Rebound Amplifiers for Discrete-Event Pattern Generation

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1 Rebound Excitability

Rebound excitability (RE) is an important electrophysiological behaviour of biological neurons. It can be defined as the transient depolarization of the neuronal membrane potential following a release from hyperpolarization (i.e. inhibitory current). When this depolarization leads to the firing of one or more action potentials, it is referred to as a post-inhibitory rebound (PIR). This phenomenon has been studied in electrophysiology for more than a century. However, to date, it has received limited attention in the brain-inspired engineering community. In this work, we propose to explore rebound excitability to facilitate the design of discrete-event systems. Both excitation and inhibition can trigger events, but the underlying mechanism and function is quite different. In rebound excitability, it is the sudden release from inhibition that triggers an event.

The inhibitory nature of the PIR mechanism makes it an interesting mechanism for pattern generation. Such mechanism aligns well with the inherently event-based nature of intelligent behaviour, as observed in biology. The intelligent interaction between an actor and its environment occurs predominantly through sensory and actuatory/motor *events*. In this context, the discrete-event network approach may prove to be a suitable methodology for the design of intelligent, event-based interaction between an actor and its environment.

2 Rebound Event Generation and Propagation

The interconnection of a rebound neuron and an inhibitory synapse provides an elementary event mechanism of event relay or amplification. We call such a motif an Inhibitory Rebound Amplifier (IRA). A network of such amplifiers can propagate events. Whenever an IRA receives an inhibitory event at its input, the rebound neuron will emit a PIR. This PIR is fed forward through an inhibitory synapse, completing the inhibition-to-inhibition transformation.

Our talk will illustrate how the intrinsic conductances of the rebound neuron can be modulated to affect the input-output characteristic of the rebound amplifier. In particular, we will analyze neuromodulation mechanisms that make the amplifier more endogenous or more exogenous. In endogenous amplifiers, the only role of the input is to trigger the event, which is entirely determined by the intrinsic properties of the amplifier. In exogenous amplifiers, the duration and strength of the input event influences the shape of the output event. Circuits of endogenous amplifiers result in autonomous behaviours, barely influenced by the environment. In contrast, circuits of exogenous amplifiers can be entrained or modulated by the environment. The key to designing autonomous machines with desirable interaction properties with their environment is to combine endogenous and exogenous properties.

We will also relate this modulatory mechanism to earlier studies of neurophysiological rebound neurons, contrasting the role of two complementary currents. Dethier et al. [1] describe two ionic currents: the hyperpolarization-activated current (I_h), which promotes an exogenous behaviour, and the T-type calcium current ($I_{Ca,T}$), which promotes an endogenous behaviour.

3 Discrete-Event Systems and Networks

The goal of our research is to design intelligent machines from the interconnection of IRAs. The archetype example is the well-studied half-center oscillator (HCO), which consists of two rebound neurons reciprocally coupled through inhibitory synapses. This elementary model is the simplest example of a central pattern generator (CPG), whose existence was hypothesized by T. G. Brown [2] more than a century ago. CPG networks lie at the foundation of multiple vital (rhythmic) functions in biology such as locomotion, digestion, heartbeating and breathing.

Starting from a HCO and the inhibition-to-inhibition motif, we will explore how larger networks can be designed in a modular manner. We will illustrate how to design various patterns with the proposed network design approach. For instance, reflexive behaviour in autonomous robots in the form of a *reflex arc* (e.g. a startle reflex) is simply the propagation of the sensing event into a sequence of actuator events.

References

[1] J. Dethier, G. Drion, A. Franci, R. Sepulchre, "A positive feedback at the cellular level promotes robustness and modulation at the circuit level", *J Neurophysiol.*, 2015

[2] T. G. Brown, "The intrinsic factors in the act of progression in the mammal", *Proc. R. Soc. Lond. B*, 1911

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