Hacking the Brain: A Simple Toy Model of Memory

Is it possible to manipulate memories? Memory is a process of storing and retrieving information by the brain cells known as neurons. If there are damages to the neurons such that they cannot transfer signals between them, you can start to experience difficulties remembering familiar tasks. As physicists, we want to understand memory formation on a microscale and find universal rules that govern information maintenance length.

At the neural level, memory is defined as the activation of neurons from voltage stimuli. Typically, a neuron at rest has a resting potential of -70mV. There are broadly 3 stages a neuron goes through while transferring information:

1. Neuron at rest receives a voltage signal (triggered by receiving a piece of information), if stimulus above threshold voltage, neuron **fires** an action potential of +40mV
2. Neuron immediately transitions into **refractory period**, during which it cannot fire a second action potential
3. At the end of the refractory period, neuron restores **resting** potential of -70mV

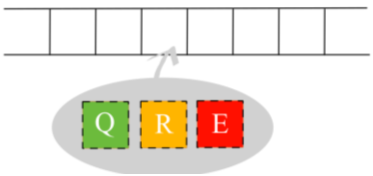

Fig. 1. A 1D lattice with possible states each site can take colour-coded: Quiescent, Refractory, Excited.

In our project, we replicated such rules in a computational model of a **one-dimensional square lattice**. Each site on the lattice represents a neuron, and it can take one of the three states: Quiescent (resting), Refractory, Excited, as shown in Fig. 1.

Fig. 2. The initial condition that the lattice starts in, with all lattice cells (neurons) in resting state except one.

We forced an initial condition on the lattice that all sites started in Q-state (resting) and only one random site is set in the E-state as illustrated in Fig. 2. The states then evolve in time according to the rules depicting the real scenarios in neural networks:

E → **R** → **Q** → **E** →…

With two conditions imposed:

1. R→Q, only after r time steps because the neuron cannot be fired twice instantly
2. Q→E, if one of the adjacent sites is already in E-state OR if the site in Q-state is chosen by the spontaneous firing probably p. The probability p in this model serves as a **noise** because it transforms any site in Q to E in an unpredictable manner.

Figure 3 shows a lattice of 128 sites, with a refractory period of 128 time steps and spontaneous probability p=0.01. Tracking the position of sites in E-state in the system over time, we see wave-like patterns emerging on the space-time graph. The blue points highlight the first activated sites in each wavefront, we them the **leaders**. We observe that with the interference of noise p, the 1D system remembers the leaders' positions, and this is the sign of long-term memory. We also obtained various statistical results which confirmed the conclusion of the **noise induced memory**.

By modelling neuron firings, we can one day find the secrets to accelerate learning and work smarter, not harder.

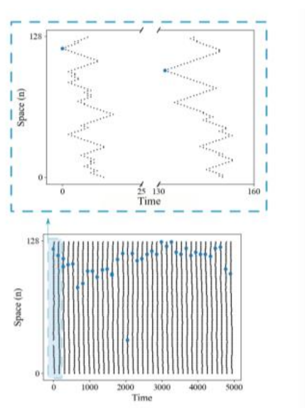

Fig. 3. Positions of excited sites for 5000 time steps. The earliest excited sites are coloured in blue.