Learning and connectivity in heterogeneous recurrent neural networks |

Martina Acevedo | Balseiro Institute

Authors:

Martina Acevedo (1, 2), Soledad Gonzalo Cogno (3), Germán Mato (1,4)

Affiliations:

(1) Balseiro Institute, Argentina.

(2) Hospital Del Mar Medical Research Institute (IMIM), Barcelona, Spain.

(3) Kavli Institute for Systems Neuroscience, NTNU, Norway.

(4) Bariloche Atomic Center, National Atomic Energy Commission, Argentina.

Neurons with different firing properties are known to be interconnected within the same circuits in the brain. Moreover, these cells are also known to be modulated by global network dynamics, such as neural oscillations with different time scales. Yet, it remains unknown what the connections between neurons with different firing properties are, and how these connections and the global network dynamics, for example in terms of oscillations, are related.

To address these questions, we first modelled recurrent neural networks (RNN) whose individual neurons responded to two variants of the Integrate-and-Fire family of models: the leaky integrate-and-fire (LIF) and the quadratic integrate-and-fire (QIF) model. We studied networks with different proportions of these neurons. The connections were random and independent. We characterized the global dynamics by calculating the participation ratio, which is an estimation of the planar dimensionality of the network dynamics. Previous studies have explored the link between the participation ratio and connectivity in systems with homogeneous intrinsic dynamics characterized by a linear relationship between the firing rate and the input current. We extended these quantifications to heterogeneous networks and analyzed the relationship between the participation ratio and the connectivity strength for different network compositions.

We found that the dimensionality approaches the functional form of that in purely linear models, although now the dependence with the connections is rescaled due to the change of gain in the non-linear models.

Next we sought to enforce specific ordered population dynamics onto the network. We applied FORCE learning to train the connections so that neural inputs would reproduce oscillatory, sequential, and Ornstein-Uhlenbeck stochastic patterns. Upon training, we analyzed the resulting connectivity. We found that the strength of the connections depends on the composition of the network. These changes in connectivity were associated to outliers in the eigenspectrum of the connectivity matrix. In addition, reciprocal connectivity motifs, in which two neurons are reciprocally connected, emerged in networks trained with oscillatory and sequential patterns. The abundance of this type of motif depended both on the neural activity time constant, and on the network composition. Sequential patterns also gave rise to divergent motifs, where one neuron forms strong connections to two other neurons. In contrast, networks trained with Ornstein-Uhlenbeck patterns exhibited no local connectivity motifs. These results are compared to statistical analysis of connectivity patterns in human and mouse cortex.