SES05-2005-000191

Abstract for an Invited Paper
for the SES05 Meeting of
the American Physical Society

Genesis and Control of bursting activity in a neuronal model

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Neurons are observed in one of four fundamental activity modes: silence, sub-threshold oscillations, tonic spiking, and bursting. Neurons exhibit various activity regimes and regime transitions that reflect their complement of ionic channels and modulatory state. The leech presents unique opportunities for experimental and theoretical studies on the dynamics of neuronal activity. The central pattern generator controlling the leech's heartbeat contains identified pairs of mutually inhibitory neurons. Bursting activity of neurons is an oscillatory activity consisting of intervals of repetitive spiking separated by intervals of quiescence. It has been observed in neurons under normal and pathological conditions. Neurons which are capable of generating bursting activity endogenously play an important role in motor control and other brain functions. Burst duration, interburst interval and spike frequency are crucial temporal characteristics of bursting activity and thus have to be regulated. Application of the bifurcation theory of dynamical systems suggests new mechanism of how bursting activity can be generated by neurons and how burst duration can be regulated. Here we describe two mechanisms for the transition between tonic spiking and bursting. First mechanism describes a smooth, continuous and reversible transition from tonic spiking into bursting in a model neuron. The burst duration increases with no bound as $1/(\boldsymbol{a}\text{-}\boldsymbol{a}_0)^{1/2}$, where $\boldsymbol{a}_0$ is a parameter determining the transition. The characteristic features of this mechanism are that (a) the burst duration can be made arbitrarily long while (b) inter-burst interval does not depend on the parameter. The second mechanism is concerned with bi-stability where simultaneous tonic spiking and bursting activities co-exist in a neuron. The mechanism is based on a saddle-node periodic orbit bifurcation with non-central homoclinic orbits. This bifurcation describes a transition between three qualitatively different types of dynamics of a neuron. If one varies the control parameter $\boldsymbol{a}$ towards the critical value $\boldsymbol{a}_0$ at which the transition from the bistability region to the region where only tonic spiking is observed, the burst duration of the bursting activity becomes proportional to $ln(\boldsymbol{a}\text{-}\boldsymbol{a}_0)$. The interburst interval does not correlate with the burst duration. In terms of neuron's activity these two mechanisms describe a biophysically plausible means for regulation of burst duration. We show how this bifurcation can be found in a Hodgkin-Huxley type model of a neuron and how to identify control parameters determining properties of bursting activity. The work is supported by NIH NS 43098.