

Chapter 10

Output Stream of Binding Neuron with Feedback

Alexander Vidybida

Bogolyubov Institute for Theoretical Physics, Ukraine

Kseniya Kravchuk

Bogolyubov Institute for Theoretical Physics, Ukraine

ABSTRACT

The binding neuron (BN) output firing statistics is considered. The neuron is driven externally by the Poisson stream of intensity λ . The influence of the feedback, which conveys every output impulse to the input with time delay $\Delta \geq 0$, on the statistics of BN's output spikes is considered. The resulting output stream is not Poissonian, and we look for its interspike intervals (ISI) distribution for the case of BN, BN with instantaneous, $\Delta = 0$, and delayed, $\Delta > 0$, feedback. For the BN with threshold 2 an exact mathematical expressions as functions of λ , Δ and BN's internal memory, τ are derived for the ISI distribution, output intensity and ISI coefficient of variation. For higher thresholds these quantities are found numerically. The distributions found for the case of instantaneous feedback include jumps and derivative discontinuities and differ essentially from those obtained for BN without feedback. Statistics of a neuron with delayed feedback has remarkable peculiarities as compared to the case of $\Delta = 0$. ISI distributions, found for delayed feedback, are characterized with jumps, derivative discontinuities and include singularity of Dirac's δ -function type. The obtained ISI coefficient of variation is a unimodal function of input intensity, with the maximum value considerably bigger than unity. It is concluded that delayed feedback presence can radically alter neuronal output firing statistics.

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“Although a neuron requires energy, its main function is to receive signals and to send them out – that is, to handle information.”

—F. Crick, *The Astonishing Hypothesis*, 1994.

INTRODUCTION

In this chapter, the main goal is to describe in mathematically exact form the output activity of a neuron, which obtains an irregular stream of impulses at its input. As the input stream we take the Poisson stream of randomly emitted impulses. As the neuronal model we take the binding neuron (BN). This model is described in detail in further sections. We consider here three cases, namely, (i) neuron without feedback, (ii) neuron with instantaneous feedback, (iii) neuron with delayed feedback. In each case we obtain exact expression for probability density function of output interspike interval (ISI) lengths distribution, and some other statistical characteristics derivable from the ISI distribution. In all three cases the output ISI distribution differs substantially from the input Poisson stream. In the case (iii) of delayed feedback the output ISI distribution has peculiarity of Dirac δ -function type, which suggests that, due to delayed feedback presence, seemingly structureless input Poisson stream can be transformed into a stream with a pronounced temporal structure. The expressions obtained are checked numerically for specific parameter values. Also numerically, we find the ISI distribution for leaky integrate and fire neuronal model with delayed feedback. The distribution found in this case is qualitatively similar to that for BN with delayed feedback.

BACKGROUND

The role of input spikes timing in functioning of either single neuron, or neural net has been

addressed many times, as it constitutes one of the main problem in neural coding. The role of timing was observed in processes of perception (MacLeod et al., 1988), memory (Hebb, 1949), objects binding and/or segmentation (Eckhorn, 1988; Engel et al., 1991b; Llinás et al., 1994; Leonards et al., 1996). At the same time, where does the timing come from initially? In reality, some timing can be inherited from the external world during primary sensory reception. In auditory system, this happens for the evident reason that the physical signal, the air pressure time course, itself has pronounced temporal structure in the millisecond time scale, which is retained to a great extent in the inner hair cells output (Cariani, 2001). In olfaction, the physical signal is produced by means of adsorption-desorption of odor molecules, which is driven by Brownian motion. In this case, the primary sensory signal can be represented as Poisson stream, thus not having any remarkable temporal structure. Nevertheless, temporal structure can appear in the output of a neuron fed by a structureless signal. After primary reception, the output of corresponding receptor cells is further processed in primary sensory pathways, and then in higher brain areas. During this processing, statistics of poststimulus spiking activity undergoes substantial transformations, see, e.g. (Eggermont, 1991). After these transformations, the eventual pattern of activity is far away from the initial one. This process is closely related to the information condensation (König & Krüger, 2006).

We now put a question: What kind of physical mechanisms might underlie these transformations? It seems that, among others, the following features are responsible for spiking statistics of a neuron in a network: (i) several input spikes are necessary for a neuron from a higher brain area to fire an output spike (see, e.g. Andersen et al., 1990; Gerstner & Kistler, 2002); (ii) a neural net has numerous interconnections, which bring about feedback and reverberating dynamics in the net. Due to (i) a neuron must integrate over a time interval in order to gather enough input impulses

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