

SYNCHRONISATION OF NEURAL ACTIVITY AND INFORMATION CODING

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ABSTRACT

The hypothesis that neuronal code at some stages of information processing in the brain is based on synchronisation of neural activity is under intensive discussions (e.g. see [1, 4, 10]). Synchronous activity of neural assembly demonstrates significant increase of the population rate level and can be considered as a code of significant event. Specific connections of winner-take-all mechanism can make the respond even sharper due to suppression activities of neighbouring populations. This mechanism has been used in many models of attention, memory, etc. [5, 11]. Another important feature of synchronous activity relates to the learning. According to the learning rule, the condition for synaptic modification requires that both pre- and postsynaptic neurons produce spikes inside of 100 msec time window. In terms of synchronisation, it means that the learning procedure requires synchronisation of pre- and postsynaptic activities.

There are many experimental and modelling evidence describing different aspects of synchronisation phenomena. In this paper we consider different approaches to a definition of synchronicity of neural system. Let us formulate some of these numerous definitions for a pair of interactive units (neurons or populations).

1. **In- phase synchronisation.** In this case the units demonstrate the same frequency and zero phase shift.
2. **Anti phase synchronisation.** In this case the units demonstrate the same frequency and a half period phase shift.
3. **Out of phase synchronisation.** In this case both units work with the same frequency and some phase shifts which differ from zero and half period.
4. **Coincidence.** The units demonstrate irregular activity but with a high probability the „event“ (spike or activity maximum) of one unit coincides with „event“ of another unit.
5. **Coincidence with time shift.** The same as above but “events” are separated by a fixed time interval.
6. **Frequency synchronisation.** Two units work with the same frequency or close frequencies but the phase shifts can vary.
7. **Frequency ratio.** The first unit has the frequency ω_1 and the second unit has the frequency ω_2 and the ratio of frequencies is a integer number: $\omega_2/\omega_1 = n$.
8. **Modulated oscillations with a low frequency synchronisation.** Each unit demonstrates quasi-periodic oscillations with high and low frequencies and they are running in phase regarding to the low frequency.
9. **Partial synchronisation.** Some sub-population of the unit demonstrates synchronous activity but another part of the unit work non-synchronously disturbing synchrony. This perturbation is not strong enough to destroy the partial synchronisation mode.

The dynamical regime of partial synchronisation is important and very useful for modelling of neural activity. For example, the input driven neural assembly can demonstrate a dynamical regime of partial synchronisation [3]. It is interesting to note that repetition of the same stimulus will cause synchronous activity of different sub-populations [9]. There are several explanations of this fact: (a) variation of input signal due to a random noise on the sensory level, (b) variations of initial neural activity of the assembly at the beginning of input signal; (c) random variations of numerous incoming signals from other populations, etc.

The synchronisation regimes in system of interactive phase oscillators with star-like coupling have been studied in our papers [3, 8]. In this paper we continue to study the regime of partial synchronisation and consider a system of interactive pacemaker neurons. Spike (burst) generation of a single unit is described by enhanced integrate-and-fire model [2] with added sinusoidal component of membrane potential [6, 7]. Due to this component, the probability of spike (burst) nearby of the sine maximum is high. We consider a frequency of the sine wave as a natural frequency of oscillatory unit. The Peripheral Oscillators (PO) are coupled by reciprocal star-like connections with the Central Oscillator (CO). We study a partial synchronisation of sub-population of POs with CO. Let suppose that connections from CO to PO are identical and equal a , connections from POs to CO are also identical and equal b . We find the bifurcation diagrams on the plane (a,b) which shows the regions of partial synchronisation in the system under variation of natural frequency of CO. These diagrams allow the programming of the dynamical behaviour of the system depending on the parameters. The application to attention focus formation and control is discussed.

Keywords: Pacemaker neuron, partial synchronisation, neural code

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