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Bursting neurons encode the time-dependent phase of the input signals

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Cortical cells operate in different firing modes. Fast spiking cells and regular spiking neurons transform the input synaptic current into fairly regular spike trains. In sensory areas, these spike sequences are known to encode information about external stimuli. Instead, intrinsically bursting neurons exhibit a stereotyped firing behaviour. During slow-wave sleep and epileptic seizures, bursting activity propagates throughout the cortex producing large-amplitude oscillations. Since these rhythmic patterns also arise in culture tissue, synchronous bursting in healthy subjects was originally thought to play only a regulatory role, mainly associated with unconscious processes.

However, in the last decade cortical bursting was also reported to encode sensory information. For example, in cat striate cortex, the length of each burst was shown to be strongly modulated by stimulus orientation [1]. There are other examples in monkey visual cortex, rat barrel cortex and rodent hippocampus [2-4]. In these cases, the activity pattern of the bursting population was different from the one observed during slow-wave sleep: cells were not synchronized, and individual responses were irregular, with a variable number of spikes per burst. In this framework, here we aim at understanding the way in which such burst-mediated codes represent sensory information. To that end, we explore a computational model of a bursting cortical cell driven by different types of input currents. We show that there is a tight correspondence between the number of spikes per burst and the phase of the driving current at burst onset. This is also applicable to stochastic time-dependent input currents, where a downstream decoder reading out the number of spikes per burst may predict the time-dependent phase of the input signal with a precision of roughly p/8.

Our results may help to interpret phase-mediated codes in cortex. For example, in the rodent hippocampus, bursting pyramidal cells encode the location of the animal within the place field in the phase difference between the theta-oscillating local field potential (LFP) and burst initiation [4]. Similarly, cells in primate visual cortex encode significant amounts of sensory information in the phase of firing relative to the LFP [5]. We show that these phase-mediated codes are a consequence of the resonator and integrator behaviour of bursting pyramidal neurons. We also present a robust mechanism to read out the input phase at the time of burst firing that simply consists of counting the number of spikes per discharge.

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