DYNAMICAL EMERGENCE OF A NEURAL SOLUTION FOR MOTION INTEGRATION

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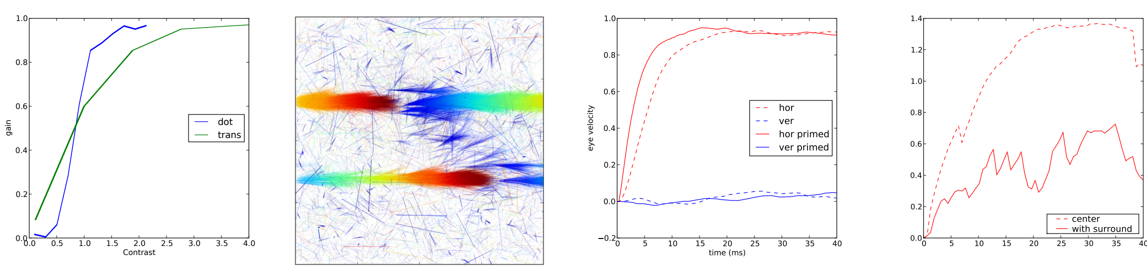
A central challenge in neuroscience is to explain how local information as processed by single neurons is integrated to give a coherent global response at population level. An illustration of this problem is the early stages of the visual system. Local motion is processed in area V1 by neurons having only access to a limited portion of the visual field, their receptive field. As a consequence, information is often incomplete and sometimes ambiguous. One well-known example is the aperture problem: when a single elongated line crosses the receptive field, it is only possible to extract the component of the speed perpendicular to its orientation. Since there is only one 1D edge, geometrical rules working at more global levels such as the Intersection-Of-Constraints rule fails. Still there are many experimental evidence that populations of higher-stage neurons, such as MT cells, can solve this aperture problem and dynamically reconstruct the 2D motion of this simple object.

Here, we explore a more parsimonious solution where these 2D motion analyzers could be understood as a product of velocity prediction. In natural scenes, translation of visual objects are highly predictable thanks to their physical properties (rigidity and inertia). We implemented this in a motion field: in a retinotopic velocity map, predictions are propagated by lateral recurrent interactions inferring that each velocity vector is approximately conserved along path-lines. In the framework of a probabilistic representation, the filtering and smoothing equations involve integrals over the hidden variables and define a dynamical Markov random motion field. A dynamical solution was approximated using Sequential Monte Carlo methods (also known as "particle filters"). We tested our model against a wide range of motion stimuli, going from random dot patterns or line-drawing objects to moving plaids and textures.

sharpening of CRF | slanted line | latency effect | surround division



Although no explicit mechanisms of 2D motion was introduced, the predictive coding constraint was sufficient to let several features of 2D motion detectors emerge from the dynamics of the probabilistic motion field. We observed that the system exhibits a non-linear binary response when tracking one or a few dots compared to the smooth response of the first-order system: As predicted by a mean-field model of the system, a dot is either tracked or lost. The algorithm exhibits several properties observed in low-level motion perception, such as sharpening of the contrast response function for a dot compared to a grating, activation along the line-endings of the moving slanted line, an advance in response latency when information was cued, or center-surround suppression (see respectively in Figure from left to right). This is consistent with neural models where interactions are heuristically tuned and may contribute to a functional approach in our understanding of low-level visual system.