# Neuromorphic Controls: From the dynamics of a cartpole to a lunar lander

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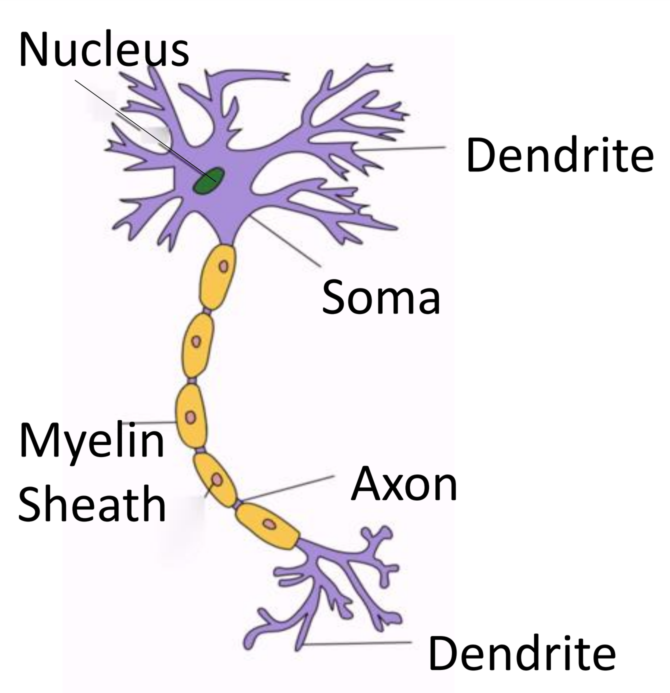
## Introduction

- Neuromorphic architecture: A promising candidate for non von-Neumann computation
- Use of spikes trains (impulses distributed spatio-temporally) for processing as opposed to continuous time signals.
- Low power computation with spiking neural networks(SNNs) for AI.
- SNNs for optimal and data-driven control: Application to cartpole balancing and soft landing of a lunar lander.

## Theory: The Leaky-Integrate-and-Fire Neuron

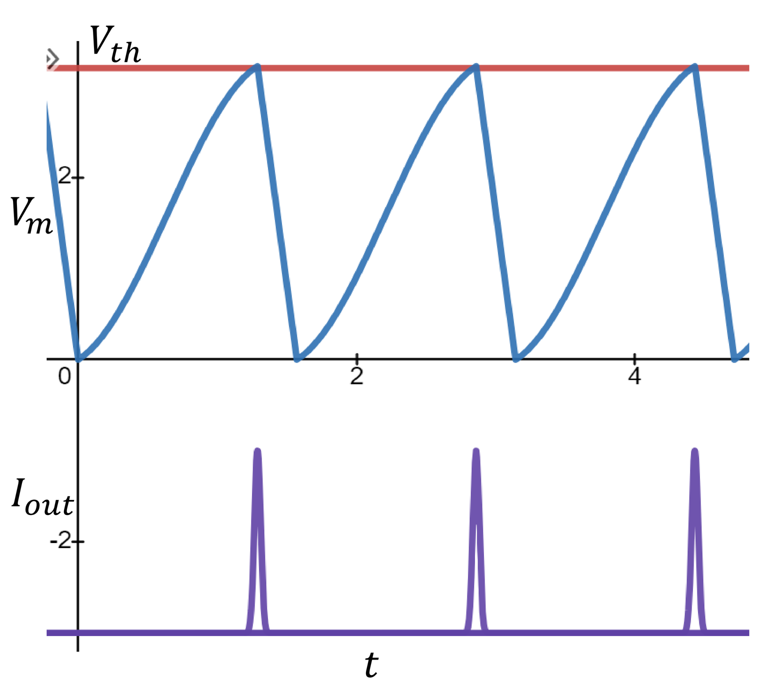


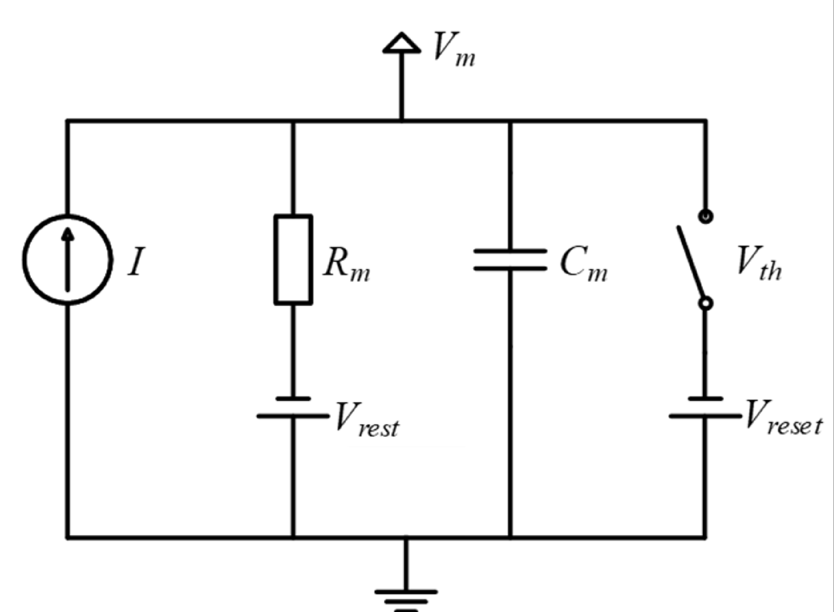

$$\tau_m \dot{V_m} = -(V_m - V_{rest}) + \left(\sum_{i=1}^{n} w_i I_{den}\right)$$

$$I_{out} = \begin{cases} I_{spk} & \ldots V_m > V_{th} \\ 0 & \ldots otherwise \end{cases}$$

$$V_m = \begin{cases} V_{reset} & \ldots V_m > V_{th} \\ V_m & \ldots otherwise \end{cases}$$

$$\tau_m = R_m C_m \,, I = \left(\sum_{i=1}^{n} w_i I_{den}\right)$$




## Aim: The Research Question

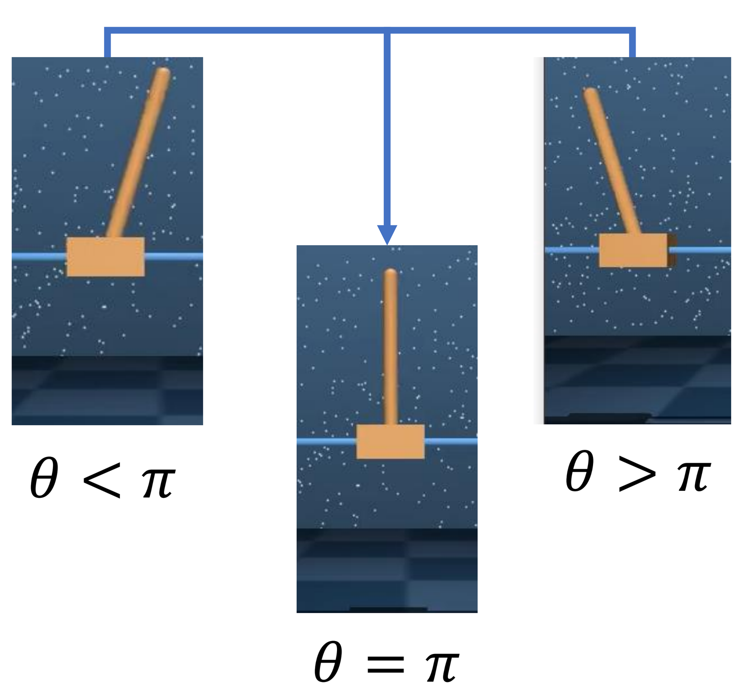
Can SNNs provide acceptable performance for applications in conventional optimal and data-driven control techniques?

## Methodology

- Python based simulation models for both cartpole and lunar-landers
- For the cartpole balancing, standard linear quadratic regulator (LQR) is used but with a single spiking neuron as a feedback matrix multiplier.
- For the lunar lander soft landing, deep Q learning (a version of reinforcement learning was used) with conventional artificial neural networks (ANNs) and SNNs to train the lander to execute soft landing on the given target area.

## Systems of Interest

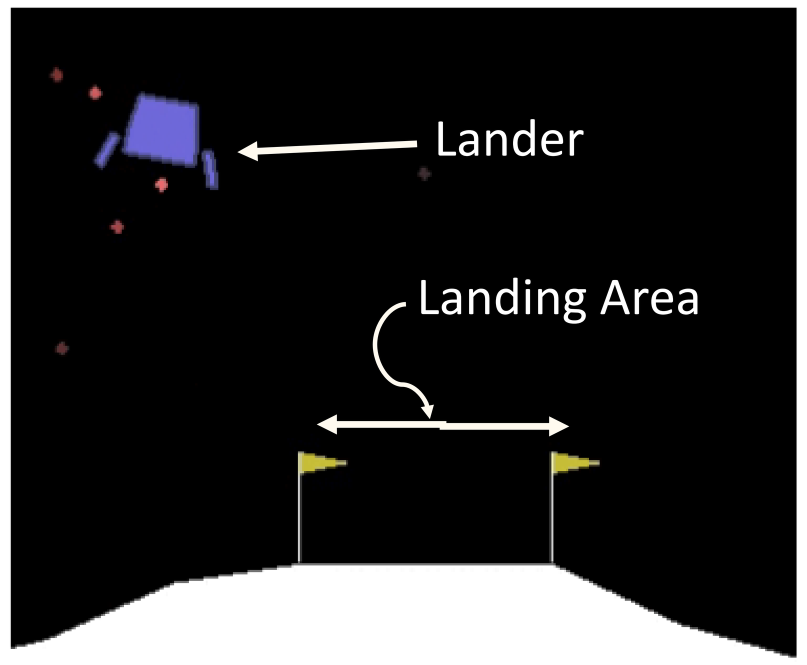
### Cartpole (Linear Control)




**Control objective**: To balance the pole on the cart for small perturbations about the unstable equilibrium position (UEP)

**Achieved**: Successful balancing with 1 spiking neuron based LQR feedback controller.

### Lunar Lander (Non-linear Control)



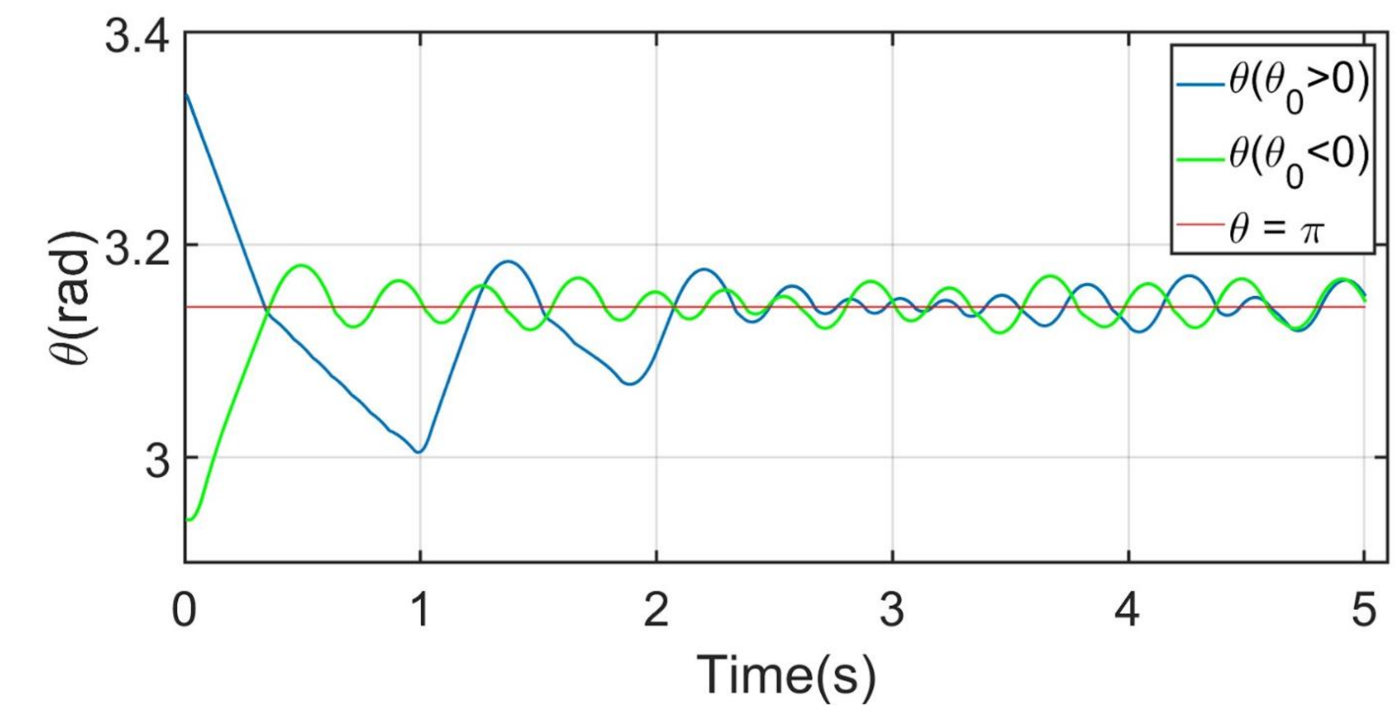

**Control objective**: To execute soft landing between the flags using three thrusters: left, right and main.

**Achieved**: Successful landing using Q learning and conventional non-spiking ANNs.

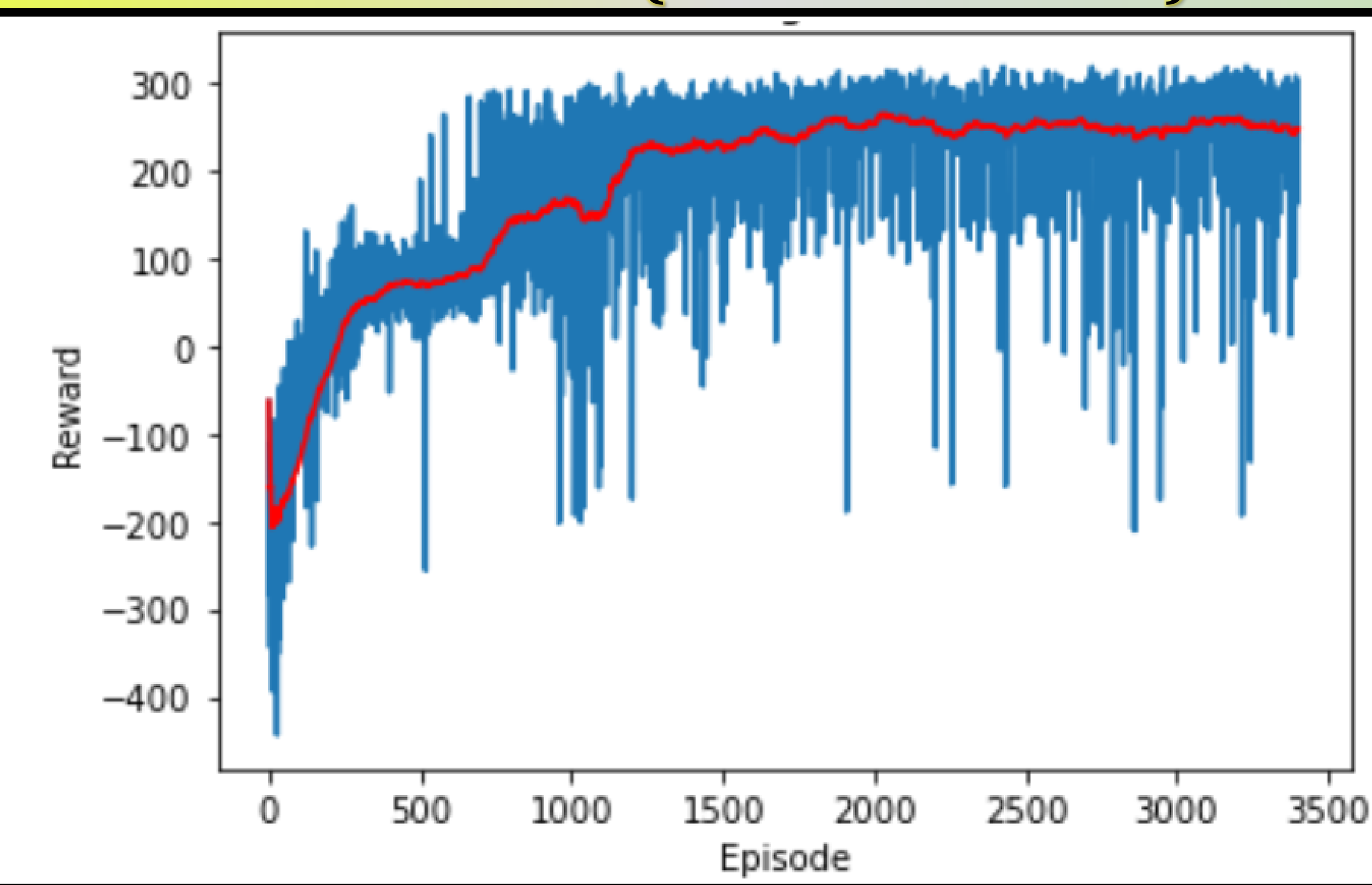
**In progress**: Learning to land using SNN based Q learning .

## Results

### Cartpole (Linear Control)

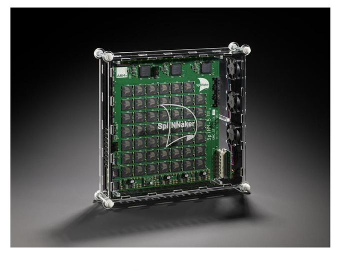



### Lunar Lander (Non-linear Control)




## Summary & Future Directions

- A single spiking neuron can provide acceptable transient and steady state characteristics for feedback control.
- Implementing both the problems on a neuromorphic hardware can be the next step, to check for power benefits.



SpiNNaker Neuromorphic Chip

## References

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