

A Cognitive Vision Model with STDP Adaptation

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Early cognitive vision is one of the most important perceptive functions in the mammalian cerebral cortex. During information processing in the visual cortex, many bioelectrical signals are exchanged between cortical neurons, across their synaptic interconnections. When modelling visual cortex processing a dynamic scene can be modelled as an optical flow field, which can, in turn, be mapped on to a neuronal network. A possible, simple network structure has neurons placed along axes arranged radially from the optical flow field centre with only nearest-neighbour, on-axis connections. The characteristics of a dynamic scene can thus be reconstructed by local computation in neurons based upon the optical flow field.

We have modelled a large-scale leaky integrate-and-fire (LIF) neuronal network in precisely this network arrangement. The model uses edge-sensitive pixels to capture the position and speed of movement of features in a moving scene. Subsequently, object identification is achieved and depth information is recovered. In this example, we have restricted movement to a straight line, with a constant relative speed between a moving cognitive model and the static scene. Each neuron has two excitatory input synapses. One connects to the edge-sensitive pixel and is referred to as the receptive synapse. The second receives a prediction of the time-of-arrival of an edge from the previous neuron in the flow field, and is referred to as the flow synapse. When an edge passes a pixel sensor, the corresponding LIF neuron will issue a spike provided that the sum of excitatory post-synaptic potential (EPSP) caused by flow and receptive synapses exceeds the neuron's threshold. In this case the spike potential propagates, in a decaying α -function mode, to the flow synapse of its successor neuron. The estimated time when this successor neuron will fire, corresponding to the time taken for an edge to travel between sensors, is encoded in the time constant of an exponentially-decaying signal from the firing neuron. Effectively, the LIF neuron will fire only if the predicted time-of-arrival and the actual time-of-arrival are within a controlled time window. For simplicity we fix flow synapse efficacy while allowing the receptive synapse efficacy to adjust according to the online adaptation mechanism of spike-timing-dependent plasticity (STDP). The aim of this adaptation is to refine the "window" within which flow and receptive synapses must receive a signal to optimise both the recognition of real edges and the rejection of spurious edges. The numerical experiments are conducted in C++ by using Euler integration method and the update step is increased with each image frame.

Simulation results show that every neuron achieves an optimised window in signal propagation, i.e., only edges that arrive within a prescribed, specific timing window will activate the corresponding neuron. The results further demonstrate that, after an initial self-organising stage, the estimated and actual depth information agree well in both artificial and real images. Furthermore, receptive synapse weights converge from an initial random distribution towards a bimodal distribution. As our aim is to implement the LIF neuron in aVLSI, our model is therefore amenable to CMOS hardware and moves towards a demonstration of an autonomous on-chip adaptation procedure, based upon biological observations, with meaningful applications.

References

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