Optimal Conditions for Reliable Representation of Asynchronous Spikes in Feed-Forward Neural Networks

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Reliable propagation of information in the brain is crucial to the modularity of the brain. Robust transmission of information represented by synchronous spikes is well-understood in computational neuroscience. [1] However, most factors affecting transmission of information represented by asynchronous spikes has remained unexplored due to the problem complexity. [2] Here, we study necessary conditions for reliable propagation of asynchronous spikes in a multi-layered feedforward neural network (FNN) with all-to-all (excitatory) connectivity.

Abstract network model offers a closed-form solution for estimating synaptic weights of FNN

- Taking advantange of homogeneity of neurons assumption [2][3] in an FFN and the goal of propogating a common signal yields a reduced synaptic weight model from an N*N matrix to an N*1 vector (Fig. 1, 2)
- Least-square method can be used for parameter estimation.

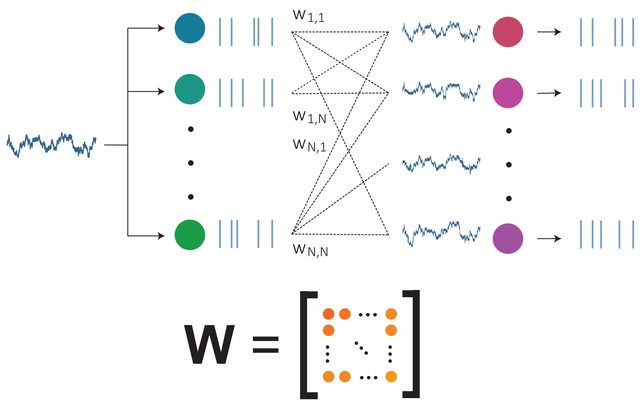

Figure 1: ***FCN-Grad - FFN with matrix representation of weights***

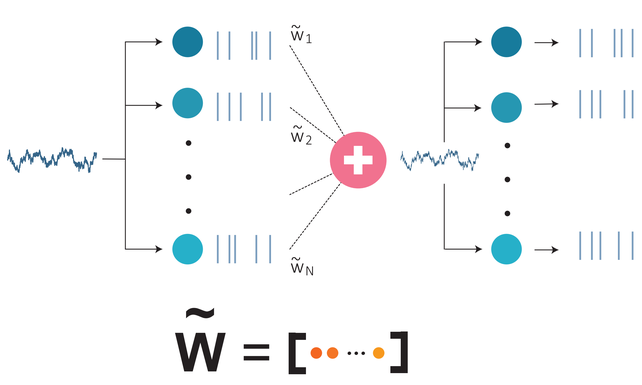

Figure 2: ***ReducedNet - FFN using reduced model with vector representation of weights***

Abstract network model mimics behaviour of FNN

- Matrix representation of weights are obtained using gradient descent optimization for FCN-Grad
- Behaviour of ReducedNet is similar to that of FCN-Grad
- Weight matrix can be approximated (FCN-Approx) using Gaussian distribution (Fig. 3)

35pA of background synaptic noise, and 300 neurons per layer provide (biologically realistic) best results for a 2-layer FNN

- Providing noise values above 20pA is crucial to maintain an acceptable coding fraction
- Biologically realistic ranges for bg. syn. noise and network size are outlined in green
- Non-biologically realistic values result in weights below 0pA/mV, or result in post-synaptic potentials greater than 25mV (Fig. 4)

(coding fraction = 1 - [L2Norm(reconstructed input - input) / L2Norm(input)]
inst. firing rate uses Gaussian kernel of std=25ms

Future direction: other necessary factors for reliable information propagation

- Optimization paradigm applied to abstract model yields successful propagation for layers 1-2 (0.76, 0.63 c.f).
- Propagation breaks down in layer 3-4 (0.44, 0.14 c.f) due to synchrony (Fig. 5).
- Spatial distribution, and heterogeneity in neuron functions and plasticity should be considered for future study of propogation of asynchronous spikes.

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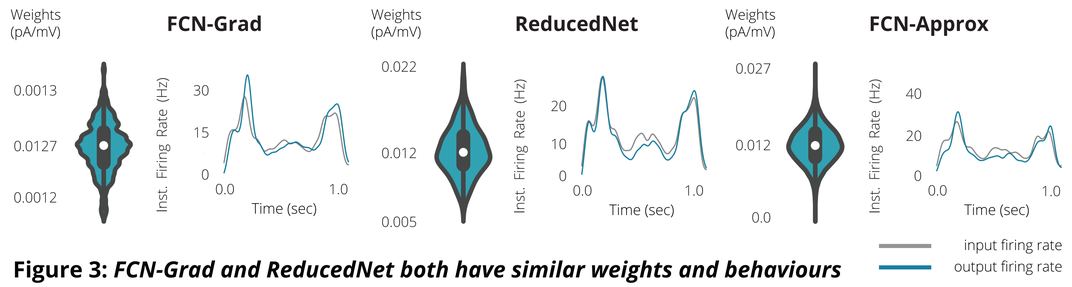

Figure 3: ***FCN-Grad and ReducedNet both have similar weights and behaviours***

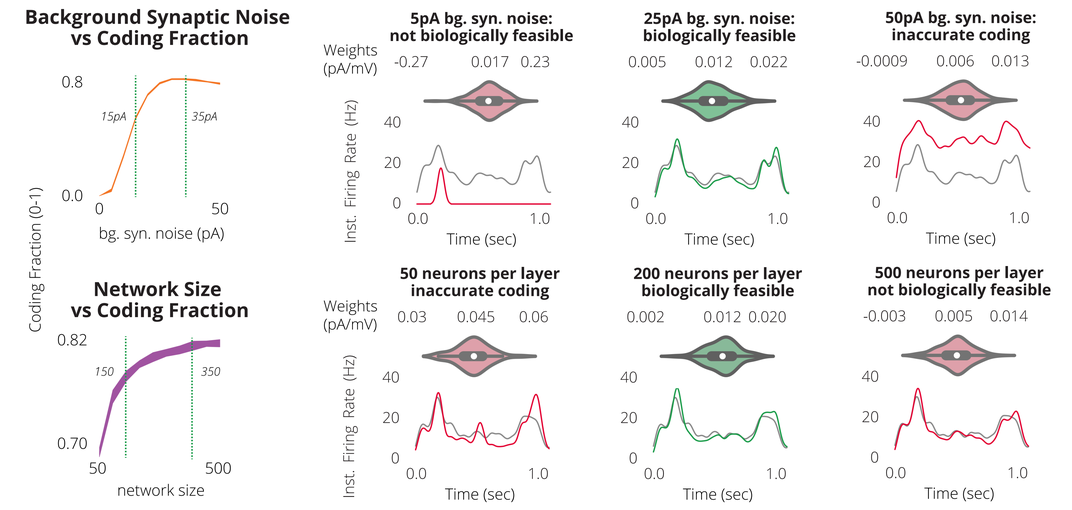

Figure 4: ***Bg. synaptic noise and # of neurons / layer impact both biological feasibility and propagation reliability.***

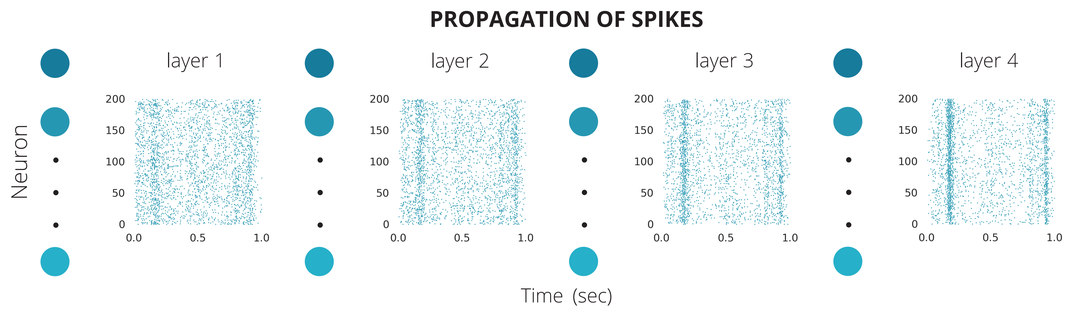

Figure 5: ***Propogation of spikes is successful until the third layer (0.76, 0.63, 0.44, 0.14 cf).***

References

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