Theoretical issues in symmetry perception

CHRISTOPHER W. TYLER
Smith-Kettlewell Eye Research Institute, 2232 Webster St., San Francisco, CA 94115, USA

O Nature, and O soul of Man! how far beyond all utterance are your linked analogies! not the smallest atom stirs or lives in matter, but has its cunning duplicate in mind.

Herman Melville, Moby Dick (1850, p. 295).

This Feature Issue is the first of a pair devoted to the topic of the human perception of symmetry relations in the visual world. At a time of increasing rapprochement between the analyses of local spatial properties and the global organization of Gestalt pattern relations, symmetry relations can provide a guiding principle to help connect the two. It therefore seems a good juncture to take stock of research in symmetry perception, which began over a century ago with the trenchant analysis of Mach (1886). The pace of investigation in the field has been accelerating over the past two decades, although this seems to be the first time a set of articles on the topic has been collected together in one publication. This first issue addresses predominantly theoretical aspects of symmetry perception, while the subsequent issue will focus on more empirical questions.

The intent of the collection is provide insight into new analyses that are being developed for the perception of symmetries of various types. The main kinds of symmetry of interest in spatial vision are reflection (or bilateral), rotation (or axial), translational (or repetition) and size-scaling (or fractal self-similarity), many of which are explored in the following papers. Taken together, the contributions to this Feature Issue, as diverse geographically as they are conceptually, reveal a multiplicity of perspectives on the processing of symmetry by the human brain.

NEURAL REPRESENTATION OF SYMMETRY

It is hard to think about the perception of symmetry without considering the nature of its neural representation. How are physical object relations, such as their inherent symmetries, represented in the brain? This raises the classic chestnut, 'To what degree is the neural representation isomorphic with the physical properties of the object and to what degree is it abstracted?'

The simplistic answer of the Gestalt school was that representation is isomorphic with the stimulus, so that a symmetric object would have a symmetric representation in the brain. Although now generally dismissed as begging the question of the
representation code, this view has been resuscitated by Shepard (1981), who argues that an isomorphic representation is necessary to allow internal transformations of the representation to match manipulations of the object in the world. This stress on a veridical representation is an elaboration of Young's (1962) paradoxical insight that higher organisms maintain their difference from the environment only by mirroring the properties of the environment in the brain. This perspective emphasizes the structural symmetry between subject and object in the act of perception. The experiments of Shepard and colleagues on such transformations as mental rotation of random objects seem to provide good evidence for a 3D neural representation of the 3D world. Indeed, the classic experiments by Penfield (1959) of the sequential readout of memory sequences, and our mental ability to replay songs and speeches in temporal order, would extend the isomorphic representation to the fourth dimension of time.

However, the problem of a representation code remains. The presence of an isomorphic copy of a relevant object in the brain may have value, but it is still subject to the criticism that the object has not been encoded into some form that captures the connotations of its features to the organism. Minsky (1975) and Pylyshyn (1986), for example, argue for an entirely propositional code for object features with no coherent spatial representation. Such a code would resemble lists of attributes associated with each object, where each item would be cross-referenced to other related properties that would constitute its meaning to the organism. This view of encoding arises from the position that much of our sense of meaning must be carried by such a propositional or cognitive code, so it is parsimonious to assume that perception is similarly coded. For symmetry, such a code would consist of a list of attributes for the base pattern motif and a specification of the transformations required to generate the complete pattern from operations on its base motif. Without such a list of transformations, the propositional code could not be said to have encoded the symmetry of the pattern.

Shepard has argued cogently that a propositional code alone is insufficient to account for many of the properties of object recognition under spatial transformations. In particular, the speed of matching objects that are rotated copies of each other is proportional to the angle of rotation but independent of the complexity of the objects. Neither result would be predicted from the inherent properties of a propositional code, but both are consistent with the idea of a neural representation of the objects in which elements that are close in physical space are represented as close in the neural connectivity space. The comparison of objects at different angles of rotation would then correspond to a matching process after the appropriate transformation has been applied to the neural representation. This transformation would correspond not to a physical rotation in the brain but to an adjustment of the local neural codes for each part of the object equivalent to such a rotation (as opposed to merely updating the propositional code for the transformation itself). One advantage of an isomorphic code is that it allows operations such as filtering, segmentation and spatial relations to be performed in a natural way by local neural operations. What is known of the neurophysiology supports the idea of an isomorphic mapping of 2D space to retinal space, of depth via binocular disparity and of time via velocity coding (DeYoe and van Essen, 1988).