Quantum Deep Advantage

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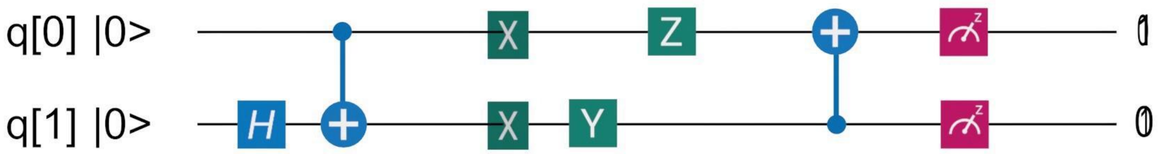
Motivation

- Automate building optimized circuits to prepare quantum states on real devices.

- We automated the quantum circuit-building process with reinforcement learning and validated our method by performing simple numerical experiments on a Bell State.



(Credit: Daniel Serrano, IBM)

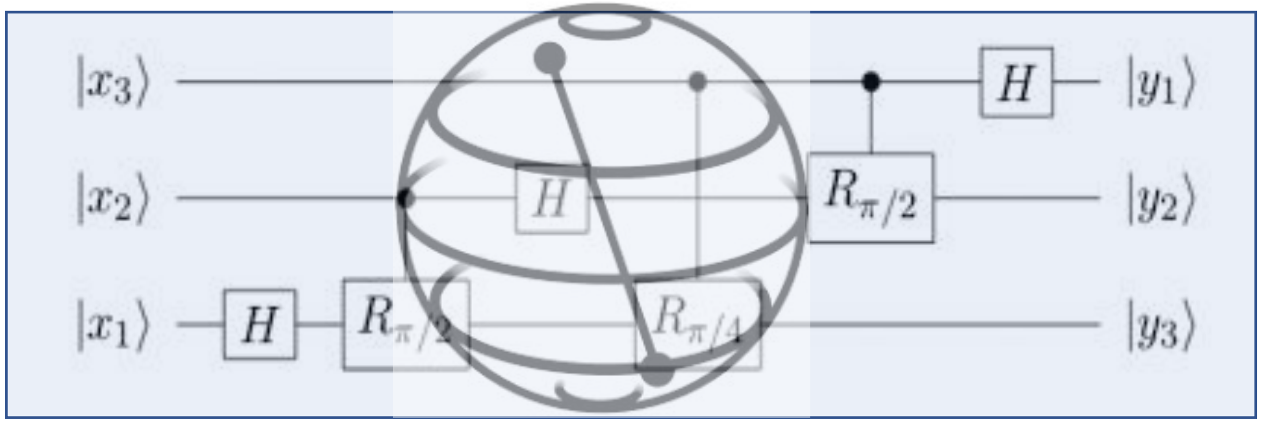
Agent

Environment rewards the agent based on **gate-count** and **accuracy.**

An agent places gates on a circuit every timestep.

Reward /Punishment

Action

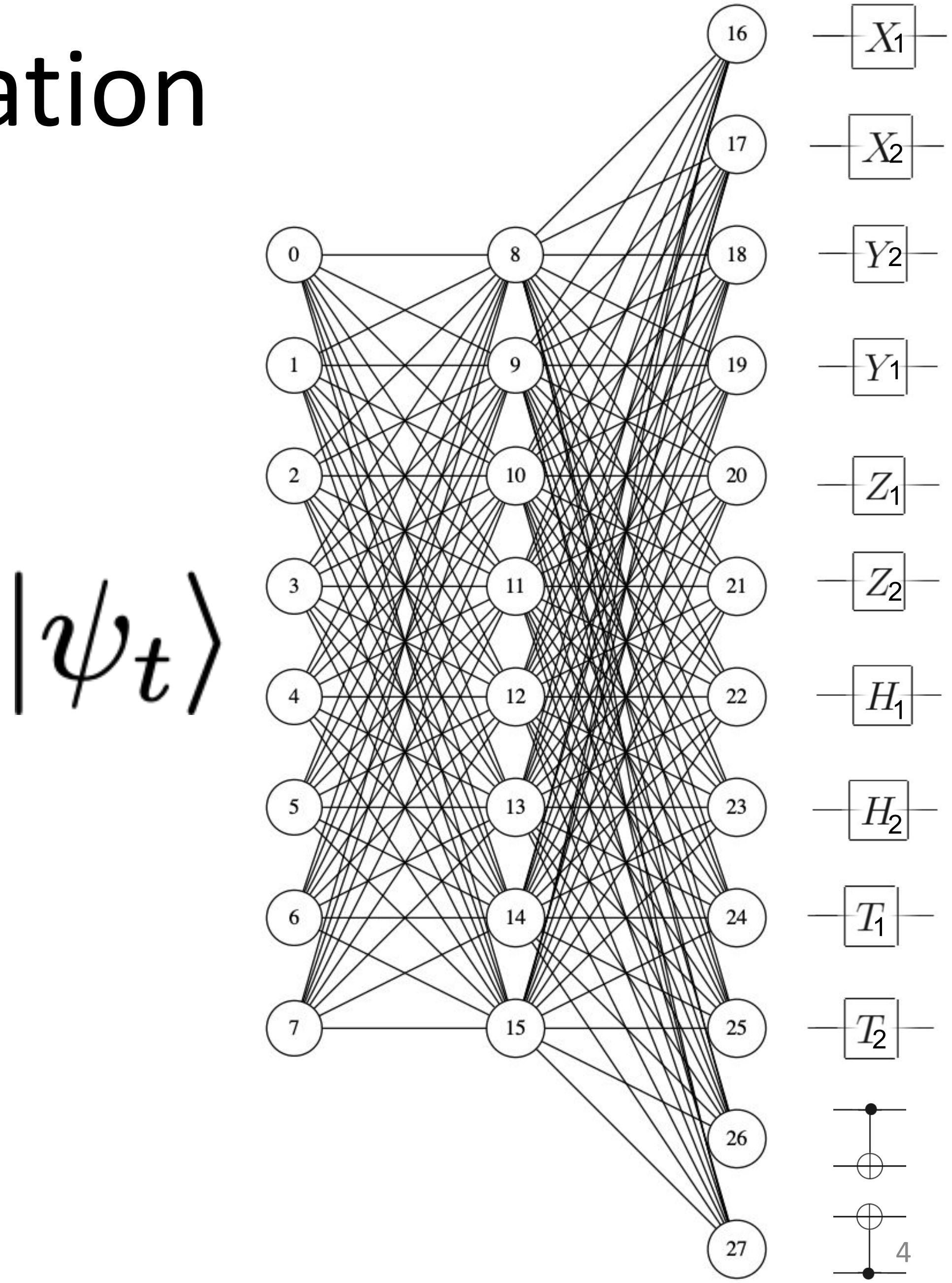


Environment: Qiskit Aer

Neural Network Implementation

- Tensorflow
  - Vanilla Neural Network
  - LSTM Network
  - **Could explore many more episodes with a GPU!**

To deal with the *Internal Covariate Shift* while training, we employ **Layer Normalization** (Ba, Kiros, and Hinton, 2016).



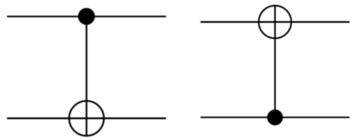
Setting up Agent and Environment

State Space

All 2 qubits states

Action Space

$$\begin{matrix} X_1 & Y_1 & Z_1 & H_1 & T_1 \\ X_2 & Y_2 & Z_2 & H_2 & T_2 \end{matrix}$$

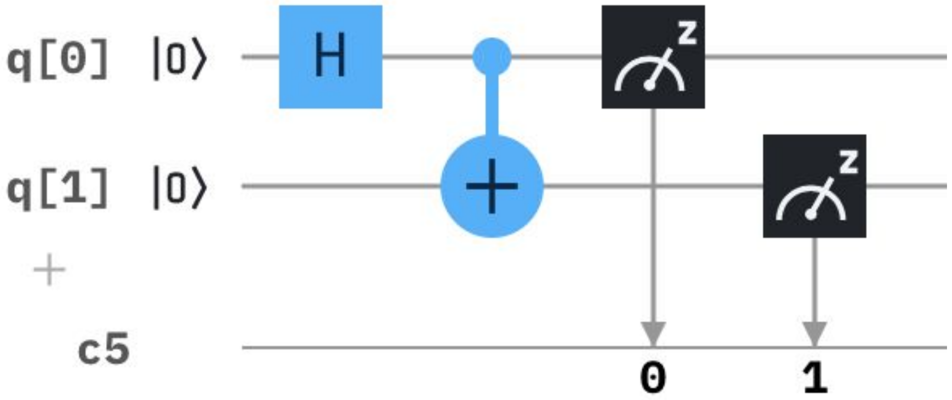


Rewards

$$\text{Reward} = \begin{cases} \color{blue}{\dfrac{100}{\#\text{gates}}} & \text{correct state} \\ \color{red}{-1} & \text{incorrect state} \end{cases}$$

Target State: Bell State

$$|\psi_{\text{target}}\rangle = \frac{|00\rangle + |11\rangle}{\sqrt{2}}$$



Qiskit as a simulator for quantum circuits

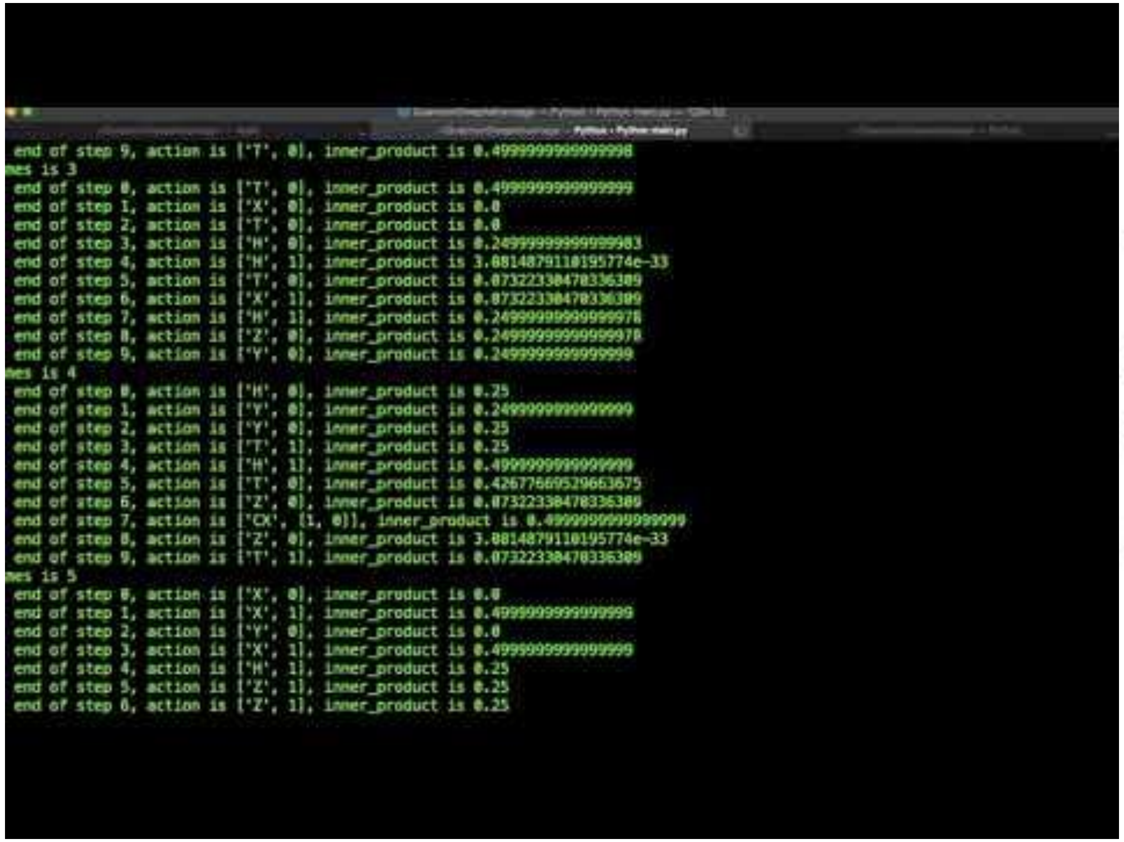
```
# apply step on qubit
qc = QuantumCircuit(2)
qc.initialize(self.state, [0, 1])
# apply X gate on qubit action[1]
if action[0] == "X":
    qc.x(action[1])
elif action[0] == "Y":
    qc.y(action[1])
```

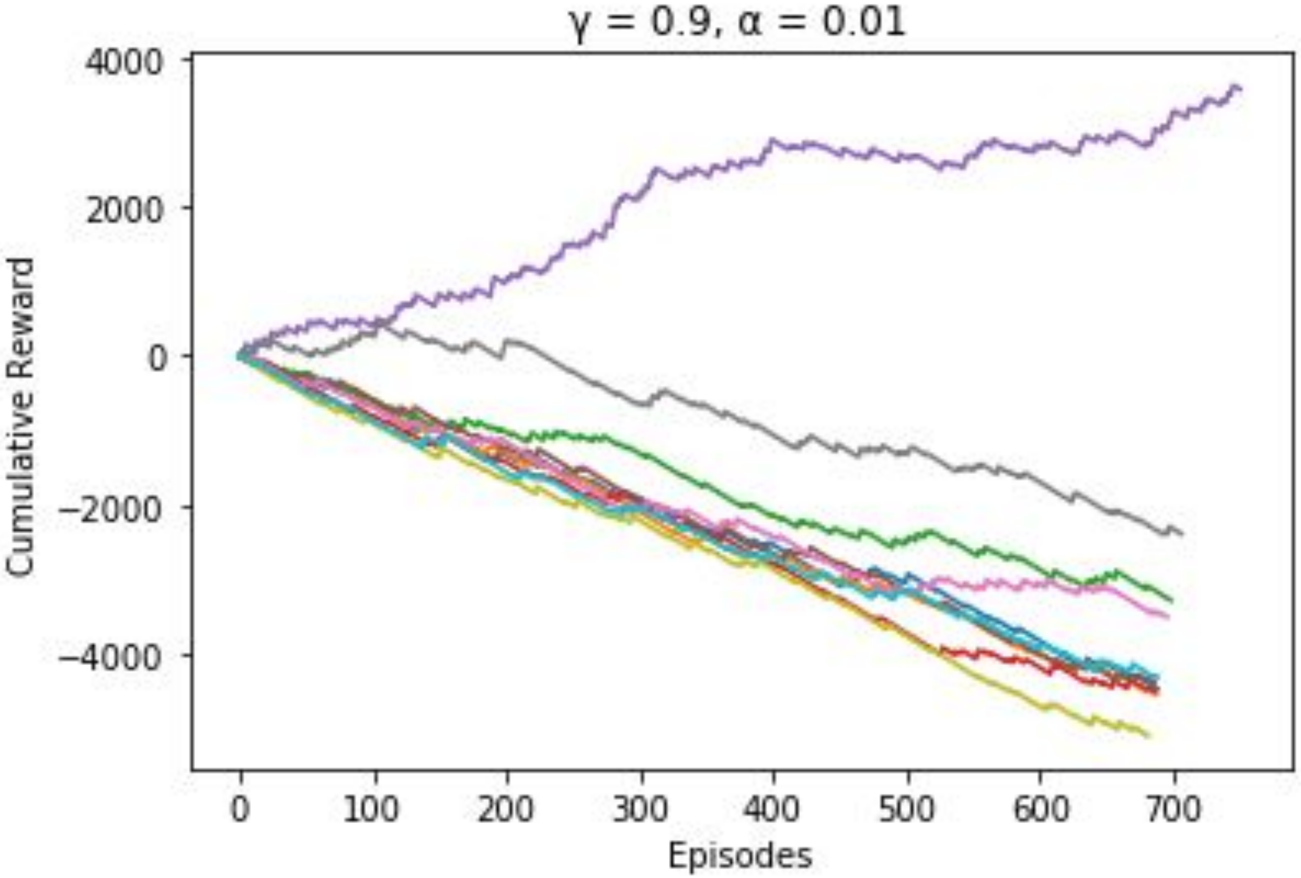
...

Qiskit Aer is a high-performance simulator framework for quantum computing algorithms. It allows us to see the full state-vector after applying each gate without destroy the entanglement.

Bell State Attempt 1: 4x4x12 – Vanilla NN

- Plot of Cumulative Reward (moving average of 100 episodes):

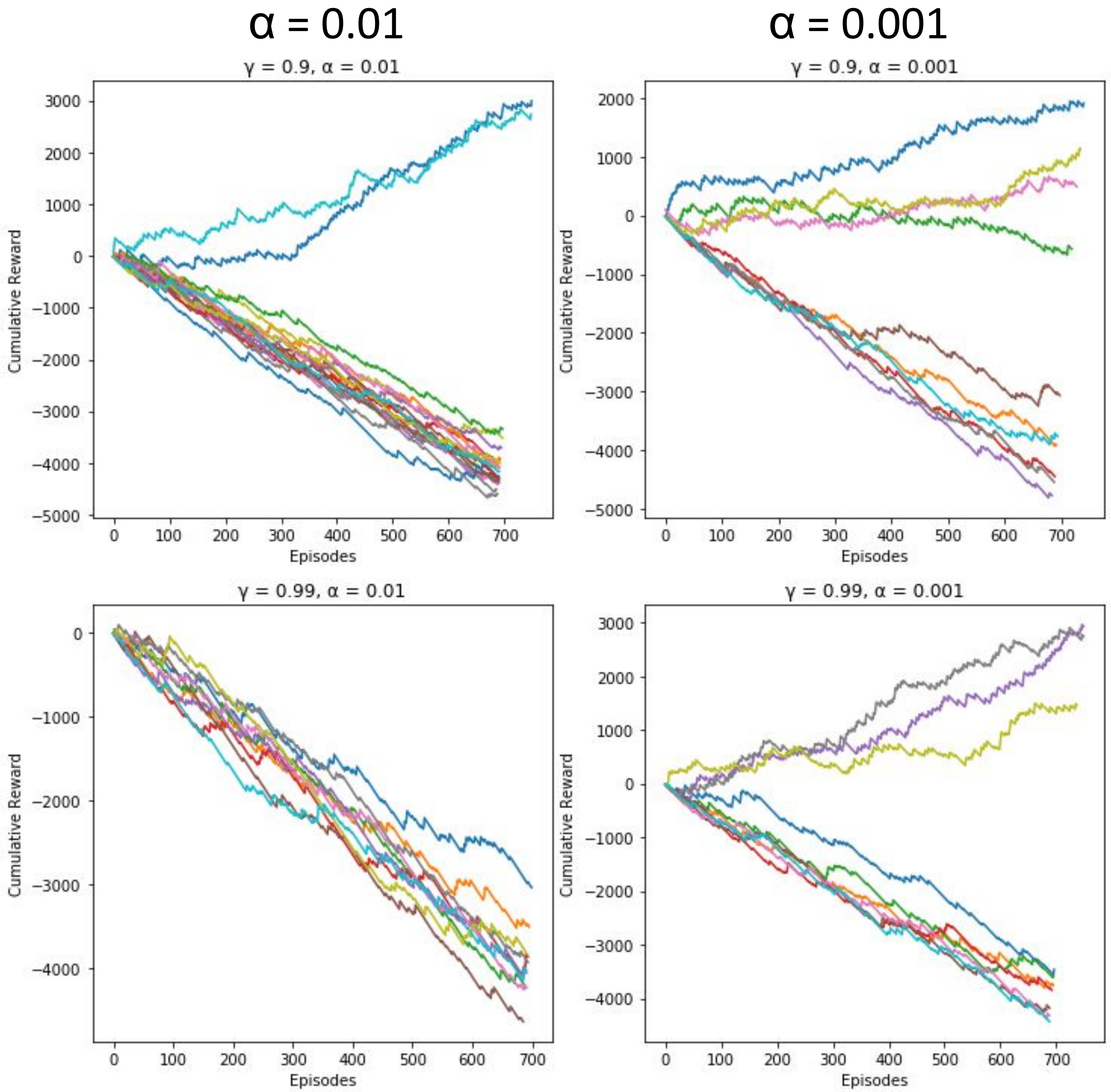




Bell State Attempt 2: 8x8x12 Vanilla NN with 0.2 Dropout

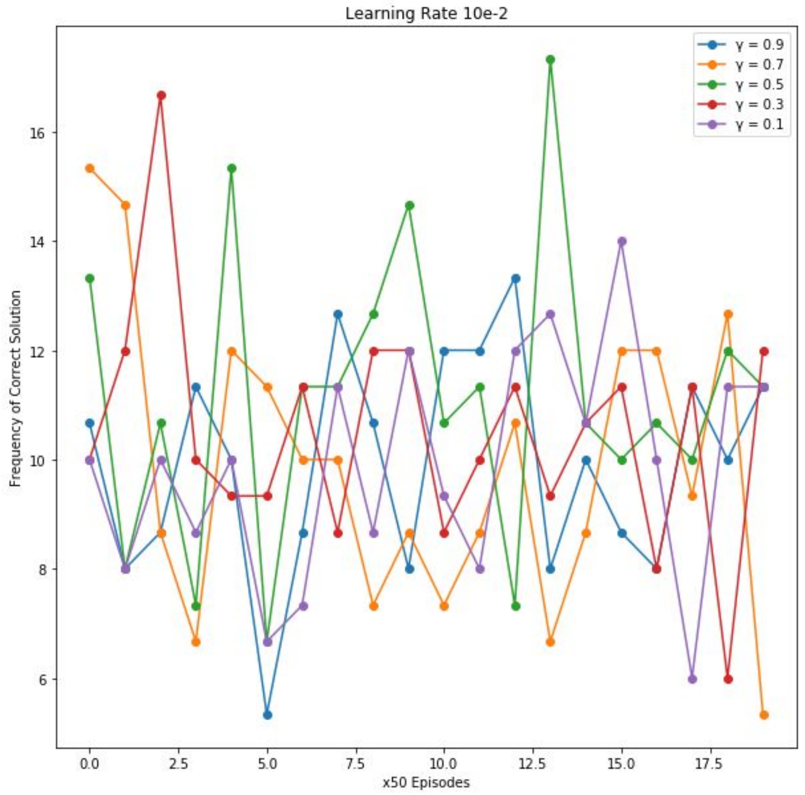
- Very sensitive to initial conditions

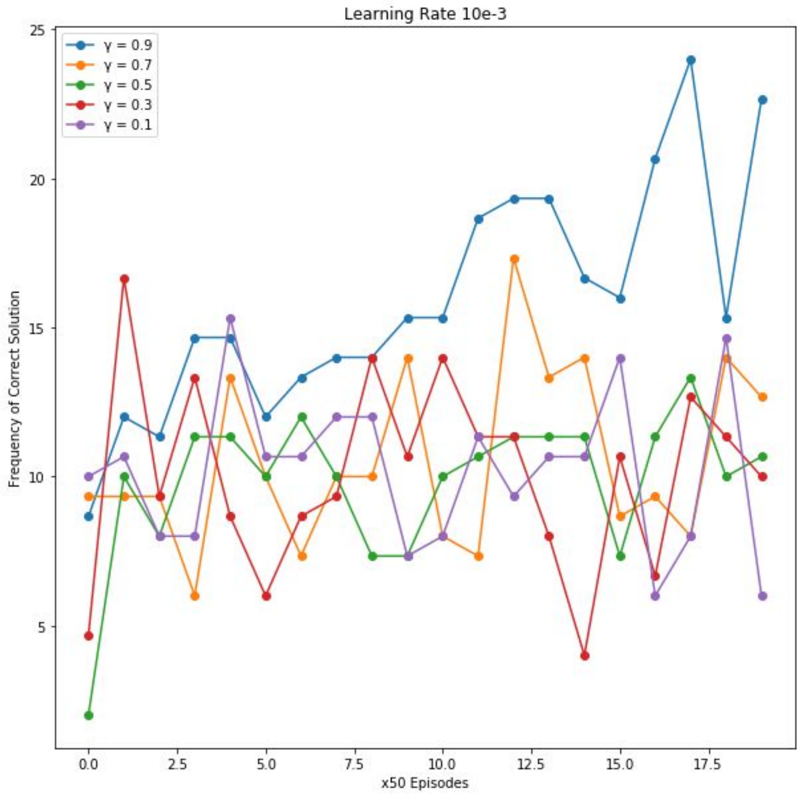
- Lower learning rate of $\alpha = 0.001$ appears to have better success.

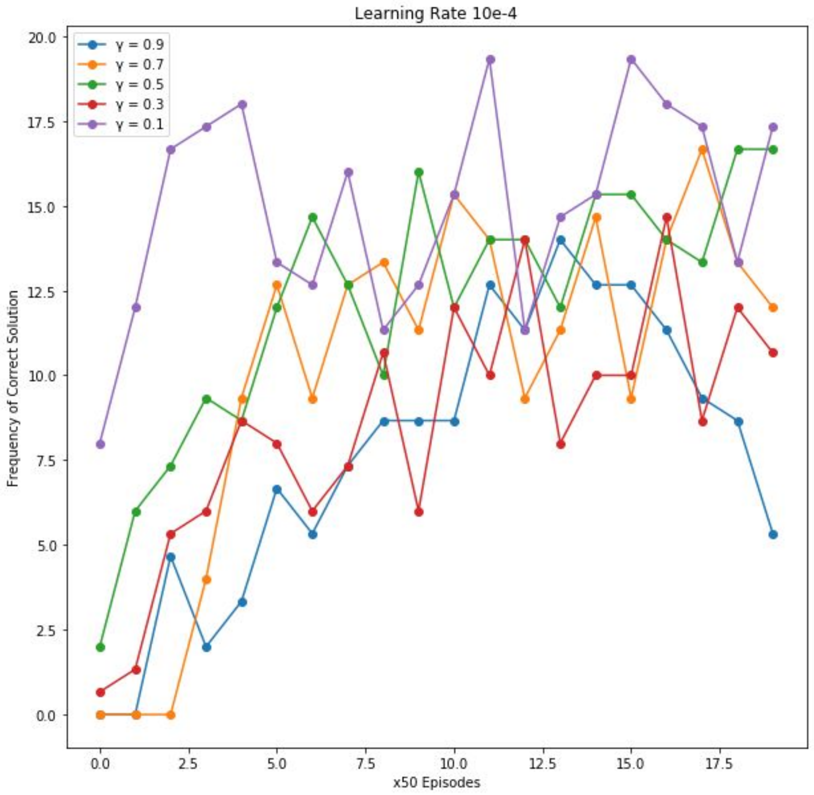


Bell State Attempt 3: LSTM 8x8x12 Example

10e-2 → Learning Rate Decreases → 10e-4







Future Work

Applications

- Larger, more complicated circuits
- Application to Solovay-Kitaev on n-qubits.
- Compare with the Initialize function in Qiskit
- Benchmark and integrate into Qiskit

Improvements to RL

- Implementing other RL methods, such as Actor-Critic/ Soft Q-Learning
- Better Hyperparameter Tuning through Meta-Learning (iterate and improve!)
- Sparse Reward Signal:
    - Reward Shaping
    - Scoring
- Implement ***Experience Replay*** and ***Target Network***.

Thank you for listening!!