Problem Set May 25: Phase and coherence
Fundamentals of Statistics and Computation for Neuroscientists
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1. Calculate the phase of a neural signal as a function of time
    a. Load data in `lect9hw2N1a.mat`. Calculate the phase time series of the 10Hz frequency component. (HINT: First calculate the continuous wavelet transform of the data and then use the `angle` function). On the top subplot, plot the raw time series overlaid with the real part of the wavelet transformed signal at 10Hz (NOTE: you may need to adjust the scale of one recording in order to see both clearly). On the bottom subplot, plot the phase as a function of time. Label the x and y axes. (HINT: Since you are only interested in the phase at 10Hz, input `[10, 10]` for the `f` variable in `WT_wu.m`.)
    b. Load data in `lect9hw2N1b.mat`. Notice the change in sampling rate. These are neural recordings from the rat hippocampus. Calculate the phase time series of the 8Hz frequency component. On the top subplot, plot the raw time series overlaid with the real part of the wavelet transformed signal at 8Hz. On the bottom subplot, plot the phase as a function of time. Label the x and y axes.
    c. In the phase time series, the theoretical peak occurs at phase 0, and the theoretical trough occurs at phase π/-π. What do you notice about the filtered theta oscillation compared to the raw theta oscillation? What is the relationship between the time of peak voltage in the oscillation and the theoretical peak of the oscillation? (HINT: Hippocampal theta (6-10 Hz) is characteristically sawtooth-shaped as you see in (b). Because of this, some researchers use alternative phase estimates that are not based on a sinusoidal basis like Fourier analysis.)
2. Characterize a phase reset of alpha oscillations in the visual cortex in response to a bright visual stimulus. Load data in `lect9hw2N2.mat`. There is a data array in which each row is the time course of voltage over one trial (the columns correspond to the time array in the same file). Before doing anything, plot the time series of each trial to get an idea of what the data look like (do not turn this in).
    a. Calculate the instantaneous phase of each trial. Plot the phase of the 10Hz component of all trials on the same axis.
    b. Calculate the phase locking value (PLV) at every point in time. Plot PLV as a function of time.
    c. In regards to the Rayleigh z-test, calculate the PLV value corresponding to a p-value of 0.05. I.e. What is the PLV value that a uniform phase distribution would be greater than 95% of the time?
    d. During what time period is the PLV greater than the 95% of what would be expected by chance?
    e. Notice that PLV is significantly greater than chance before time 0. However, when looking at the raw voltage traces, it is clear that the phase reset does not occur until time 0. Why is this the case?

    f. What is the phase of the alpha oscillation at time 0? Is it near the peak or trough? (HINT: Calculate the angle of the mean phase vector)
    g. From this result, what conclusion can you draw about the effect of the bright visual stimulus on alpha oscillations?
3. Coherence between electrodes. Load data in `lect9hw2N3.mat`. There are three data arrays, one for each electrode (`dataA` is electrode A, `dataB` is electrode B, and `dataC` is electrode C). The voltage samples of these arrays correspond to the time array in the same file. Before doing anything, plot the time series of each trial to get an idea of what the data look like (do not turn this in).
    a. Calculate the phase time series for the 6Hz component for each electrode. Plot these time series for the first 2 seconds. Plot all electrodes on the same axis
    b. Calculate the phase-locking value for each electrode pair.
    c. Which two electrodes are most coherent? What is the phase offset between them?
    d. Generate a null distribution for PLV using surrogate statistics. To do this, introduce a random time shift in one of the electrodes in the most coherent pair (Hint: use `circshift`) and recalculate PLV between these electrodes. Perform this 10,000 times and report the number of times you obtained a PLV greater than the original PLV calculated without any time shifting. Divide this number by 10,000 to get your empirical p-value.