Implementing Spiking Neural Networks with the Biological Complexity of Cortical Neurons

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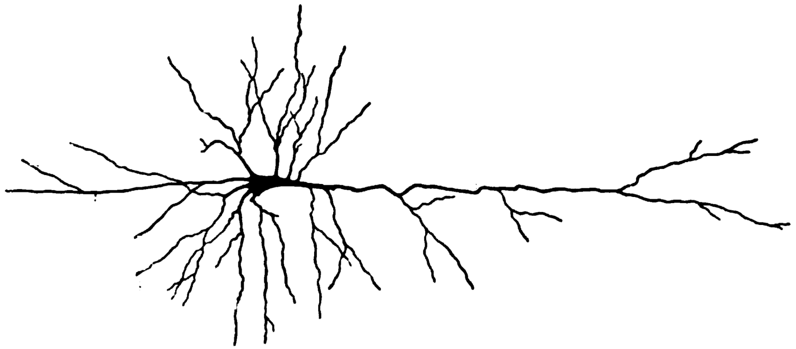
Situation Audit

- Human cortical neurons have an average of **10,000 synapses**
- **200-300 synapses** with active post-synaptic potentials can cause **neural firing** in human cortical neurons
- Spikes arrive at synapses **asynchronously** in human neurons
- The **rate of change of membrane potential** can affect spiking threshold in human neurons



Assumptions for this analysis

- These neuromorphic neurons are **analog**/pulse and timing circuits
- These neuromorphic neurons are implemented as **leaky integrate and fire neurons**
- Dendritic spiking that complicates the comparison is not included in the current analysis
- **Spike arrival time** is important to mimic biological neurons when implementing a neuromorphic system, as the spiking patterns convey important information

Hypotheses

- Larger neurons (with more synapses) are **more efficiently implemented** than smaller neurons

- **Spike arrival time variations** create diverse neural behaviors

Example: Large Neuron vs. Smaller Neuron Network

Assume

- a neuron with N synapses, requiring M synapses to fire.
- an alternative neuromorphic network with neurons containing only M synapses each.

➡ Thresholding could cause loss of information that must be recovered (example following)

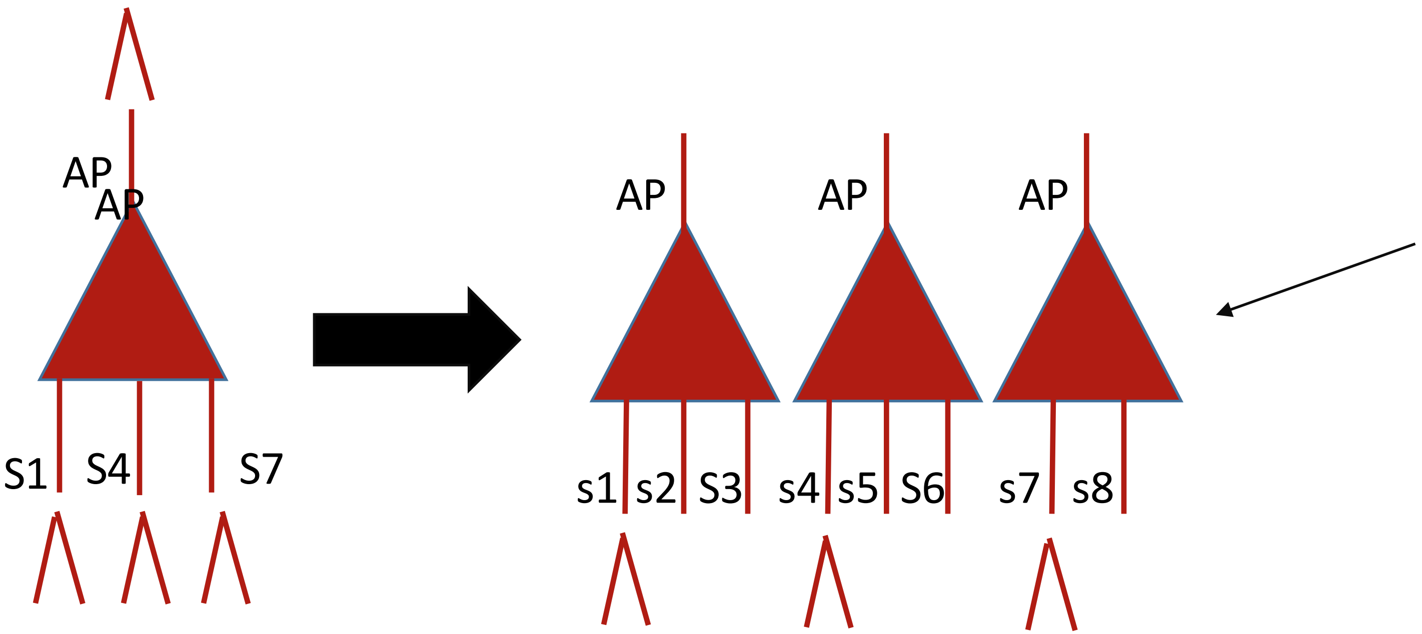
In the worst case, covering the large neuron properly means that we must examine all possible combinations of inputs, M at a time, to see if there are enough spikes that could cause the larger neuron to fire.

This could be modeled (erroneously) as an ”N choose M” problem that would demonstrate exponential complexity of the neuromorphic network because the threshold operation for each small neuron would lose information unless all M inputs happened to be present at one of the simpler neurons

Solution1 – Use the simpler neurons to “add” all active synapses in an adder tree containing the simpler neurons – probably linear complexity with a large constant factor.

Solution2 – unary to binary encoding NN, and a comparator NN

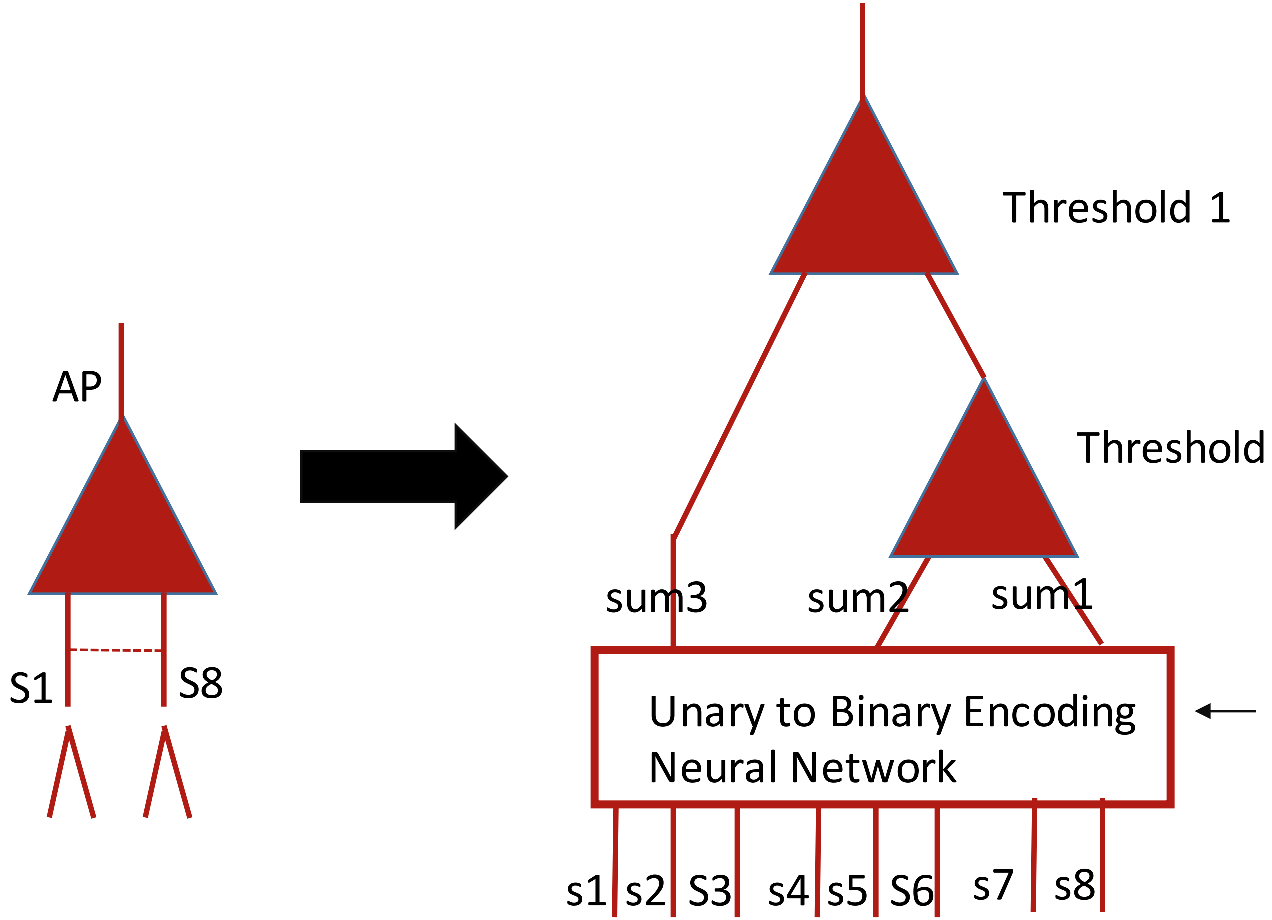
Simple Illustration – Replacing an 8-synapse neuron that has threshold set to 3 active inputs with 3 3-synapse neurons



Thresholding causes information loss! None of the smaller neurons would fire

Therefore we need more computations

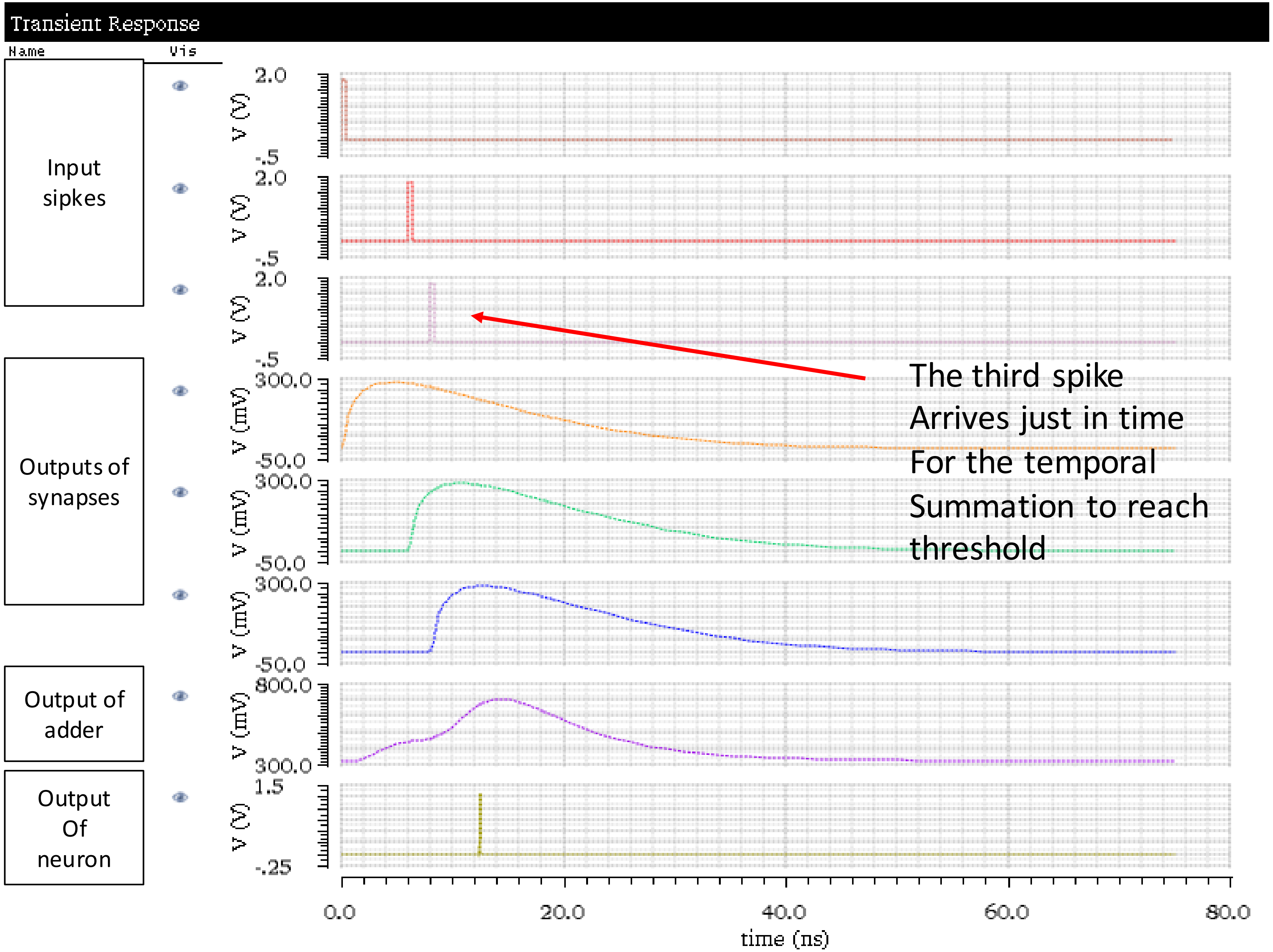
Simple Illustration – Change the computation the smaller neurons perform and use more neurons – inefficient but accurate



Multiple spiking circuits

Multiple synapses/input spike?

What about arrival spike timing?



Thank You