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Transmission of spiking-rate information through layered networks: the role of recurrent and feedback connections

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Background

It is a widely accepted tenant that one of the means by which the nervous system and brain encodes information about external stimuli is via the spiking-rate of neurons. Such a spiking-rate code necessitates the transmission of an elevated spiking-rate through successive neurons in a structured network, such as occurs in the auditory and visual pathways. Recent studies, however, have raised serious questions about our understanding of the propagation of such spiking-rate information through structured networks. In networks consisting of successive layers of integrate-and-fire neurons with conductance synapses with feed-forward of information from one layer to the next, it has been found that the mean spiking-rate in deep layers is essentially independent of the input spiking-rate [1]. The neurons within each layer tend to synchronize with each other, resulting in a synchronous volley of action potentials through successive layers, reminiscent of synfire chains. The average spiking-rate in deeper layers either decays to zero or reaches a stable fixed-point, depending upon the model parameters. This behaviour was also observed in an *in vitro* study using a dynamic patch clamp [2].

Methods

A network consisting of many layers of neurons is analysed using both analytical and computational techniques. Within each layer the neurons (both excitatory and inhibitory) are recurrently connected. Adjacent layers are connected to each other through both feed-forward and feedback excitatory connections. The neurons receive *specific* (or *driving*) excitatory synaptic input from inputs in the previous layer and *non-specific* (or *background*) excitatory inputs from neurons outside the layered network. Both Poisson neurons and integrate-and-fire neurons with conductance synapses are analysed [3]. The fixed-point behaviour of the transmission of spiking-rate information is analysed analytically. Dynamical aspects of the behaviour are analysed computationally.

Results

It is found that, with a sufficient level of recurrent excitation and background input, the response of the neurons within a layer to input that is external to the layer can be described as a threshold-linear function to a very good approximation over a wide range of input intensities. Activity-dependent synaptic scaling is used to determine the effective gain of the threshold-linear response. The conditions under which spiking-rate information can be reliably transmitted through successive layers are deduced using a fixed-point analysis and are found to depend upon the relative amounts of excitatory feed-forward and feedback input between layers.

Conclusion

It is found that there is a set of *privileged* neural parameters allow the propagation of spiking-rate information through deep layered networks and that this set of parameters can arise naturally as a result of simple well-founded principles. This represents a significant result demonstrating that the propagation of spiking-rate information can be achieved when the feedback and recurrent connections, that were absent in previous feed-forward layered models, are incorporated. Also, in contrast to feed-forward models, there is in the present model a clear rationale for the privileged sets of neural parameters that allow the transmission of spiking-rate information.

References

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