

Latencies and processing speed in early visual processing

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Abstract

Response latencies and temporal integration in the visual system are strongly contrast dependent. We use short-term synaptic depression of the recurrent connections to create a model of an adaptive integrator network. The model reproduces many physiological findings concerning visual response latencies. We show that it improves performance on discrimination task as compared to simple feedforward networks. The model proposes a functional role for the abundant recurrent connections in the cortex.

Introduction

Although the visual system works usually rapidly, it slows down at low contrasts. The response latency is known to increase at low stimulus contrast in V1 (Albrecht and Hamilton, 1982; Carandini and Heeger, 1994; Gawne et al., 1996; Bair et al., 2002), MT (Raiguel et al., 1999), and in superior temporal cortex (Oram et al., 2002).

Our interpretation of this effect is that the visual system needs to adapt its temporal integration dependent on the quality of the stimulus.

We use model that

- requires strong recurrent connections
- requires synaptic depression

and create a network that adaptively integrates stimuli.

Model

The model is a firing rate model. The firing rate $r(t)$ describes the average firing rate of a small population of cells, e.g. a micro-column

$$\tau \frac{dI(t)}{dt} = -I(t) + I_{input}(t) + gP_{rel}(t)r(t)$$

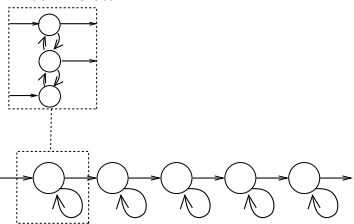
where $I(t)$ is the net current into the node, g is the recurrent gain ($g \approx 1$), and τ is the synaptic time-constant.

Synaptic depression is modeled as

$$\tau_{depr} \frac{dP_{rel}(t)}{dt} = P_0 - [1 + \tau_{depr}r(t)(1 - f)]P_{rel}(t)$$

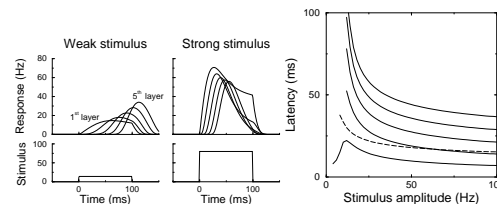
here $P_{rel}(t)$ describes the average release probability of the synapse, f describes the reduction of $P_{rel}(t)$ with every spike, and τ_{depr} describes the synapse's recovery time.

Finally, a weakly non-linear F/I curve relates the current to the firing rate, $r(t) = h(I(t))$.

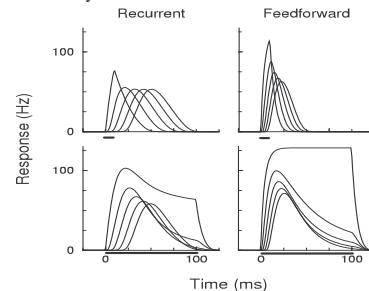


The nodes are connected in a chain.

Latencies



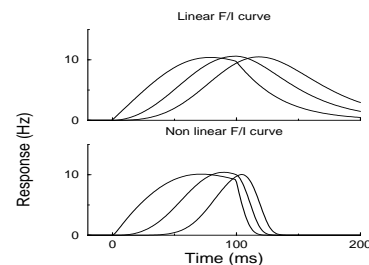
The response latency in the model is strongly contrast dependent. The deeper the layer, or the weaker the stimulus, the longer the latency.



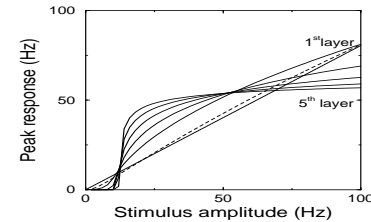
The response duration becomes independent of the stimulus duration (left), unlike feedforward models (right). In particular, short stimuli can lead to long lasting responses.

Non-linear F/I curves

The F/I curve is weakly nonlinear. As compared to a threshold-linear F/I curve the model gains additional realism and results in two effects:



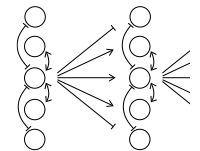
The onset and, in particular, the offset of the response are steep, consistent with data (Oram et al., 2002; Bair et al., 2002).



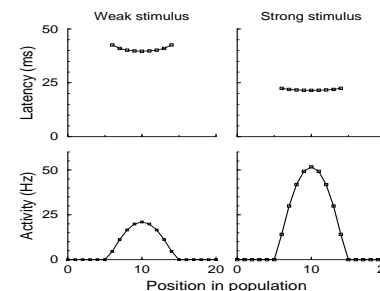
Secondly, the weak nonlinearity is strongly amplified by the recurrence, leading to a more or less binary response in deeper layers (Sclar et al., 1990).

Population coding

In experiments both the lowering stimulus contrast or presenting a non-preferred stimulus lead usually to a weaker response. However, a striking experimental observation is that latency is independent of stimulus preference (Gawne et al., 1996; Oram et al., 2002).



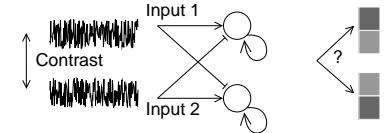
To model this we implement a population coding network. The inter- and intra-layer connections are modeled by center-surround profiles (local excitation, global inhibition).



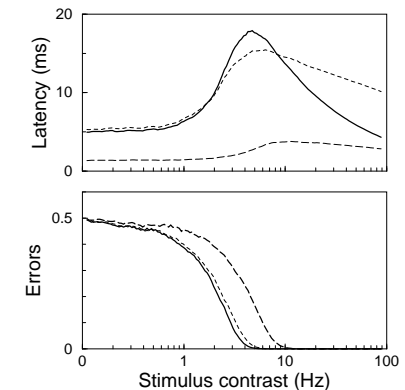
The latencies are again strongly contrast dependent. However, for a given contrast, the latencies within a layer are very similar. Like in the data, the contrast and not the response amplitude determines the latency.

Performance

We demonstrate the improved performance of this type of network architecture in a discrimination task. The network has to decide which of the two image patches is brighter. This is done using a comparator network.



We characterize the response by both the error rate and the time to reach half-maximum. Ideally, the network is fast for strong stimuli, but integrates weak stimuli. The depressing recurrent network indeed behaves this way.



Performance of the comparator network expressed in both the latency to half-maximum response and fraction of errors. Adaptive network (solid line), non-recurrent network with short time-constant of 5 ms (dashed line), and a non-recurrent network with a long time-constant of 20 ms (dotted line).

Conclusion

The cortex has abundant lateral connections (Douglas et al., 1995), which are known to be strongly depressing (Markram and Tsodyks, 1996; Abbott et al., 1997). We propose that the role of these connections is to make the cortical network adapt to changes in the stimulus quality (contrast). Currently, multi-layer computations are studied.