A model for the evolution of gene regulatory networks governing social traits

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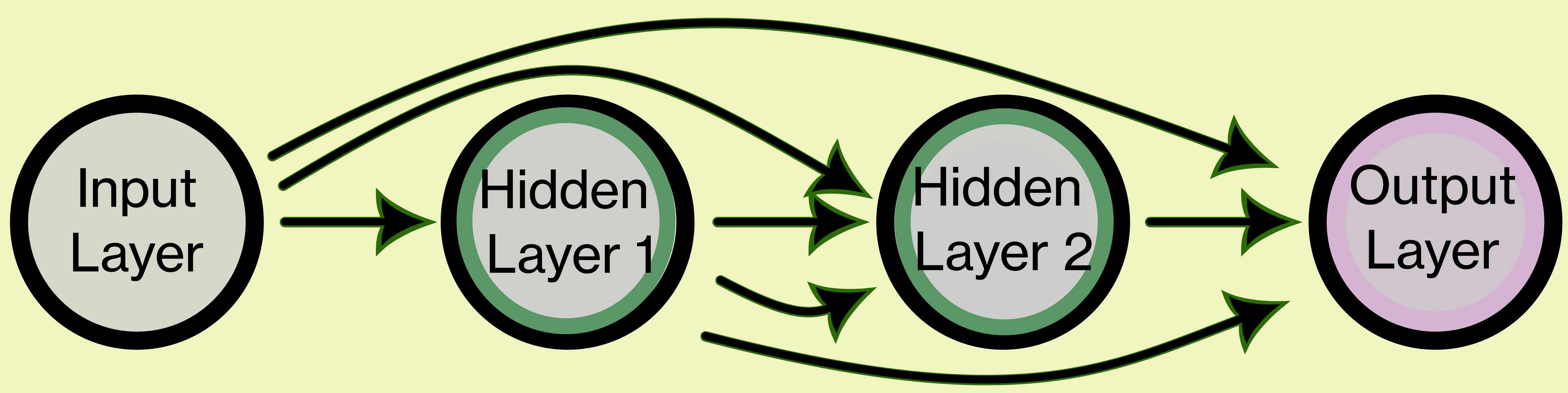
Modeling a gene regulatory network as a neural network



The input layer receives offers of cooperation and passes them to the hidden layers

Hidden layers transmit or block signal from other nodes depending on their genetically determined weights

The model accepts any number of hidden layers, simulating an arbitrarily complex regulatory network

Network outputs determine the level of cooperation offered to a partner in social interactions

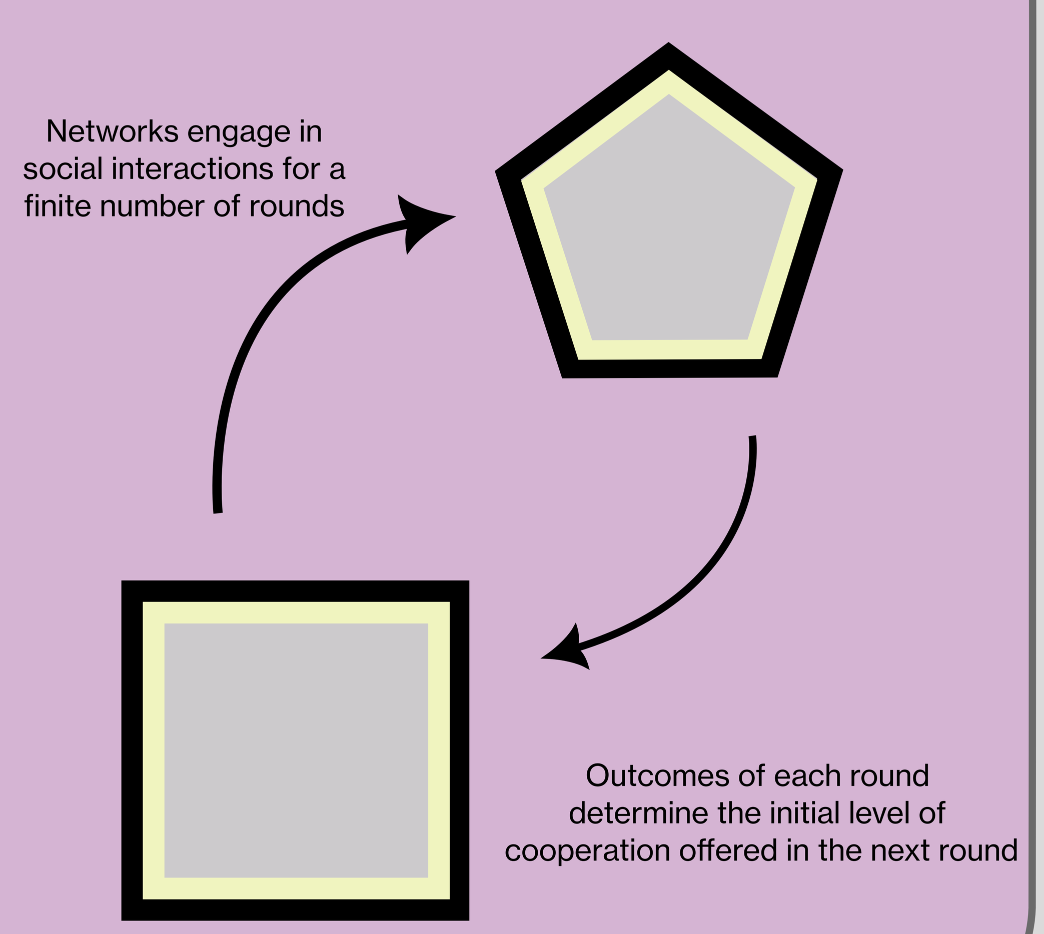
Introduction

Here we present a model of the evolution of a social trait with a complex genetic architecture. This model is capable of simulating a wide variety of genetic regulatory network topologies, and may be extended to simulate social interactions of arbitrary complexity.

In this feedforward neural network model [1], each layer has the potential to activate all subsequent layers. Inputs at each layer are calculated as the sum of the input from all preceding nodes, as well as a node's specific bias. These are then passed through an activation function to determine the node's contribution to activation of later nodes. This is analogous to a linear gene regulatory network, where a series of genes activate each other sequentially.

Mutatable elements in green

Social Interactions

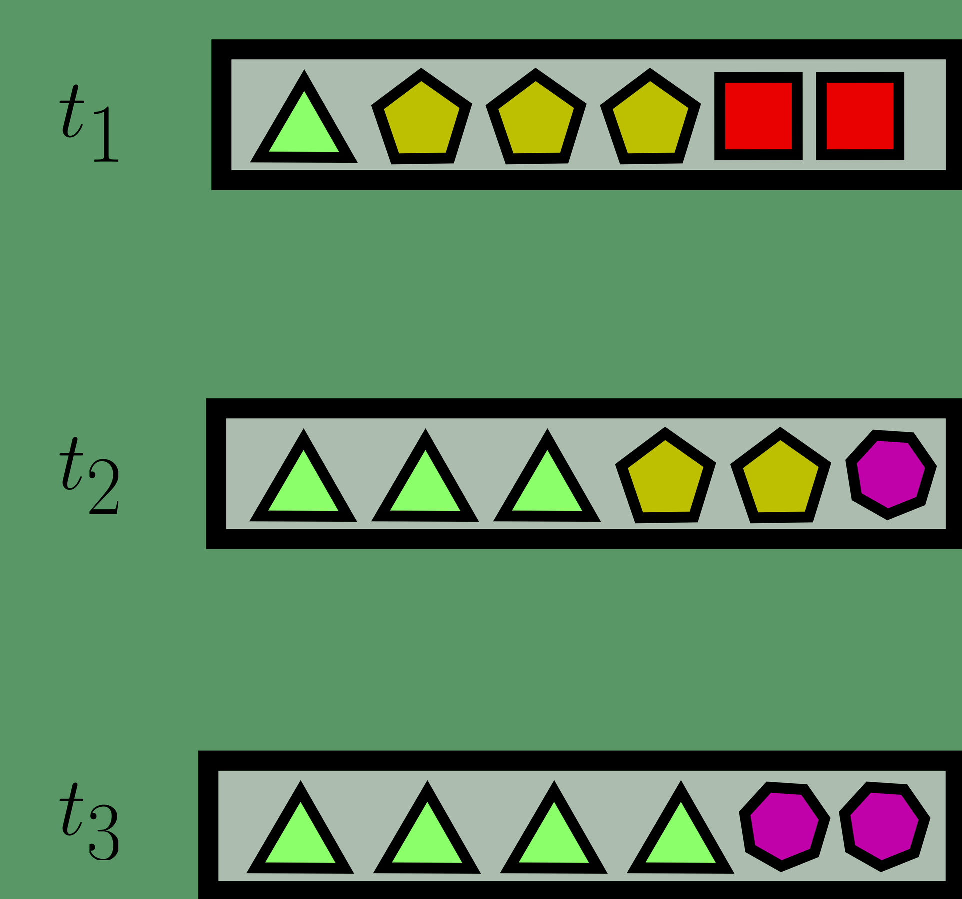


Networks undergo rounds of social interaction modeled using the iterated prisoner's dilemma [2]. Outcomes from these interactions determine a network's fitness in reproduction.

Iterations of these two processes will encourage networks to evolve towards cooperation or defection depending on the relative cost and benefit of cooperation.

Populations undergo the Wright-Fisher process. At each timestep, fitter networks produtce more offspring, with each birth having a chance to produce mutants

Reproduction and Mutation



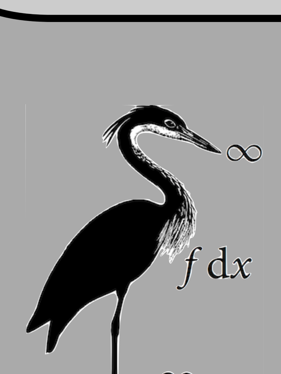
References

[1] Le Nagard, H., Chao, L., & Tenaillon, O. (2011). The emergence of complexity and restricted pleiotropy in adapting networks. BMC Evolutionary Biology, 11(1), 326. https://doi.org/10.1186/1471-2148-11-326

[2] André, J.-B., & Day, T. (2007). Perfect reciprocity is the only evolutionarily stable strategy in the continuous iterated prisoner's dilemma. Journal of Theoretical Biology, 247(1), 11–22. https://doi.org/10.1016/j.jtbi.2007.02.007

Acknowledgements

We would like to thank Ernest-Richard Kausche for supplying several activation functions used in the generation of figure 2.



https://vancleve.theoretical.bio/

Evolution of cooperation with relative cost

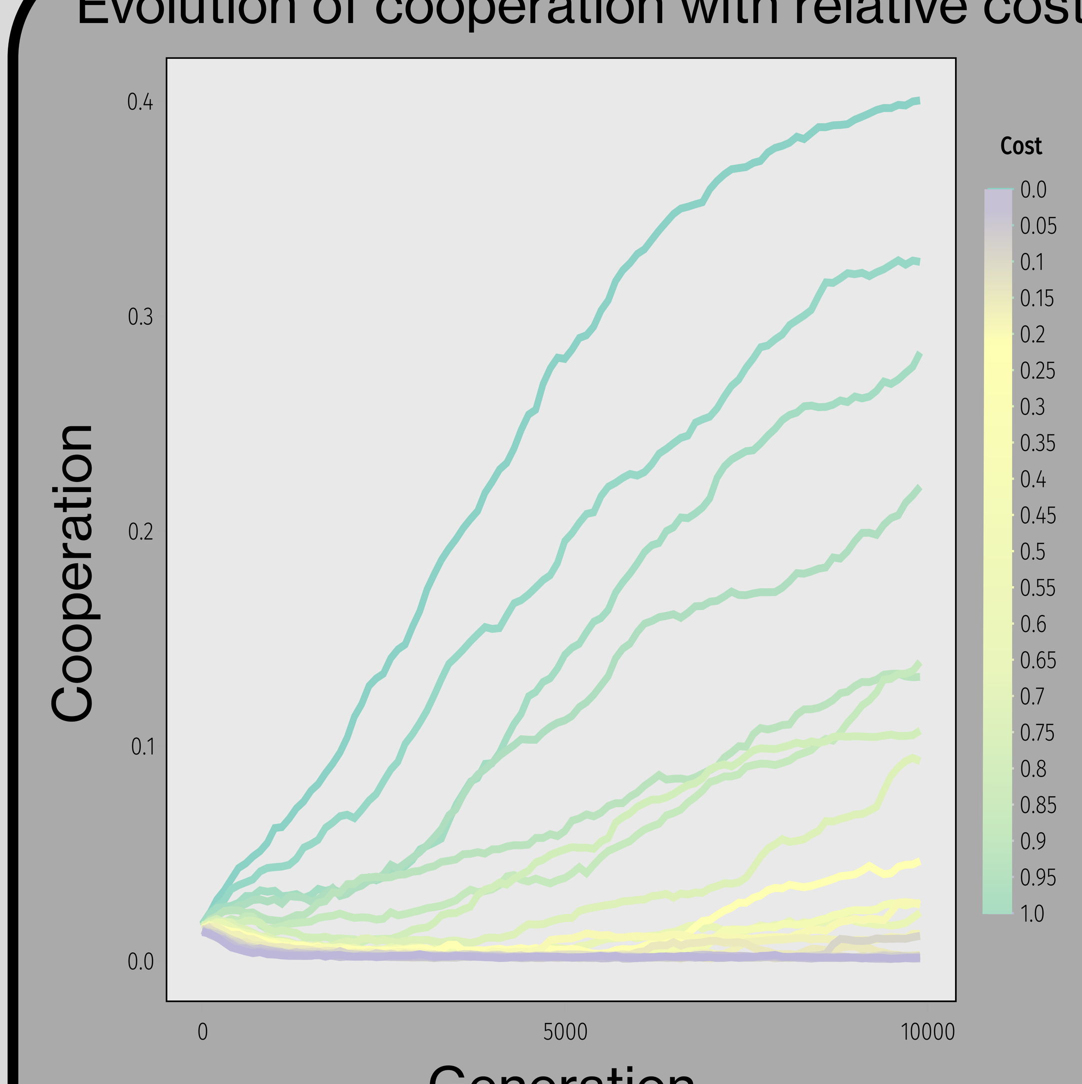


Fig 1: Comparison of different values for the cost of cooperation, relative to the benefit. Notice that increasing costs of cooperation reduce the population's final evolved level of cooperation. Simulations ran with 500 individuals for 10,000 generations under linear network activation.

Impact of different activation functions

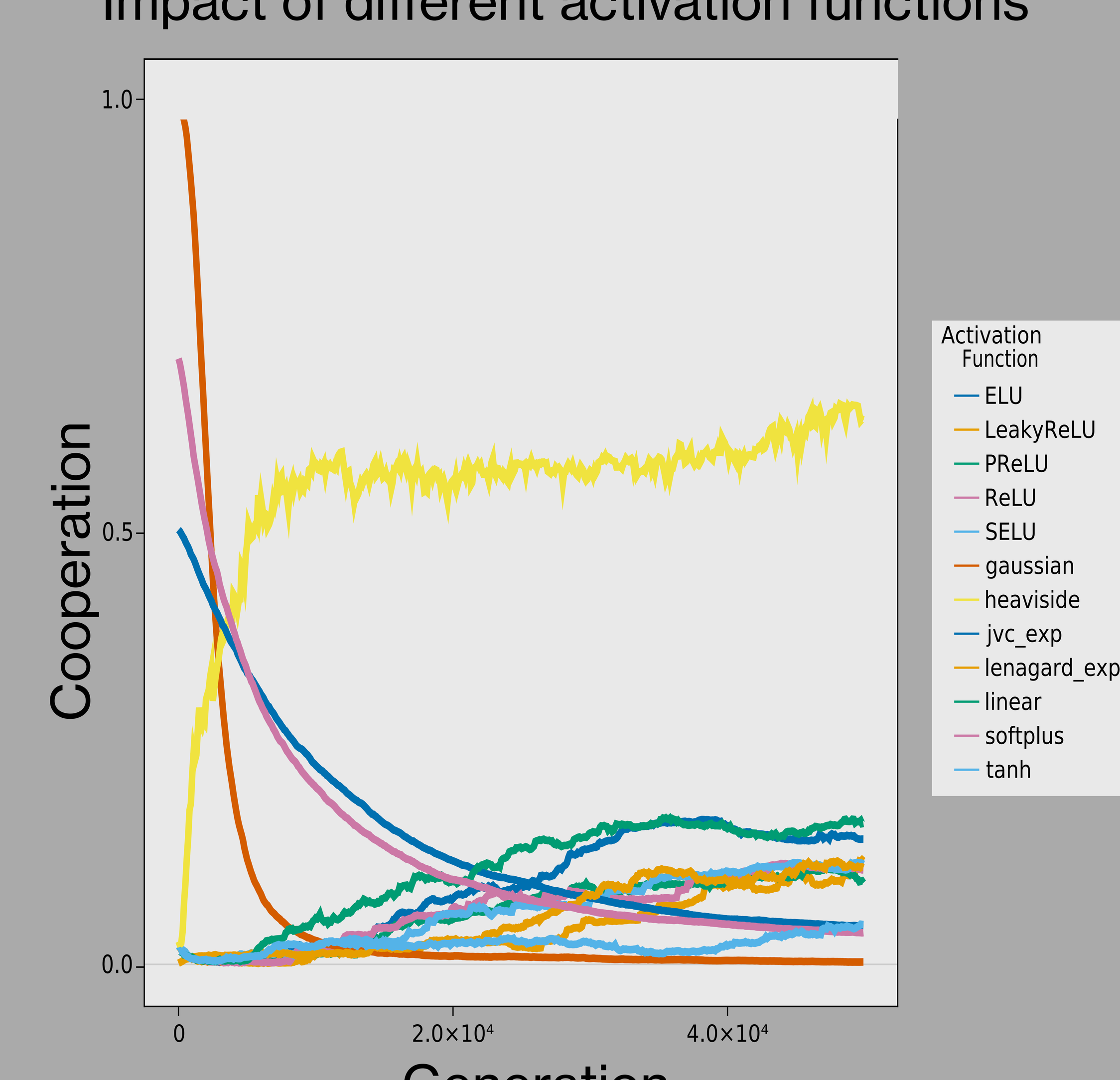


Fig 2: Comparison of various neural network activation functions impact on the evolved level of cooperation. Each function represents a different response for gene activation, demonstrating that choice of network parameters will result in different evolutionary outcomes. Simulations ran with 500 individuals for 50,000 generations at *b = 1.0, c = 0.5*