Attractor Dynamics in the Energy vs. Accuracy Space in an Artificial NeuroVascular Network (ANVN)

Bhadra S Kumar, Nagavarshini Mayakkannan, N Sowmya Manojna, V Srinivasa Chakravarthy

Introduction

What do we know?

- Neural Networks perform classification & function approximation tasks on optimal training
- In artificial neural networks, the concept of energy is absent.
- Performance generally increases with increase in number of neurons in hidden layer
- However, energy plays a very crucial role in biological neural networks.
- This energy is provided by a dense layer of vascular network.

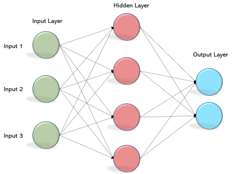

Figure 1: Artificial Neural Networks

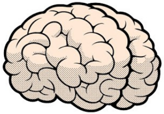

Figure 2: Biological Neural Networks

What does our study focus on?

- Is vascular architecture tailored to bring efficient neural performance?
- How do the vessels influence neural computation?
- Is there an optimum hidden neuron size in biological networks where maximum accuracy and minimum energy consumption is achieved?

Model Architecture

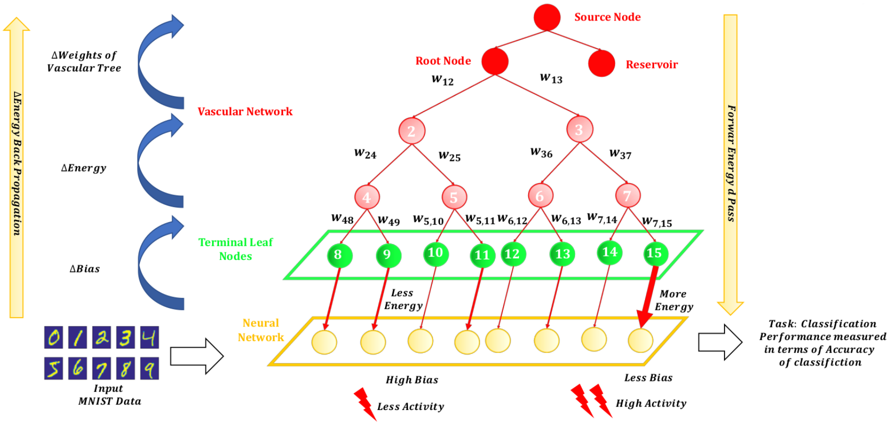

Figure 3: Architecture of Artificial NeuroVascular Networks (ANVNs), which comprises of an MLP connected to an Vascular tree. The green colored nodes depict the leaf nodes of the Vascular tree, which feed the corresponding hidden neurons of the MLP, depicted by the yellow colored nodes. The dark red colored nodes depict the feeder/root nodes which are the main source of energy to the Vascular tree. The weights determine the fraction of energy each child node receives from the parent node. These weights are trained based on the feedback received from the Neurons. In this case, the MLP was trained to classify MNIST images.

Results - Training of vascular layer improves network performance

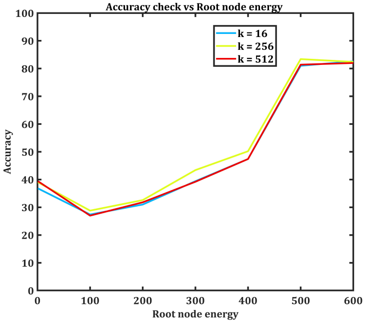

Figure 4: Accuracy across Root Energies with untrained vascular tree. We can see that at lower root energies, the accuracy of the network is very low and that it increases as the root energy increases.

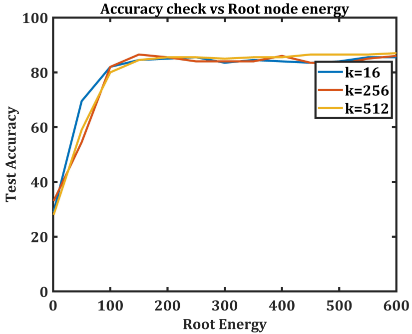

Figure 5: Accuracy across Root Energies with trained vascular tree. We see that the accuracy of the network swiftly increases even at lower root energies and remains approximately constant at higher root energies.

- Untrained vascular tree (uniform energy distribution) is connected to the MLP.
- Accuracy is low at lower root energies

- Simultaneous training of neural and vascular network is carried out
- Higher accuracy is observed at lower root energies

Results - Attractor dynamics in Energy - Accuracy Space

The dynamics of the system under different initial energy configurations (by changing the energy received by the root node from the supply node - governed by $W_{allowable}$).

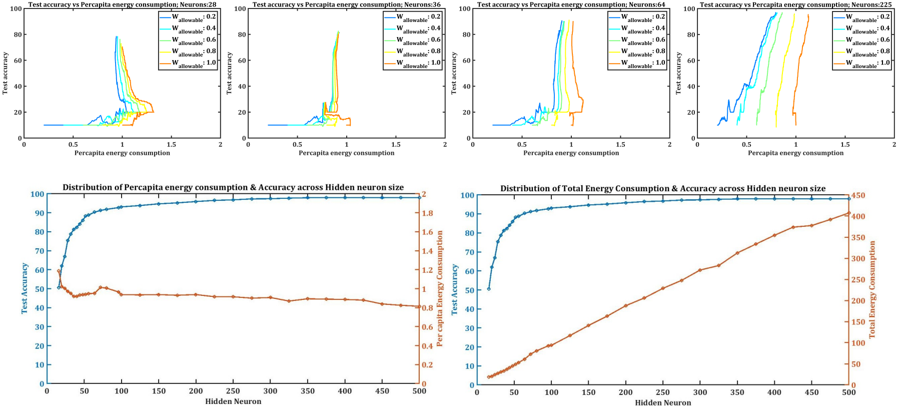

Figure 6: Transition from point attractor to line of attractors. (a) In case of lower number of hidden neuron size - 28, we see that the accuracy is low and the final position in the Accuracy-Energy graph, to a small degree, depends on the initial condition. (b) At the hidden neuron size - 36, we can see a very steep growth in the accuracy plot and the network follows a point attractor dynamics. (c and d) As the hidden layer neuron size increases (64 and 225 respectively), we see that the network diverged from the point attractor and now behaves like a line of attractors. (e) Percapita Energy consumption of the Network, Accuracy across different hidden neuron size. (f) Total Energy consumption of the Network, Accuracy across different hidden neuron size.

Results & Discussions - Attractor dynamics in Energy - Accuracy Space

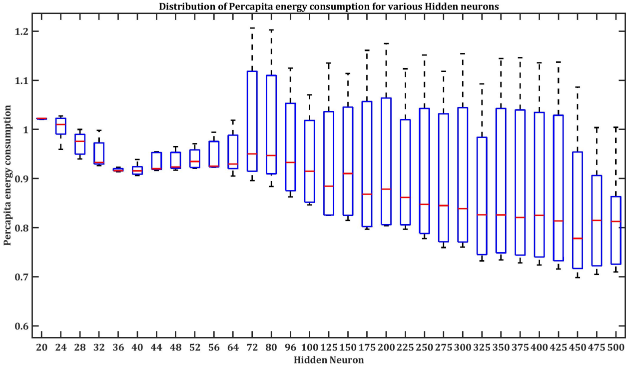

Figure 7: Standard deviation of final percapita energy across hidden neurons. We can clearly see that the spread initially decreases and the minimum percapita energy consumption and minimum spread is reached at a hidden neuron size of 36. As the hidden neuron size increases, the spread also increases, without significant increase in the accuracy.

Conclusion:

- The ANVN achieved higher performance for lower root-energies when the vascular network is trained.
- For a smaller value of hidden neuron size, the network approaches a stable fixed point in the percapita energy consumption - accuracy space, whereas once the hidden neuron size crosses a threshold, the fixed point appears to vanish giving place to a line of attractors.
- Our study demonstrated that the vessels play an important role in neural computation.