A method for the estimation of distal dendro-dendritic gap-junctional parameters

Isak Falk, Yulia Timofeeva

i.falk@warwick.ac.uk, y.timofeeva@warwick.ac.uk

Complexity Science, University of Warwick, Gibbet Hill Road, Coventry, CV4 7AL

Background

Neurons are specialised cells which form the fundamental computing unit of the brain and the central nervous system. Each neuron consist of a cell body, dendrites and an axon, where the dendrites receive pulses of voltage from other neurons axons, which act like an output.

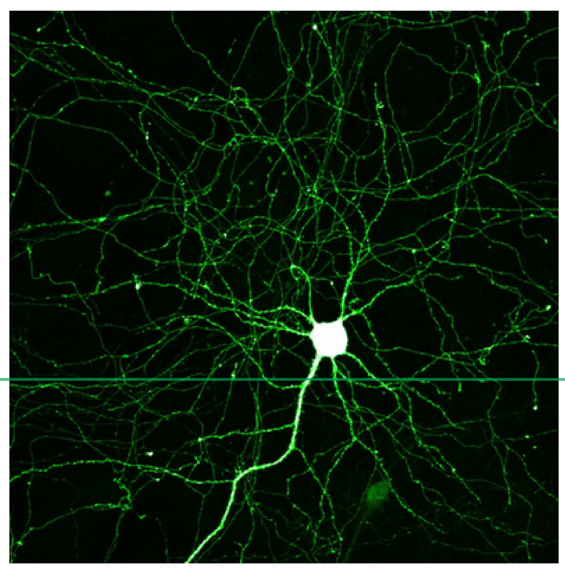


Figure 1: A neuron with an action potential going down the axon

Through voltage, the neurons may communicate to each other and this is what gives rise to the cognitive processes in any animal. When enough voltage enter a neuron, it spikes and send signals at a constant rate to all neurons connected to it, a so called action potential.

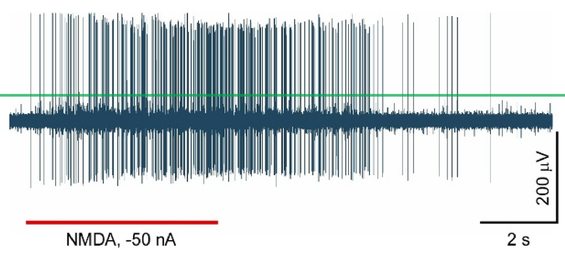


Figure 2: Recording of membrane potential of a neuron

On the level of a small scale network, or a single neuron, knowing the input/output relation when the cell membrane is subjected to an electrical current or spike lets us know a lot about the dynamics. The research of this poster investigates this question.

Basic Concepts

In our work the dynamic network is a series of graphs, that is, $DN = G_t(V_t, E_t)$, where $E_t \subseteq V_t \times V_t$ $(\forall t \geq 0)$. The initial network, G_0, is considered as a parameter of the process. The **node set fixed** and we worked with an about **constant number of edges**. We assume that the evolution of the network can be described as the result of an edge creation and an edge deletion process. We define G_t as the **snapshot network** and

$$G_T = \left(\bigcup_{t=0}^{T} V_t, \bigcup_{t=0}^{T} E_t\right) \text{ for } T \geq 0.$$

as the **cumulative network**.

Models

ER1 G_0 is a random graph. Add each non-existing edge with p_A, delete each existing edge with p_D probability.

ER2 G_0 is a random graph. Add k_A uniformly selected random new edges and delete k_D existing edges.

ER3 G_0 is a random graph. Rewire k_{RW} edges.

SPA (*Snapshot preferential*) G_0 is a scale free network. Add k_A edges from a random node with preferential attachment based on the snapshot network. Delete k_D existing edges.

CPA (*Cumulative preferential*) G_0 is a scale free network. Add k_A edges from a random node

Method

During my research I used a model which takes into consideration the resonant properties of the cell membrane caused by voltage-gated channels. The model is derived by considering the famous cable equation $\lambda^2 \frac{\partial^2 V}{\partial x^2} = \tau \frac{\partial V}{\partial t} + V$. Linearising non-linear dynamics due to the h-current, the resulting system of equation gives us the model of the membrane-voltage.

As the model is linear, we can specify the dynamics of the membrane-voltage completely by the so called Green's function $G_{ij}(x, y, t)$ which specifies how the voltage at length x of branch i develops in time with regards to a delta spike at length y of branch j at start. Throughout my project I only focused on the Green's function on the twin-cell network.

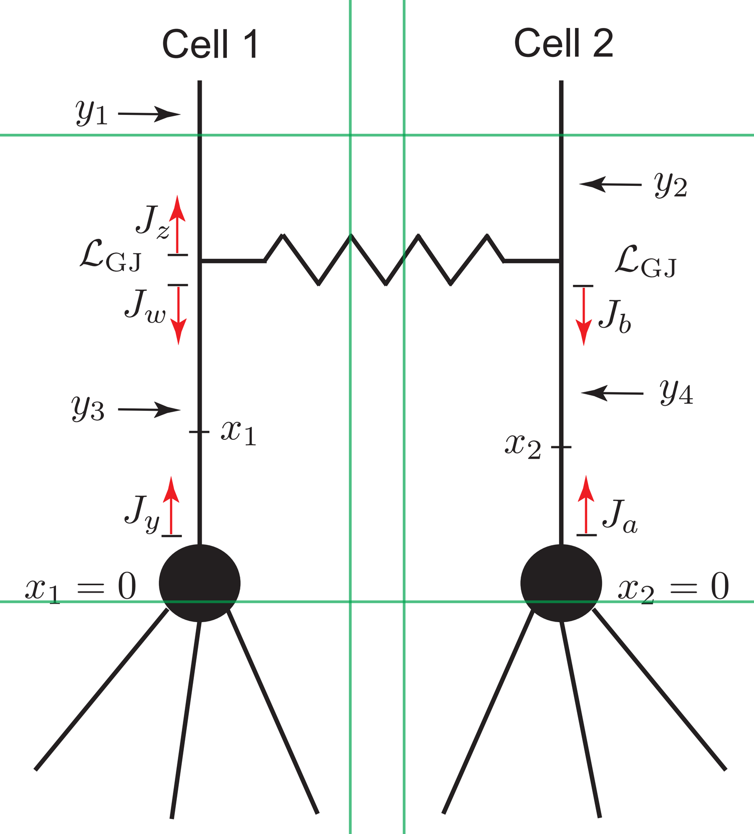
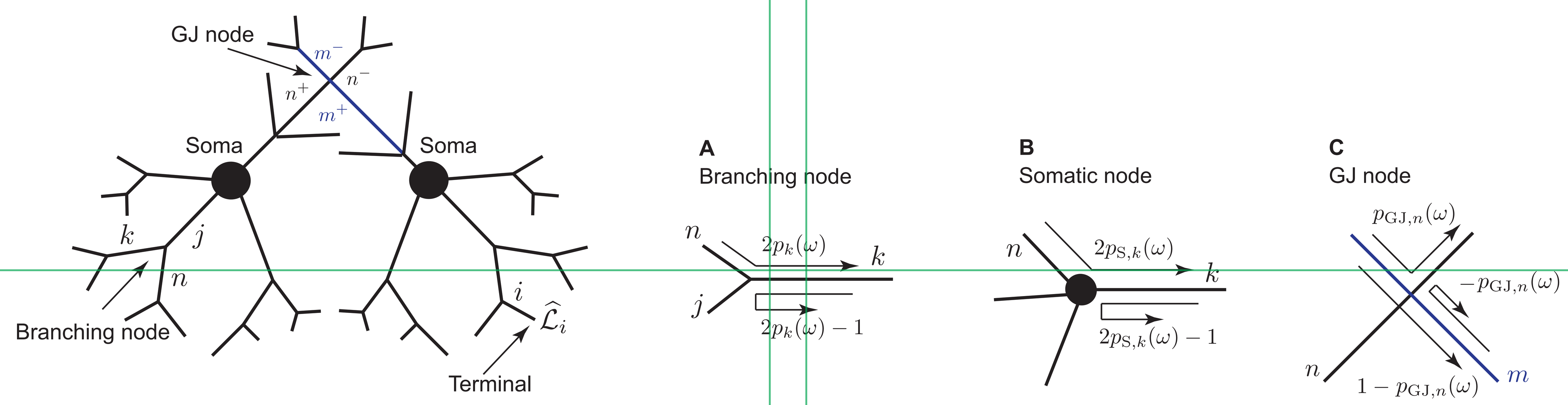


Figure 3: Schema of twin-cell network

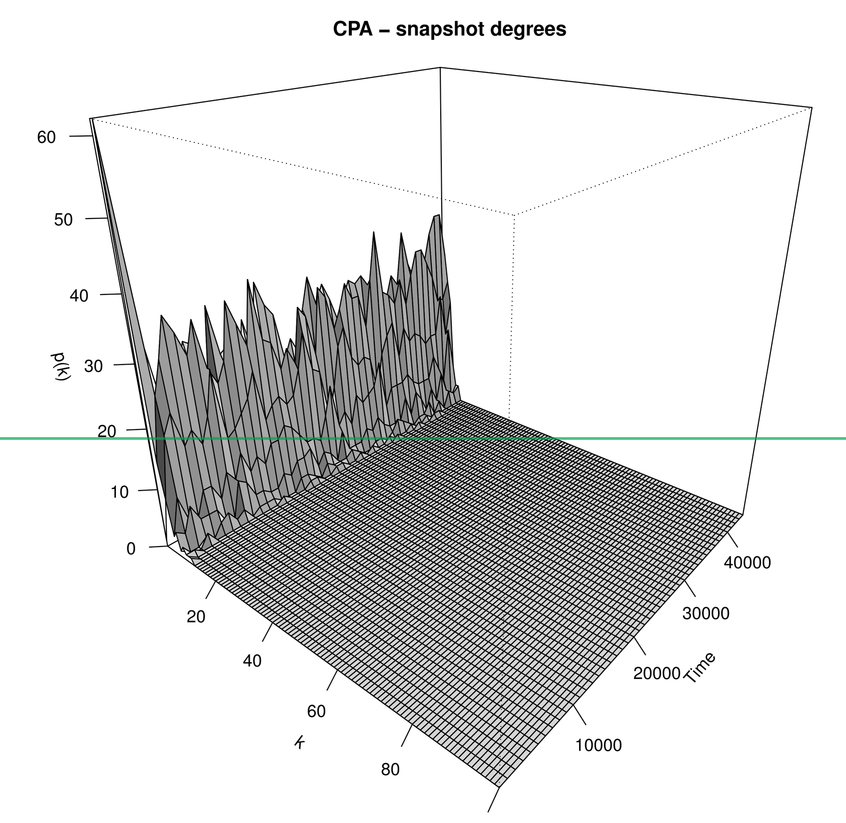
To calculate the Green's function in the frequency domain we use the method of local point matching which depends on trips over the network from x to y.

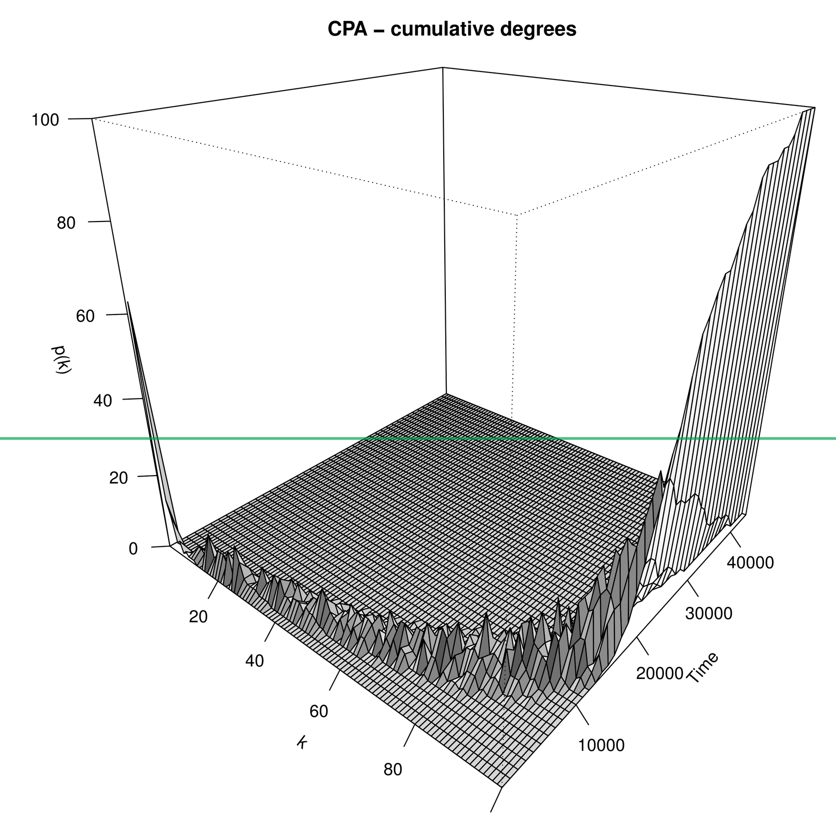


The above figures show the type of nodes in the network and how the trips are modified by multiplication of constants depending on how they traverse the network going from x to y.

Results

Degree distributions are exceptionally sensitive to the length of the aggregation window. **The same dynamic network may produce a normal, lognormal or even power law distribution for different aggregation lenghts.** The digree distribution of the snapshot and cumulative network is inherently different. The following surfaces show the CPA model until it approaches the complete network.





Taking slices of the cumulative 3D charts shows us how the degree distribution changes. The log-log charts below show the progression of these changes as the aggregation window gets larger.