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Riemannian Geometric Framework for Perceptual Binding and Object "Oneness"

Jun Zhang

Department of Psychology
University of Michigan
Ann Arbor, MI 48109-1109, USA
junz@umich.edu

Parallel processing of a visual attribute (such as motion) across locations require that those locations occupied by one object be segregated into a single region or "chunk" that reflects the "oneness" of that object. This grouping / binding is both dynamic, in the sense that it depends on the object's momentary location and the region of space it occupies, and automatic, in the sense that it depends only on the bottom-up sensory operations uniformly applied to all locations to start with. However, sensors that directly compute raw image features do not immediately provide such constancy. For example, the output of local motion sensors necessarily confound object velocity with image luminance structure (the so-called "aperture problem"), and therefore are not uniform across the region occupied by the moving object. In order to properly bind those locations corresponding to rigid motion, it has been demonstrated that motion sensors' output must be construed as a map of vectors under a Riemannian (non-Euclidean) geometry that is induced by the momentary image structure (Zhang and Wu, 1990). The Levi-Civita connection, which determines how vectors in nearby locations are to be compared (under the rule of parallel transport), has been derived and related to the image luminance function. The Riemann curvature is proven to be identically zero, indicating that vector comparison is well-defined (path-independent) within a region. This guarantees the mathematical feasibility of this differential geometric approach to perceptual binding. Also derived are the metric tensor, which is equal the product of the Hessian matrix of image luminance function, and the set of geodesics, which connect those points at which the first-order image luminance gradient are constant. This framework is applied to the problem of motion segregation in the random-dot kinematogram a la Braddick (1974), in which the segregation of a surface patch depends on an underlying 2-D rigid translation alone. A simple algorithm is provided to implement neural computation of the proposed geometry by using orientation and direction selective units (Zhang, 1995). Figural segregation is achieved through comparison and congruency of the motion vector field with families of orientation maps that are simultaneously calculated to represent the image geometry.