Stereopsis and motion parallax
I have found in teaching that perhaps the most confusing areas of perception textbooks are those concerning motion parallax and its relationship to stereopsis. The one fact that all books agree on is that these two depth cues are based on very similar geometry, both depending on differences in the perspective view of a scene when it is viewed from different vantage points. In stereopsis, the scene is viewed from two vantage points simultaneously. In motion parallax, from two (or more) successive vantage points. So far so good. Why is it then that these two seemingly equivalent ways of registering the world from different vantage points are described so differently from each other in textbook accounts? For stereoscopic vision, crossed and uncrossed disparity are the major descriptive terms. For motion parallax, there are two definitions. One is that objects move against the movement of the head to a degree that depends on their distance from the observer. The other is that movement against the head occurs at distances nearer than the fixation point and movement with the head at further distances. Few, if any, textbooks explain the relationship between these two aspects of motion parallax, and even fewer describe how they are related to crossed and uncrossed disparity. All of these concepts become clearer, however, if analysis begins with the information in optic arrays. Optic arrays specify the geometry of the information (structured light) coming from a scene to a particular vantage point. In vision, an optic array specifies information relative to the location of the eye independently of where the eye is looking within the array. The concept of the optic array was explicitly introduced into perception by Gibson (1961), but the principles developed by the Renaissance painters (eg Alberti 1435) for painting in perspective actually describe the relationship between optic array and scene properties, with the optic array approximated by the picture plane. What follows is an attempt to apply this concept to clarifying the common geometry shared by motion parallax and stereopsis.

Motion parallax. When the vantage point moves laterally relative to a scene, points in the optic array move in the opposite direction to a degree inversely proportional to the distance of their point of origin in the scene. You could record such changes in the optic array by taking a series of photos of a scene at progressively more lateral positions. You would see the nearer points changing position in the photos more than more remote points. We could call this ‘array parallax’. If the vantage point is an eye, and the eye does not move in its socket during a head motion, retinal motion will simply reflect array motion. However, the motion resulting from a head movement can also be analysed relative to the fixation point. If fixation is at a medium distance in the optic array, when the eye changes vantage point it will not remain fixed but will rotate to maintain fixation. (Note that rotation of the eye does not change its vantage point. It merely changes what part of the optic array the eye is looking at.) This eye movement compensates for the changing location of the fixation point in the optic array. Relative to this point, nearer points still move in a direction opposite to the observer motion, because the eye rotation is not sufficient to compensate for their motion in the optic array, which is greater than that of the fixation point. Points further than the fixation point move in the same direction as the observer. Why? After all they too move in the opposite direction in the optic array. The reason is that the motion of the eye which compensates for the motion of the fixation point overcompensates for motion of the more remote points which move less in the optic array than the fixation point. That is why they move in the same direction as the observer. Motion relative to the fixation point could be called ‘crossed and uncrossed’
motion parallax (although I have never seen these terms used). Illustrating a common source of confusion in this area some textbooks (eg Bruce et al 1996; Goldstein 2006; Snowden et al 2006) state that the image of a near object travels further across the retina than the image of a far object when the head moves laterally. They are actually describing motion in the optic array, and are able to call this ‘image motion on the retina’ only because they are assuming that the eye remains looking rigidly straight ahead as a head movement changes its vantage point. Only in this case do retinal and optic array motions coincide. However, if and how images move on the retina when the head moves laterally depends on fixation. It might thus be less confusing to describe the movements that are inversely proportional to distance as optic array rather than retinal motions.

Stereopsis. A very similar analysis can be made of stereopsis, with uncrossed and crossed disparity resembling motion with and against the head in motion parallax. Compare the optic arrays for the left and right eyes when looking at a scene. Again, these can be approximated by taking photos from two positions separated by the interocular distance of the left and the right eyes such as are used in a stereoscope. Relative to points far away (often called ‘infinity’) which have no disparity, closer points have a greater and greater ‘crossed’ disparity (difference in position in the optic array such that the right image is increasingly to the left and vice versa). This has been called ‘array disparity’ (Barrand 1979). Retinal disparity corresponds to array disparity if the eyes are looking at infinity and are parallel. However, disparity is usually not defined relative to points at infinity. It is usually defined relative to the fixation point. The eyes converge on a matching feature in the two optic arrays and compensate for the array disparity there. Relative to the fixation point, nearer points have crossed disparity since the convergence of the eyes is not sufficient to null it out. The nearer the point, the more this is the case. Points further than fixation have uncrossed disparity because the vergence overcompensates for their array disparity to a degree which increases with their distance.

Array disparity is exactly what Helmholtz (1867/1962) described as ‘stereoscopic parallax’. It describes disparity independently of what the eyes are doing, as in Helmholtz’s description of the disparities of nearer points relative to points at infinity in stereoscopic pictures. Traditionally, however, stereopsis, unlike motion parallax, has been regarded as ‘sensory’ and tied to retinal correspondence and disparity from that (retinal disparity), and, indeed, binocular cells in V1 and most cells in V2 encode retinal disparity. It is interesting to note that, although the absolute retinal disparity of a point varies with vergence, the relative retinal disparity of a pair of points does not, and is the same as optic array disparity. The same applies to relative motion parallax which is independent of eye rotation.

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