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Feedback in a hierarchical model of object recognition in cortex

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Substantial evidence exists showing V1/V2 cortical activity in response to illusory contours (e.g. Kanizsa's triangle)[1]. V1 represents information that correlates with visual perception but does not arise from the ordinary feedforward pathways (retina and LGN), suggesting this response is driven by feedback connections from higher-level areas. At the same time, several authors have emphasized the important role played by feedback connections in visual perception and have suggested hierarchical Bayesian inference as a plausible underlying interpretation [2-5]. The proposed model aims at providing a functional interpretation of the illusory contour phenomenon and, more generally, of the role of feedback connections in visual perception under the perspective of a Bayesian inference framework.

The model takes as a starting point the HMAX model, a well-known cortex-based object recognition model [6,7], and shows how this feedforward architecture can also be interpreted in probabilistic terms and extended to include feedback using the Bayesian Belief Propagation algorithm. Feedforward responses are understood as probability distributions of the set of features at the different positions, which build up hierarchically obtaining at the top level the most probable object represented by the input image. Activity relating to the stored invariant prototype of this object is then fed back down the network and combined with the feedforward response at each level to obtain the resulting belief. However, high-level invariant object prototypes generate ambiguous and diffuse feedback that needs refinement. The disambiguation process, based on cues from existing feedforward responses, uses a local extrapolation algorithm that exploits co-linearity, co-orientation and good continuation to guide and adapt feedback.

Simulation results show successful feedforward object recognition, including cases of occluded and illusory images. Recognition is both position and size invariant. The model also provides a functional interpretation of feedback connectivity which accounts for several observed phenomena. Model responses qualitatively match representations in early visual cortex of occluded and illusory contours [1]; and fMRI data showing that high-level object recognition reduces activity in lower areas [8]. Additionally a dynamic mechanism for illusory contour formation is proposed which can adapt a single high-level object prototype to Kanizsa's illusory figures of different sizes, shapes and positions. The mechanism is supported by experimental studies that suggest the interaction between contextual feedback signals and local evidence in V1 is responsible for contour completion [1,9]. By imposing top-level priors the model can also simulate the effects of spatial attention, priming and visual search.

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