



Bayesian network modeling of the consensus between experts: An application to neuron classification



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ABSTRACT

Neuronal morphology is hugely variable across brain regions and species, and their classification strategies are a matter of intense debate in neuroscience. GABAergic cortical interneurons have been a challenge because it is difficult to find a set of morphological properties which clearly define neuronal types. A group of 48 neuroscience experts around the world were asked to classify a set of 320 cortical GABAergic interneurons according to the main features of their three-dimensional morphological reconstructions. A methodology for building a model which captures the opinions of all the experts was proposed. First, one Bayesian network was learned for each expert, and we proposed an algorithm for clustering Bayesian networks corresponding to experts with similar behaviors. Then, a Bayesian network which represents the opinions of each group of experts was induced. Finally, a consensus Bayesian multinet which models the opinions of the whole group of experts was built. A thorough analysis of the consensus model identified different behaviors between the experts when classifying the interneurons in the experiment. A set of characterizing morphological traits for the neuronal types was defined by performing inference in the Bayesian multinet. These findings were used to validate the model and to gain some insights into neuron morphology.

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1. Introduction

The morphologies, molecular features and electrophysiological properties of neuronal cells are extremely variable [1–4]. Neuronal morphology is a key feature in the study of brain circuits, as it is highly related to information processing and functional identification. Except for some special cases, this variability makes it hard to find a set of features that unambiguously define a neuronal type [3]. In addition, there are distinct types of neurons in particular regions of the brain. Indeed, neurons in the cerebral cortex can be classified into two main categories based on their morphology: pyramidal neurons and interneurons (Fig. 1). In general, pyramidal neurons are excitatory (glutamatergic) cells which display spines in their dendrites and have an axon which projects out of the white matter. Their name refers to the pyramidal shape of their soma. Interneurons are cells with short axons that do not leave the white matter and their dendrites show few or no spines. These interneurons appear to be mostly GABAergic (inhibitory) and constitute ~15–30% of the total neuron population, but they display chemical, physiological and synaptic heterogeneity [3]. Thus, the identification of classes and subclasses of interneurons is clearly critical for gaining a better understanding of how these cell shapes relate to cortical functions in both health and disease. This paper focuses on GABAergic interneurons, which also show a remarkable morphological variability between species, layers and areas [5]. The Internet has made it possible for researchers to share digital three-dimensional reconstructions of neuronal morphology in publicly accessible databases [6,7]. With such amount of available data, a com-

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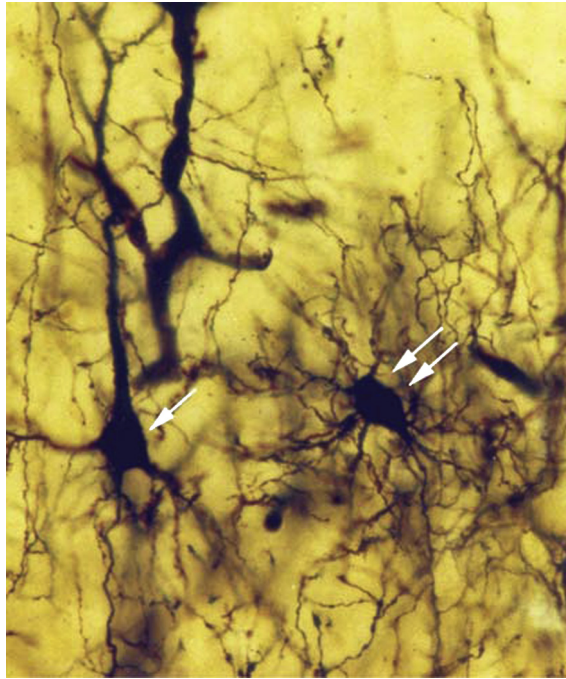


Fig. 1. Photomicrograph from Cajal's preparation of the occipital pole of a cat stained with the Golgi method, showing a pyramidal cell (one arrow) and an interneuron (neurogliaform cell) (two arrows). From DeFelipe and Jones (Cajal on the Cerebral Cortex, Oxford University Press, New York, 1988).

mon nomenclature for naming cortical neurons is a crucial prerequisite for advancing in our knowledge of neuronal structure [3,8].

Bayesian networks [9,10] are a kind of probabilistic graphical model that provides a natural way of modeling uncertainty in artificial intelligence. Therefore, they have been successfully applied across a large number of problems from very different domains [11]. Bayesian networks are specially well suited for modeling and incorporating expert's knowledge, although this kind of analysis has not been applied to its full potential for neuron classification. There are two approaches for integrating this information into a Bayesian network. First, we can elicit both the structure [12] and the parameters [13] of the Bayesian network. Second, we can build a dataset which reflects the behavior of the expert and learn a Bayesian network from the data. This paper focuses on the second approach, i.e., a consensus Bayesian network is built based on data which reflects expert opinions.

We present a methodology for building a Bayesian network that models the opinions of a group of experts. First, a Bayesian network was learned for each expert, representing his/her behavior in the classification task. Second, a clustering algorithm was run on the Bayesian networks to find groups of experts with similar behaviors, and a representative Bayesian network was induced for each cluster of experts. Expert behavior when classifying the set of interneurons was extremely variable. Therefore, experts with similar behaviors have to first be clustered and then combined. Otherwise, combining all experts behaviors into a single consensus model would presumably hide some of these differing behaviors [14,15]. In this way, we can explicitly model each group of similar experts as a representative Bayesian network for the cluster. Third, the final consensus model was a Bayesian multinet [16] encoding a mixture of Bayesian networks [17,18], where each component was the Bayesian network which represented the opinions of a cluster of experts. A similar idea has been proposed for case-based Bayesian networks [19,20], where the authors cluster the observations before learning a Bayesian network which captures the different properties of each cluster. Bayesian multinets are a kind of asymmetric Bayesian network which allows to model different statistical (in)dependencies between the variables for different values of a distinguished variable. Bayesian multinets can capture local differences between variables and model the problem domain more closely, allowing for sparser models and more robust parameter estimation. For instance, they have been shown to outperform other Bayesian network models in supervised classification problems [21].

The model was studied at length to validate the proposed methodology and to gather useful knowledge for neuroscience research. The resulting consensus Bayesian multinet can be used to analyze the behavior of a set of experts and to reason about the underlying classification task. The representative Bayesian networks for each cluster can be compared to find similarities and differences between groups of experts and to identify different behaviors or currents of opinion. Also, we can use the consensus model to reason about the task the experts were asked to perform. For instance, we can introduce some evidence into the consensus Bayesian multinet and infer "agreed" answers to those queries. These "agreed" answers could be compared to those obtained by each representative Bayesian networks to find clusters of experts with outlying behaviors against experts with moderate opinions.

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