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Binocular 3D Motion Perception as Bayesian Inference

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Perception may be understood as a form of statistical inference that solves the inverse problem by estimating distal stimulus characteristics from noisy proximal cues (Knill et al., 1996; Pizlo, 2001). Bayesian inference provides an elegant way of combining uncertain or ambiguous information extracted from images on the retina with prior assumptions about the nature of objects in the world. Weiss et al. (2002) proposed a Bayesian model that estimates perceived 2D motion direction and speed by combining velocity constraints with a 2D prior for slow speeds. Depending on the ratio between noise in the velocity constraints and motion prior they could explain a range of 2D motion phenomena. However, this model as well as related models (Lages, 2006; Welchman et al., 2008) are limited to 2D motion on a plane and therefore cannot explain true 3D motion perception. Local image velocities in the left and right eye reflect important 3D environmental information. The human visual system encodes monocular motion and binocular disparity input before it is integrated into a single 3D percept. Here we propose a biologically-plausible model of human 3D motion perception that solves the aperture problem in 3D by assuming that (i) velocity constraints arise from inverse projection of local 2D velocity constraints in a binocular viewing geometry, (ii) noise from monocular motion and binocular disparity processing is independent, and (iii) slower motions are more likely to occur than faster ones.

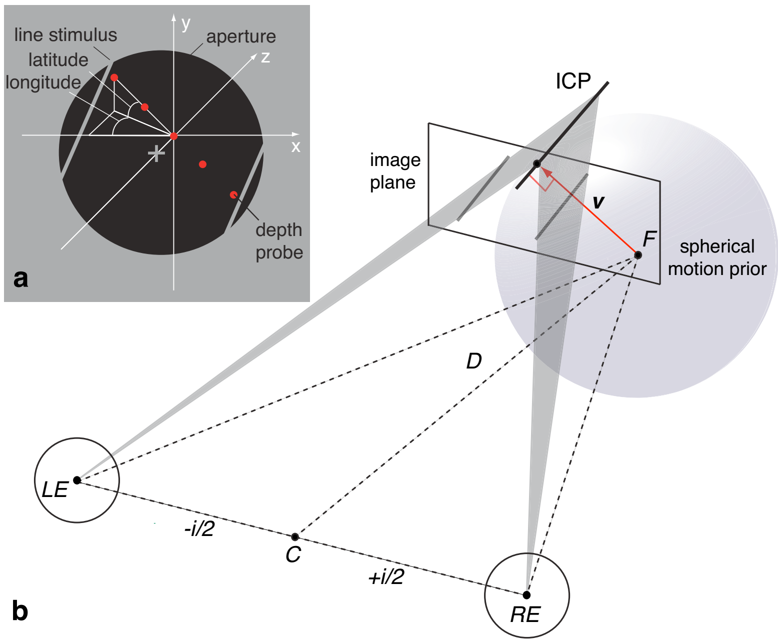

Fig. 1. *(**a**) Illustration of the stimulus display during matching task with a string of red dots. (**b**) Illustration of Bayesian model with left and right eye constraint planes (shaded triangles) and intersection of constraint planes (ICP) for an oriented line stimulus moving through 3D.*

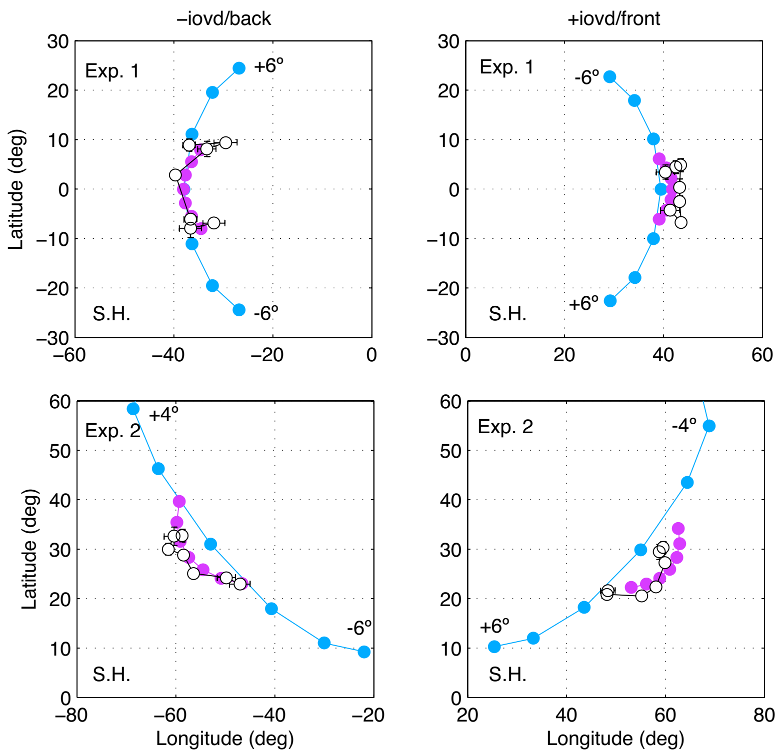

Fig. 2*. Perceived motion directions of a representative observer, expressed as longitude and latitude angle for a vertical (Exp. 1) and oblique line stimulus (Exp. 2). Blue and purple dots denote best-fitting estimates of the BVN1 and BVN2 model, respectively.*

Results from two psychophysical matching experiments favor a Bayesian model with independent noise parameters for monocular motion and disparity processing (BVN2) rather than a model with a single parameter (BVN1). The two noise parameters suggest a weak prior with a stronger contribution to perceived 3D motion direction from disparity compared to motion processing. The probabilistic approach introduced here provides a promising framework for optimal integration of local motion and dynamic disparity input because it resolves the aperture problem in 3D and a full implementation may provide a dense vector-field of velocity estimates for natural scenes.