Homework #9 (NEURL-GA 3042, Fall 2022)

Hierarchy of timescales in a multi-regional model of monkey cortex
Due date: Monday December 19

Based on inter-areal connectivity data, a dynamical model was developed for a multi-regional macaque monkey cortex (Chaudhuri R, Knoblauch K, Gariel M-A, Kennedy H, Wang X-J (2015). A large-scale circuit mechanism for hierarchical dynamical processing in the primate cortex. Neuron 88, 419-431). The model was built in three steps: (a) the model structure was constrained by anatomical data, (b) each local area was described by a canonical local circuit model with an excitatory neural population and an inhibitory neural population, (c) spine count per neuron was used as a proxy of excitatory input strength, which displayed a macroscopic gradient along the cortical hierarchy. The code in Python can be found at https://github.com/xjwanglab/book/tree/master/chaudhuri2015, version HW10.py

(1) Simulate the model with the reference parameter values, save the time series of the excitatory neural population $r_{E,k}(t)$ from each cortical area k. Follow the two steps from Chaudhuri et al. (2015) to extract a dominant time constant: (1) compute the autocorrelation function of $r_{E,k}(t)$,

$$ACF_k(\tau) = \frac{< (r_{E,k}(t') - < r_{E,k}(t') >)(r_{E,k}(t+t') - r_{E,k}(t+t') >) >}{< (r_{E,k}(t') - < r_{E,k}(t') >)^2 >}$$

where $< x(t) >$ denotes the time average of x.

(1) Plot $ACF_k(\tau)$ for the 14 areas as in Figure 3C of Chaudhuri et al. (2015). Fit each with either a single exponential function ($\exp(-t/\tau_k)$), or a weighted sum of two exponentials ($w_{k,1}\exp(-t/\tau_{k,1}) + w_{k,2}\exp(-t/\tau_{k,2})$ with $w_1 + w_2 = 1.$) in which case $\tau_k = w_{k,1}\tau_{k,1} + w_{k,2}\tau_{k,2}$. Plot τ_k against the hierarchical position i of area k as in Figure 3D of Chauhduri et al. (2015).

Does the model system show a hierarchy of time constants? What is the range of time constants?

(2) What happens to the time constants when the macroscopic gradient of synaptic excitation is absent in the model (when H_i is replaced by a constant equal to its average over all areas i)?

Bonus. In the control case (1), the system is linear when the input is above threshold for all neural populations. Compute the eigenvalues of this linear system, the real part of each eigenvalue (with a minus sign) is the inverse of a time constant. List and consider all the time constants.

Compute the corresponding eigenvectors, and examine how each of them is spatially distributed (e.g. localized or widespread). Which areas are dominated by fast versus slow time constants? Interpret your findings in terms of functions of different cortical regions (early sensory areas versus higher association areas).