Organization For Computational Neurosciences

Studying neural mechanisms in recurrent neural network trained for multitasking depending on a context signal.

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Most biological brains, as well as artificial neural networks, are capable of performing multiple tasks **[1]**. The mechanisms through which simultaneous tasks are performed by the same set of units are not yet entirely clear. Such systems can be modular or mixed selective through some variables such as sensory stimulus **[2,3]**. Based on simple tasks studied in our previous work **[4],** where tasks consist of the processing of temporal stimuli, we build and analyze a simple model that can perform multiple tasks using a contextual signal. We study various properties of our trained recurrent networks, as well as the response of the network to the damage done in connectivity. In this way, we are trying to illuminate those mechanisms similar to those that could occur in biological brains associated with multiple tasks.

Idea:

Consider a RNN with N units → train it to perform temporal tasks with context signal

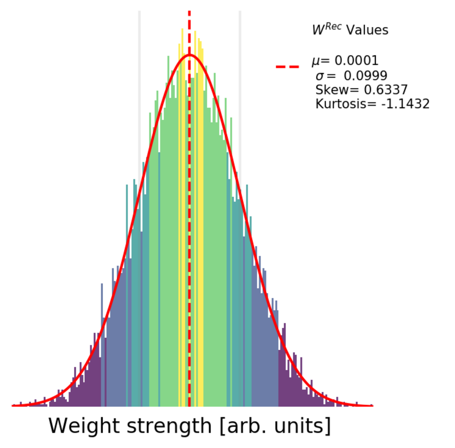
→ Study the properties via population analysis techniques → Statistical studies on weights matrices of trained networks.

A description of the model

- The connectivity matrix W of the RNN rules the dynamics of the system.
- State of the system represented by a point in the N-dimensional space of neural activity: $\frac{dh_i(t)}{dt} = -\frac{h_i(t)}{\tau} + \sigma\left(\sum_j w_{ij}^{Rec} h_j(t) + \sum_j w_{ij}^{in} x_j\right)$
- Different tasks give rise to different behavior in the space state.
- **More on the properties and dynamics:**

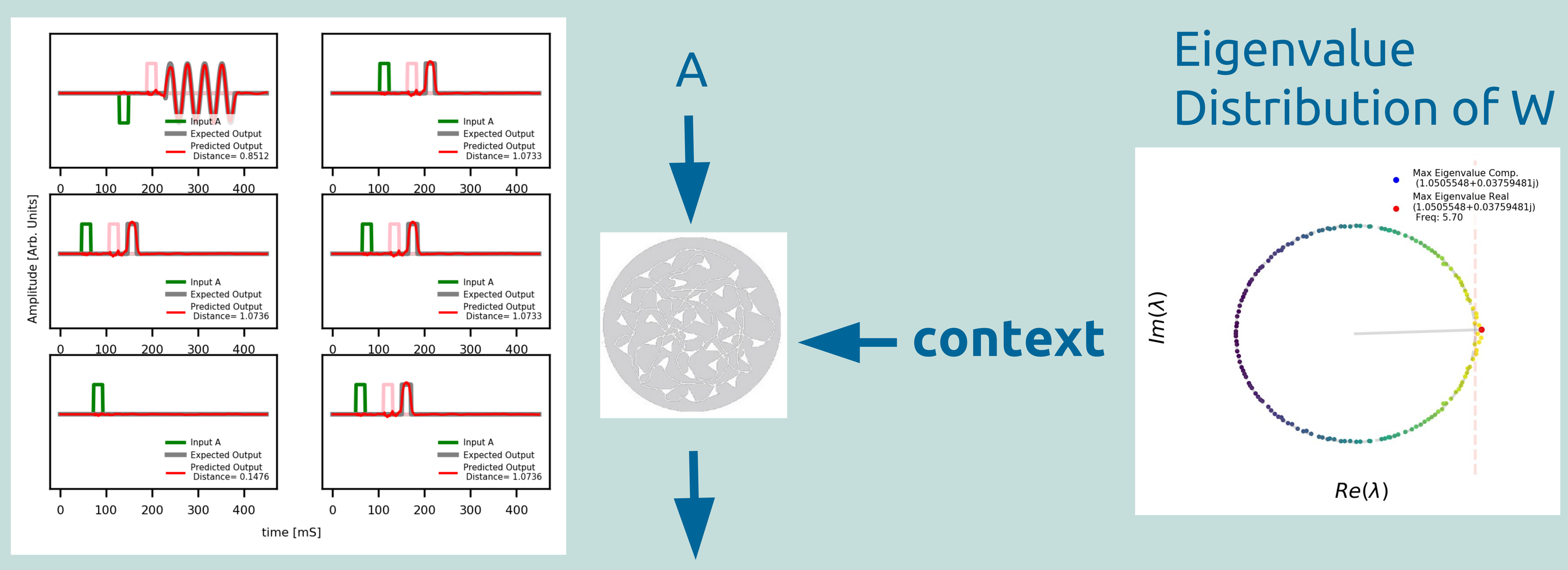
https://arxiv.org/abs/1906.01094
https://arxiv.org/abs/2005.13074

Training the network

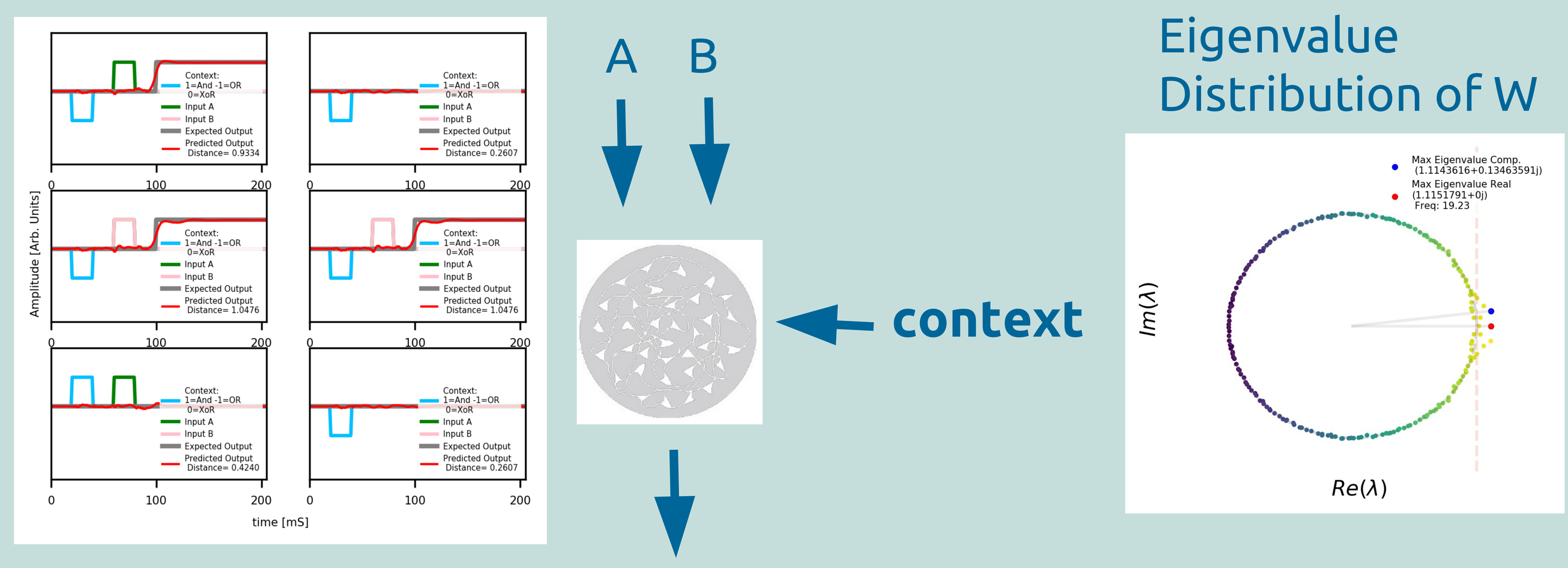


- Supervised learning
- Adaptive SGD training method.
- Initial recurrent weights: orthogonal random normal distribution.
- Noisy input with several training samples.
- Output with simulated time delay answer.

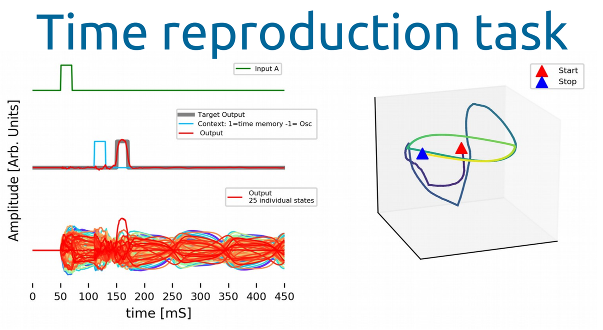
One input tasks with one context input:



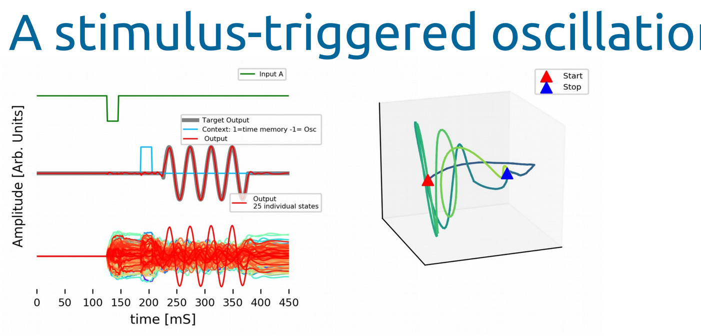
Two input tasks with one context input:

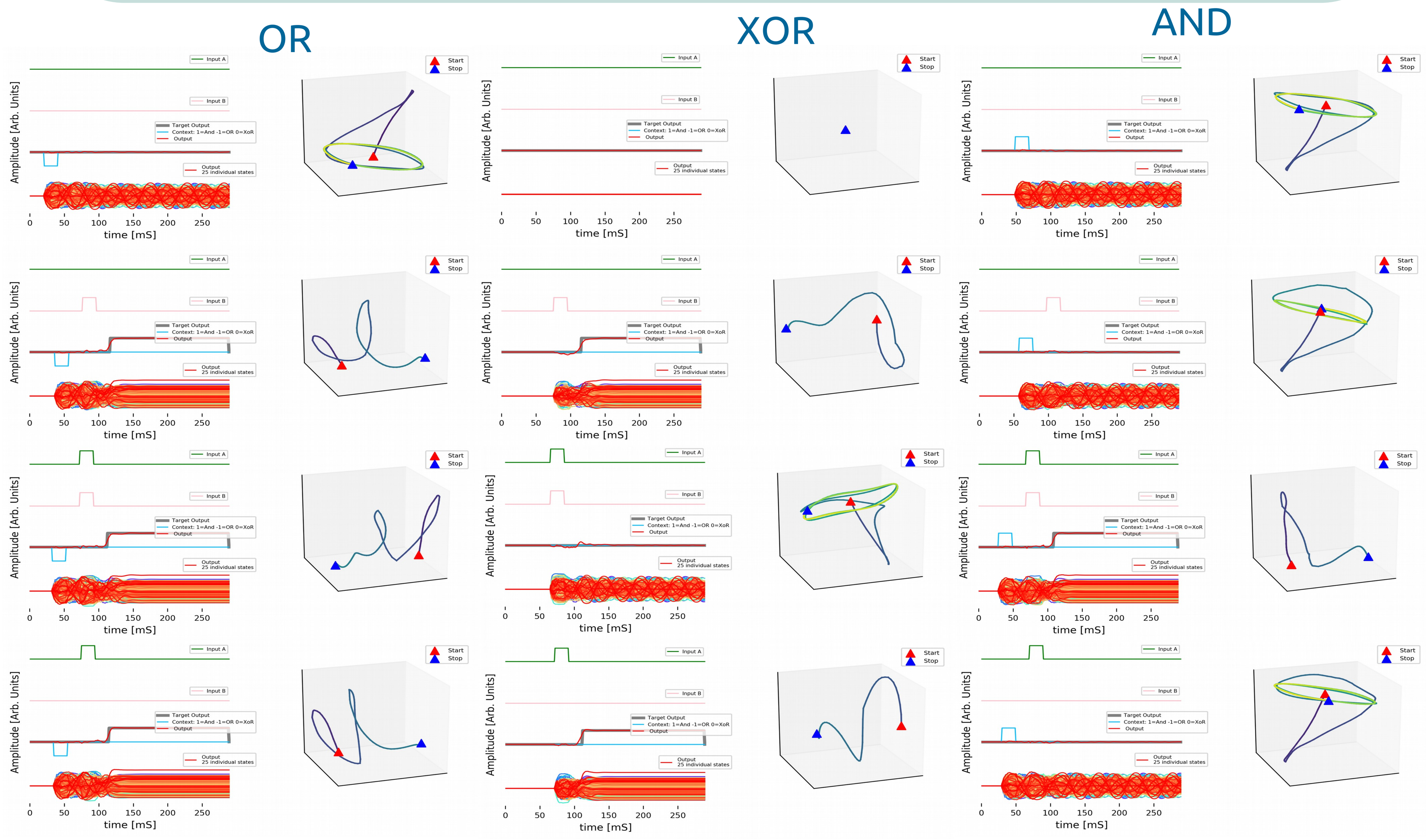


Time reproduction task



A stimulus-triggered oscillation





We chose tasks :

*Relevant to information processing and flow control.

*That traditionally were used in previous works to model the behavior of different brain areas, particularly cortex.

Processing of stimulus as temporal inputs:

1. Time reproduction task.

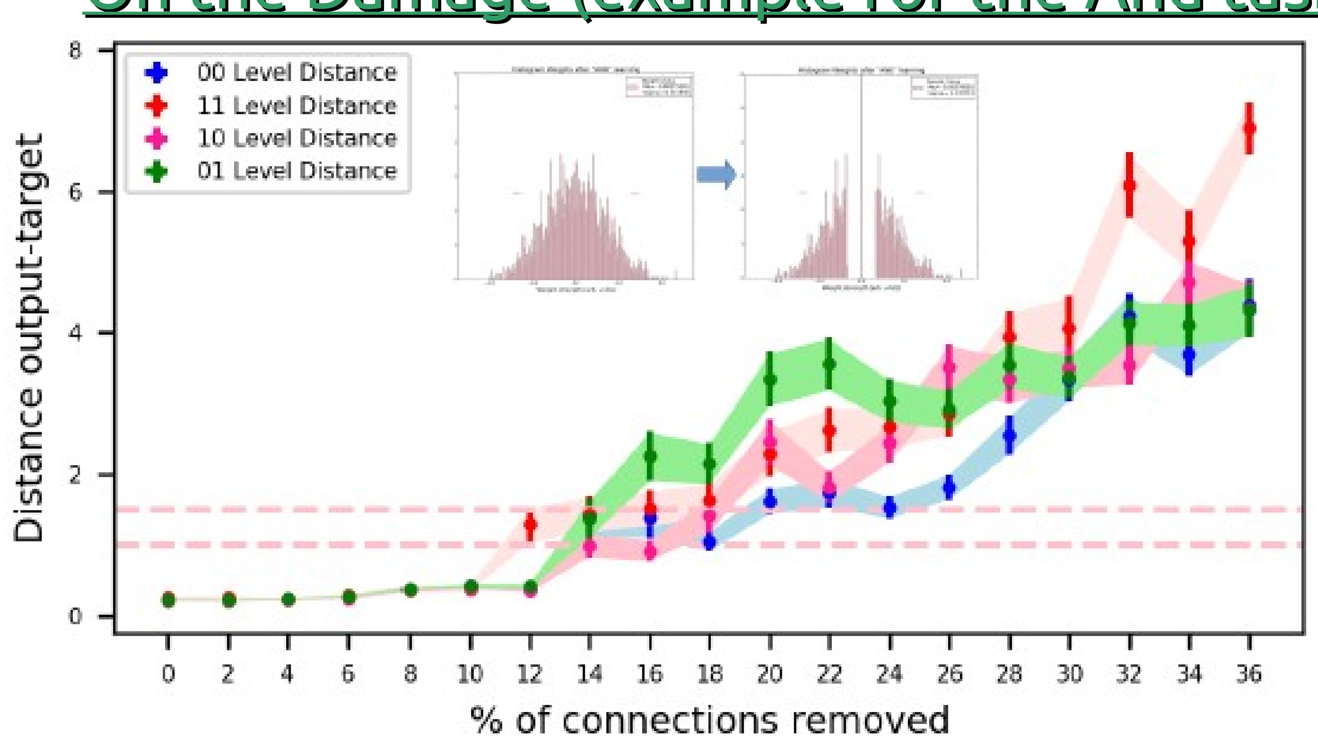
2. Logic gates with temporal stimuli (AND, OR, NOT, XOR)

3. A stimulus-triggered oscillation of a certain duration.

Motivation:

To model the dynamics of the Cerebral Cortex and how it processes the flow of information.

On the Damage (example for the And task):



Network that was previously successfully trained was damage by removing connections. Then the performance of the network was measured as a function of the percentage of lower removed connections. It was in terms of output-target distance for each state. The Dash line shows the limit where the output deteriorates.

Results:

-Successfully used Keras and Tensorflow for training RNN with context multitasking (open source code).

- More units to perform well than one task training, as expected.

- Still a small set of eigenvalues remain outside the circle and dominate dynamics.

-Fix-point and oscillatory states coexist depending on context and input.

-Oscillatory state remains in a manifold **[5]**.

-It is possible to remove between 10 and 12% of the lowest connections before the learned task deteriorates.

Further work

-Further statistical studies on weights matrices.

-Studies with excitatory and inhibitory networks.

-Scaling the network size.

-More complex temporal tasks.

References

[1] Guangyu Robert Yang, Madhura R. Joglekar, Francis Song, William T. Newsome Xiao-Jing Wang. Task representations in neural networks trained to perform many cognitive tasks. 2019 Nature Neuroscience 22(2). DOI:10.1038/s41593-018-0310-2 **[2]** Guangyu Robert Yang, Michael W Cole and Kanaka Rajan. How to study the neural mechanisms of multiple tasks. Current Opinion in Behavioral Sciences 2019, 29:134-143. https://doi.org/10.1016/j.cobeha.2019.07.001 **[3]** Rigotti Mattia, Barak Omri, Warden Melissa R, Wang Xiao-Jing, Daw Nathaniel D, Miller Earl K, and Fusi Stefano. The importance of mixed selectivity in complex cognitive tasks. Nature 2013, 497:585. **[4]** C. Jarne, R. Laje. A detailed study of recurrent neural networks used to model tasks in the cerebral cortex. https://128.84.21.199/abs/1906.01094v2 **[5]** Saurabh Vyas,Matthew D. Golub, David Sussillo and Krishna V. Shenoy Annual Review of Neuroscience Computation Through Neural Population Dynamics.