An LGN Inspired Detect/Transmit Framework for High Fidelity Relay of Visual Information with Limited Bandwidth

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Abstract. The mammalian visual system has developed complex strategies to optimize the allocation of its limited attentional resources for the relay of behaviorally relevant visual information. Here, we describe a framework for the relay of visual information that is based on the tonic and burst properties of the LGN. The framework consists of a multi-sensor transmitter and receiver that are connected by a channel with limited total bandwidth. Each sensor in the transmitter has two states, tonic and burst, and the current state depends on the salience of the recent visual input. In burst mode, a sensor transmits only one bit of information corresponding to the absence or presence of a salient stimulus, while in tonic mode, a sensor attempts to faithfully relay the input with as many bits as are available. By comparing video reconstructed from the signals of detect/transmit sensors with that reconstructed from the signals of transmit only sensors, we demonstrate that the detect/transmit framework can significantly improve relay by dynamically allocating bandwidth to the most salient areas of the visual field.

1 Introduction

The mammalian early visual pathway serves to relay information about the external world to higher brain areas where it can be analyzed to make decisions and govern behavior. However, this relay is constrained by the availability of limited attentional resources. Because mammals can only attend to a small fraction of the visual field at any given time, the early visual pathway must carry out two distinct tasks: the detection of salient input to direct the deployment of attentional resources and transmission of detailed features of those stimuli to higher brain areas. Neurons in the lateral geniculate nucleus (LGN) of the thalamus have two response modes known as tonic and burst, and there is evidence that these response modes serve to facilitate the tasks of detection and transmission (for review, see [1,2]).

The LGN relays the output of the visual system's peripheral sensors in the retina, making both feedforward and feedback connections with the visual system's computational center in the cortex. The response mode of an LGN neuron is determined by the state of a special set of low-threshold voltage-dependent channels

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known as T channels [3]. When the membrane is depolarized and the neuron is firing frequently, the T channels are inactivated, and the neuron is in tonic mode. In tonic mode, the spontaneous firing rate is high, and modulations in the response are linearly related to modulations in the visual input, allowing the neuron to faithfully relay both excitatory and inhibitory features to the cortex. When the membrane is hyperpolarized for a prolonged period of time and the neuron is silent, the T channels are de-inactivated and the neuron enters burst mode. When the neuron is in burst mode, depolarization of the membrane opens the T channels, resulting in a wave of current which further depolarizes the membrane and causes a stereotyped burst of closely spaced action potentials. This allows the neuron to signal the appearance of a input with an amplified response.

During visual stimulation, the membrane potential (and thus, response mode) of an LGN neuron is controlled in part by feedback connections from the cortex [4]. Thus, the thalamocortical circuit is thought to perform both detection and transmission as follows: In the absence of a salient input, the membrane is hyperpolarized, the T channels are de-inactivated, and the neuron is in burst mode. Upon the appearance of a salient stimulus, the membrane is briefly depolarized and a burst is triggered. Cortical feedback then maintains the depolarization of the neuron, switching it to tonic mode and increasing the spontaneous firing rate. While the stimulus persists, tonic firing transmits detailed information about the stimulus. When the stimulus disappears, the neuron falls silent, cortical feedback hyperpolarizes the membrane, and the cycle repeats. This silence/burst/tonic/repeat response pattern has been observed in both anesthetized and awake animals, in the LGN responses to sinusoidal gratings [5,6] and natural scene movies, as objects moved in and out of the receptive field [7].

Here, we develop a detect/transmit framework for the relay of visual information based on the tonic and burst properties of the LGN. The framework consists of a multi-sensor transmitter (LGN) and receiver (cortex) that are connected by a channel with limited total bandwidth (attention). Each sensor in the transmitter has two states: tonic and burst. In burst mode, a sensor transmits only one bit of information corresponding to the absence or presence of a salient stimulus. In tonic mode, a sensor attempts to faithfully relay the visual input with as many bits as are available. The mode of each sensor is determined by the salience of the recent visual input. To evaluate the detect/transmit framework, we compare video reconstructed from the outputs of detect/transmit sensors with that reconstructed from the outputs of transmit only sensors. The results demonstrate that the detect/transmit framework can significantly increase the fidelity of relay by dynamically allocating bandwidth to the most salient areas of the visual field.

2 A Detect/Transmit Framework for the Relay of Visual Information

Based on the tonic and burst properties of the LGN that facilitate the detection and transmission of visual inputs, we have developed a framework for the high