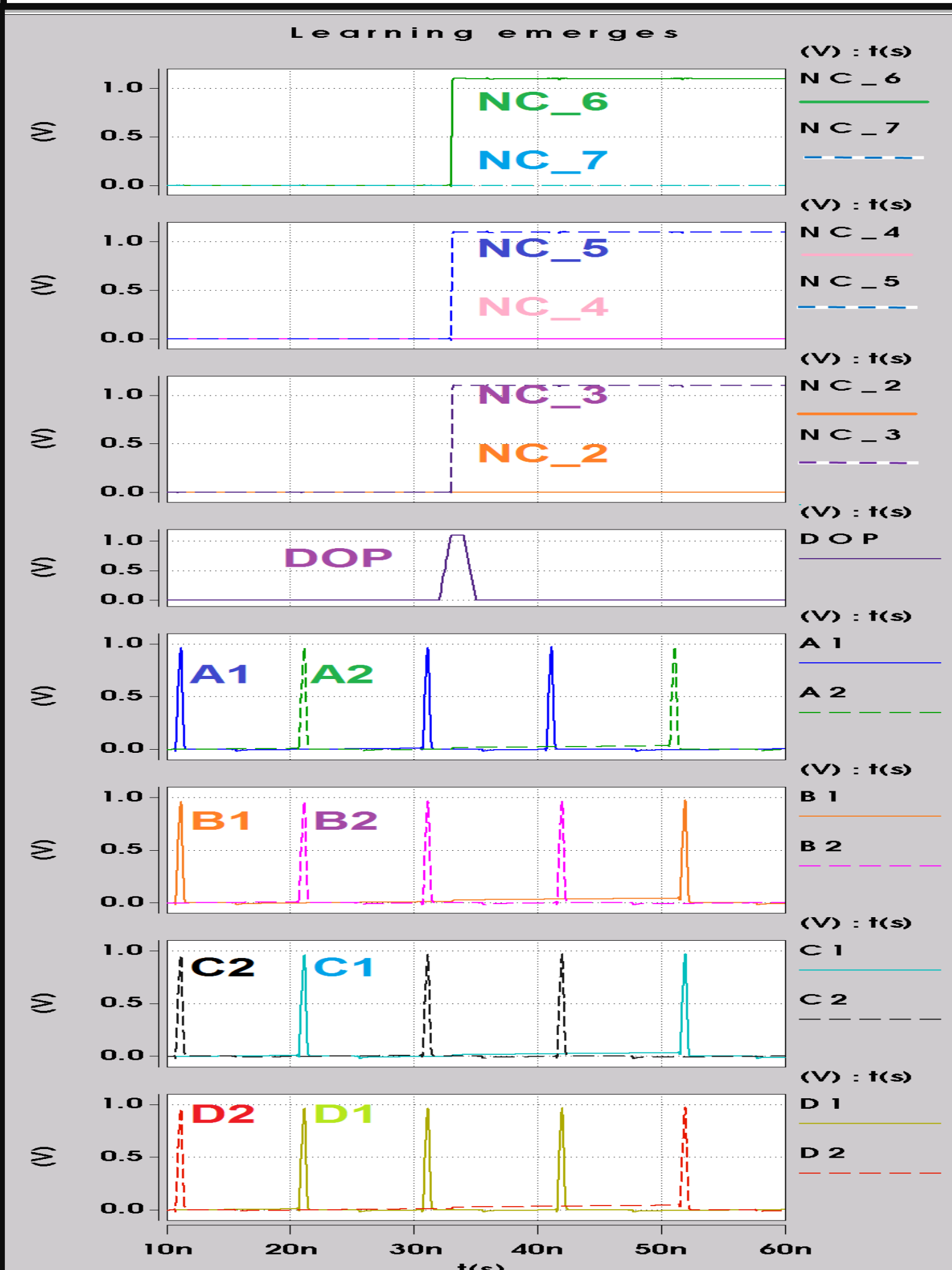


# An Analog Neural Network that Learns Sudoku-Like Puzzle Rules

Saeid Barzegarjalali, Alice C. Parker

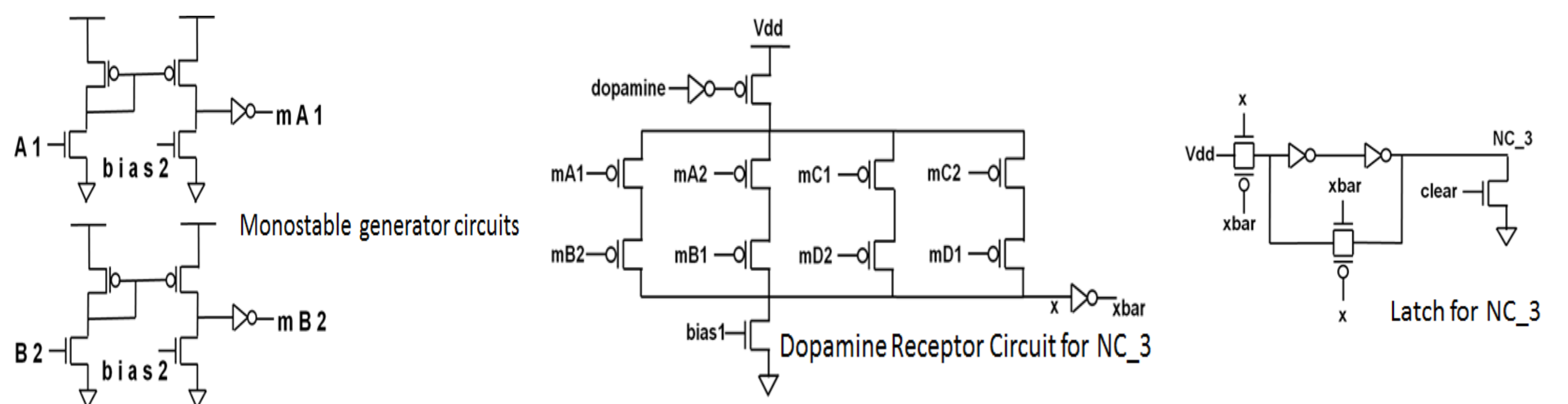
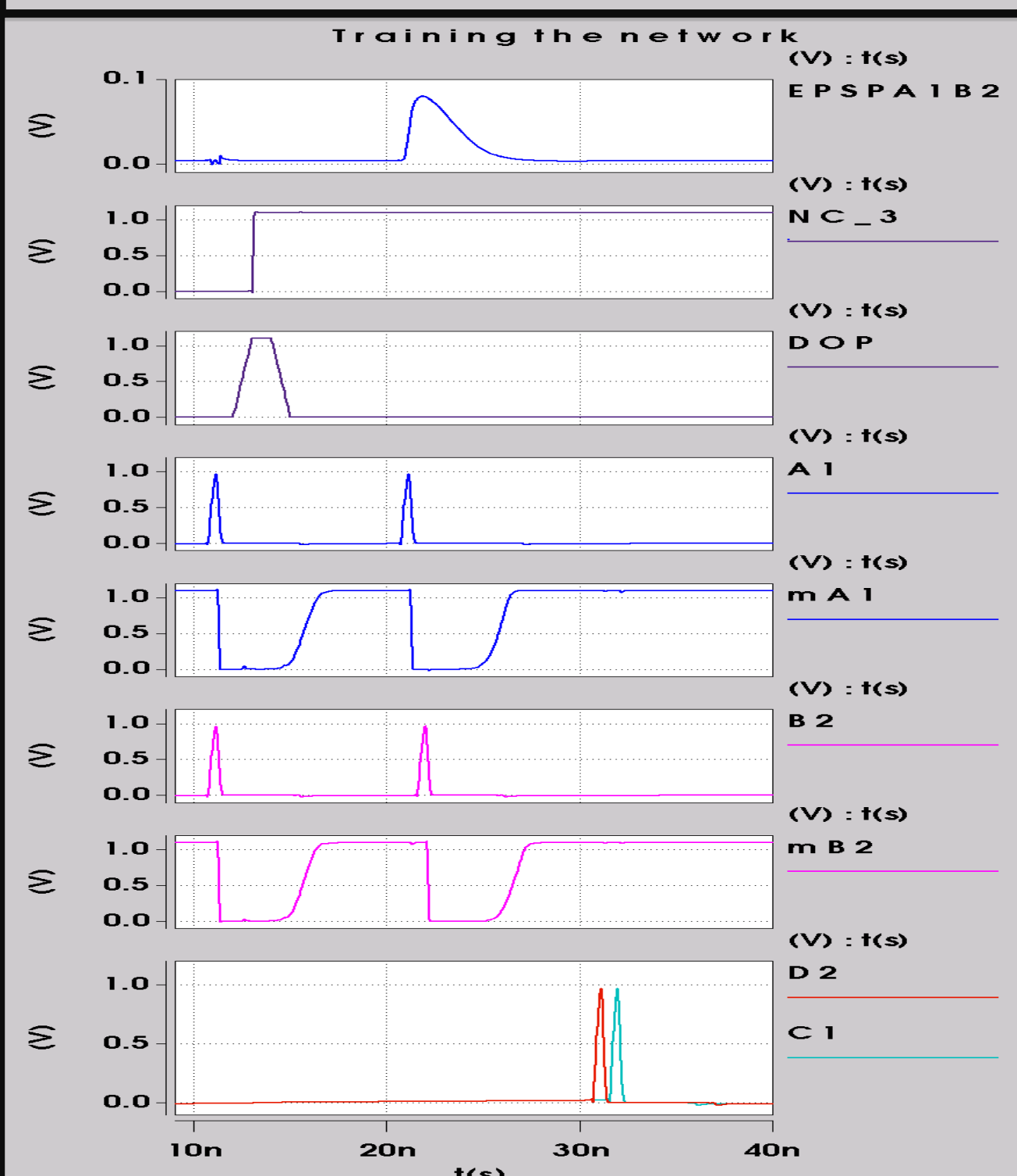
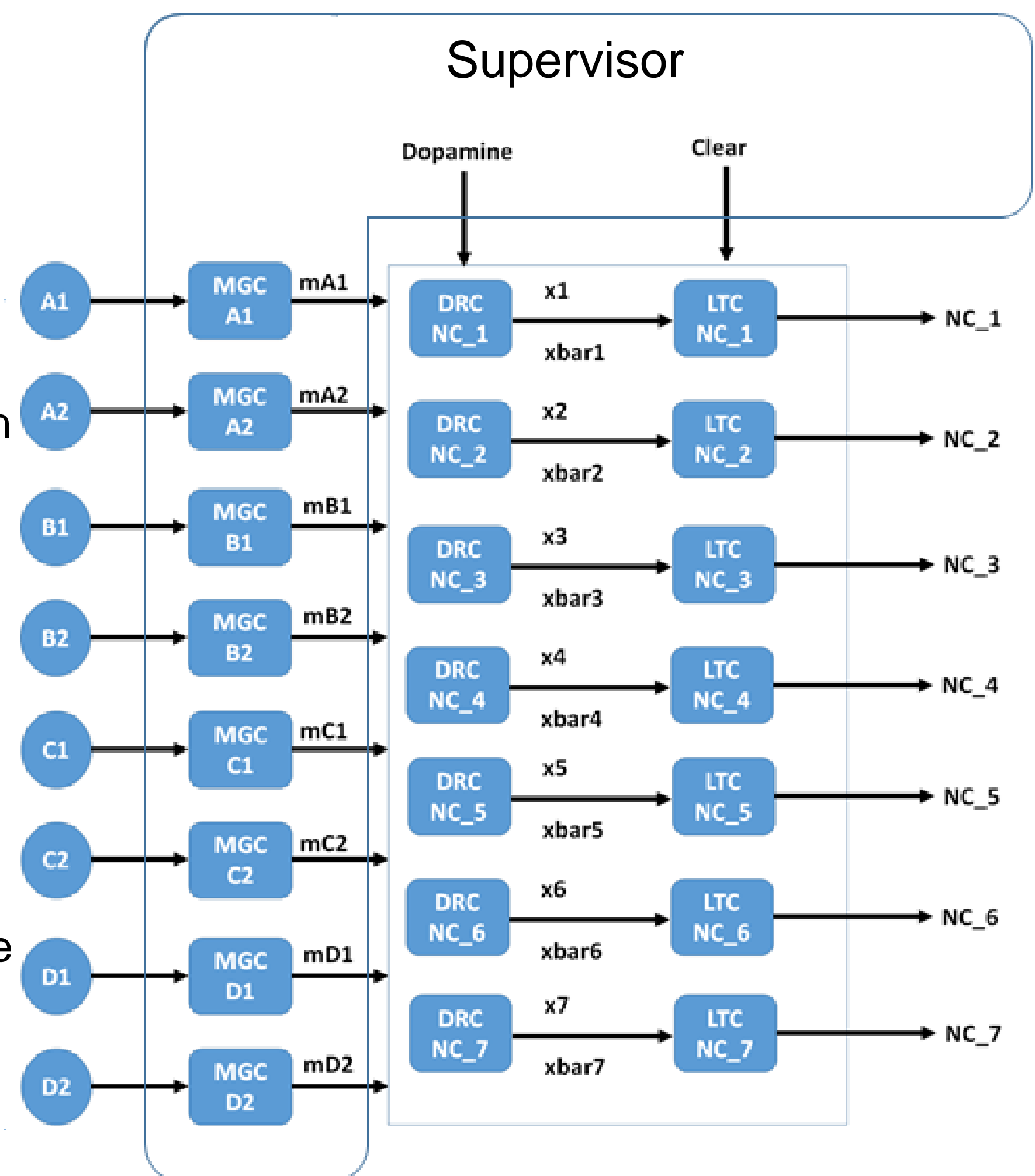
## Introduction

- We have designed a fully-connected neural network implemented as an analog circuit consisting of 8 neurons and 64 synapses that can learn rules of 2-by-2 Sudoku or Sudoku like puzzles and then can solve them.
- In this circuit, learning is mediated by giving a dopamine reward signal to correct actions, which has a biological basis and is known as reinforcement learning.
- Regular architecture of the circuit helps it to generalize learned rules and as a consequence expedites the learning procedure.
- The circuit receives dopamine externally from a trainer circuit and therefore learning is supervised.
- Injected dopamine will strengthen some of the existing excitatory synapses similar to biological synaptic plasticity.
- Previously, we had designed a bio-inspired circuit that learns spatiotemporal patterns in an unsupervised mode using structural plasticity. In the human brain, learning is mediated by both types of plasticity. The long-term goal of our research group is combining these two types of plasticity (synaptic and structural) to design a network with higher level of learning capabilities and more complex cognitive skills to imitate the biological brain.



- At  $t=10n$  and  $t=20n$ , neurons fire and generate different patterns. These patterns are not solutions to a 2-by-2 Sudoku, so no reward is provided by the supervisor.
- At  $t=30n$ , neurons generate an acceptable solution to a 2-by-2 Sudoku, and they receive Dopamine as a reward. This sets all the corresponding NC (Neurotransmitter Concentration) signals.
- From now on, the network only generates solutions to the Sudoku.

1	2	2	1
2	1	1	2



- At  $t=10n$ , A1 and B2 fire simultaneously. mA1 and mB2 both go low.
- Dopamine is provided by the supervisor for this firing pattern and NC<sub>3</sub> is set.
- Synapses that are connecting neurons on the same row with different numbers are strengthened.
- Next time when A1 fires, B2 fires as a response.
- The circuit has learnt that numbers on the same row should be different.
- Therefore, when D2 fires, C1 fires a response.