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BenchQC – Scalable and modular benchmarking of industrial quantum computing applications

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QUEST-IS, Palaiseau, November 2025

BenchQC
Consortium

Industrial QC applications

REPLY MACHINE LEARNING

BMW

OptWare

QUANTINUUM

Fraunhofer IIS

Fraunhofer IKS

Munich Quantum Valley

Building full-stack quantum computers

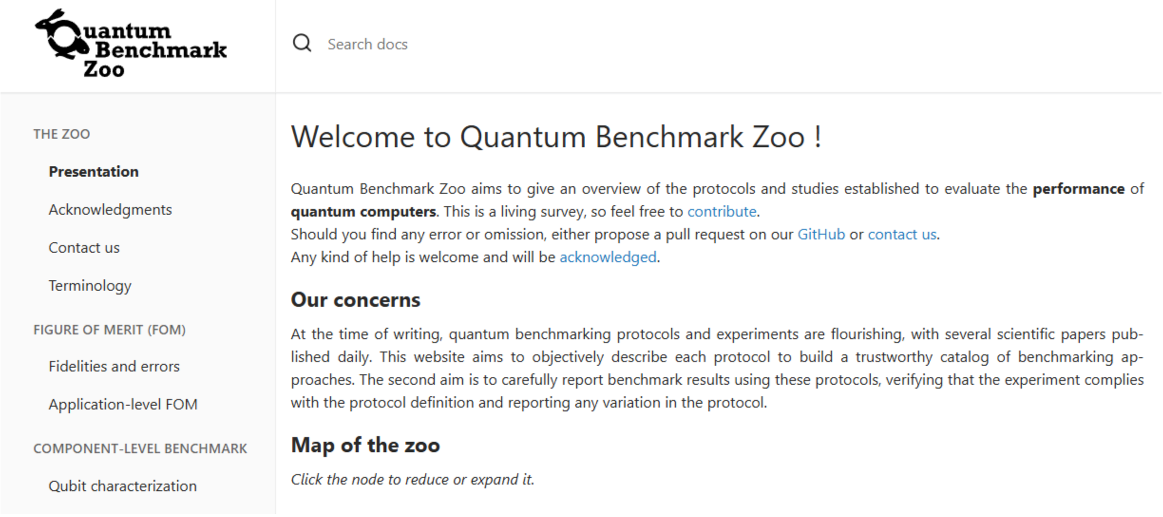
Lighthouse project **BenchQC**

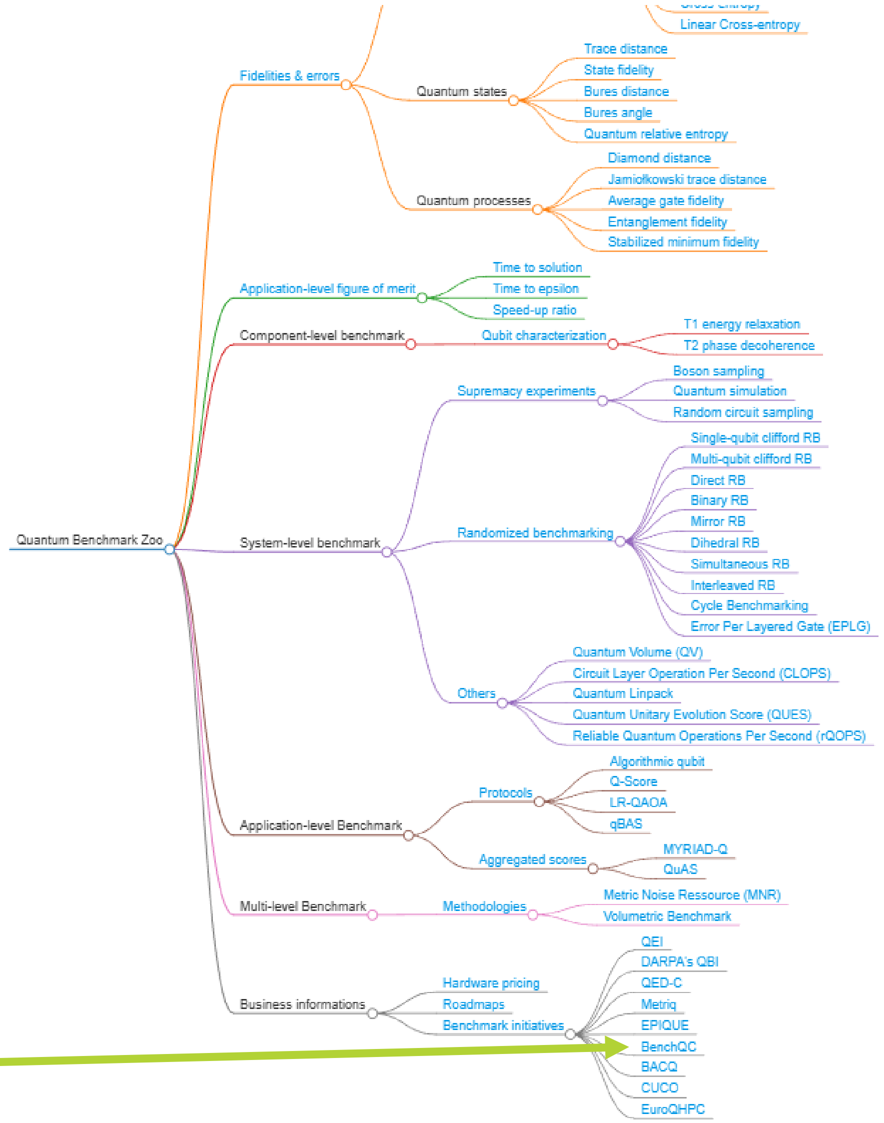
Benchmarking of industrial applications

Overview paper: https://arxiv.org/abs/2504.11204

Quantum computing benchmarking

An overview





BenchQC:

- Application-centric (incl. QML)
- Tooling (QUARK)
- Holistic metrics

https://quantumbenchmarkzoo.org/

Emerging technology:
Quantum computing

With more powerful hardware emerging, quantum computing (QC) has the potential to lead to disruptive changes in many industrial areas:

- **Simulation** of quantum mechanical systems (development of new drugs, chemical sector with battery development,…)
- **Optimization** problems (Logistics, production, pharma,…)
- **Quantum machine learning** (Computer vision, mobility,…)

But for which applications will QC really offer an advantage in practice?

→ Application-driven benchmarking procedure required!

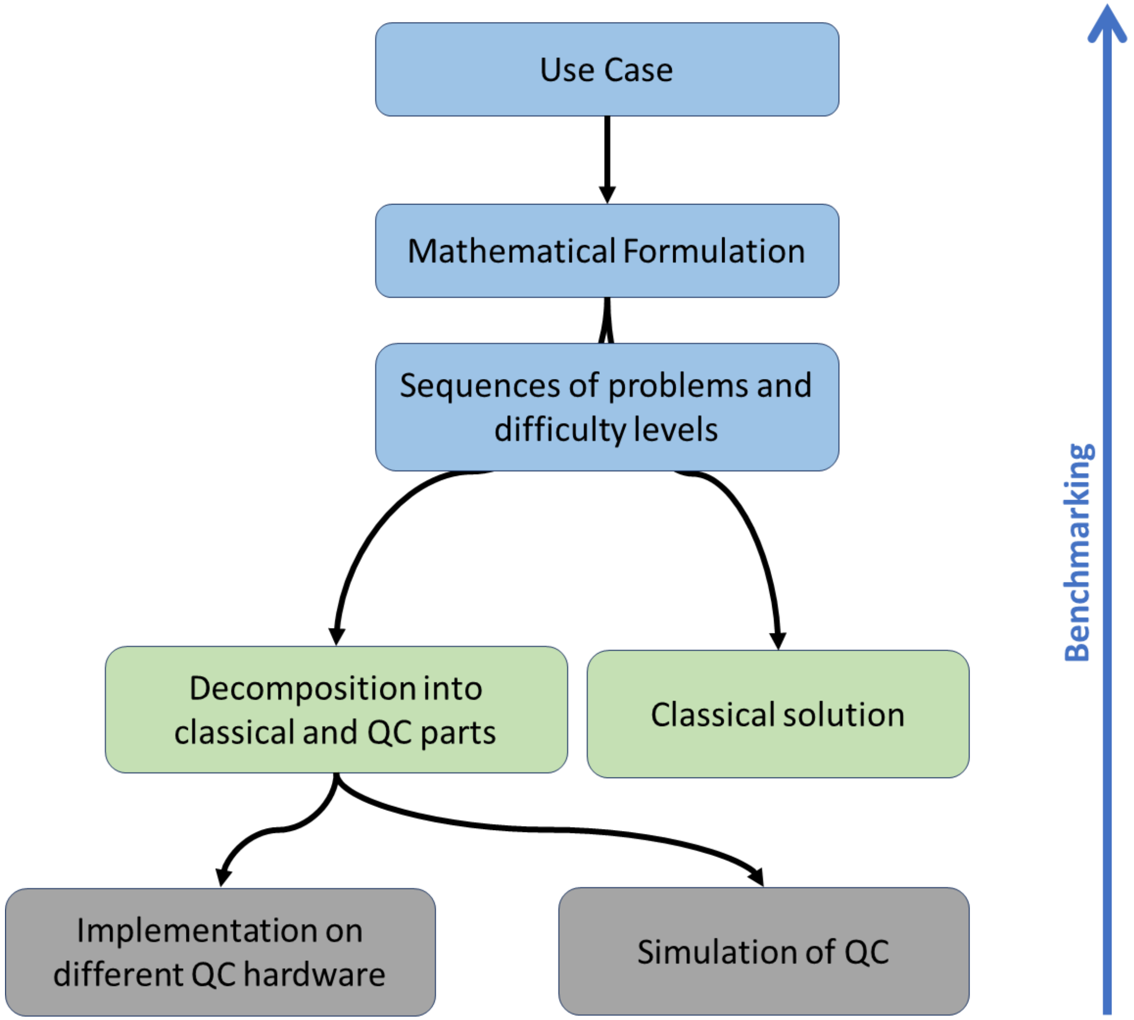
  Public

Application-driven benchmarking of quantum computers

Potential analysis from the application perspective

Application-driven benchmarking of QC:

- Identification of use cases suited for a **practical** quantum advantage.
- Consider mathematical **decomposition** and **sequence scaling** of problem
- Which **QC-hardware** technology (in which size, in which quality)?
- Considering the **full path** to the solution of a problem (e.g. including the data transfer to quantum computers, and post-procession of a quantum solution and integration into an industrial workflow)

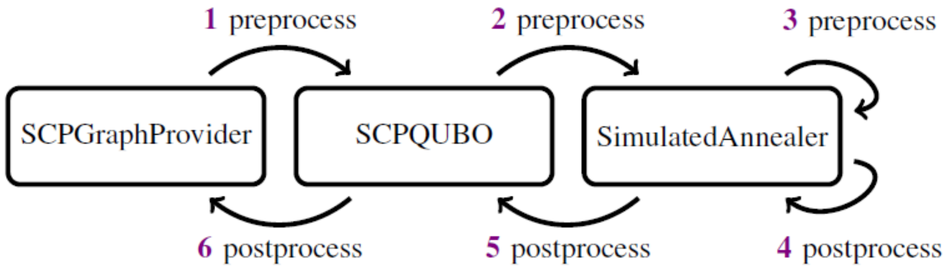


QUARK

V3+

https://quark-framework.readthedocs.io/en/dev/
https://github.com/QUARK-framework/QUARK
https://pypi.org/project/QUARK-framework/

```yaml
plugins: ["quark_plugin_tsp", "quark_plugin_dwave"]

first_layer:
  &first_layer [
    "tsp_graph_provider": { nodes: 4, seed: 42 },
    "tsp_graph_provider": { nodes: 5, seed: 42 },
    "tsp_graph_provider": { nodes: 6, seed: 42 },
  ]

second_layer: &second_layer "tsp_qubo_mapping_dnx"

third_layer: &third_layer [
  "simulated_annealer_dwave": {num_reads: 1},
  "simulated_annealer_dwave": {num_reads: 1000},
]

pipeline1: &pipeline1 [
  *first_layer,
  *second_layer,
  *third_layer,
]

pipeline2: &pipeline2 [
  *first_layer,
  "classical_tsp_solver",
]

pipelines: [*pipeline1, *pipeline2]
```



Key features

- Modular structure via **plugins**, application-agnostic core
- Simple **pipeline configuration** in single file
- Customization of **pre-/post-processing**
- Integrated **metrics**
- Diverse **hardware** interfaces
- **Datasets** handled by individual user

Benchmarking along the solution pipeline

Metrics

*Implemented in Quark for selected applications

Hardware

- Number of qubits*
- Coherence times
- Gate fidelities
- Quantum volume
- Q-factor

Quantum Circuit

- Expressibility*
- Entanglement*
- Normalized effective dimension
- Fourier composition

Resources

- Sample complexity*
- Learning steps*
- Number of shots*
- Classical-quantum interactions

Performance

Application-specific performance:

- QML*
- Optimization*
- Simulation

Generic performance:

- Runtime*

Problem Complexity

- Input/output scaling*
- Model scaling/non-linearities
- Feature ranking/selection
- Sensitivity to input perturbations*

Component level

System level

Application level

BenchQC

Use cases

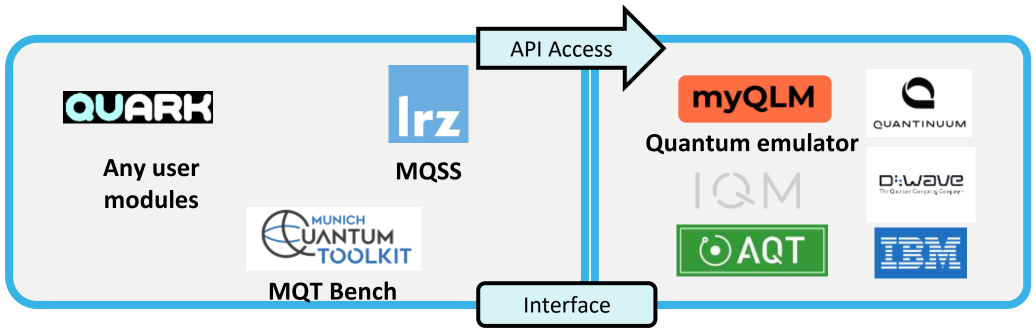
Category	Model	Use case
QML	Classification	Defect detection
	Generative models	Generative design for constructional elements
		Data augmentation for quality inspection
	QRL	6G Beam management
Optimization	VQE, QAOA, Quantum Annealing	Multipath-connectivity across aerial vehicles
		Sensor placement in water networks
		Software verification strategies
		LiDAR sensor configuration
		Assembly line scheduling and packet sequencing
		Financial asset optimization
Simulation	Hamiltonian simulation	Dynamics of electrons in materials
		Low-temperature state preparation of materials
		Nuclear magnetic resonance simulation

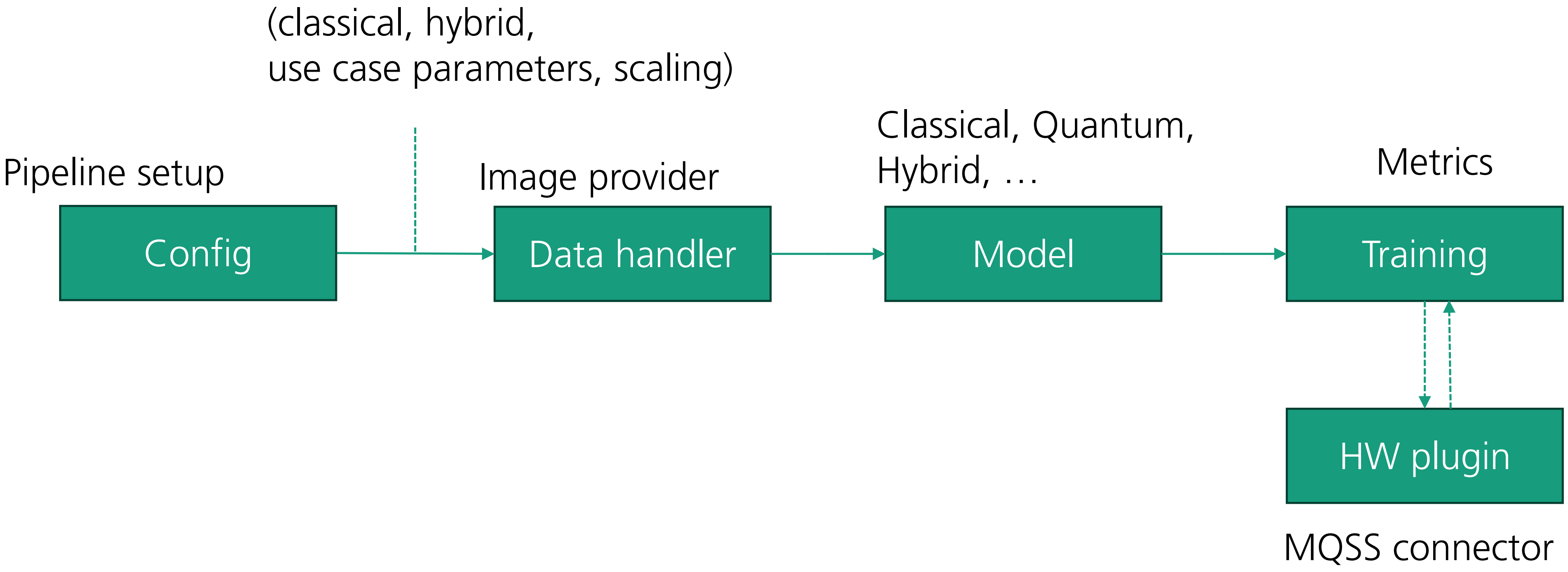
https://arxiv.org/abs/2504.11204

Road crack dataset: Binary classification problem, image size 224x224

Quantum-Classical Image Classification (I)

Quark pipeline

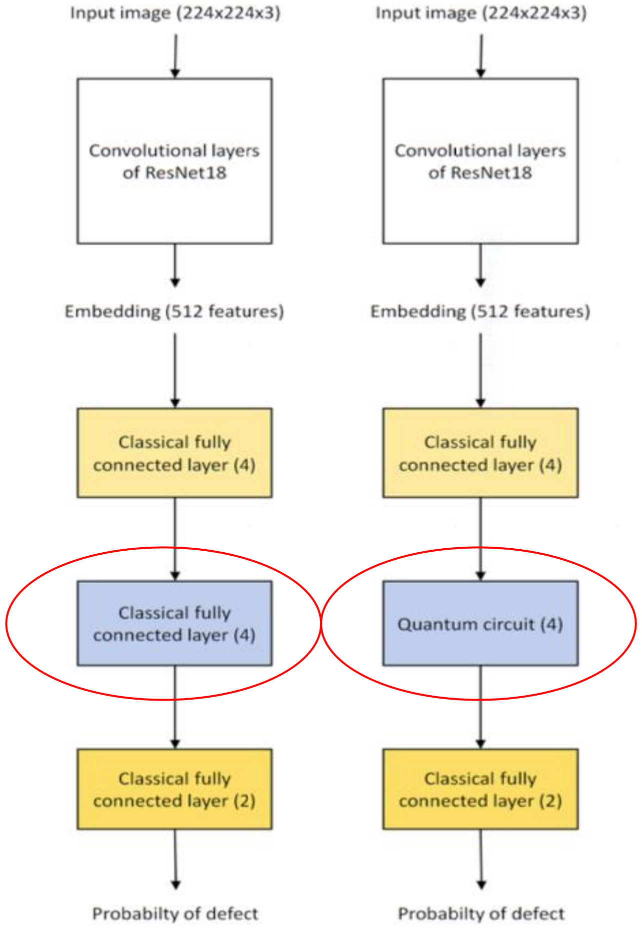


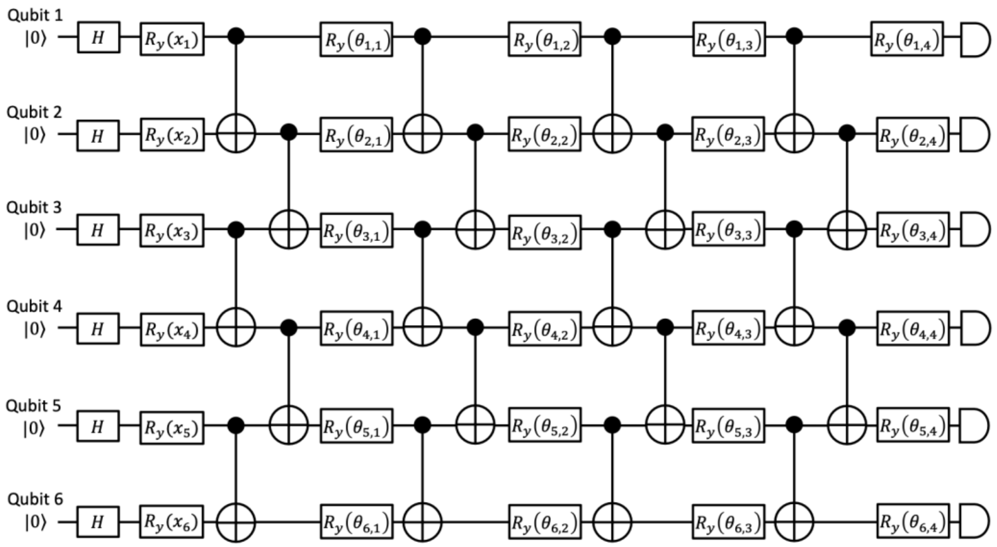


  Public

Quantum-Classical Image Classification (II)

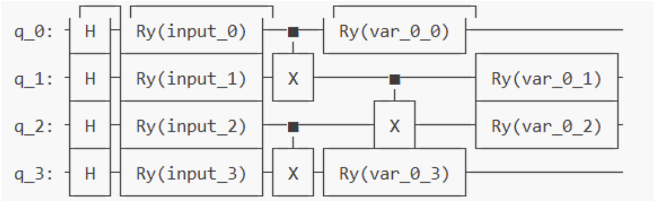
System design





Angle encoding, 6 qubits, strongly entangled Ansatz

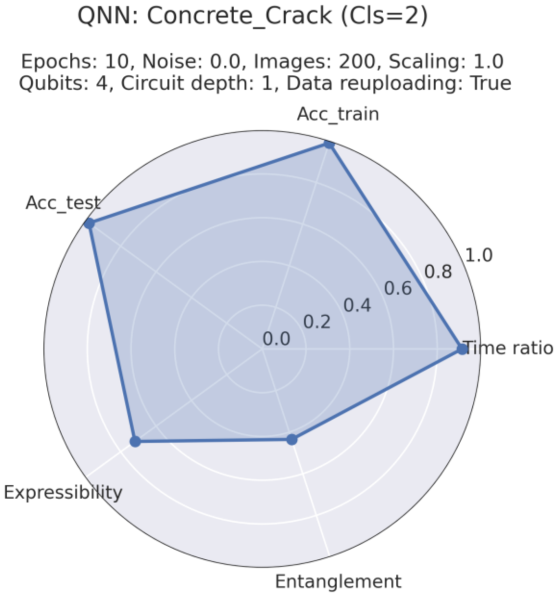
Noise variation study



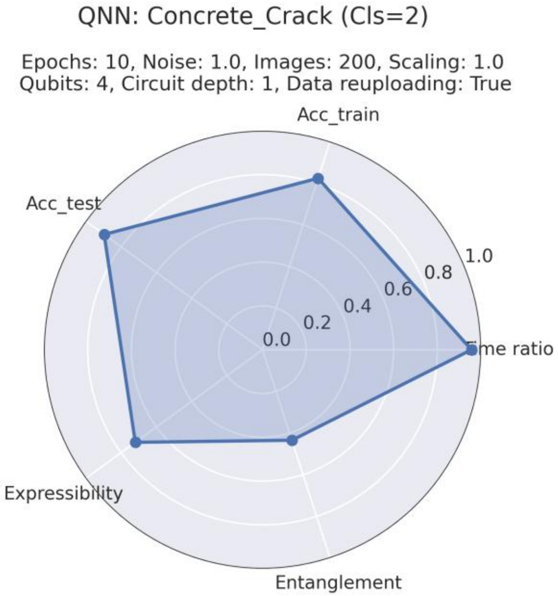
Observations

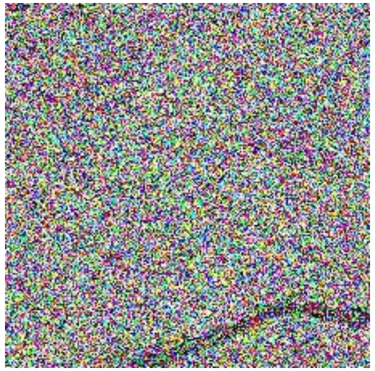
- **Addition of noise** is an effective measure to gradually increase problem complexity
- **Fixed**:
  - Circuit design
  - Number of training epochs

Noise = 0

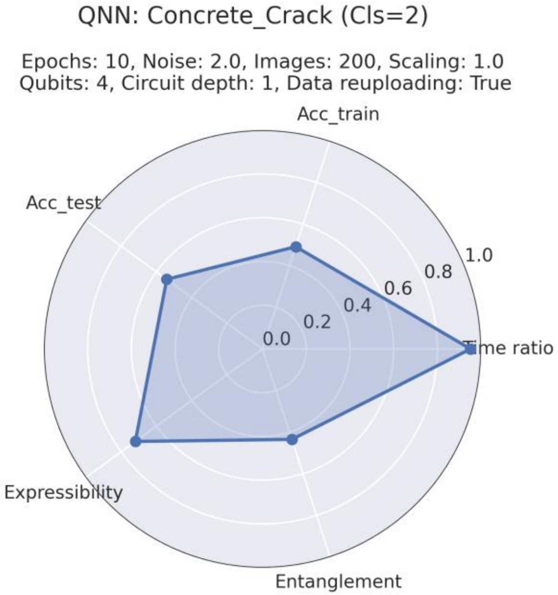


Noise = 1





Noise = 2



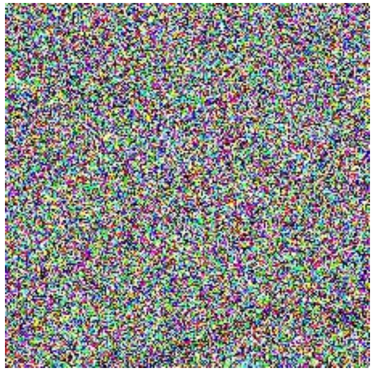
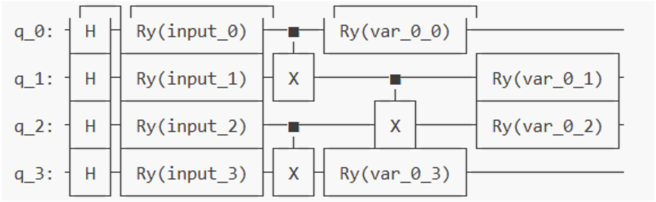


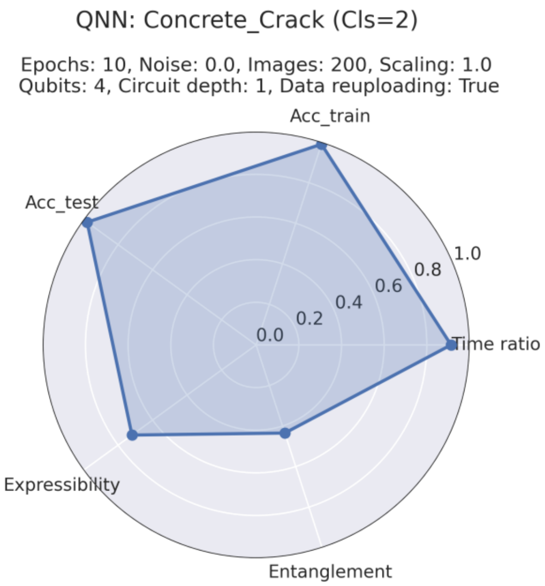
Image rescaling study

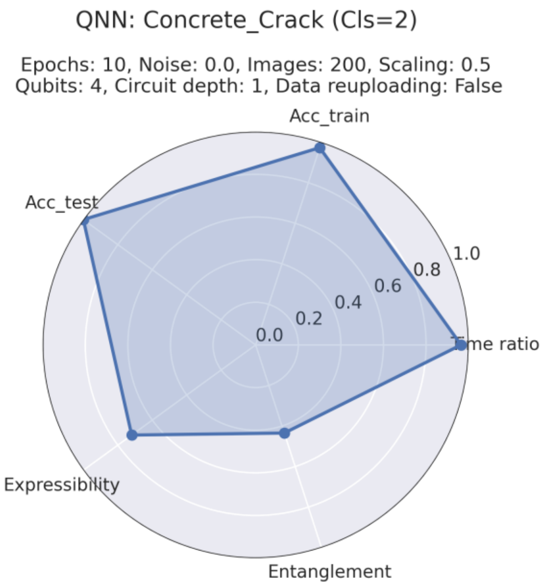
Scale_factor = 1.0

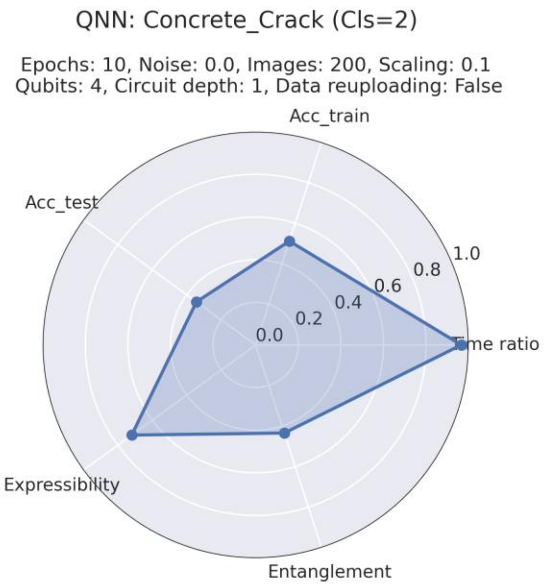
Scale_factor = 0.5

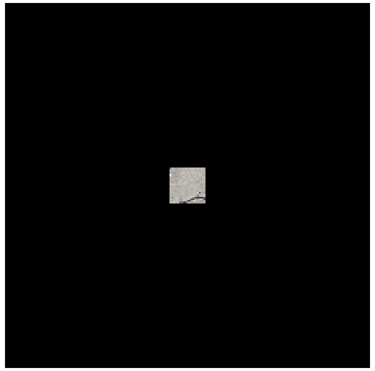
Scale_factor = 0.1







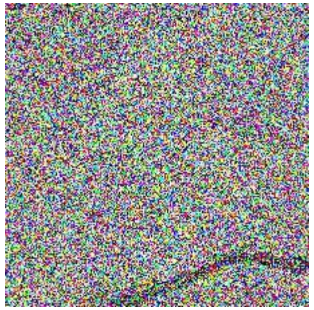




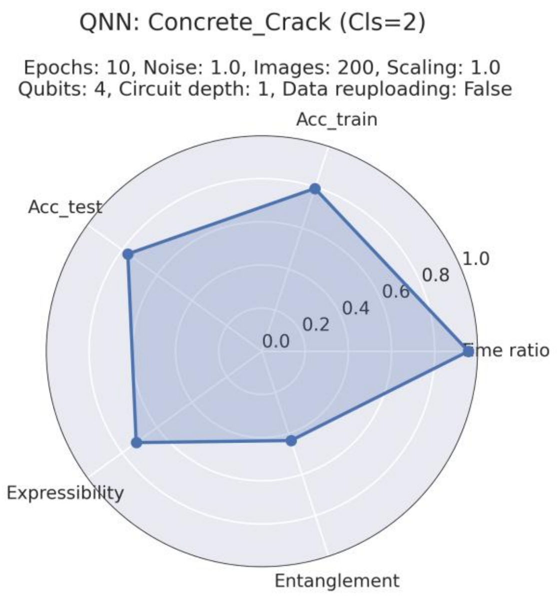
Observations

- Image **rescaling** can be tolerated to some extent, but eventually accuracy collapses
- **Fixed**:
  - Circuit design
  - Number of training epochs

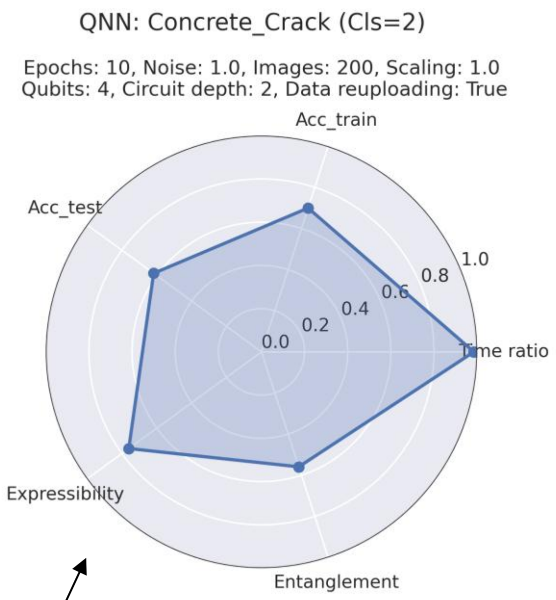
Circuit depth study
(with data reuploading)



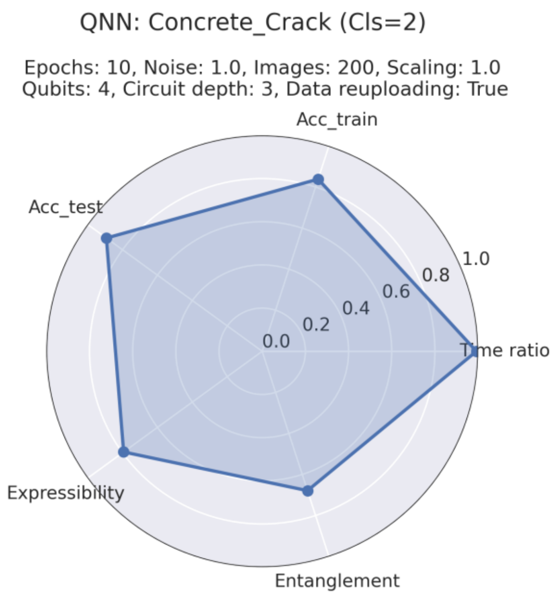
d = 1



d = 2

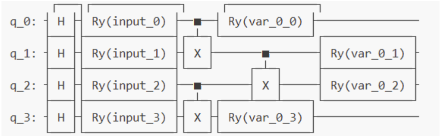


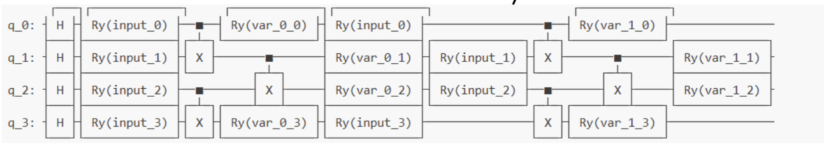
d = 3

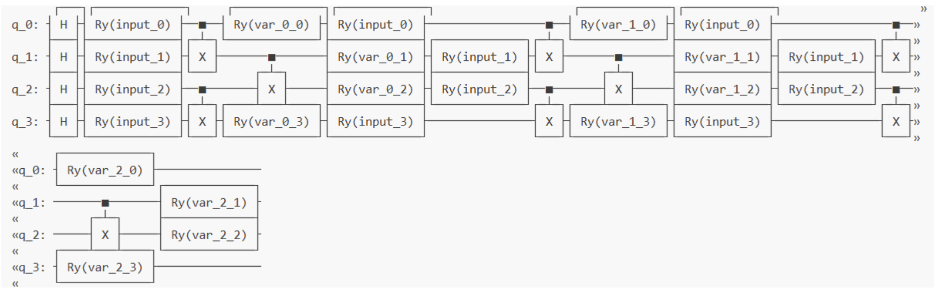


Observations

- Deeper circuits **increase expressibility and entanglement**
- Accuracy **not necessarily** much better?
- Fixed: 10 Epochs of training, average of 3 runs

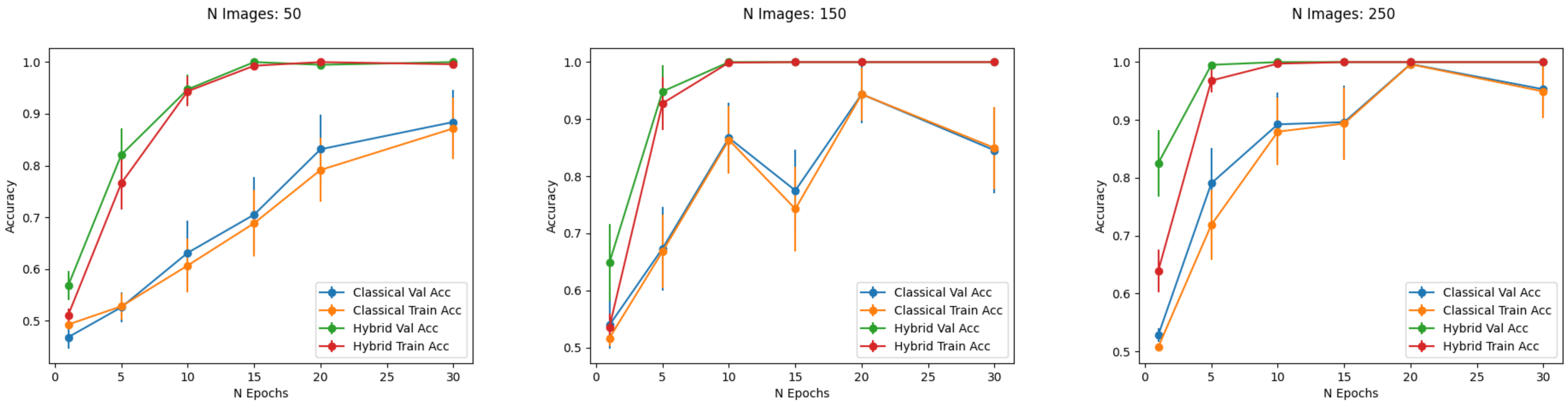






Dataset size study

- Road crack dataset
- 4 qubits
- Strongly entangled Ansatz



Benchmark potential benefit of hybrid-quantum NN compared to classical:

- Learns a given performance with **less training steps**, if **data is scarce**
- Gap closes with **more epochs or more samples**
- **Quantum circuit metrics** (expressibility, entanglement) is still **low**

Summary

- To benefit from quantum computing in real applications, a **practical quantum advantage** is required
- This advantage will not only depend on quantum hardware properties, but on **the full hardware and software stack**
- We need the **right tools** to do holistic benchmarking (e.g. QUARK)
- In the field of QML, a practical quantum advantage is still unclear, yet promising trends emerge. Benchmarking can guide the way to **best combinations of algorithms, metrics, hardware, etc.**
- Results can help establish a route towards **standards**

Application-driven benchmarking