Delayed but not much: the role of inhibition in neuronal synchronization

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Anticipated synchronization (AS) is a phenomenon that can occur when a unidirectional influence from a dynamical system A to another dynamical system B is accompanied by a negative phase, or even time, difference between the dynamics of A and B. In fact, what happens is that B is predicting the future dynamical behavior of A. AS has been proposed in 2000 as a solution for two unidirectionally coupled dynamical systems, when the receiver is subject to a negative delay feedback. Afterwards, AS has been also found in a variety of periodic and chaotic systems both theoretically and experimentally. More recently, anticipated synchronization has been observed in neuronal circuits both in models and experiments. Models included single neuron descriptions based on, e.g., the Hodgkin and Huxley equations, as well as unidirectionally coupled populations of excitatory and inhibitory neurons. In both case, the analysis revealed the important role that inhibitory neurons play in the transition from the more intuitive delayed synchronization to the counterintuitive anticipated synchronization regime.

Granger Causality is one of the most used techniques to measure directional influence to infer, e.g., effective connectivity in the brain. When this index reveals that one region (the sender) strongly influences another (the receiver), a positive phase lag is also often expected. The assumption is that the time difference implicit in the relative phase reflects the transmission time of neuronal activity. However, Brovelli and coworkers (Brovelli, et al., 2004. Beta oscillations in a large-scale sensorimotor cortical network: directional influences revealed by Granger causality. Proc. Natl. Acad. Sci. U. S. A. 101, 98499854. 2004) observed that, in monkeys engaged in processing a cognitive task, a dominant directional influence from one area of sensorimotor cortex to another may be accompanied by either a negative or a positive time delay. This diversity in the observed behaviors can be explained in the framework of AS. By reproducing the experimentally measured delay times and coherence spectra, the modeling results provided a theoretical basis for the underlying mechanisms of the observed dynamics. It also highlighted the role that inhibitory neurons play and suggested the idea that the primate cortex could operate in a regime of Anticipated Synchronization as part of normal neurocognitive function.