Dynamic aspects of delay activity

The neural substrate of working memory is an important topic in neuroscience. The current view is that this neural substrate is formed by delay assemblies. Delay assemblies are groups of neurons that respond with activity above baseline, once they receive input from specific external stimuli, and that are able to maintain this elevated activity, once the external stimulus is removed. A seminal model of delay activity in the cortex was introduced by Amit & Brunel (1997). They modeled a cortical column in terms of populations of leaky integrate-and-fire (LIF) neurons. A cortical column, in their model, consists of an inhibitory and an exhibitory population. The inhibitory population had no substructure, the excitatory population contains subpopulations that can be stimulated by specific stimuli. They made a mean-field approximation: each neuron in a population effectively receives the same input as other neurons. They also assumed that the input of each neuron effectively is a Gaussian white noise. For a large number of afferents, this is a very plausible assumption indeed (Amit & Tsodyks, 1991). Using these assumptions, they set up a system of consistency equations, one equation for each population. Using these equations, it is possible to find the steady-state firing rates of the populations, in terms of network and neuron parameters. For a suitable and biologically plausible choice of parameters they demonstrated that delay activity can exist in the cortex at low rates, despite the presence of cortical background activity.

This model is very useful, but it has a major disadvantage: it describes a steady-state situation, where delay activity was introduced in the past. The methods that are employed in this model cannot easily be extended to describe time-dependent phenomena. And obviously, some of the interesting aspects of working memory are dynamic. Brunel himself for instance notes that in network simulations of LIF neurons the lifetime of the delay activity is dependent on the potentiation of the delay assembly. (The potentiation of a delay assembly is determined by a parameter that describes how much stronger the internal efficacies of the delay assembly are, on average, compared to the average efficacies in the rest of the excitatory population.)

Recently, Knight, Omurtag, Sirovich and others introduced a novel technique for the simulation of populations that consist of a large number of neurons (e.g., Omurtag et al., 2000). They define a population density, and by making a simple and very plausible assumption for the dynamics of this population, they define a partial differential equation, that describes the time evolution of the population state in terms of an external input function. The external input function describes the rate and magnitude of the input to that population. In (Omurtag et al., 2000) they consider the situation that the magnitude of an input spike is given by a Gaussian probability density.

Although conceptually different, there is a close mathematical correspondence between a population which receives a high firing rate of spikes, whose magnitude is determined by a Gaussian probability density, and the Gaussian white noise which was used in the model of Amit & Brunel. The idea is that using populations in a similar way as Amit & Brunel, but describing them using the pdf given in (Omurtag et al., 2000), it is possible to describe dynamical aspects of delay activity.

So far, we have generalized the equation given in (Omurtag et al., 2000). We have allowed the possibility of negative potential jumps (an artificial cut-off was used in (Omurtag et al., 2000) restricting the Gaussian to positive potential jumps only), and introduced the possibility for non-zero reversal and reset potentials (both were restricted to zero). Currently, we are experimenting with a novel algorithm to solve the pdf, which looks more stable than the one given in (Omurtag et al., 2000).

We have also observed that populations that receive an input which is sub-threshold can still cause a population to fire, if there is a large enough variability in the input (this was also reported in (Knight et al., 2000)). Since this was one of the crucial ingredients of the model of Amit & Brunel, we are fairly confident that we can formulate a model of delay activity
in this way. The first dynamic phenomenon that we will investigate is the life time of delay activity as a function of the potentiation of the delay assembly. It will be very interesting to see if a plausible time dependence will emerge, and to confront this result with direct simulations. If this technique turns out to be viable, it may be very useful, especially since the techniques from (Omurtag et al., 2000) may be extended beyond LIF neurons.

References:
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