A Review of:
"Influence of dendritic structure on firing pattern in model neocortical neurons"

Zachary F. Mainen & Terrence J. Sejnowski, Nature 1996

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Research Objectives

The goal of this research project was to study this seminal paper as an introduction to the field of computational neuroscience, from a background of theoretical physics.

Background

This paper aimed to gain a clearer understanding of how morphology, specifically dendritic structure, affects neuronal activity. Previously, variations in firing patterns had been attributed mainly to differences in ionic channel properties rather than dendritic structure.

Method

Four types of neurons were studied, with varying morphologies (Fig. 1). Different firing patterns were observed, corresponding to the different dendritic geometries. A reduced two-compartment model was examined in order to investigate the effects of dendritic electrical structure on firing patterns, as defined by the axo-somatic to dendritic membrane area ratio (ϱ), and coupling resistance ($\boldsymbol{\kappa}$).

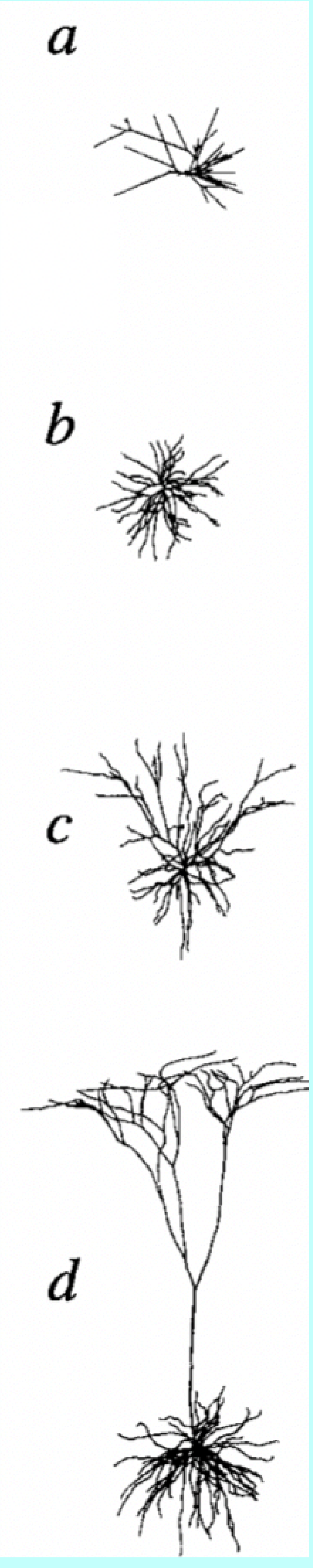

Fig. 1

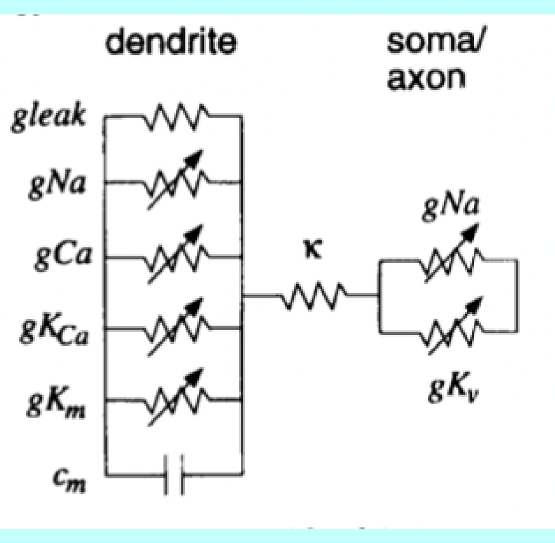

Fig. 2

Fig 1. Digital reconstruction of the four different types of neurons investigated from rat cortex (a) and cat cortex (b,c,d) , in order of increasing dendritic arborizations. a) Smooth stellates. b) Layer 4 spiny stellates. c) Layer 2 and 3 pyramidal neurons. d) Layer 5 pyramidal neurons.

Fig 2. Two-compartment circuit model of neuron.

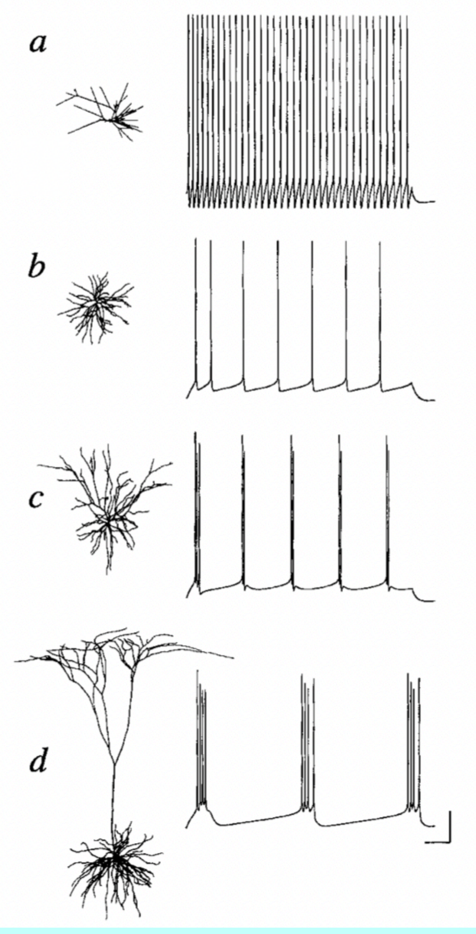

Fig. 3. Different firing patterns produced by dendritic structures

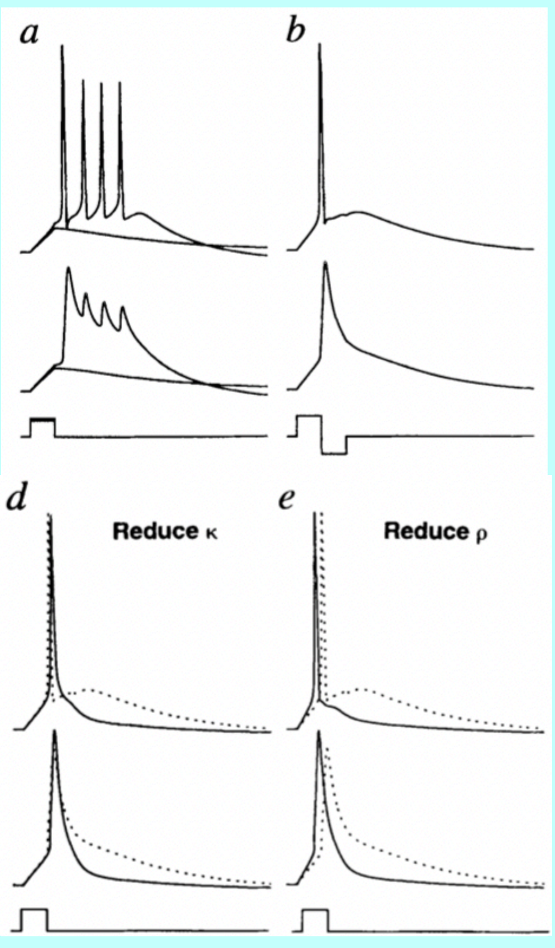

Fig. 4. Spike after-depolarisation (ADP) and bursting

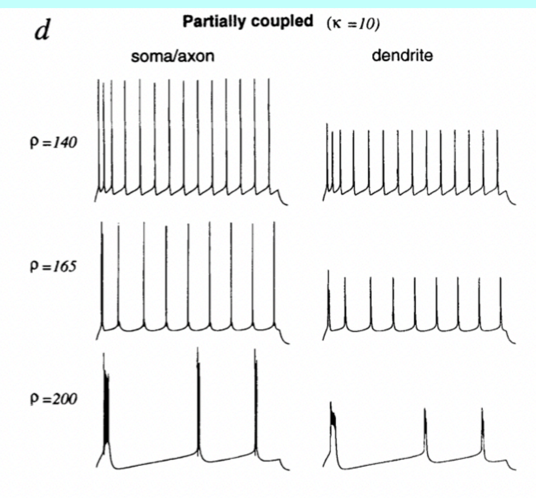

Fig. 5. Effects of variations in ϱ

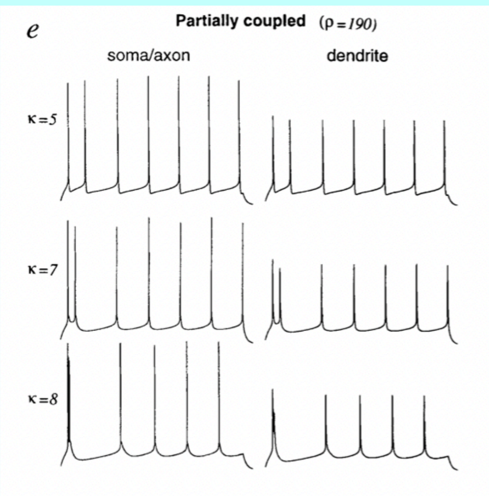

Fig. 6. Effects of variations in $\boldsymbol{\kappa}$

Results

It was found that different morphologies produced a wide range of firing patterns. Fig. 3 shows non-adaptive, adaptive and burst firing in neurons with the same channel types and densities, but different morphologies.

Fig. 4 shows that dendritic Na+ channels were critical to ADPs and bursting. Bursting could be supressed when the inital current pulse was followed by a short hyperpolarising pulse (Fig 3*b*). Reducing $\boldsymbol{\kappa}$ and ϱ also reduced the delayed depolarisation, supressing ADPs and bursting (Fig 3*d*,*e*).

When the dendritic and axo-somatic compartments were fully coupled ($\boldsymbol{\kappa}$=0), only a limited set of firing properties were produced (not shown). With a weak to moderate coupling strength, a full range of firing patterns was produced. Small changes in $\boldsymbol{\kappa}$ or ϱ resulted in dramatic changes in firing pattern (Fig. 5, 6).

Conclusions and Discussions

This paper challenges the previously common assumption that variation in firing patterns depends primarily on ionic channel variation and is largely independent of dendritic structure.

Using compartmental models of reconstructed cortical neurons with evenly distributed ionic channels, it was proved that an entire spectrum of firing patterns can be obtained depending solely on variations in dendritic morphology.

This suggests that several aspects of the heterogeneous firing properties of neocortical neurons can be explained by heterogeneity in their dendritic structure, and emphasizes the importance of active dendritic conductances in neuronal function.

References:

Mainen, Z., Sejnowski, T. Influence of dendritic structure on firing pattern in model neocortical neurons. *Nature* 382, 363-366 (1996). https://doi.org/10.1038/382363a0

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