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Computational anatomy and functional architecture of striate cortex: A spatial mapping approach to perceptual coding

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Abstract

The spatial inhomogeneity of the retino-striate system is summarized by the vector cortical magnification factor. The logarithm of retinal eccentricity provides a good fit to the integrated cortical magnification factor. Under the assumption that the cortical map is analytic (conformal), this implies that a complex logarithmic function of retinal coordinates describes the two-dimensional structure of the cortical representation of a visual stimulus. This hypothesis is in good agreement with the measured global structure of rhesus, squirrel, and owl monkey retino-striate mappings, as well as that of the upper visual field of the cat.

The geometric structure of the local hypercolumnar unit of striate cortex may also be characterized in terms of the complex logarithmic mapping: thus, the retino-cortical

system may be thought of as a concatenated complex logarithmic mapping. A simple developmental mechanism is capable of constructing a map of this form, and the general mathematical properties of conformal mappings allow some insight into the nature of the minimal coding requirements which must be specified to encode a neural map.

Complex logarithmic mapping yields a cortical â€œGestaltâ€ which is pseudo-invariant to size, rotation, and projection scaling: these symmetries, for a given fixation point, result in a linear shift of an invariant cortical pattern. The term computational anatomy refers to the possibility that the anatomical structure of the retinotopic mapping may simplify certain aspects of perceptual coding. Similar uses of the complex logarithmic mapping, in computer pattern recognition, are cited in support of this concept. Furthermore, it is shown that columnar structure, together with topographic mapping, may also provide a direct computational function. If two topographic mappings are appropriately interlaced, by columns, then the *difference mapping* of the two independent inputs is encoded within a spatial frequency channel determined by the period of the columns.

A quantitative model of the human visual cortex is developed and used to portray the detailed structure of certain visual stimuli, as they would appear at the level of the striate cortex. The local and global geometric structure of the striate map suggests a simple explanation for several visual illusions. Thus, it is demonstrated that the geometric structure of visual stimuli, at the level of striate cortex, may be of significance to perception.

Finally, the concept of computational anatomy is discussed in relation to other contemporary notions of perceptual coding. It is argued that both single cell feature extraction models and Fourier analysis models of visual coding are inconsistent with the known properties of the visual system, and moreover, have never been adequately formulated in computational terms. The approach of the present paper is to suggest that the basic data structure of perceptual coding consists of two-dimensional laminar mapping, and that successive stages of remapping, along with columnar architecture, may provide important computational functions.

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