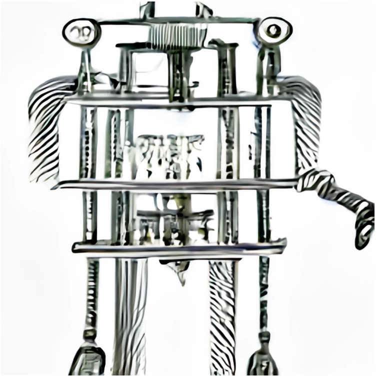
Quantum Computers, Machine Learning & Noise

Hans Hohenfeld

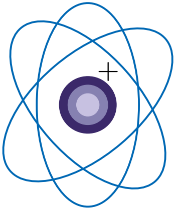
January 24th, 2023



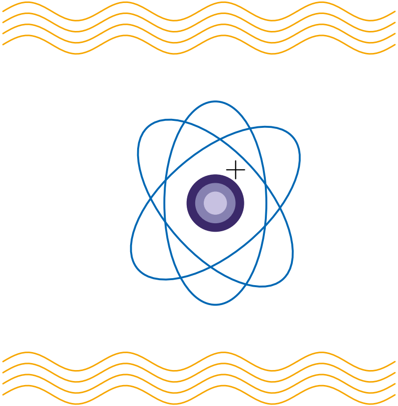
Universität Bremen

Deutsches Forschungszentrum für Künstliche Intelligenz GmbH

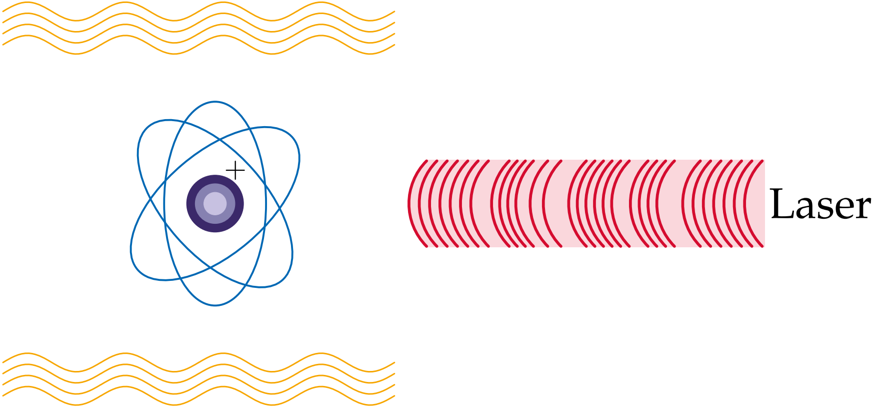
Qubit



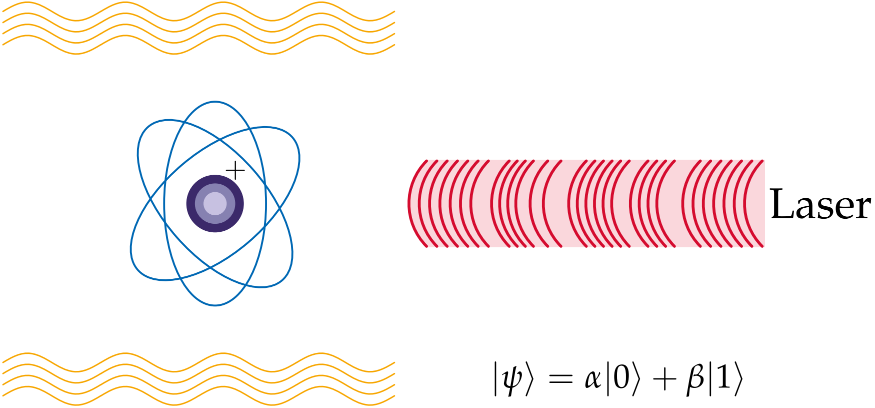
Qubit



Qubit

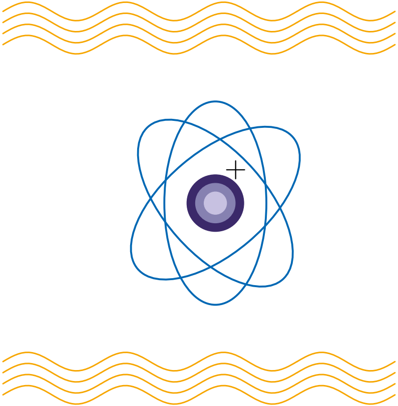


Qubit

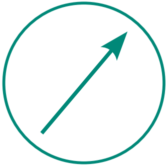


$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

Qubit



Measurement

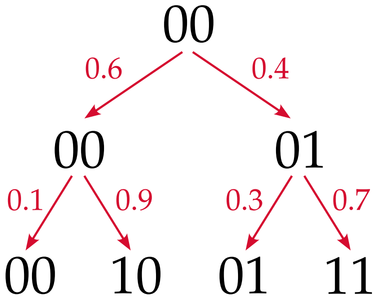


Either

- $|0\rangle$ or
- $|1\rangle$

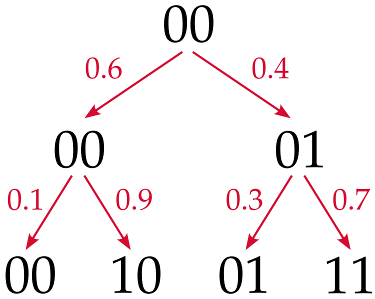
with some probability.

Classical



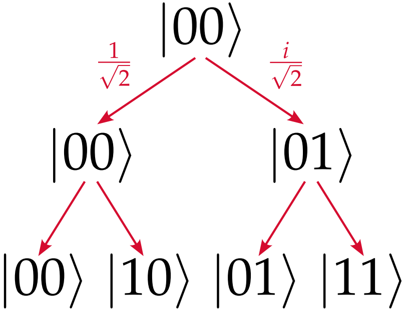
$$Pr(x) := \sum_{\text{path to } x} \prod_{e \in \text{path}} p_e$$

Classical

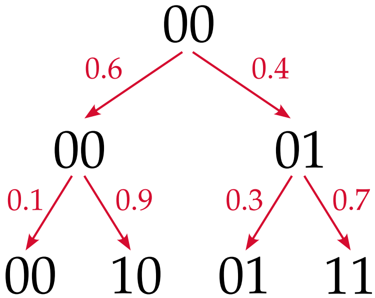


$$Pr(x) := \sum_{\text{path to } x} \prod_{e \in \text{path}} p_e$$

Quantum

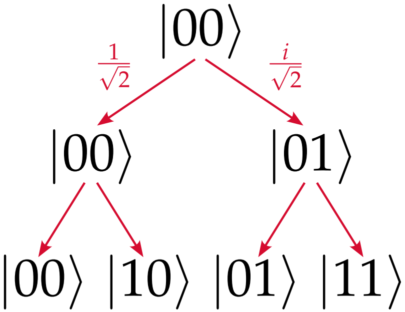


Classical



$$Pr(x) := \sum_{\text{path to } x} \prod_{e \in \text{path}} p_e$$

Quantum



$$Pr(x) := \left| \sum_{\text{path to } x} \prod_{e \in \text{path}} \alpha_e \right|^2$$

Quantum ML

Basically three directions:

Quantum ML

Basically three directions:

- Formulate known ML algorithms in terms of QC.

Quantum ML

Basically three directions:

- Formulate known ML algorithms in terms of QC.
- Formulate new ML algorithms leveraging quantum mechanics.

Quantum ML

Basically three directions:

- Formulate known ML algorithms in terms of QC.
- Formulate new ML algorithms leveraging quantum mechanics.
- Hybrid approaches: Optimize parameterized quantum computation with classical techniques.

Why Quantum ML?

Potential advantages:

Why Quantum ML?

Potential advantages:

- Computational complexity,

Why Quantum ML?

Potential advantages:

- Computational complexity,
- Sample complexity and/or

Why Quantum ML?

Potential advantages:

- Computational complexity,
- Sample complexity and/or
- Model complexity.

Unstructured Search

Let $f : \mathbb{B}^n \to \mathbb{B}$ be a function on bit strings of lengths n that is 0 everywhere but 1 for exactly one $s \in \mathbb{B}^n$.

Unstructured Search

Let $f : \mathbb{B}^n \to \mathbb{B}$ be a function on bit strings of lengths n that is 0 everywhere but 1 for exactly one $s \in \mathbb{B}^n$.

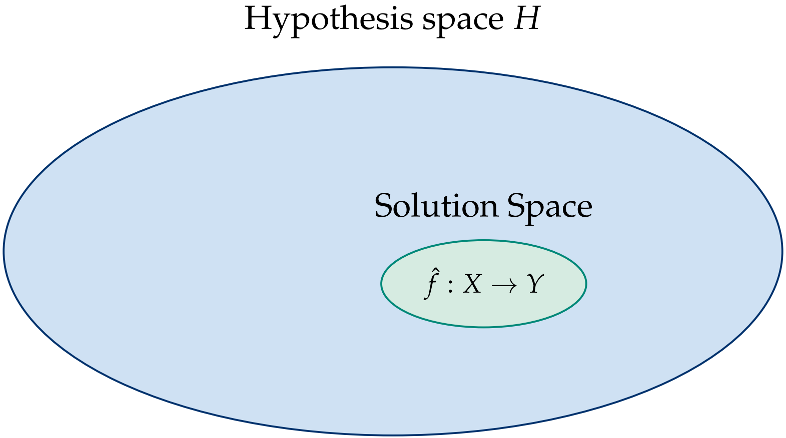
- A classical computer has no better strategy than to try all possible $N = 2^n$ possible bit strings.

Unstructured Search

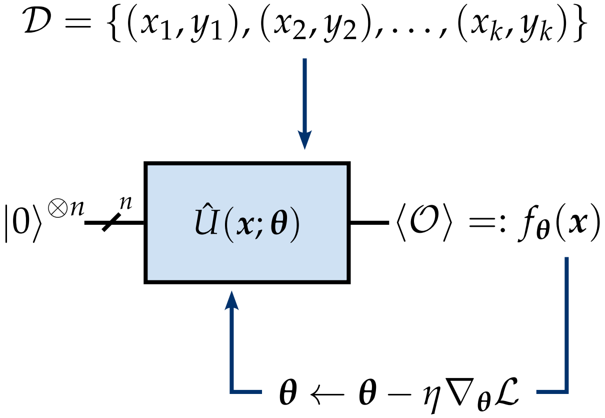
Let $f : \mathbb{B}^n \to \mathbb{B}$ be a function on bit strings of lengths n that is 0 everywhere but 1 for exactly one $s \in \mathbb{B}^n$.

- A classical computer has no better strategy than to try all possible $N = 2^n$ possible bit strings.
- A quantum computer needs only $\approx \sqrt{N}$ steps for the same task!

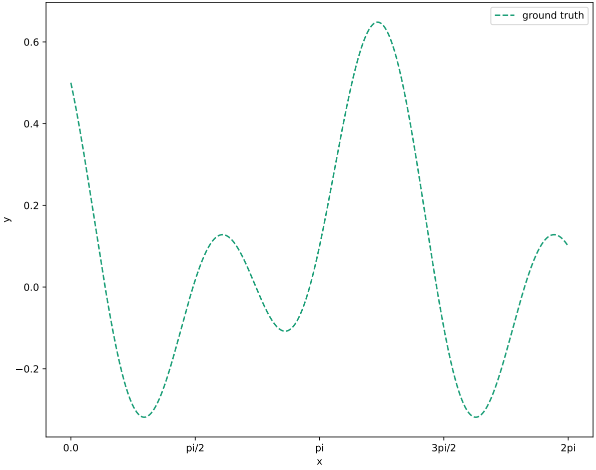
ML as hypothesis search



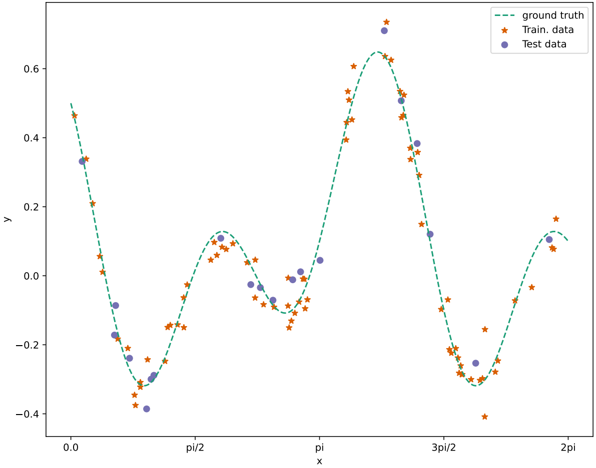
Hybrid Quantum ML



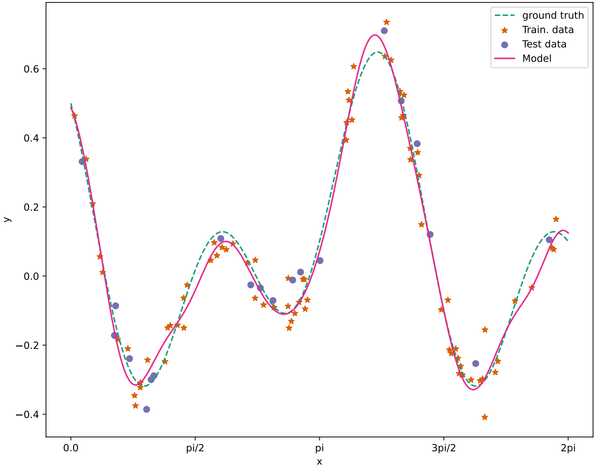
The ML Problem



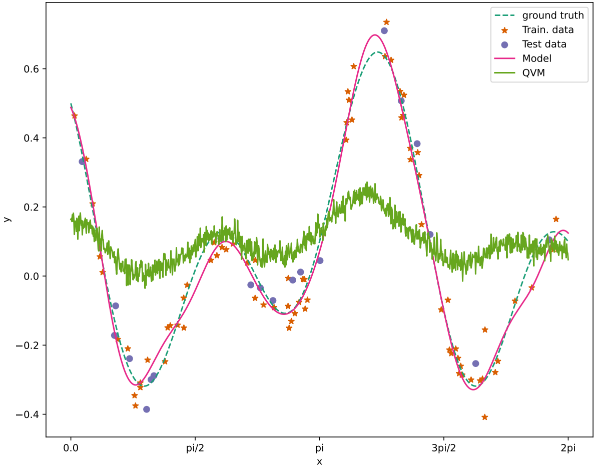
The ML Problem



The ML Problem



The ML Problem



Noise

We face two types of noise:

- **Coherent errors** caused by quantum operations not being arbitrarily precise.

Noise

We face two types of noise:

- **Coherent errors** caused by quantum operations not being arbitrarily precise.

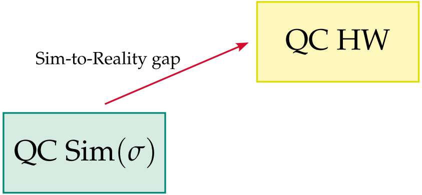
We can understand this noise as the effect of adding a small random constant parameters of each operation.

Noise

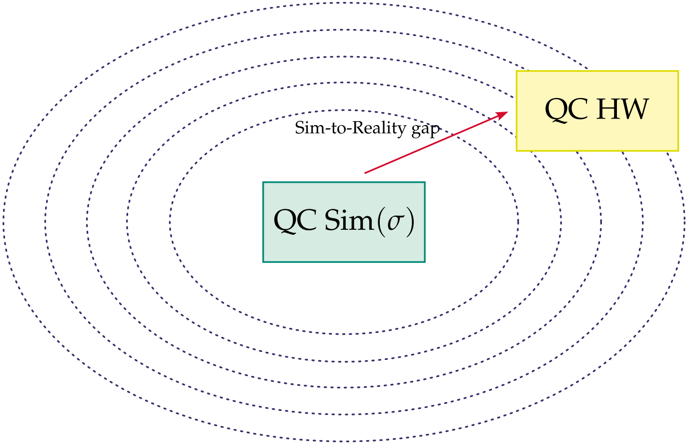
...and **Incoherent errors**, caused by interaction with the environment, that is:

- State agnostic bit-flips.
- Energy dissipaticon decaying qubits from $|1\rangle$ to $|0\rangle$.
- Spontaneous excitation.
- Phase flips.
- Uniform decoherence / depolarization.
- Read-out errors.
- ...

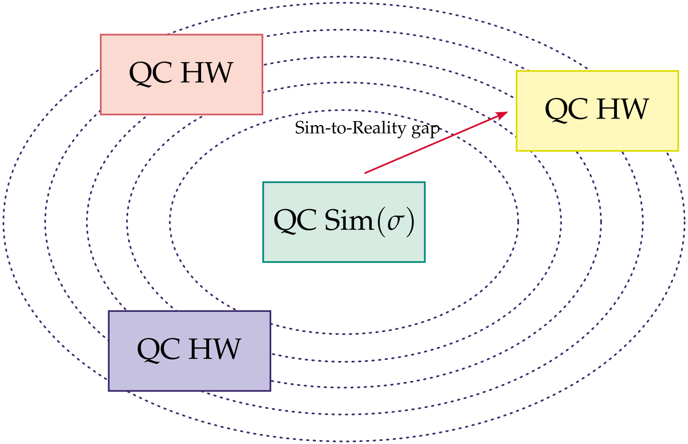
Domain Randomization



Domain Randomization



Domain Randomization

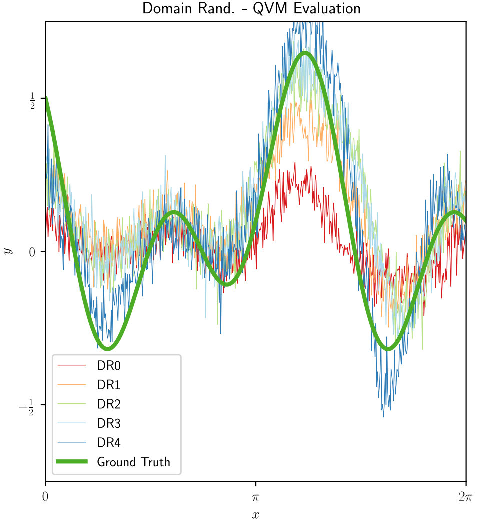


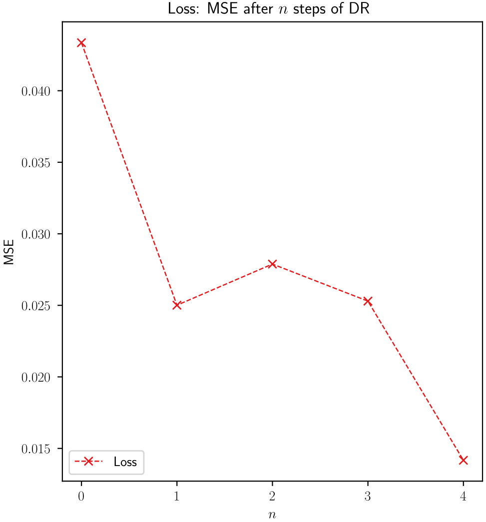
Domain Randomization

Procedure:

1. Train model in ideal, noise-free simulator.
2. Sample noise model σ for simulator.
3. Train some further epochs on the noisy simulator.
4. Repeat 2. and 3. till convergence.

Preliminary Results





Get involved!

- Bachelor/Master Thesis.
- QML Seminar (03-IMS-QML) in the summer semester 2023.
- Student assistant jobs.

Feel free to contact me: hans.hohenfeld@uni-bremen.de

Questions?