Optimizing neuronal efficiency during experiential Neural Darwinism: A Computational Model

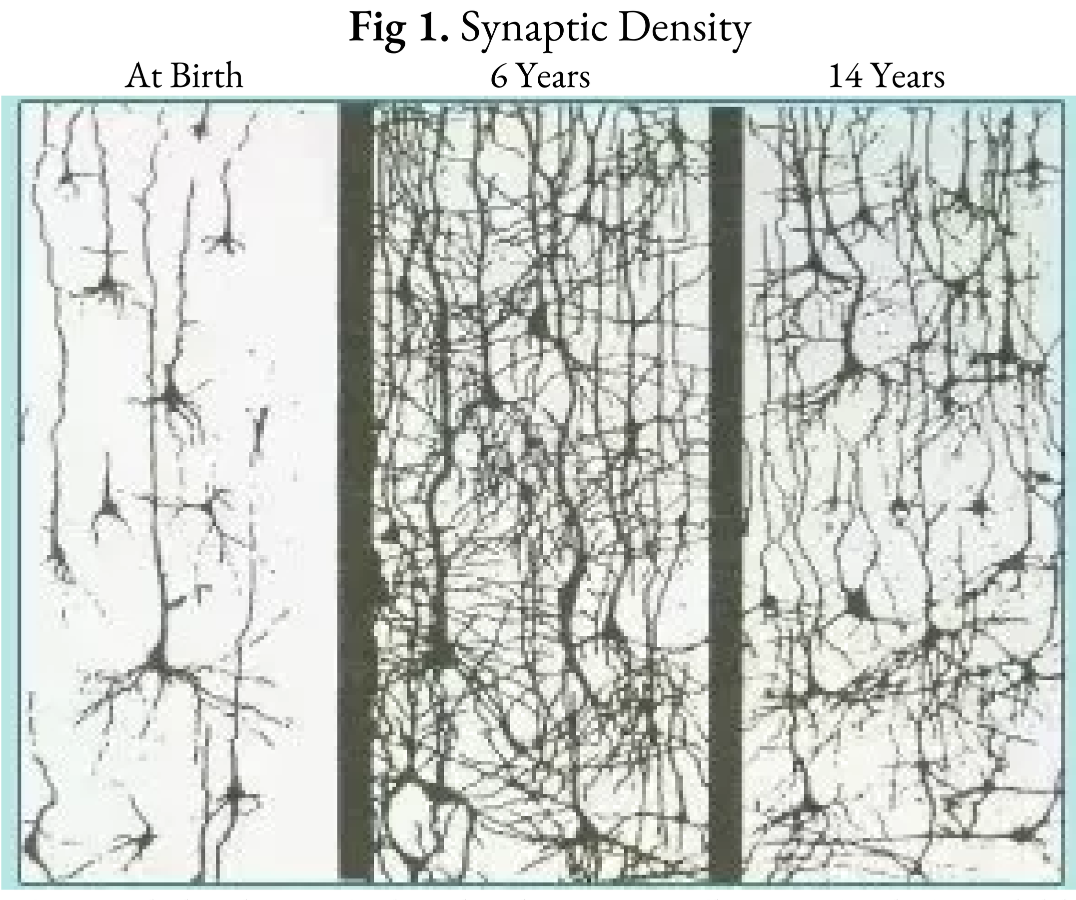
Amber Li[1,5], Alexander Liang[2,5], Scott Song[3,5], Jinni Wang-Bai[4,5]

University High School, AZ[1]; Archbishop Mitty High School, CA[2]; BASIS Tucson North, AZ[3]; Plano West Senior High School, TX[4]; Boston University, MA[5]

Introduction

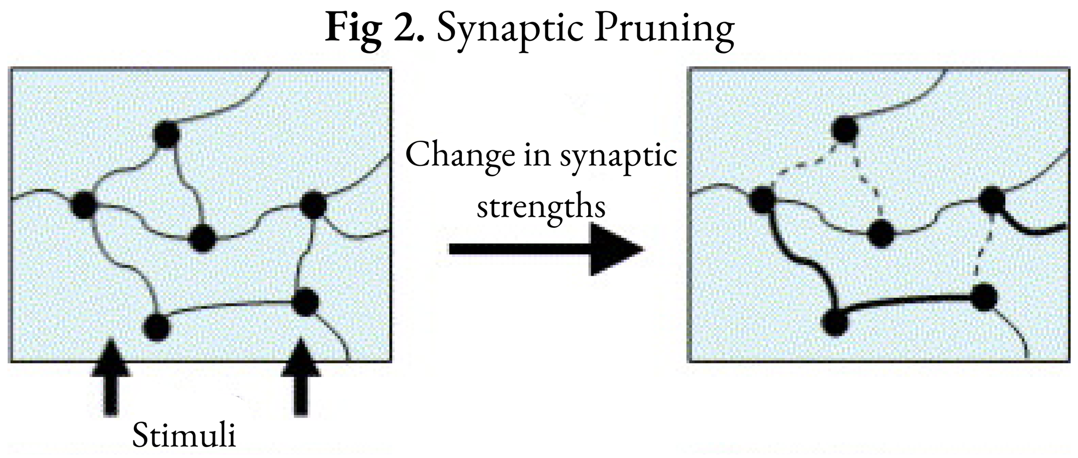
- From the ages of eight to the end of puberty, the brain undergoes a process of **experiential Neural Darwinism** where disfavored neurons, synapses, and networks weaken (Fig. 1 and 2) [2]
  - Increases neural signaling speed and efficiency
  - Crucial to the development of the adult brain
  - Dependent on childhood behavior and environment

Fig 1. Synaptic Density



Source: Rethinking the Brain, Families and Work Institute, Rime Shore, 1997-Founders Network slide

Fig 2. Synaptic Pruning



Methods

- Created and ran our own model in Python using NEURON
- Based on ball-and-stick mechanisms
  - Two-compartment Hodgkin-Huxley model
- 1:1 ratio of excitatory to inhibitory synapses
- Input: one spike to the first soma
- Each soma has *n - 1* synapses connected

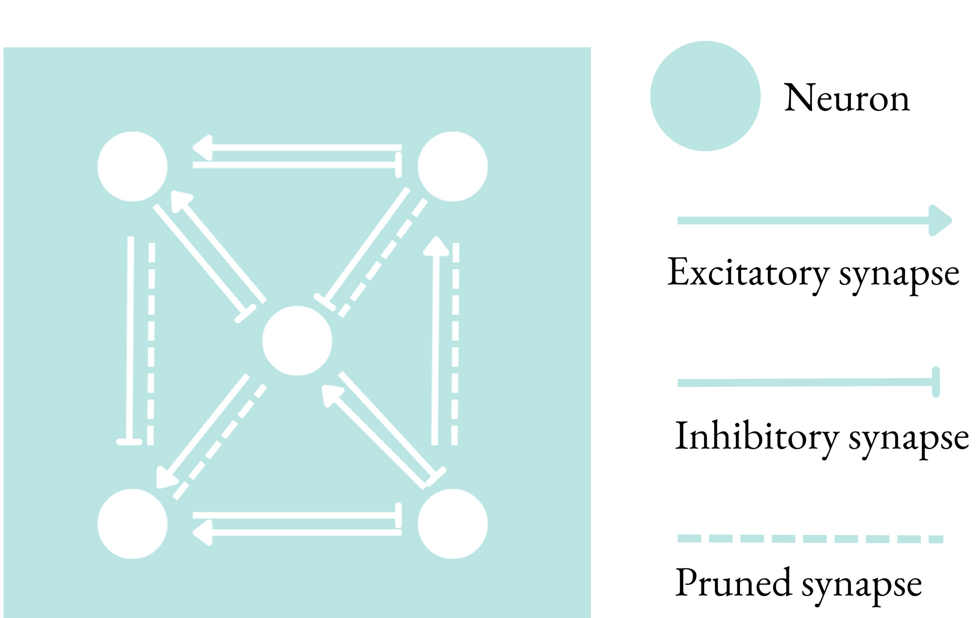


Fig. 3 Conceptual diagram

- Which synapses get pruned:

$$P_{prune} = C \cdot r$$

where **P** is the probability a synapse is pruned
C is the pruning constant
r is the percent error between average accumulated voltage and the accumulated voltage of a synapse

- Accuracy measured as MSE (mean squared error) of the number of spikes for each neuron
- 8024 trials: each trial is an entire simulation of the network

Results

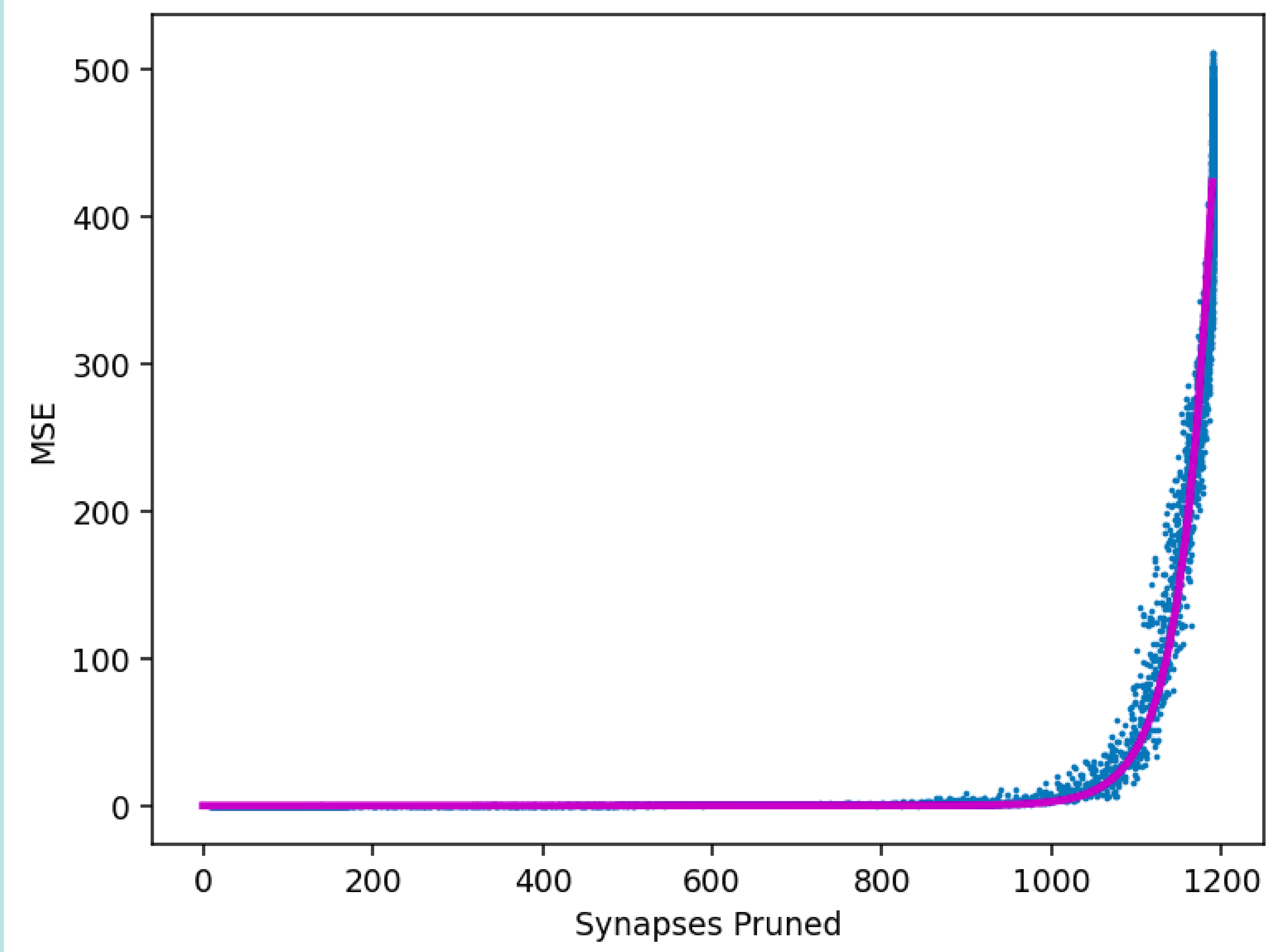


Fig 4. Large network (1200 synapses)
Network error compared to number of pruned synapses

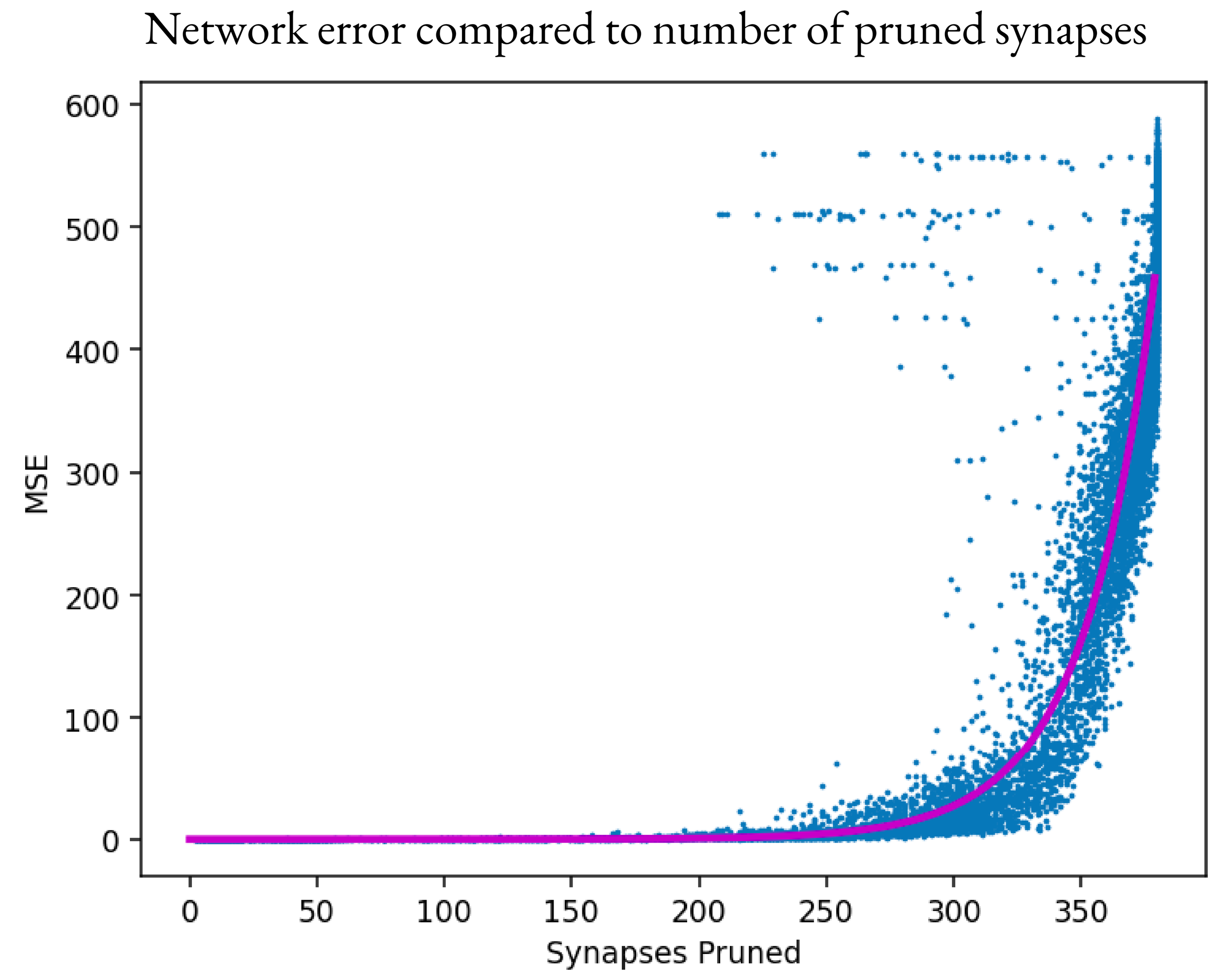


Fig 5.Small network (400 synapses)
Network error compared to number of pruned synapses

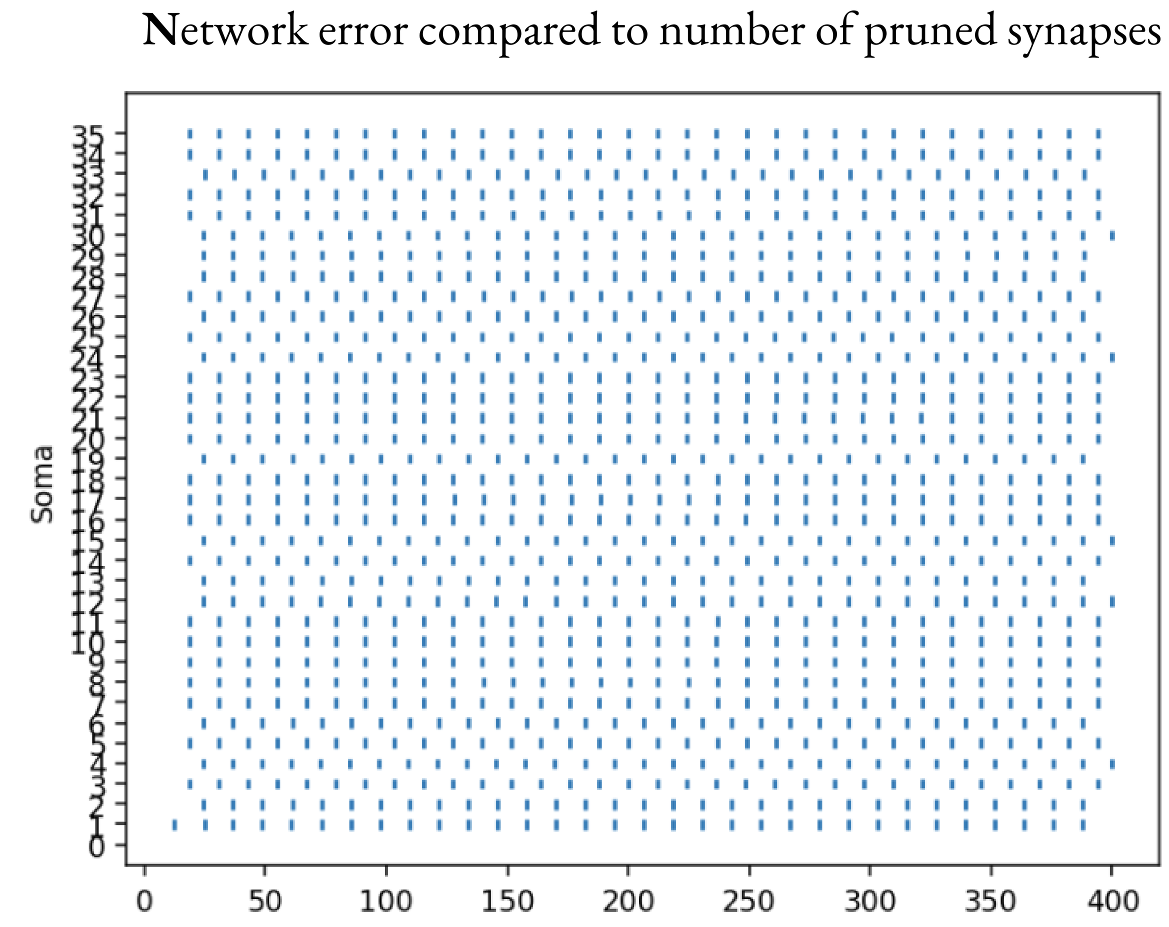


Fig 6. Raster plot with no pruning

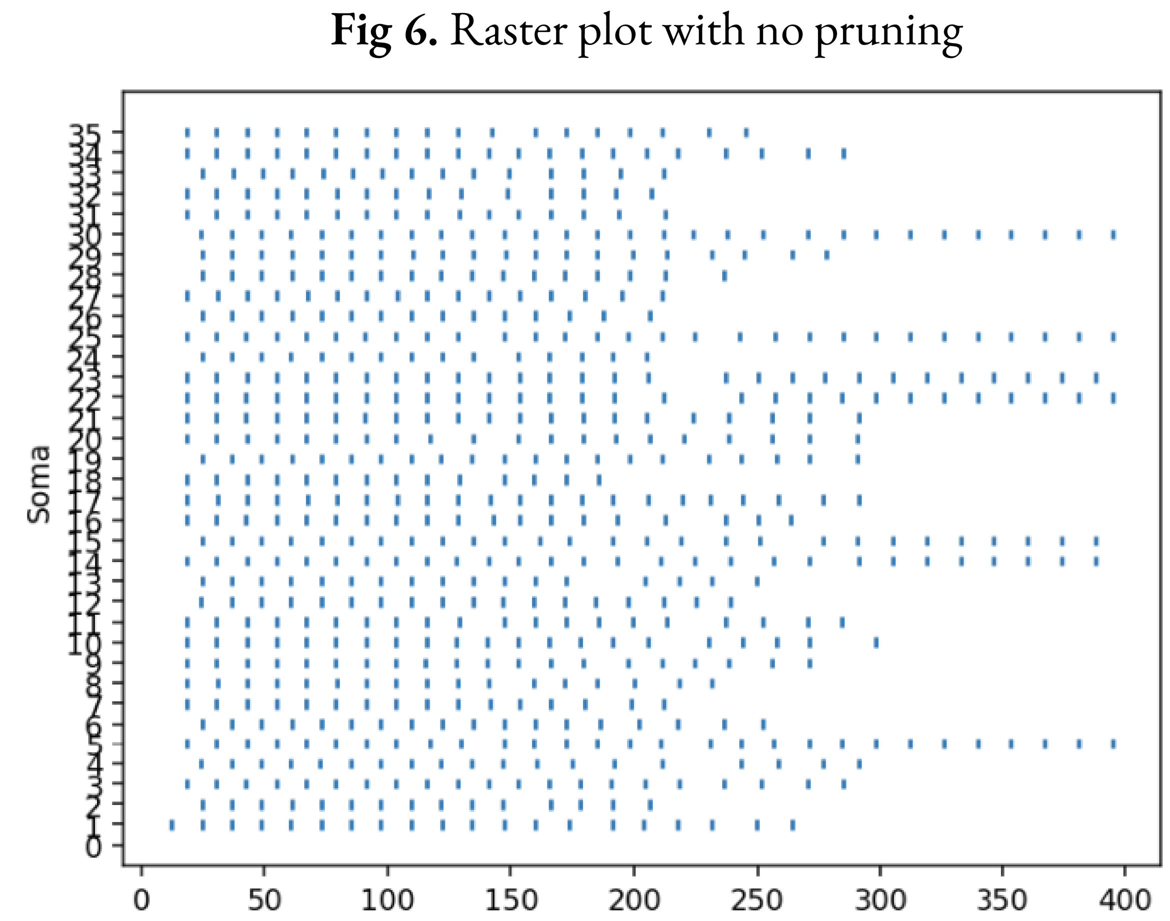


Fig 7. Raster plot with high pruning

Discussion/Conclusions

- **Analysis**
  - Accuracy to efficiency changeover point :
    - Small network: 250/400 pruned or 62.5%
    - Large network: 1000/1200 synapses pruned, or 83.33%
    - Accuracy measured as MSE (mean squared error)
    - Efficiency measured as synapses pruned
    - **Exponential** relationship, pattern remained consistent between network sizes
    - Network is very fault-tolerant and can handle many losses before becoming unstable, suggesting that Neural Darwinism occurs at a high rate and aggression during childhood
- **Modeling limitations**
  - Shorter time period than is realistic: Neural Darwinism occurs over years while our model simulates milliseconds
  - Scale-down: the larger model contains just 1200 synapses
- **Applications for the future**
  - These results could, through the refinement of pruning algorithms and the removal of extraneous synapses, improve scalability, speed, and efficiency of future
    - Biophysical neuronal simulations, particularly those of complex processes such as
      - Memory
      - Cognition
      - Planning
    - Neural networks/deep learning algorithms
  - They also act as a theoretical illustration of experiential Neural Darwinism:
    - By demonstrating the brain's incredible redundancy and resiliency
      - A synapse's importance is judged by its activity and in this way, less-active synapses that are pruned are unlikely to affect the network due to low centrality

References

1. Chervyakov, A. V.; Sinitsyn, D. O.; Piradov, M. A. Variability of Neuronal Responses: Types and Functional Significance in Neuroplasticity and Neural Darwinism. *Frontiers in Human Neuroscience* **2016**, 10. DOI:10.3389/fnhum.2016.00603.
2. Edelman, G. M. *Neural Darwinism: The Theory of Neuronal Group Selection*; Basic Books, 1987.
3. Szilágyi, A.; Zachar, I.; Fedor, A.; de Vladar, H. P.; Szathmáry, E. Breeding Novel Solutions in the Brain: A Model of Darwinian Neurodynamics. *F1000Research* **2016**, 5, 2416. DOI:10.12688/f1000research.9630.1.

Acknowledgements

We would like to thank Lucious Kelton Wilmerding, Karla Montejo, Amy Monasterio, Ryan Senne, and Patrick Bloniasz for their contributions to this project. We would also like to thank the RISE program for giving us this amazing opportunity.