Extracting knowledge from data recorded in primates visual system

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Abstract. The brain, as an assembly of relatively slow units—neurons—processes complex information in an extremely fast, effective way. *How is this done?* Our central hypothesis is that each neuron is tuned to a large number of attributes in a unique way, and responds to *simultaneous* changes in the respective properties of *all* the attributes. This is in contrast to the usual hypothesis of experimentalists, who register a neuron's response to a change in only one attribute of the stimulus at a time, and assume that interactions with other attributes are noise. The question, therefore, is: what criteria should be used to differentiate something that is simply noise from an important property of the brain? In anesthetized monkey, we have analyzed large amounts of data from the cells in the lateral geniculate nucleus (LGN)—which is the second station after the retina in the visual pathway and which sends to and gets information from the visual cortex. We have shown that the visual system works not as a hierarchical system but as a network of strongly coupled subsystems. In particular, the receptive fields (RF's) in the higher cortical areas, with larger sizes and more complicated properties, have strong multiplicative influences on the RF's in lower structures. As a consequence, when we look into regularities in properties of the RF's in lower structures, they have large residual values related to more complex RF's or stimuli attributes, which by most experimentalists will be dismissed as error.

Keywords: lateral geniculate nucleus, visual cortex V1, backprojection, data mining, 49er.

1 Introduction

The brain, as an assembly of relatively slow neurons, processes complex information in an extremely fast and effective way. How is this done, has been the subject of extensive research. We analyze the functioning of the early parts of the visual system. Our empirical data come from the lateral geniculate nucleus (LGN, thalamus), which is the second station after the retina in the visual pathway and which sends information to the visual cortex.

2 Background

It was assumed that thalamus transfers information in a feedforward manner, so that neural responses are relative simple, and attributes of the visual stimulus presented in the receptive field of each LGN are determined locally. In accordance with that theory, the definition of the classical receptive field (RF) of a neuron in visual cortex assumes that the neuron responds only to stimulation from a certain, limited area of the visual field. Recently it has been shown, however, that stimuli from outside of the classical RF which, by themselves, do not evoke any response from the neuron, can *modulate* responses evoked from the classical RF (Sillito *et al.*, 1995). Recent research suggests a strong feedback from responses that form in the visual cortex on the activity of the thalamic neurons (Przybyszewski *et al.*, 1998, 1999; Sillito *et al.*, 1994; Sherman and Koch, 1986). Our central hypothesis is that each LGN neuron recognizes changes of a large number of attributes of the visual stimulus, and responds to combinations of attribute values in specific ways. This is in contrast to the usual hypothesis of experimentalists, who register a neuron's response to change in only one attribute of the stimulus at a time, and assume that interactions with other attributes are noise.

3 Data collection methods

Standard surgical and anesthetic procedures were used (Jacobson *et al.*, 1993). After initial anesthesia (Ketamine 10-15 mg/kg, Brevital in increments of 3 mg/kg, respiration with a mixture of 70% nitrous oxide and 30% oxygen) and loading with a bolus of sufenta (Sufentanil) (2 μg/kg) in individual doses, we infused at a rate starting at 2 μg/kg/hr, with upward adjustments in dose whenever any significant increases in arterial blood pressure or heart rate were observed. Doses greater than 2 μg/kg/hr were generally needed, but we started with this dose to avoid severe hypotension. Monkeys were paralyzed by continuous infusion of Pavulon (pancuronium bromide) (0.2 mg/kg per hr) in 5% dextrose and saline. Two recording microelectrodes were placed, one in LGN, and the other one in the visual cortex. The visual stimuli presented on the computer's monitor were drifting sine-wave gratings (Lennie *et al.*, 1990). The visual cortex (are a V1) was inactivated by cooling its surface.

4 Data analysis methods

Our currently collected data are on the order of several millions data points, while the experiments continue. Independent variables include properties of visual stimuli, such as contrast, spatial and temporal frequencies and size, in various combinations, with or without selectively inactivating the higher visual structures. Each experiment must be repeated many times. A single recording for each experimental condition produces 2000-5000 spikes. In search for the right

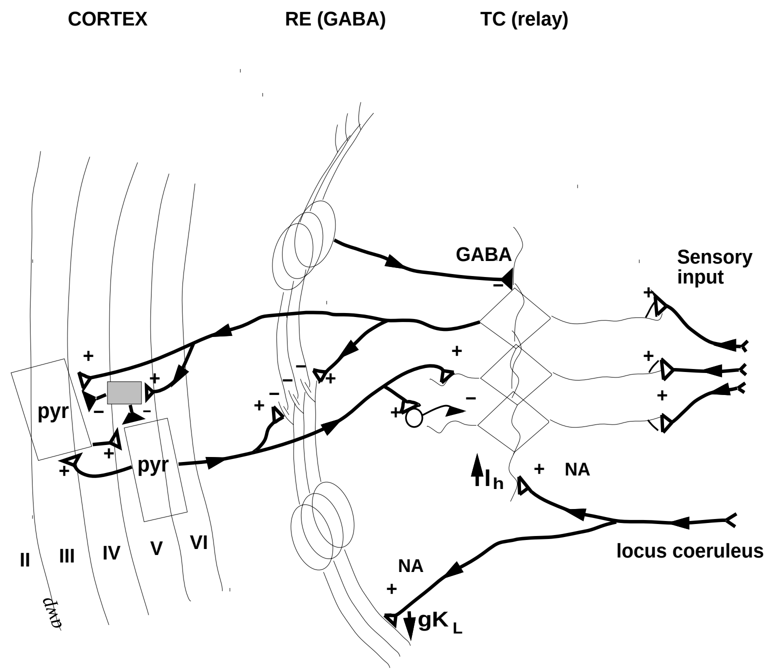

Fig. 1. Schematic diagram of different connections between LGN and primary cortex; RE - reticular thalamic nucleus, TC - thalamic relay LGN cells, pyr - pyramidal cells in cortex, open triangles - excitatory synapses, black triangles - inhibitory synapses. Influence of the noradrenergic neurons of the locus coerules on RE and TC cells was shown as an example. Other systems like serotoninergic, cholinergic and histaminergic also interact with transittion of the information from retina to cortex.

language to relate responses to independent attributes and the investigated structures of visual neurons, a sequence of spikes can be converted into many dependent attributes, that capture different properties of each sequence of spikes, such as the mean responses to the stimulus, different frequency components in the spike trains, and many others. The space of all attributes has so many dimensions that the "manual" search is unlikely to succeed.

Different forms of knowledge that can be captured by the discovery system 49er (Zytkow & Zembowicz, 1993, 1997) have immediate relevance to the objectives of this research. One of the main tasks is differentiation between noise and the complex response patterns. To prove our hypothesis we must demonstrate that specific neuron's responses to complex visual stimuli can be separated from what has been previously treated as noise. Separation of noise and statistically significant relations is a computationally complex problem. The main object of our study – thalamus is the station with enormous number of interactions between different systems (e.g. see Fig.1). Our evolutionary metaphor treats is as a symbiosis of noise and regularities. Many criteria must be tried, and many properties of the response must be examined before those are found which show the relations in the most clear form.

Contingency tables can express statistical properties of LGN cells responses to stimuli. Some contingency tables capture individual attributes of the stimulus and relate them to different attributes extracted from the spike trains. Other tables can capture jointly several attributes of the stimulus and relate them to one or more properties extracted from spike trains. One type of contingency tables can summarize the experimental situations when backprojecting pathways from the cortex to the LGN are intact, and another when they are inactivated by cortex cooling. By comparing these contingency tables, our mechanism should be able to find functions (equations) describing properties of the LGN cells in these two conditions, are determined not only by the contrast and activity of backprojecting pathways, but that they are also dependent on the other attributes, like the size of the stimulus. In the next step, we added to contingency tables another attribute: the spatial frequency which characterize the changes in the RF size. In this way, using knowledge discovery machinery, we have extracted and described those attributes of visual stimuli which play the most critical roles in the visual recognition process for different cells and in different experimental situations.

5 Summary

We have investigated the effects of feedback from primary visual cortex (V1) upon the activity of cells in the lateral geniculate nucleus (LGN). From cortical cooling experiments we find that the effect of feedback, as reflected in the contrast response curve, is more complicated than a simple excitation or inhibition. A model of this interaction suggests that corticofugal feedback consists of two components, a contrast-dependent excitation and a baseline inhibition.

A comparison of an additive model of extended surround/classical center interaction is shown to be insufficient to account for data measuring feedback-mediated responses to grating stimulation. The complexity and subtlety revealed by these feedback interactions lend further weight to the concept that the LGN, far from being a mere relay station, performs sophisticated top-down-dependent processing of visual information.

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