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Non-classical receptive field properties reflecting functional aspects of optimal spike based inference

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The classical receptive field (cRF) is a concise characterization of cell responses in the visual processing pathway. However, many studies found that stimulation from outside the cRF can significantly modulate responses triggered from within the cRF. Several nonlinear mechanisms (e.g. divisive normalization, gain control) have been suggested to describe these puzzling effects, but their functional roles are not yet fully understood.

According to normative theories, the key point of perception is to infer the state of the world that caused the sensory input. In this work, we show that non-classical RF phenomena follow as a natural consequence of the dynamics governing this inference process for naturalistic stimuli.

More specifically, we show how a network of spiking neurons can infer on-line the objects present in the visual scene. We use a simple generative model (GM) describing how quickly objects appear and disappear, as well as which sensory pattern they typically cause (their "causal field"). Different layers of spiking neurons try to "invert" this causal model: they integrate their noisy input in order to detect objects or events responsible for the sensory data. The temporal dynamics of single units resemble those of simple integrate and fire neurons. To disambiguate the information contained in the correlated input, the model predicts divisive lateral connectivity that is both input-selective and dependent on the activity of neighboring cells. Going well beyond gain modulation, divisive inhibition contextually reshapes the feed-forward receptive field to concentrate it on the most informative features.

The output spike trains predicted by this on-line inference reproduce the statistics of visual spike trains, in particular the Poisson-like variability and transient response to stimulus onset. It reproduces the center-surround structure of cRFs as well as many ncRF phenomena like the context and contrast dependence of cRF measurements, the reversal of contextual effect from facilitating to suppressive with contrast, and the size dependence of contrast response curves. These effects are characteristic footprints of an underlying inference process, reflecting a coarse-to-fine gradient in sensory integration for increasing signal-to-noise ratio.

We illustrate how the network can be realized with biophysically plausible neurons. This goes beyond a proof of biological feasibility as it presents a new perspective to understand the functional connectivity underlying many ncRF effects. Bayesian approaches to neural processing provide a link between levels of analysis, from specific currents at the single cell level to processing at the network level and perception.