Neural Synchronization

Jaeseung Jeong, Ph.D
Department of Bio and Brain Engineering,
KAIST
What is neural synchronization?
Phase synchronization in chaotic systems

- Coupled chaotic oscillators can display phase synchronization even when their amplitudes remain uncorrelated (Rosenblum et al., 1996). Phase synchronization is characterized by a non-uniform distribution of the phase difference between two time series. It may be more suitable to track nonstationary and nonlinear dynamics.
Neuronal oscillations allow for temporal segmentation of neuronal spikes. Interdependent oscillators can integrate multiple layers of information. Neuronal oscillations are a natural mechanism for forming cell assemblies since most brain oscillations are inhibition based, and inhibition can segregate spike train messages. The cerebral cortex generates multitudes of oscillations at different frequencies, but how the various rhythms interact with each other is not well understood.
A well-studied mechanism is cross-frequency coupling. As described first in the hippocampus, the phase of theta oscillations biases the amplitude of the gamma waves [phase-amplitude (P–A) coupling or “nested” oscillations].
What is the role for theta-gamma coupling?
Y Maze Activity: Test for Spontaneous Alternation
What are the key factors for synchrony?

**Oscillations: Definition**

- Oscillations: Rhythmic, periodic fluctuations in the electrical activity of the brain.
- Groups of cells doing same thing at same time
- Correlate with specific behaviors

**Mechanisms of rhythmic synchrony**

- Pacemaker
- Network connections
Nonlinear coupling among cortical areas
Measures of nonlinear interdependency

The brain can be conceived as a complex network of coupled and interacting subsystems. Higher brain functions depend upon effective processing and integration of information in this network. This raises the question how functional interactions between different brain areas take place, and how such interactions may be changed in different types of pathology.
Mutual information of the EEG

• The MI between measurement $x_i$ generated from system X and measurement $y_j$ generated from system Y is the amount of information that measurement $x_i$ provides about $y_j$. 

Recent MI studies on the EEG


Phase synchronization

We then couple the systems at $R_c=0.7 \, \Omega$.

The peaks in the power spectrum are at exactly the same frequency.

• ‘Synchronization of chaos refers to a process, wherein two (or many) systems (either equivalent or nonequivalent) adjust a given property of their motion to a common behavior due to a coupling or to a forcing (periodical or noisy)’ (Boccaletti et al., 2002).
Phase synchronization and interdependence

Definition of synchronization: two or many subsystems sharing specific common frequencies

Broader notion: two or many subsystems adjust some of their time-varying properties to a common behavior due to coupling or common external forcing


Generalized Synchronization

- Generalized synchronization exists between two interacting systems if the state of the response system $Y$ is a function of the state of the driver system $X$: $Y = F(X)$. Cross prediction is the extent to which prediction of $X$ is improved by knowledge about $Y$, which allows the detection of driver and response systems.

- The nonlinear interdependence is not a pure measure of coupling but is also affected by the complexity or degrees of freedom of the interacting systems.