# Exploring gap junction location and density in a network of model neurons with resonant dendrites

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An electrical synapse, also known as a gap-junction, is a mechanical and electrically conductive link between two adjacent nerve cells. Without the need for receptors to recognise chemical messengers, gap-junctions are much faster than chemical synapses at relaying signals. From theoretical and modelling studies, it is known that although gap junctions can act to synchronise network output, they can also give rise to many other dynamic patterns including anti-phase and other phase-locked states. Electrical synapses are believed to contribute to both normal and abnormal physiological brain rhythms, including epilepsy. A particular network pattern that may arise depends on intrinsic properties of cells as well as the strength and location of the gap junctions.
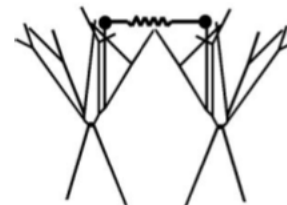
The main goal of this project is to investigate how the resonant properties of a dendritic membrane and the modulation of gap-junction can affect network dynamics. The study will comprise both theoretical and computational parts. As a starting point we consider two gap-junctionally coupled neurons, each is modelled by an active soma with a dendrite equipped with voltage-gated ion channels. The focus will be on those ion channels that can exhibit sub-threshold oscillatory behaviour and resonances (for example, Ca^{2+}-activated K^+ and hyperpolarisation-activated (h) channels). Fully nonlinear dynamics of the soma and dendrite will restrict the analysis of the model to brute-force numerical simulations. In addition to numerical simulations we aim to advance our knowledge of the system behaviour through direct mathematical analysis. This might be achieved by considering the reduced versions of the two model cells. First of all, it is proposed to describe the dynamics of the dendrite by a quasi-active membrane model. The Green's function technique initially developed for a single cell (Coombes *et.al* Biol Cybern 2007) can be extended to the cells connected by gap-junctions (results are currently in preparation). Although this technique works well for the cases of a passive and quasi-active soma these simplifications for the somatic membrane model are not appropriate for our study. The shape of an action potential is vital in a gap junction coupled networks as it is communicated directly between cells. Therefore, to retain the mathematical tractability of this model we are limited to use piece-wise linear or threshold-type models for the somatic dynamics. The results of our analysis will be compared with numerical simulations of more biophysically realistic models. A framework that we aim to develop can then be generalised for larger networks coupled by gap-junctions with more realistic morphologies for neuronal cells (for example, the single cell models of three components: dendrites, soma, and axon). The outcome of the project will be of interest to theoretical/computational and experimental neuroscientists alike.

Some relevant publications:

1. S Coombes, Y Timofeeva, C-M Svensson, G J Lord, K Josic, S J Cox, C M Colbert (2007) Branching dendrites with resonant membrane: a "sum-over-trips" approach *Biological Cybernetics* Vol 97.

2. F Saraga , F K Skinner (2004) Location, location, location (and density) of gap junctions in multi-compartment models *Neurocomputing*, Vol 58-60.

3. F Saraga, L Ng, F K Skinner (2006) Distal gap junctions and active dendrites can tune network dynamics, *Journal of Neurophysiology*, Vol 95 (3).

4. J Gansert, J Golowasch, F Nadim (2007) Sustained rhythmic activity in gap-junctionally coupled networks of model neurons depends on the diameter of coupled dendrites, *Journal of Neurophysiology* Vol 98 (6).