Reading reports

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The Prefrontal Cortex as a Quintessential "Cognitive-type" Neural Circuit -- Wang XJ (2013)

This paper is a review for prof. XJ Wang's work about working memory and decision making, by constructing their underlie neural circuit model.

This paper indicates that unlike the transient dynamics in sensory cortex, the persistent activities observed in the local circuits in prefrontal cortex should result from network feedback or reverberations, which is related to the function of working memory. Those persistent network dynamics can be mathematically described as "attractors", which are self-sustained and stable states of network. However, based on ordinary "attractor" theory, pure positive feedbacks lead to high oscillatory state, which would not happen in cortical network. Meanwhile, the way to achieve multiple steady states in a single network is to be understood.

In Wang's work, they constructed a modeling layout, which adapted slow excitation and fast inhibition mediated by NMDA receptors, to demonstrate spatial memory experiments. Their network can potentiate local persistent spiking activities of neuron population, generated by visual cues. And the brief summarized points go as follows:

1. With this modeling scheme, each neuron prefers cue with different spatial orientations. In this way, spatial working memory can be indicated by continuous bumping population activities in network with each neuron labeled by different degrees.
2. Strong excitations ensure that firing events persist for a delay periods, which form bump attractors. And synaptic inhibition ensures those active firing activities wouldn't spread far away to sustain bell-shaped bumps.

3. This model reveal the homeostatic mechanisms in real cortical network while it has heterogeneity for each single neuron, which prefer different oriented visual cues.

   According to numerical simulation mentioned in this work, fast excitation and slow inhibition recurrent circuit would lead to a dynamical instability. However, slow excitation and fast inhibition mediated by NMDAR definitely ensure stable firing states. Sufficiently high NMDA/AMPA ratio would lead to a sustainable firing activity, while the actual ratio value depends on detailed biological structures.

Apart from the network feedback mentioned above, three other feedback processes which might participate the generation of persistent spiking activity are mentioned in this paper.

1. Positive feedback in individual pyramidal neuron in terms of inducing intrinsic ion current to facilitate the depolarization of membrane potential. In this way, less slow NMDAR-mediated synaptic transmission is need to ensure stable persistent activity;
2. In frontal cortex, local synaptic connections between pyramidal neuron pairs shows short-term facilitation in terms of short-term synaptic plasticity, which would persist the localized spiking activation for a certain time period.
3. Depolarization-induced suppression of inhibition(DSI). With spike-frequency adaptation, spiking activities would trigger negative feedback process to reduce its firing rate. By introducing DSI, the negative feedback process would be reduced so that spiking activities would maintain for a while. Meanwhile, DSI reduces the noise-induced random drift of the persistent activity pattern.(Not explained in detail) In addition, the paper mentioned a simulated agonist for cannabinoid receptors, which has the opposite contribution compared with DSI.

The network model has a fixed E-I balance regardless of its changing dynamic regime. Meanwhile, inhibition is slightly stronger than excitation.

Unlike in temporal lobe and parietal lobe, neurons in prefrontal cortex might persist spiking activities under external distracting inputs. One of the hypothesis is that active neurons in PFC recruit inhibition to suppress other neurons under the impact of distractors.

In those worksm the model for working memory experiments can be applied to reward-based accumulative decision-making process. *I haven't finished my reading for this part. And I would make it up as soon as possible.*

Brain structure and dynamics across scales: in search of rules -- XJ Wang, Henry Kennedy (2016)

This paper is a brief review of studies of cortical network structure and their dynamical characteristics (mainly time constant of circuits) across different system levels.

More and more abundant data for anatomic network structure and synaptic properties make it possible to model large-scale dynamical circuits across different cortical area. Experiments investigate dense connection within local neuronal network in cortex. Is described that synaptic strength of local circuit forms a functional pattern which significantly contributes to the global function of cortical network. In order to deepen our understandings, more studies should be addressed on those subnetwork, which would provide important infrastructure supporting global and local integration.

Meanwhile, previous works have illustrated a number of features sharing between local and inter-areal connections, including lognormal distribution of weights and an exponential decline in connection weight. Typically, the exponential distance rule indicate the infeasibility of pure topological model of cotical network, which is not able to characterize the spatial organization.

By adapting the idea of spatial organization of network, Wang's group develop a dynamical model for the primate cortical system, with inter-areal directed- and weighted-constrains from monkey experiments. This model interestingly demonstrate a hierarchy of timescales across different network system. For instance in V1, the local circuits have transient responses toward inputs, while in higher level circuits, such as those in PFC, inputs integrate over time and network activities would persist for a delay period. This work addresses that the hierarchy of timescales critically depends on the interareal connection pattern, and the timescale of different local circuit would diverge across area.

In the end of the paper, two questions are addressed.

- How higher area of network impact dynamics in lower area?
- Comparing this modeling scale and scale-free dynamical model, which one describe the network dynamic across cortical area more precisely? (different time-scaled dynamics in different area vs. a homogeneity of complex neural dynamical regardless of cortical location) More anatomical experiments and data are required.