Identification and Mitigation of Biases in Quantum Machine Learning

Nandhini Swaminathan[1] and David Danks[2]

University of California, San Diego

Summary: We identify biases in Quantum Machine Learning (QML) that arise from the distinct properties of quantum systems, which differ from biases in classical machine learning and review existing mitigation strategies.

Featured Examples

Encoding Bias

PROBLEM: Encoding Bias arises from the interaction between the transformation of classical data into quantum states, and the quantum algorithm.

OUR EXPERIMENT: To examine this bias, we conducted an experiment using various encoding techniques applied to a fixed QNN architecture on the MNIST dataset for classification tasks. Our results (see below) show the significant impact of encoding choice on model performance

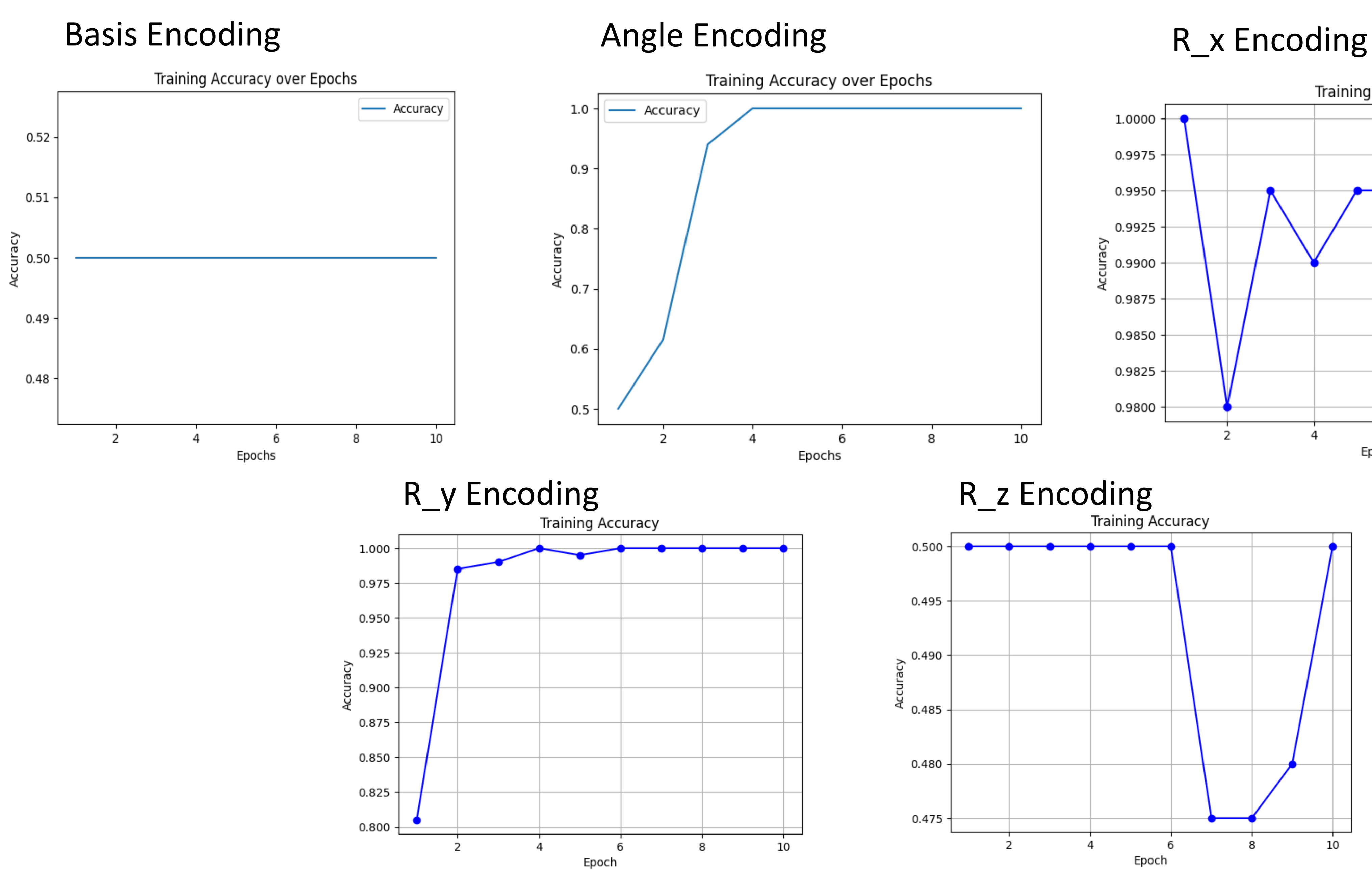

Figure 1: Performance differences on MNIST dataset due to Encoding Bias (Training accuracy vs Epoch)

State-Dependent Bias

PROBLEM: Qubits tend to relax to their lower energy state (0), causing measurement bias that favors detecting 0 over 1

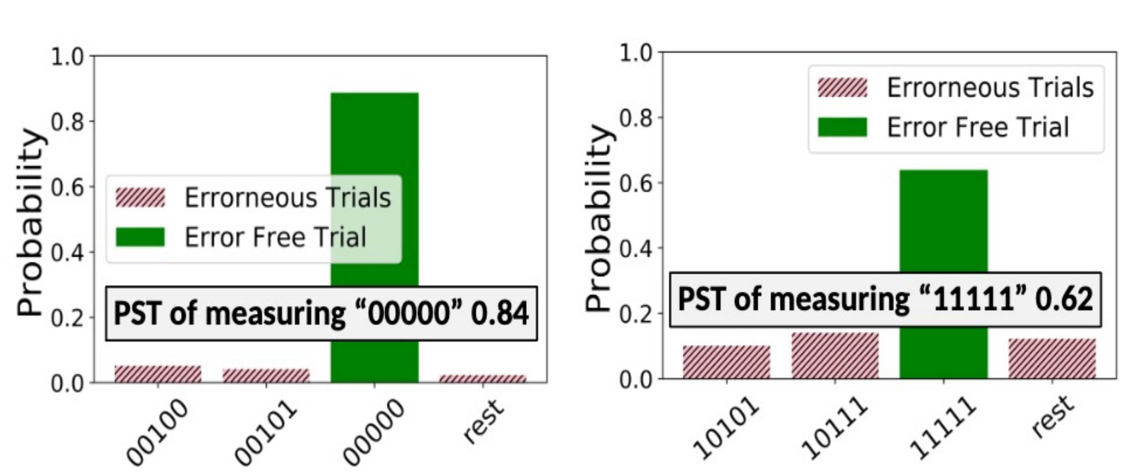

Figure 2: On five qubit ibmqx4, probability of successfully measuring a state (a) All-zero state "00000" (b) All-ones state "11111"

MITIGATION STRATEGY
(Adapted from Tannu et. al 2019)

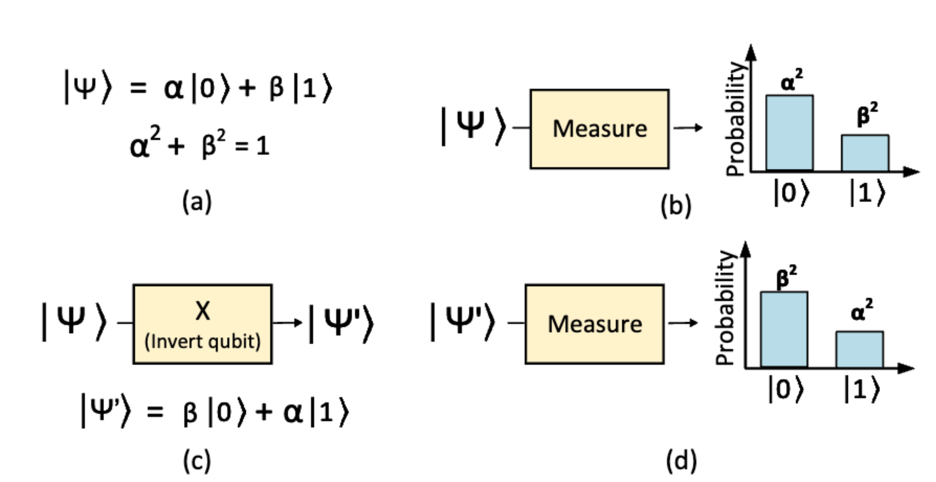

Figure 3: a) Quantum state is a superposition of $|0\rangle$ and $|1\rangle$ (b) Measurement of a qubit is probabilistic (c) X-gate inverts the qubit state (d) Measurement of inverted qubit

Overview

This previous examples illustrates some of the critical challenges, but it's just one piece of a larger puzzle. We have identified other key biases that can arise through features of the data, algorithms, or measurements and we consider each of them.

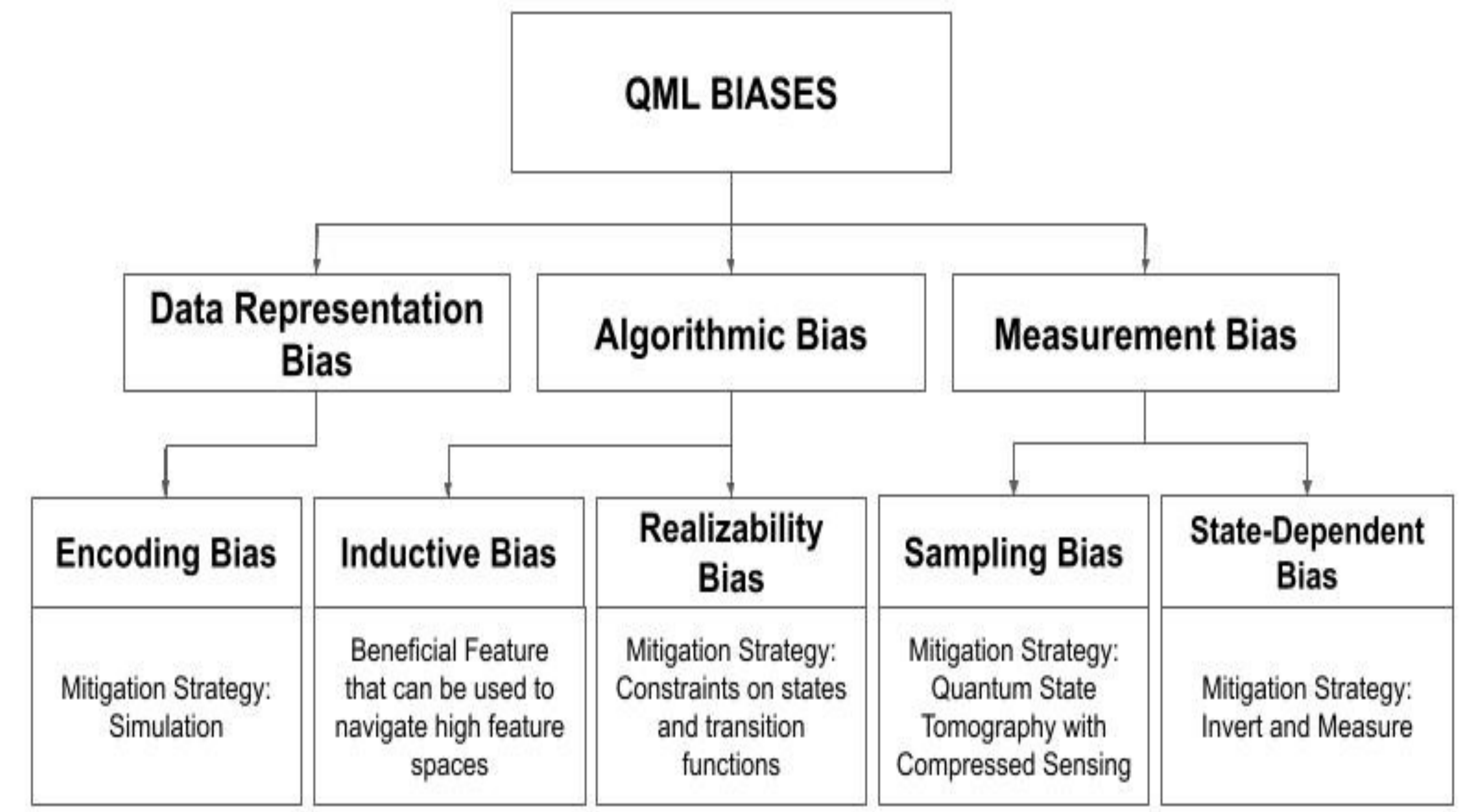

Figure 4: Overview of biases unique to QML

Takeaways

- QML systems are subject to unique biases arising from quantum properties. These biases can significantly impact the fairness, reliability, and performance of QML models.
- Understanding and addressing these biases is crucial as QML applications expand into high-stakes domains.
- Current mitigation strategies exist, but more research is needed to fully address these challenges.