Dynamics brain-state allocation using echo state network

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Introduction

- We explore the potential of Echo State Networks (ESN) for dynamical brain state allocation of neuroimaging data.
- Brain States are transiently stable and recurrent patterns of activity in the spontaneous EEG or fMRI, thought to represent fundamental computational properties of the brain shaping behaviour and brain function [1].
- The identification of the Brain States and their transitioning is an area of active research [2-4]. Of particular interest are brain state allocation methods that can handle the natural non-linear dynamics of the brain, in a manner that affords subsequent biological interpretability [1].
- ESN is a recurrent neural network with randomly connected neurons, with random weights, acting as a nonlinear dynamic system [5] (Eq. 1).
- Only the weights at the readout layer are adapted [Figure 1]. Here the readout layer comprised cluster labels of the Reservoir nodes in their steady state.

Methods

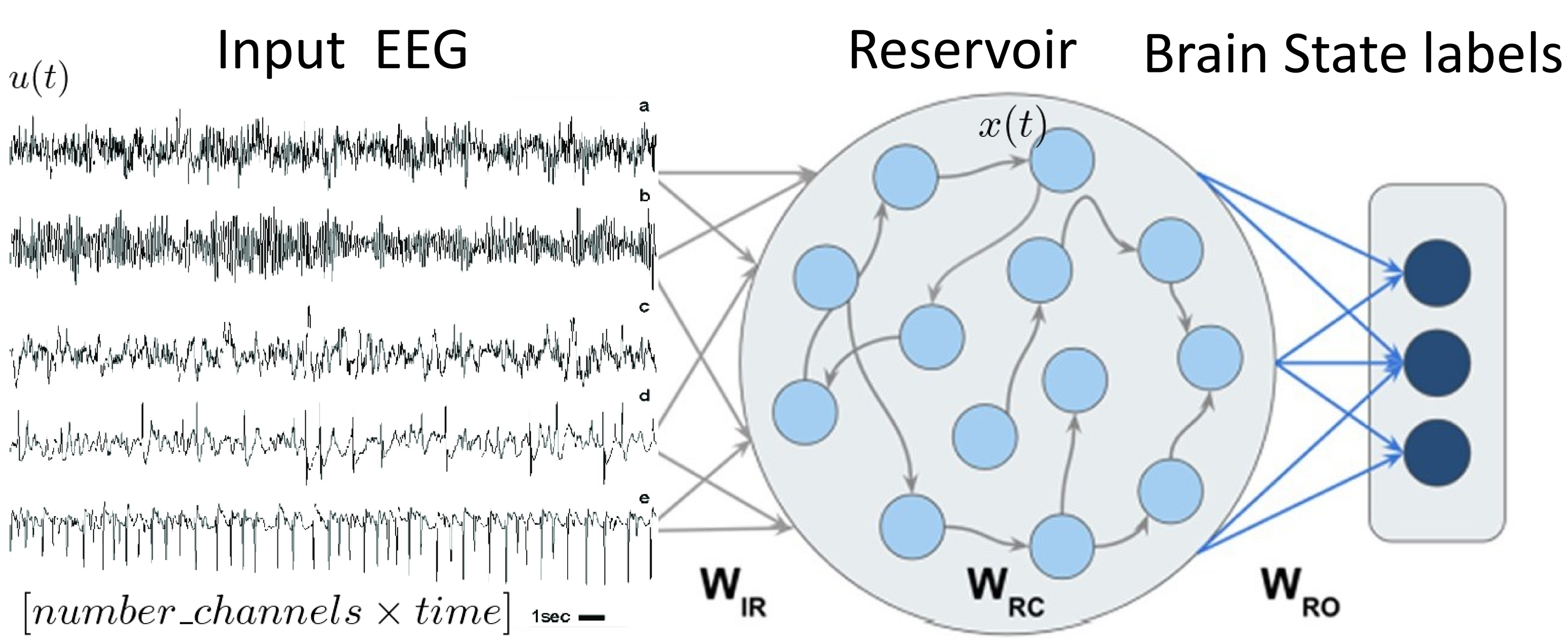

Figure 1. ESN layout. The entire EEG sequence is passed through the Reservoir via random input weights (W_{IR}). The (random) recurrent connections within the Reservoir (W_{RC}) create a representation of the non-linear dynamics underpinning the data with the activation equation of Eq. 1. The output layer (W_{RO}) clusters the Reservoir states, and outputs the cluster which corresponds to the brain state labels. The clustering will be performed using K-means.

$$x(t) = tanh(W_{in}u(t) + W_{RC}x(t-1)) \qquad \text{Eq. 1}$$

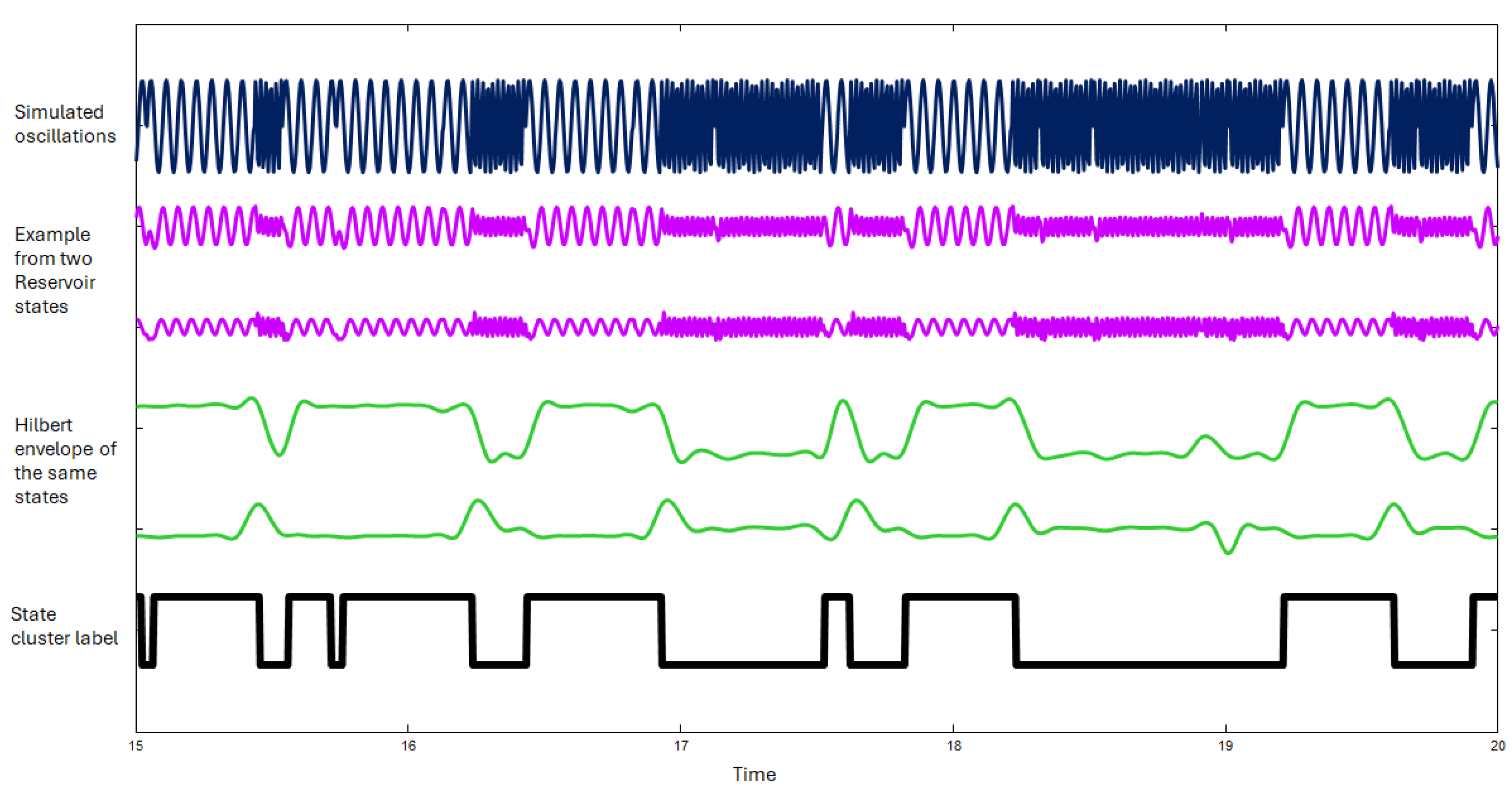

Figure 2. Toy example. A sequence was generated from two randomly switching oscillations (analogous to brain states) at 3.5 Hz and 11.5 Hz for 12 s at a sampling frequency of 55 Hz. The data sequence was fed into a reservoir of 10 fully connected nodes (only two reservoir states are shown in violet). The Hilbert envelope of the reservoir nodes (in green) was clustered resulting in a sequence of state labels (in black). In this case, two states were detected.

Results

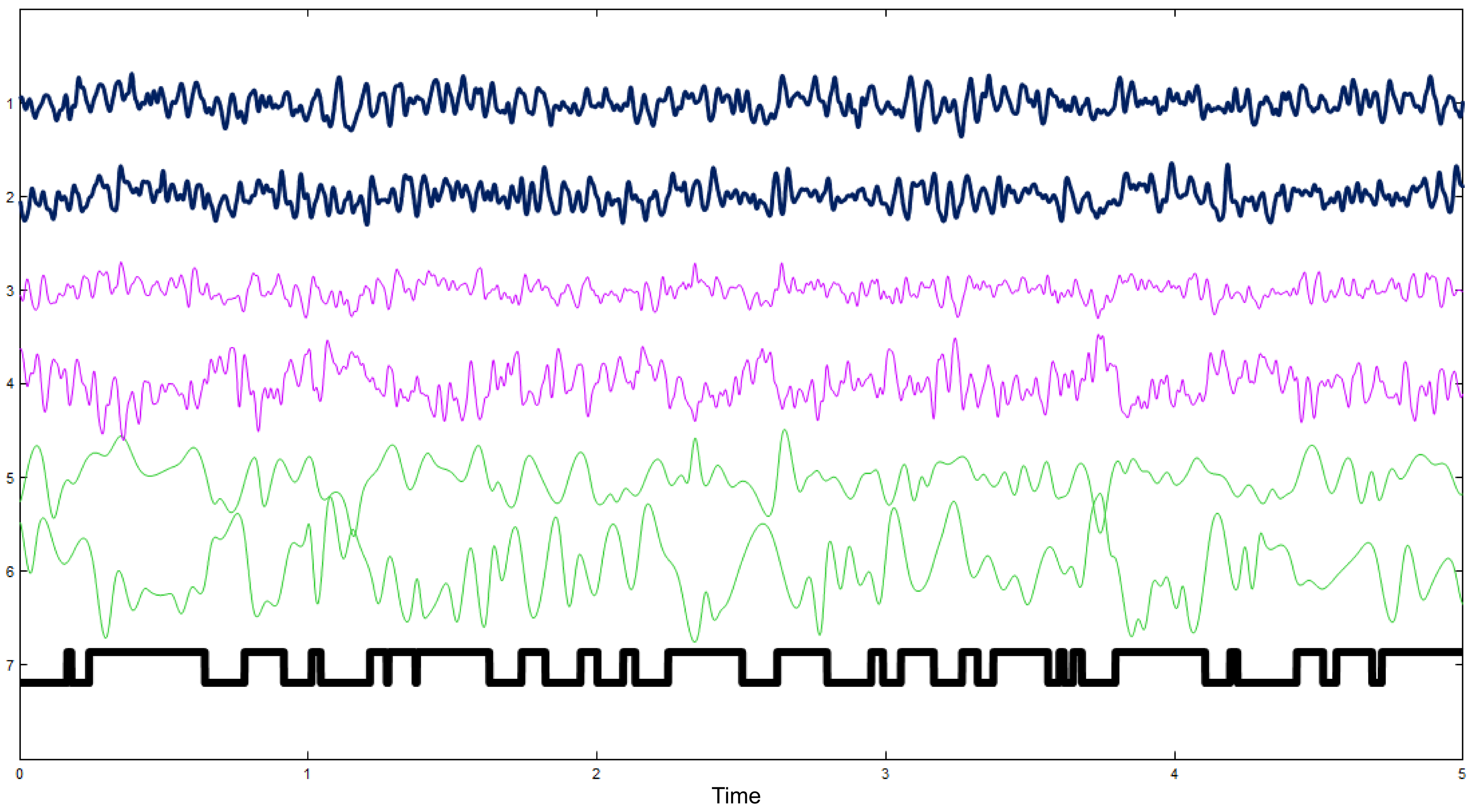

Figure 3. Neural Field model data. EEG-like time series were generated using the thalamo-cortical neural field theory model with fitted parameters for eyes-closed resting state. Two states were detected, remarking the capacity of ESN to assign state labels even in cases likes this one, when resulting Hilbert envelopes have high variance.

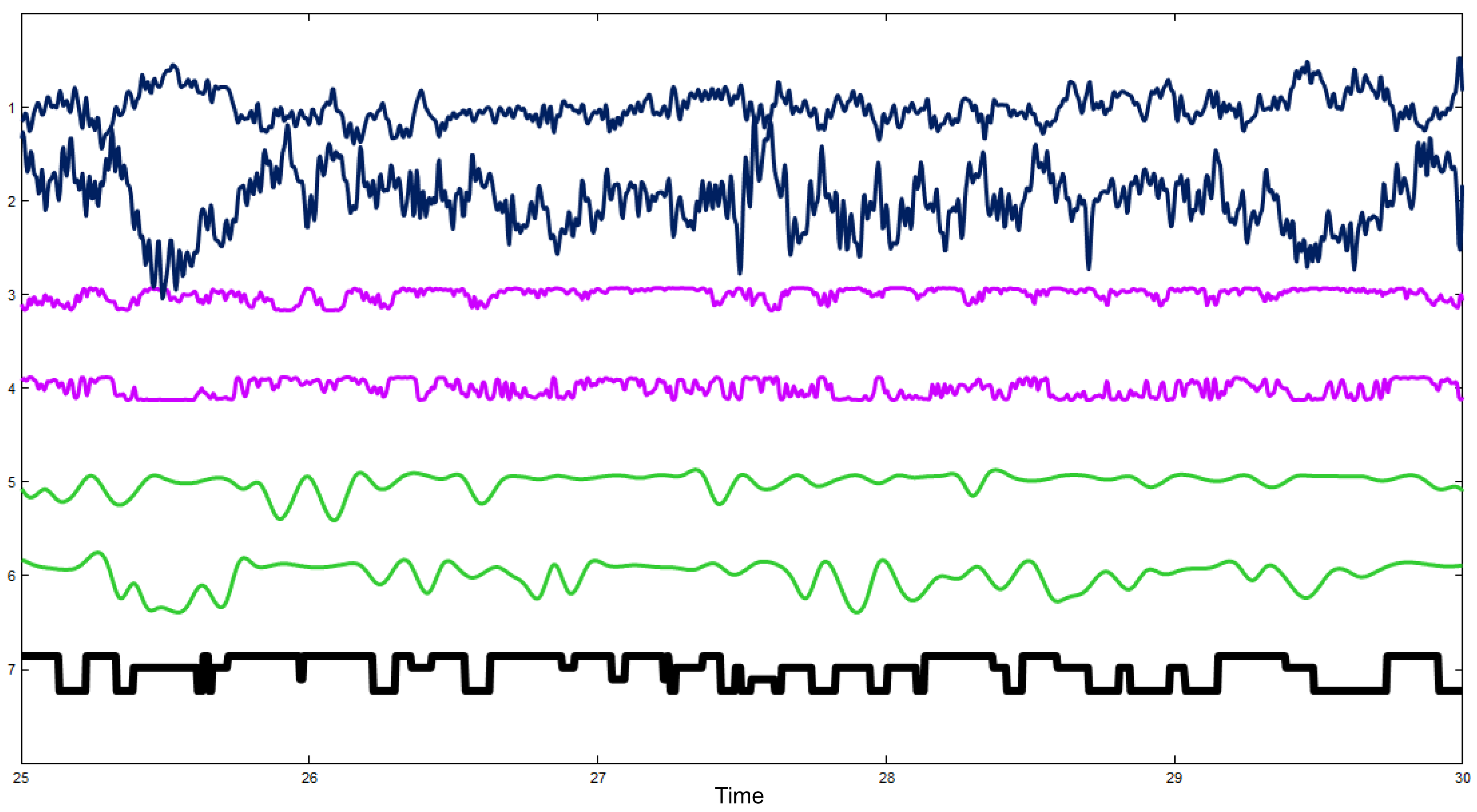

Figure 4. Resting-state EEG. The EEG sequence fed into the reservoir originates from the eyes-open resting-state EEG recording of a young subject. The clustering of the Hilbert envelope of the reservoir nodes resulted in four brain states detected.

Conclusions

- The Echo State Network (ESN) captured the dynamics of the simulated and real electrophysiological data, with the reservoir states providing inputs for k-means clustering to identify quasi-stable Brain States.
- As with other Brain State allocation methods, the number of states requires optimization using model comparison.

References

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