NOTE

WEBER'S LAW AND PERCEPTUAL CATEGORIES: ANOTHER TELEOLOGICAL VIEW

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As an alternative to optimum-processor models in which sensors attempt to circumvent internal and external noise, a mechanism-independent argument is presented for Weber's law in vision and hearing. In vision, the argument is that categories of objects should be independent of the light intensity on these objects. In hearing, sound categorization should be independent of the distance from the sound source. An analogous desideratum for computer-based image segmentation is also presented.

H. Hatze (1979) has presented a cogent model of sensory processing whereby the Weber–Fechner (logarithmic) transformation gives optimum information flow for a given level of internal processing noise. The applicability of this model is limited by evidence that, plotted against the logarithm of stimulus intensity, receptor response is a sigmoid rather than a straight line (Cornsweet, 1970; Normann and Werblin, 1974; see also the analytical formulation of Resnikoff, 1975). Although the sigmoid has a linear region in the log domain, this region (particularly in vision) is substantially narrower than the domain over which Weber's law (that a just-noticeable increment \( \Delta I \) in stimulus is proportional to the prevailing stimulus \( I \)) holds. On the other hand, a model exists whereby Weber's law holds even when receptor transduction is not intrinsically logarithmic, but is instead a saturating nonlinear response (Brill, 1976). Adelson (1979) showed that a large class of visual models with saturating nonlinearities obey Weber's law. These models are deterministic; the variety of models increases when stochastic components are introduced, even when statistical optimality is invoked (Buchsbaum, 1980; Massof and Starr, 1980; Martynov and Shkurskii, 1980). These results bear out the warnings of Yilmaz (1967) and LeGrand (1968) that just-noticeable differences cannot be integrated to give a sensory nonlinearity. We therefore present in this note a simple teleological explanation of Weber's law \( \Delta I/I = \text{constant} \) that is independent of Fechner's integration of it (to \( \log (I) = \text{response} \)). The discussion is restricted to vision and hearing, but presupposes no mechanism of information
processing. It is equally applicable to eye, ear or electronic pattern recognizer.

We first present the argument for vision, and then generalize it to encompass the auditory sense.

Part of the evolutionary significance of vision lies in making distinctions of object color independently of illuminant. Models of color constancy (illuminant-invariant assessment of chromatic relations) have been discussed elsewhere (Land and McCann, 1971; Brill, 1978, 1979). Here we extend the notion of illuminant invariance to the operational assessment of 'sameness' between two objects: sameness should, in itself, be independent of the accident of lighting under which two objects are compared. Of course, any two objects in nature can in principle be distinguished by some physical measurement, so the quality of sameness is an operational assessment made by an animal in the interests of survival. For example, suppose two pieces of food are under the same light and the animal knows one of them is not spoiled. The tolerance for sameness might be crucial to survival: if too lenient, the animal might eat the other piece and die of food poisoning; if too stringent, the animal may starve to death. Needless to say, the power of operational distinction would be useless if it could be nullified by changing the light on the two pieces of food.

How can a visual system assess operational 'sameness' of objects that are somewhat different, independently of the light hitting the objects? The problem is generally difficult. In fact, a trichromatic eye (which sees only three qualities of each reflected-light spectrum) will not be able to preserve assessments of color sameness under all changes of illuminant, no matter how it sets tolerances. This is because two reflecting objects that look exactly the same to the eye under one light (independent of tolerance) may become different under a different light—a phenomenon known as metamerism.

We therefore address a simpler problem: how can a visual system assess operational sameness of achromatic objects (whose reflectance spectra are wavelength-independent), independently of the intensity of the light under which they are compared? Since a visual system has access only to reflected lights (not to object reflectances), it must categorize on the basis of compared reflected light intensities, but end up assessing sameness independently of incident light intensity.

Suppose a fiducial object has reflectance $r_1$, an unknown object has reflectance $r_2$, and the prevailing incident light has intensity $I$. Let $\Delta r$ be the difference between $r_1$ and $r_2$ within which the two reflectances are best judged to be the same. (The definition of 'best' is made in a survival context via judgements external to the present argument—that any such