link vector and excitation vectors of differential color stimuli. The greater the deviance of the differential stimulus from the conditional one, the smaller the inner product and the lower the response probability (Sokolov 2000). This results in a reciprocal relationship between color difference and response probability, in accordance with Shepard's generalization theory.

A very important argument for the universal character of the four-dimensional spherical model of color space was obtained by intracellular recordings from bipolar cells of carp retina. Six types of tonic bipolar cells were found: four types of opponent cells (red+green; green+red; yellow+blue; blue+yellow) and two types of non-opponent cells (brightness and darkness). Opponent color cells work on an "either-or" basis, so that only two cells can be simultaneously activated. Two non-opponent cells are activated to a certain degree, instantly. Thus, a maximum of four types of color-coding cells can be active at once. For all wavelengths of colors the sum of squared amplitudes of the four types of cells was equal to a constant value, demonstrating the sphericity of four-dimensional color space (Chernorizov & Sokolov 2001).

Shepard's mirrors or Simon's scissors?

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Abstract: Shepard promotes the important view that evolution constructs cognitive mechanisms that work with internalized aspects of the structure of their environment. But what can this internalization mean? We contrast three views: Shepard's mirrors reflecting the world, Brunswik's lens inferring the world, and Simon's scissors exploiting the world. We argue that Simon's scissors metaphor is more appropriate for higher-order cognitive mechanisms and ask how far it can also be applied to perceptual tasks. [BARLOW; KUBOVY & EPSTEIN; SHEPARD]

What's in the black box? To understand the contents of the mind, we should consider the environment in which it acts and in which it has evolved. SHEPARD's work has done much to spread this important ecological perspective, focusing on a particular vision of how the external world shapes our mental mechanisms. For SHEPARD, much of perception and cognition is done with mirrors: key aspects of the environment are internalized in the brain "by natural selection specifically to provide a veridical representation of significant objects and events in the external world" (SHEPARD, this issue, p. 582). Without entering into arguments over the need for representations of any sort (see e.g., Brooks 1991a), we can still question whether representations should be veridical, constructed to reflect the world accurately, or, instead, be useful in an adaptive sense. Clearly, not all veridical representations are useful, and not all useful representations are veridical. A less exacting view of internalization can be seen in the work of Egon Brunswik (as discussed by **BARLOW**, this issue), who proposed a "lens model" that reconstructs a representation of a distal stimulus on the basis of the uncertain proximal cues (whose availability could vary from one situation to the next) along with stored knowledge of the environmental relationships (e.g., correlations) between those perceived cues and the stimulus (Brunswik 1955). For Brunswik, the mind infers the world more than it reflects it. Herbert Simon expressed a still looser coupling between mind and world: bounded rationality, he said, is shaped by a pair of scissors whose two blades are the characteristics of the task environment and the computational capabilities of the decision maker (Simon 1990). Here, the mind must fit closely to the environment, but the two are complementary, rather than mirror images.

We expect that the mind draws on mechanisms akin to all three tools, mirrors, lenses, and scissors, from its adaptive toolbox (Gigerenzer & Todd 1999a). The question now becomes, where can each be applied? In perception, using Shepard's mirror or Brunswik's lens may often be the right way to look at things, but there are also instances where these tools are inappropriate. Consider the problem of a fielder trying to catch a ball coming down in front of her. The final destination of the ball will be complexly determined by its initial velocity, its spin, the effects of wind all along its path, and other causal factors. But rather than needing to perceive all these characteristics, reflect or model the world, and compute an interception point to aim at (with screw displacements or anything else), the fielder can use a simple heuristic: fixate on the ball and adjust her speed while running toward it so that her angle of gaze – the angle between the ball and the ground from her eye – remains constant (McLeod & Dienes 1996). By employing this simple gaze heuristic, the fielder will catch the ball while running. No veridical representations or even uncertain estimates of the many causal variables in the world are needed – just a mechanism that fits with and exploits the relevant structure of the environment, namely, the single cue of gaze angle. How widely such scissors-like heuristics can be found in perception remains to be seen, but some researchers (e.g., Ramachandran 1990) expect that perception is a "bag of tricks" rather than a box of mirrors.

Extending an ecological perspective to higher-order cognition. When we come to higher-order cognition, Simon's cutting perspective seems the most appropriate way to extend SHEPARD's ecological view. Consider a simple cognitive strategy that has been proposed as a model of human choice: the Take The Best heuristic (Gigerenzer & Goldstein 1996). To choose between two options on the basis of several cues known about each option, this heuristic says to consider one cue at a time in order of their ecological validity, and to stop this cue search with the first one that distinguishes between the options. This "fast and frugal" heuristic makes decisions approximately as well as multiple regression does in many environments (Czerlinski et al. 1999), but usually considers far less information (cues) in reaching a decision. It does not incorporate enough knowledge to reasonably be said to reflect the environment, nor even to "model" it in Brunswik's sense (because it knows only cue order, not even exact validities), but it can certainly match and exploit environment structure: When cue importance is distributed in an exponentially decreasing manner (as often seems to be the case), Take The Best cannot be outperformed by multiple regression or any other linear decision rule (Martignon & Hoffrage 1999). In this situation, the two scissor blades cut most effectively. As another example, the QuickEst heuristic for estimating quantities (Hertwig et al. 1999) is similarly designed to use only those cues necessary to reach a reasonable inference. QuickEst makes accurate estimates with a minimum of information when the objects in the environment follow a J-shaped (power law) distribution, such as the sizes of cities or the number of publications per psychologist. Again this crucial aspect of environment structure is nowhere "built into" the cognitive mechanism, but by processing the most important cues in an appropriate order, QuickEst can exploit that structure to great advantage. Neither of these heuristics embodies logical rationality – they do not even consider all the available information – but both demonstrate ecological rationality, that is, how to make adaptive decisions by relying on the structure of the environment.

Why might Simon's scissors help us understand cognitive mechanisms better than SHEPARD's mirror? We (and others) suspect that humans often use simple cognitive mechanisms that are built upon (and receive their inputs from) much more complex lower-level perceptual mechanisms (Gigerenzer & Todd 1999a). If these heuristics achieve their simplicity in part by minimizing the amount of information they use, then they are less likely to reflect the external world and more likely to exploit just the important, useful aspects of it, as calculated and distilled by the perceptual system (which may well base its computations on a more reflective representation).[1] While **KUBOVY & EPSTEIN** (this issue) would probably argue that neither metaphor, mirrors or scissors, helps us in specifying cognitive mechanisms, we feel that such metaphors are vital in guiding research by providing an image of the sort of mechanisms to seek (as has been the case throughout the history of psychology – see Gigerenzer 1991). This is why it is important to point out that Simon's scissors may be a better model to have in mind than Shepard's mirror when studying a range of mental mechanisms, particularly higher-level ones.

Thus, in extending **SHEPARD**'s search for the imprint of the world on the mind from perception to higher-order cognition, we should probably look less for reflections and more for gleams. To achieve this extension, we must also discover and consider more of the "general properties that characterize the environments in which organisms with advanced visual and locomotor capabilities are likely to survive and reproduce" (SHEPARD, this issue, p. 581); these might include power laws governing scale invariance (Bak 1997), or principles of adaptively unpredictable "protean behavior" (Driver & Humphries 1988), or dynamics of signaling between agents with conflicting interests (Zahavi & Zahavi 1997), or costs of time and energy in seeking information (Todd 2001). With characteristic structures such as these before us as one half of Simon's scissors, we can look more effectively for the cognitive mechanisms that form the other, matching half.

NOTE

1. This is not to say that simplicity and frugality do not also exert selective pressure on perceptual mechanisms – **SHEPARD** appreciates the need for simplicity and speed of computation in those systems as well, for instance proposing screw displacement motions as representations because they are "geometrically simplest and hence, perhaps, the most quickly and easily computed" (Shepard, this issue, p. 585). But the amount and manner of information and processing may differ qualitatively from that in higher-order cognitive mechanisms.

Measurement theory is a poor model of the relation of kinematic geometry and perception of motion

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Abstract: The Kubovy-Epstein proposal for the formalization of the relation between kinematic geometry and perception of motion has formal problems in itself. Motion phenomena are inadequately captured by the relational structures and the notion of isomorphism taken over from measurement theory.
[**KUBOVY & EPSTEIN**]

KUBOVY & EPSTEIN (K&E) use measurement theory as a model to couch the relation of kinematic geometry and perception of motion in more formalist terms than **SHEPARD**. A virtue of successful formalization is the conceptual organization and clarification of a group of phenomena through succinct expression of their essential aspects. However, to be appropriate, the tools of formalization must adequately mirror the corresponding empirical domain. As I will argue, measurement theory falls short as a model for motion phenomena.

Measurement may be formalized by singling out some physical entities and procedures involved in the empirical process of taking measures, and identifying their mathematical counterparts. **K&E** use the example of formalizing weight measurement. In this case, on the physical side one would consider, first, some objects having weights, second, a physical procedure of comparing the weights of two objects, and third, another physical procedure of putting two objects together so their weights combine. In counterpart, on the mathematical side, there are, first, numbers corresponding to the numerical values of weights, second, the mathematical relation of comparison of two numbers, and third, the mathematical operation of addition of two numbers. When the physical objects are considered together with the above procedures, they form a particular logical "relational structure"; similarly, the mathematical objects and procedures form another relational structure. I will call "measurement domains" such logical structures whose constituents are a set of elements, a relation of comparison, and an operation of composition. The motivation for considering such entities is the construction of a mathematical measurement domain as a model of a physical measurement domain. This is accomplished when, as in the above example, the two domains are homomorphic, that is, when their corresponding constituents map one-to-one onto each other, so that their logical structures are equivalent.

K&E consider two physical and two perceptual domains. The domain of "kinematic geometry" is the mathematical counterpart of the domain of "physical motions," whereas the domain of "models of perception" is the counterpart of the domain of "perception of motion." **K&E** claim, first, that the four domains are measurement domains in the above sense, and second, that the relations between them are homomorphisms (see their Fig. 2). I dispute both claims and argue that the proposed formalization is inadequate.

Consider first the structures of the domains. As the structure of the perceptual domains is somewhat unclear, I will concentrate on the physical domains. To establish that a domain of interest is a measurement domain, what is needed is to identify its constituents, that is, the elements and the appropriate relation and operation. In the domain of "physical motions," the elements are presumably objects that can exhibit motions. But what could be the appropriate relation of comparison of two motions, analogous to the comparison of weights of objects A and B? The problem is that "motion" is a far richer notion than "weight": In comparing motions of objects A and B, should one consider their speed, path length, duration of motion, shape of trajectory, or manner of motion along the trajectory? How do two motions compare if object A takes a shorter time but traverses a longer extent than object B, or if object A accelerates from a slower speed whereas object B decelerates from a faster speed, or if object A moves on a rectilinear path whereas object B moves on a circular path? One might choose some particular criterion for particular comparison purposes, but the problem is to define a reasonable, general way to decide which of two arbitrary motions is "greater than" the other. However, in contrast to weight comparisons, where such a decision is always possible, forcing motion comparisons into the template of a "greater than" type of relation does not appear to be generally useful. A similar problem would apply for the definition of the appropriate operation of motion composition. Since a measurement domain must exhibit an appropriate relation and operation, these formal problems suggest that "physical motions" is not one.

Related problems arise in the analysis of the logical structure of the domain of "kinematic geometry." In the weight measurement model, the elements in the mathematical relational structure are single numbers, the numerical values of weights. However, scalars are inadequate to express motions. Even for the motion of a single point in space one needs a temporally varying 3-D vector, that is, three infinite sets of numbers. This again shows that measurement domains are poor models for describing motions.

One way to avoid these difficulties is to concede that the particular relational structure taken over from the measurement model is indeed inadequate to analyze motions, but to claim that this problem can be amended by constructing a more elaborate and adequate logical structure. Such a structure should be appropriately suited for motions, and its constituents would involve the notions of shape and length of trajectories, speed, uniform and non-uniform motion, acceleration, and so on. However, such a new structure would not, in my judgment, be substantially any different from the already existing physical theories of motion, that is, kinematics and dynamics, and thus would provide little conceptual advance.

Consider now the structural relation between the domains of "physical motions" and "perception of motion," which, according