# Brent Doiron / The mechanics of neuronal variability

The activity of cortical neurons is highly irregular, showing non-precise firing across time, trials and experiments, etc. Why there is such variability? One possibility is that physiology is not exact, but that’s not likely. The heart is highly reliable. If you record from neurons of the somato-gastric ganglia in crab or the electric field of the electric fish, we see highly regular firing. Even with cortical neurons in vitro, a similar stimulation generated a reliable and precise firing. So, when you take cortical neurons outside the intact brain, they are quite reliable.

Where does this noise come from?

* The noise is an inherent property from outside inputs
* Variability reflects interactions between neurons

**Internally generated variability: network-driven variability**

Now we’ll look at the other possibility for the source of variability, which is the connectivity between neurons.

In a simple **mean field theory** model, we are going to look on a representative pyramidal cell and see how its activity is influenced by outside output together with inputs from a group of pyramidal neurons and a group of interneurons which have recurrent connections.

Diagram

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We will mark the different populations (either E or I) as α and β. Important parameters:

* : the synaptic strength from population β to population α.
* : the number of neurons in population β
* : the probability of connection between population β and population α
* : the number of presynaptic β, such that:

We assume we have a sparse network, in which the number of pre-synaptic α/ β neurons (K) is much smaller than the total number of neurons (N). The mean and variance of the membrane potential of the population α will be:

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**What is the relation between the number of inputs (K) and J (the synaptic strengths)?** One possibility is to make J ~ . However, this leads to vary small variance at larger number of inputs.

This can be normalized by assuming J is a function of . This is also supported by real data. In data published in 2016, PSPs were recorded from single neurons and the number of connections of each neuron was estimated. The strength of PSP indeed was distributed as a function of ., which is approximate to .

Chart, scatter chart

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However, in these networks, if K is large, the mean firing rate of the excitatory neuron will either blow up (if the E drive is stronger) or will go to zero (if the I drive is stronger). This can be solved by balancing the synaptic scaling between excitatory and inhibitory neurons (**balanced networks**). In other words:

Chart

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* Large synaptic weights produce excessive net excitation that would result in saturated spiking activity
* Large recurrent inhibition dynamically tracks and balances the excitatory current so that the net input current is moderate

A picture containing graphical user interface

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* The variability in input current produces spiking activity which is irregular across both time and trials

This model generates irregular firing rates, and high heterogeneity between neurons, such that neurons with more inputs have higher firing rates.

If we reduce the range of J, the interactions between neurons, the neurons will be more synchronized to each other. This happens because of the coupling between the excitation and inhibition.

What kind of phenomena can balanced networks replicate?

* Poisson-like spiking variability, with FF~1 (without inputted noise)
* A log-like distribution of firing rates, such as we see in vivo
* With dense wiring (K>>0), we still get irregular firing

**Modelling cortical dynamics with firing rate models**

If Jee < 1, we will have a set point even without inhibition. If Jee > 1, I will get a set point only with inhibition.

If I increase inhibition and Jee<1, we’ll see the inhibitory firing rate goes down. But if I increase the inhibition and Jee > 1, the inhibition will “win over” the excitation and excitatory drive will not be enough.

**Asynchronous cortical state**

According to balance theory, the average noise correlations we expect the noise correlation to be distributed abound zero, *p*~1/K.

However, in real recordings, we see the average noise correlation is not close to zero. Furthermore, it seems that noise-correlations seems to change as a function of external stimulus presentation or brain state (like anesthesia).

In her work, Marlene Cohen did dimensionality reduction for the noise correlation, and saw that the shared variability has a low dimensionality.

**How can we replicate this in balanced network models?**

* If we have a network with disordered connectivity, and we assume inhibition is faster than excitation, we will get irregular firing.
* In real life, we know that neurons that are closer to each other are more likely to be connected. Rosenbaum did balance network which are ordered in space, and so again irregular firing.
* However, in real life, we know that inhibition is slower than excitation. If that’s the case, inhibition can’t cause irregular firing of pyramidal cells. In the case of disordered connectivity, we will get synchronous firing with no noise, different from what we see in the brain.
* However, if we assume inhibition is slower than excitation, and the network is order spatially, we get irregular firing and low-dimensional co-variability, like we see in