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FURSCA End of Summer Report

Summer 2022

Synergistic Information Processing in Feedforward Neural Networks

Over the course of the summer, my research was focused on how and why neuron connections affect their ability to pass a signal in the brain. With the help of my mentor, Dr. Cho, and my partner, Karina Muñoz, the goal was to create a model via MATLAB to simulate neural networks. From there, the model could be run for as long as necessary to collect data. We could then analyze said data (time raster data, to be precise) and calculate the synergy. This would tell us more about the impact connections had on information processing. Previous results from researchers at Indiana University Bloomington had shown that when neurons were connected in a “feedback” manner, with a connection from downstream neurons to upstream neurons, neurons were less likely to pass a signal, and had less synergy. Likewise, in a “feedforward” neural network, with all upstream connections, neurons were more likely to pass signals, and had more synergy. Through enough modeling, we wanted to understand why this happens.

The first thing we had to do was make sure we understood what synergy was. Synergy can be directly derived from the mutual information of two variables, or how much one thing happening can tell us about the chances of the other. We did calculations by hand with some more simple examples to grasp the concept at first, and were later able to calculate the mutual information and synergy for more complex examples with many variables (Figure one). Soon after, we calculated the synergy of different neuron connections by hand (Figure two). We were able to produce numbers that were accurate with what the previous findings on synergy had described. This was a big accomplishment, because it meant that once we started coding models of neural networks, we had results to compare the output of the code to. As a result, we could easily see if the model was working as intended and refine it as necessary.

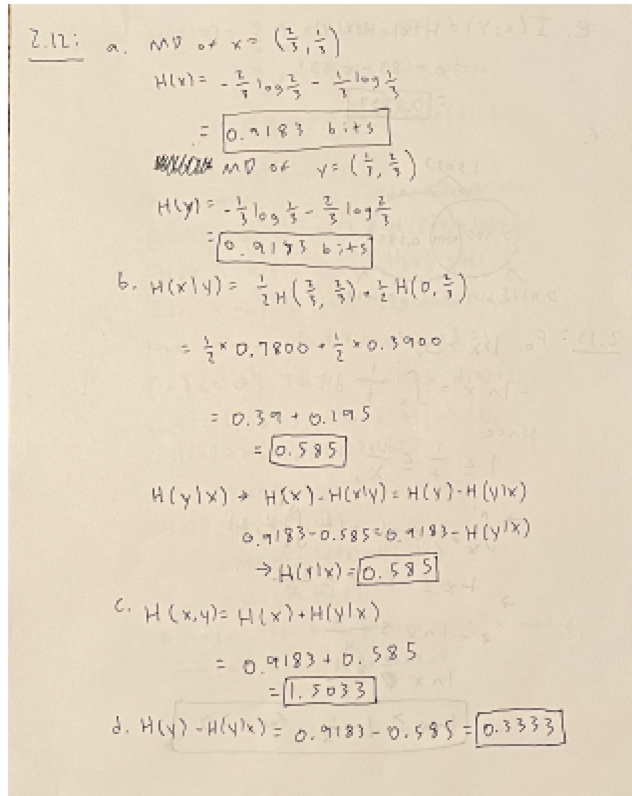

Figure one: An example of calculating synergy and mutual information for connected events.

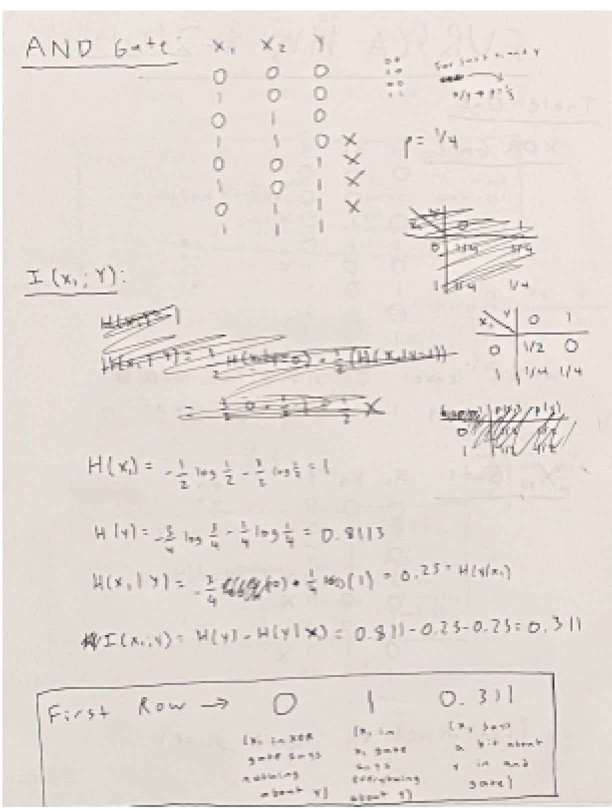

Figure two: Calculating synergy from time raster data of a given neural network.

We started the coding portion of the project soon after we were able to produce accurate numbers. Having not worked with MATLAB before, we started very simple, with a program that would output a string of length n of random numbers. Then we focused on making strings of set length of ones and zeroes. Once we had three of those side by side, we essentially had a model of three random neurons firing independently. The hardest part was the connections. We had to figure out a way to make the outputs of the neurons depend on the previous outputs of the other two neurons. Karina and I would spend our nights typing up code and sending it to Dr. Cho for feedback. It took us a while to figure out, but we got it. The last thing our model needed was weights. In the brain, each neuron has a certain signal threshold, and if input signals are not strong enough (or at a certain weight) to meet this threshold, the signal doesn't get passed. We were successfully able to code in weights and thresholds into the model, and after a bit more refining we had a more accurate simulation of the neural network (Figure three).

```
timeraster =

     1     0     1     0     1     0     1
     0     1     0     1     0     1     0
     1     0     1     0     1     0     1


shiftedraster =

     1     0     1     0     1     0     1
     0     1     0     1     0     1     0
    -2     1     0     1     0     1     0
```

Figure three: An example of what the program could output for a smaller number of time steps (6 is used in the above image).

Once we had a program that could produce time raster data for three neurons, we set out making sure that the synergy calculations from the program matched the ones we calculated by hand. Another program was utilized to easily calculate the synergy and mutual information of the neuron triads, and we were able to see that the neurons behaved in a way that previous studies on actual mouse brain neurons described. However, the smaller simulations were not enough to tell us why this occurs. We would be interested in running larger simulations with more connected neurons and with different types of connections in the future to better answer this question. Some things we were able to take away from this research experience are a better understanding of how neurons work in the brain, a better understanding of synergy between events, and a model that can accurately simulate neuron triads and their outputs given certain weights and thresholds. We look forward to continuing our work in the future, as well as presenting at the Elkin R. Isaac Research Symposium and MID-SURE in 2023. We were able to learn a huge amount over topics that are not generally understood very well, and made a big advancement into working on the future of the field, which is a fully artificial, working brain. I want to give a special thanks to my partner, Karina, for working so hard with me and my mentor, Dr. Cho, for pushing us to learn more about areas we knew nothing about and showing us that sometimes diving into something head-on is the best way to learn.

To the Bruce A. '53 & Peggy Kresge '53 Endowed Science Fellows- Thank you for giving me the opportunity to participate in Albion's FURSCA program this summer. This summer provided many benefits that will greatly influence my future education and research endeavors. Thank you!