Ashok Kumar's project

Several theories have argued that the sparse connectivity of cerebellar granule cells (GCs) is optimal for classification and associative learning (e.g. Litwin-Kumar et al. 2017, Cayco-Gajic et al. 2017). In all these theories, networks with different mossy fiber-to-GC connectivity are constructed, assuming that each GC receives exactly the same number of inputs (in other words, the "in-degree" of GCs is identical for all cells). In this setting, an in-degree of 4, which matches the average number observed anatomically, is optimal. In reality, the connectivity of GCs is heterogeneous and likely best-described by some distribution over possible in-degrees.

In this project, you will analyze the consequences of heterogeneous in-degree distributions across GCs.

1) Reproduce the result of Fig. 3A or B in Litwin-Kumar et al. 2017. Note that in this plot, as K (the in-degree of GCs) is varied, the number of GCs is also varied so that the total number of connections always remains fixed (so networks with large K have fewer GCs). You may want to start with Fig. 3A (the Drosophila mushroom body) since it's a smaller network which will speed up the simulations.

2) Now make the same plot but for a heterogeneous in-degree distribution. You could draw the in-degree of the GCs from a Poisson distribution with average K, for instance (but maybe other choices are superior). Ensure that the total number of connections in your networks is fixed compared to the networks in (1) by drawing GCs until you reach the maximum number allowed. See whether this distribution increases or does not increase the dimension.

You will likely need to choose the threshold of each GC separately, so that each GC has the same coding level (fraction of inputs to which it responds). This is easily accomplished by computing the input current to each GC across all input patterns, and then setting the thresholds to achieve the desired coding level.

You will either find that there are distributions that are better than a fixed in-degree for all cells (and it would be cool to characterize this distribution), or that a fixed in-degree is always optimal (which raises the question of why biological networks exhibit the heterogeneity they do). Establishing either result would be an interesting advance.

3) In the larval Drosophila mushroom body, it appears that Kenyon cells (the analog of GCs) are added sequentially, with cells with small in-degree added first, followed by larger ones (Eichler et al. 2017). One could imagine a sequence in which neurons with K=1,2,3... are added in order, such that the number of each type is such that the likelihood of any two neurons receiving identical inputs is assured to be low. Try implementing such a "developmental program" for adding neurons with specified in-degrees and see if this is a more efficient way to build a system than drawing neurons randomly.