The weighted harmonic vector average: a new approach to the aperture problem

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A central problem for the visual system is how to compute the speed of objects as they move in the world. The motion processing system in monkey and man is arranged in a hierarchy of anatomically distinct brain areas containing neurones whose receptive fields increase in size, response selectivity and computational complexity with increase in rank [1]. The evident variation across the hierarchy in the spatial range of motion analysis, as indicated by receptive field size, leads to some unavoidable computational problems. Initial local analysis is limited by the aperture problem, a result of which is that neurones typically signal motion orthogonal to contours. These essentially independent estimates need to be brought together through some computation that can deliver the global motion of an object as a whole.

We can study motion integration experimentally using an array of Gabor elements (Gaussian windowed moving sine gratings). The local speeds of object contours vary systematically with the cosine of the angle between the component of the local velocity orthogonal to the contour and the global object motion direction. A spatial distributed array of Gabor elements whose speed depends on local spatial orientation in accordance with this pattern can appear to cohere and move as a single surface. A number of models have been proposed to explain how the visual system might achieve this result. If we assume a single rigid translation, the global direction of motion can be found from at least two elements with different orientations, using a strategy known as the intersection of constraints (IOC). This strategy has usually been contrasted with the vector average. However, the vector average over local vectors that vary in direction always provides an underestimate of the true global speed, and if we have a biased set of local motions with respect to the global motion, the global percept is shifted towards the average direction, which is inconsistent with the IOC strategy. We need to look for an approach that will resolve these problems.

If we plot the normal component motion vectors in a velocity space they lie on a circle through the origin. This circle when inverted in the unit circle maps to a line, allowing a least square estimate of the IOC and an average inverse velocity for a set of normal components. This average, inverted once more in the unit circle, is the harmonic vector average (HVA) [2]. The harmonic vector average provides the correct global speed and direction for an unbiased sample of local velocities with respect to the global motion direction. The HVA over biased samples provides an aggregate velocity estimate that can still be combined through an IOC computation to give an accurate estimate of the global velocity, which is not true of the vector average. Psychophysical results for a biased distribution of Gabor arrays show perceived direction and speed falls close to the intersection of constraints direction for Gabor arrays having a wide range of orientations but the IOC prediction fails as the mean orientation shifts away from the global motion direction and the orientation range narrows. In this case perceived velocity generally defaults to the harmonic vector average. Neither the IOC nor the HVA can account for human global motion perception in biased arrays, however the perceived direction of motion appears to be bounded by the IOC and the HVA. Here we consider how a weighting scheme, in which the local velocity measures are weighted according to their reliability, might shift the harmonic vector average in the direction of the perceived global motion.

References

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[2] A. Johnston & Scarfe, P. The role of the harmonic vector average in motion integration. Frontiers in Computational Neuroscience 7, pp.146, 2013.