areas of the brain are activated in the presence of facial stimuli, but not in the presence of other objects [13]. Moreover it seems that each hemisphere contributes something different to face recognition: The right hemisphere may contribute more of the overall recognition of the outline of the face, while the left hemisphere may be better at analyzing small details [6].

Further evidence for the existence of a face-object separation can be found in some experimental dissociations. For example, it is not very easy to decide which of the inverted images of Figure 1 represents the same person as the top image, or even if the two images are different from one another. Turning them upside down, makes the answer obvious, as well as the image transformation. In contrast, the same type of transformation applied to the image of an object, as shown on Figure 2 can be detected without any problems (For a detailed review of this phenomenon, called the "Thatcher illusion" see [2].)

Another major difference between object and face recognition is that, whereas object recognition requires stimuli to be assigned to relatively broad categories, face recognition requires the discrimination of stimuli within the category "face." It is not enough to decide that a given stimulus is a face; it is necessary, in addition, to decide which particular face it is. This difference becomes important when considering that in order to recognize an object in a 3 dimensional (3D) space, the visual system possesses only 2 dimensional (2D) retinal information. As a consequence, an infinity of 3D objects have the same 2D projection, and a given object gives an infinite number of 2D projections. To sum up, pattern recognition is an ill-defined problem because the visual system does not have enough information to solve it. Yet, we are all able to recognize objects around us.

A face!

A

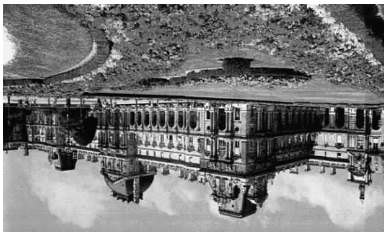
B

Which of these pictures represents the face presented above?

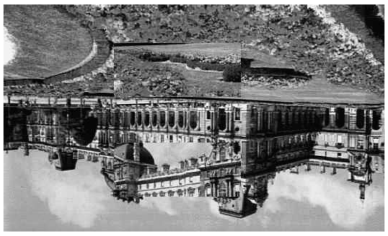
FIGURE 1. The famous Thatcher illusion, from [14].

According to Marr's viewpoint, invariant descriptions of the objects are computed from the retinal inputs and stored in memory. For example, Marr and Nishihara [8] proposed that a given object can be described using a coordinate system centered on the principal axis of elongation of the object. Some other authors (e.g., [3, 10]) have proposed that objects can be represented using a restricted set of basic shapes that can be derived from the properties of 2D images and are invariant over most orientations (e.g., spheres, cylinders, or bricks.) Although this type of approach seems to be relevant for the general domain of object recognition, its extension to

A famous monument!



A



B

Which of these images represents the monument presented above?

FIGURE 2. The famous Thatcher illusion is not convincing with the Louvre!

the specific case of face recognition is problematic. Because all the faces have the same overall shape—an oval with two eyes, a nose and a mouth arranged roughly in the same configuration—broadly similar 3D structures would be obtained for all faces and no discrimination would be possible.

The papers presented in this special issue propose some alternative models of face categorization and recognition. These models are inspired by recent advances in the neurobiological or the computational properties of perceptual systems. The first two papers describe models of low level biological vision, or more precisely, of the primitives used by the human visual system to solve face processing problems. The first paper addresses the temporal binding property of the visual system and the second one its spatial properties. The third paper presents a model of the theoretical properties of the visual system. Finally, the goal of the last two papers is to evaluate the ecological validity of a computational model based on a biological system. While all these models differ in the way in which they represent facial information and in the architecture they use, they all converge to the important point that some cognitive tasks can be simulated using simple architectures when the low level properties of the stimulus and of the visual system are captured.

In what follows, we highlight the main points of the papers collected in this issue:

- Wallis demonstrates the importance of temporal correlation in face processing. After showing that time-based associations between views of different faces lead human subjects to perceive these views as representing the same face, the author proposes a computational model exhibiting the same behavior. This model is inspired by single cell recording data, suggesting that cells in the inferior temporal sulcus of monkeys preferentially tuned to a given image respond also to images seen in close succession to the preferred image. In the Wallis model, the association of views of faces on the basis of their appearance in time is implemented using a "trace rule" (i.e., a generalization of the Hebbian learning rule incorporating a temporal decay parameter.) This biologically plausible learning rule, used in conjunction with a feed-forward competitive network, provides a way of simulating time-based association mechanisms without assuming the existence of an external superviser.
- Huntsberger, Rose and Ramaka present a face processing system, which they call "Fuzzy-Face," based on some spatial properties of the human perceptual system. Faces are represented using a bi-orthogonal wavelet decomposition that separates facial information into two channels: an "average channel" coding the global configuration of the face and a "detail channel" coding the featural information. Both the average and detail channels serve as input to a self-organizing feature map network. Using a fuzzy c-means algorithm, the network finds an optimal partitioning of the set of input patterns into a predefined number of classes. A series of simulations shows that Fuzzy-Face is able to learn a set of faces, to generalize to new views of the faces taken under different lighting conditions, and to some extent categorize faces according to their gender. An analysis of the inner working of the model shows that the average channel is rather sensitive to global changes in the input images, whereas the detail channel is more sensitive to local changes.
- Edelman emphasizes two major problems in modeling face recognition: the problem of "constancy" (i.e., the fact that the visual appearance of a given face changes with view angle, expression or illumination) and of "discriminability" (i.e., the fact that two views of two different faces might be more similar to each other that two views of a given face.) To solve these two problems, he proposes an approach based on a filter representation of the faces, followed by an analysis of the similarity of the faces with stored faces, which he calls "reference faces." In this framework a face is encoded with respect to its location in the space spanned by reference faces (i.e., the face-space.) This type of face representation is likely to remain invariant as a face undergoes transformations (as long as the reference faces have undergone similar transformations.)
- Deffenbacher, Hendrickson, O'Toole, Huff, and Abdi explore the usefulness of a neurally-inspired representation system to predict the behavior of human observers in a relatively natural setting. They manipulate the gender features (or eigenvectors) extracted by a face autoassociative memory from a set of

male and female face images so as to modify the perceptual gender appearance of the faces. The predictive power of these manipulations is demonstrated in a series of three human experiments. The results of these experiments are then interpreted in terms of their implications for a hierarchical perceptual system. Specifically, the authors defend the contention that the processes of face gender categorization and recognition are two independent processes operating in parallel.

- Edelman, Valentin and Abdi examine the psychological relevance of a computational model, using a fine grained analysis of its power to predict human classification behavior for specific faces. They explore the capabilities of a pixel-based linear autoassociator, trained to gender classify face images, to generalize this knowledge to novel and partial stimuli. After learning to classify full face images, the model is tested on both novel full faces and portions of learned and novel faces. Predictions derived from these tests are then compared to human subject performance on both a global and an item level. Although capable of simulating the general pattern of human subject main effects, the model fails to predict an interaction between face gender and face area shown by the human data. Furthermore, the model also fails to predict the rank-order difficulty of the individual faces. Yet, human subjects do not agree with each other in this regard either. What emerges from this study is evidence for a strong item effect of faces as stimuli, combined with individual differences of human observers, indeed, a challenge for computational modeling.

References

[1] Bahrick HP, Bahrick PO and Wittlinger RP, Fifty years of memory for names and faces: A cross-cultural approach. *Journal of Experimental Psychology: General* **104** (1975) 54–75.

[2] Bartlett J and Searcy J, Inversion and configuration of faces. *Cognitive Psychology* **25** (1993) 281–316.

[3] Biederman I, Recognition by components: A theory of human image understanding. *Psych. Review* **94** (1987) 115–145.

[4] Farah MJ, Specialization within visual object recognition: Clues from prosopagnosia and Alexia. In *The Neuropsychology of High-Level Vision*, ed. by Farah MJ and Ratcliff G, (Lawrence Erlbaum, Hillsdale, 1994) pp.133–146.

[5] Goren CC, Sarty M and Wu PYK, Visual following and pattern discrimination of face-like stimuli by newborn infants. *Pediatrics* **56** (1975) 544–549.

[6] Hillger LA and Koenig O, Separable mechanisms in face processing: Evidence from hemispheric specialization. *J. Cognitive Neurosciences* **3** (1991) 42–58.

[7] Johnson MH and Morton J, *Biology and Cognitive Development: The Case of Face Recognition* (Blackwell, Oxford) 1991.

[8] Marr D and Nishihara HK, Representation and recognition of the spatial organization of three dimensional structure. *The Proceedings of the Royal Society, London B* **200** (1978) 269–294.

[9] Pascalis O and de Schönen S, Mother's face recognition by neonates: A replication and an extension. *Infant Behavior and Development* **18** (1995) 79–85.

[10] Pentland A, Perceptual organization and the representation of natural form. *Artificial Intelligence* **28** (1986) 293–331.

[11] Perret D, Rolls E and Caan W, Visual neurons responsive to faces in the monkey temporal cortex. *Experimental Brain Research* **47** (1982) 329–342.

[12] Rolls ET, The processing of face information in the primate temporal lobe. In *Processing images of faces*, ed. by Bruce V and Burton M, (Ablex Publishing Corporation, Norwood, NJ, 1992) pp. 41–68.

[13] Sergent J, Ohta S, MacDonald B, and Zuck E, Segregated processing of facial identity and emotion in the human brain: A PET study. In *Object and Face Recognition*, ed. by Bruce V. and Humphreys GW (Lawrence Erlbaum, Hillsdale) (1994) pp. 349–369.

[14] Thompson P, Margaret Thatcher: A new illusion. *Perception* **9** (1980) 483–484.

[15] Wacholtz EH, Can we learn from the clinically significant face processing deficits, prosopagnosia and Capgras dilusion? *Neuropsychology Review* **61** (1996) 203–257.