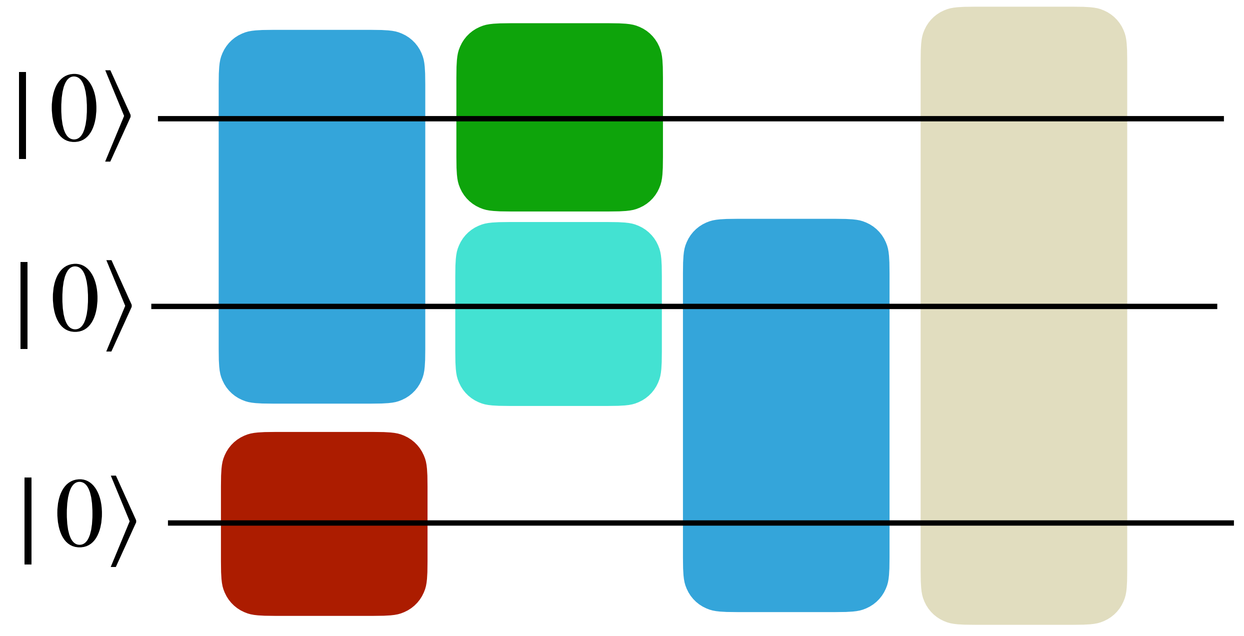
Quantum computing in a noisy world

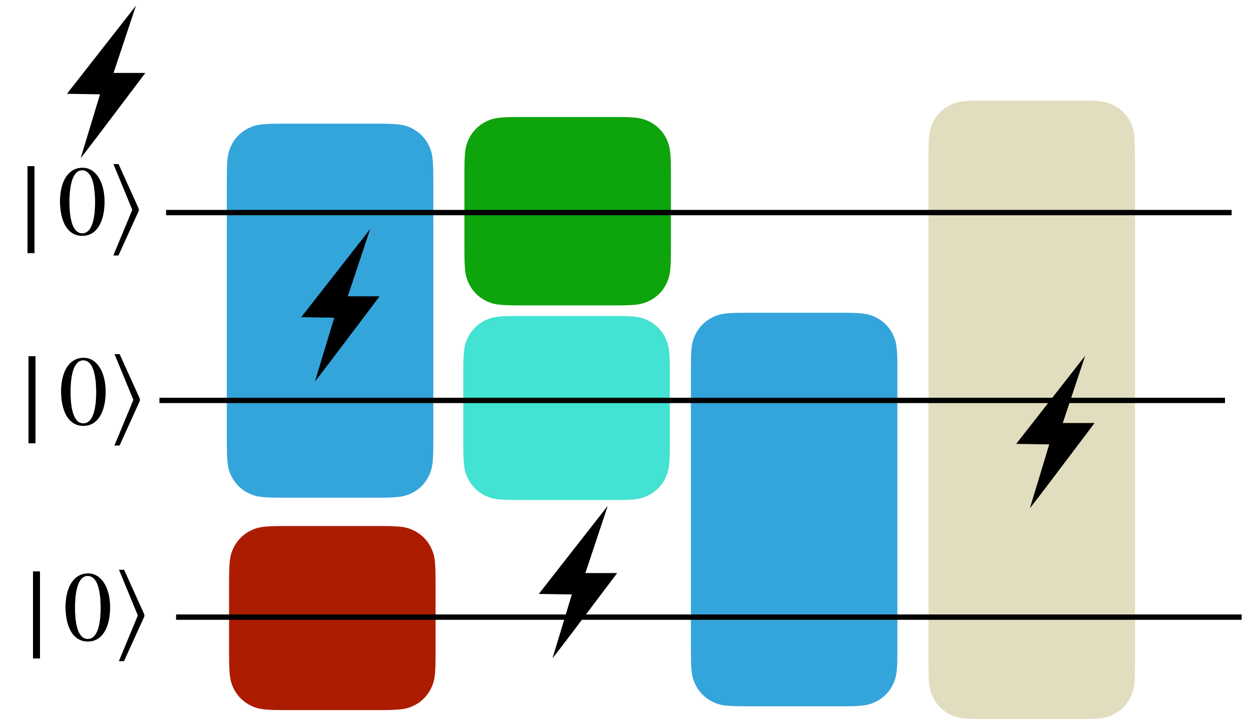
Characterization and mitigation of errors.

Jonas Helsen - 30/04 CWI Scientific meeting

Quantum computers: the problem of noise



Ideal quantum computation

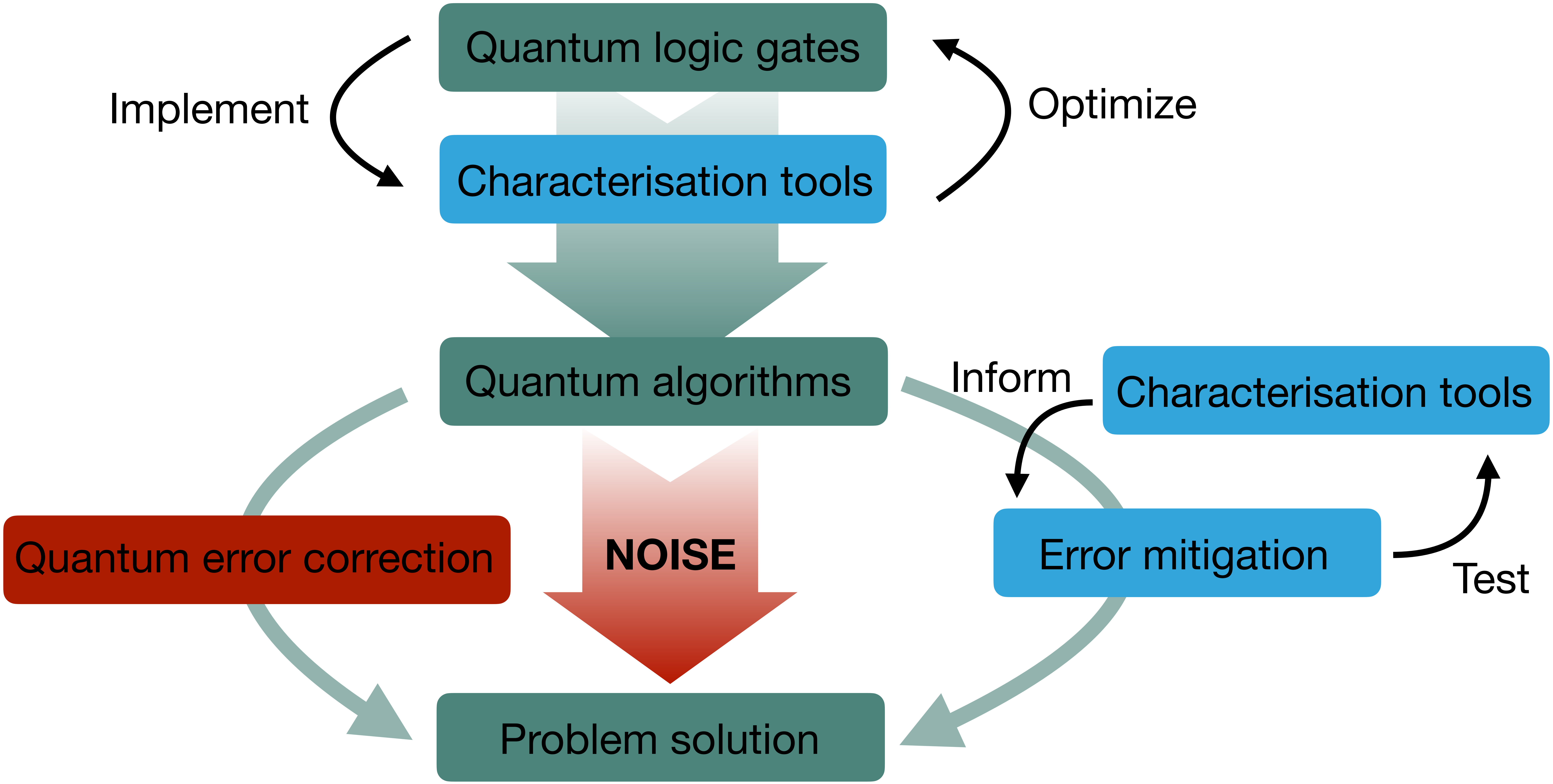


Real quantum computation

Quantum computers are noisy!

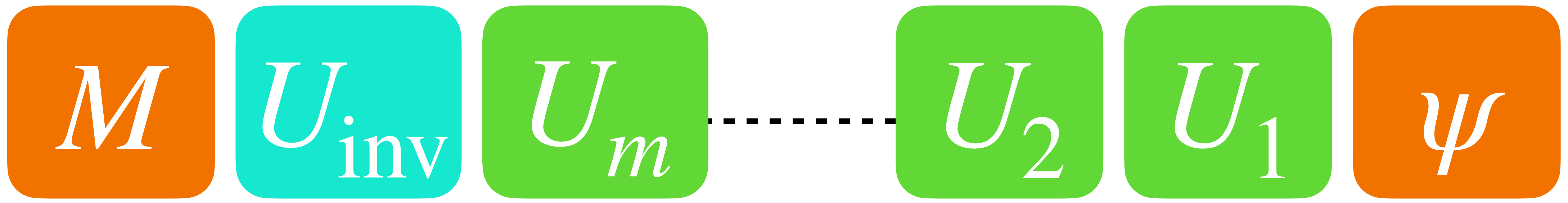
- What can we learn about this noise? **(Characterisation)**
  - At the level of gates
  - At the level of algorithms
- Can we correct/ mitigate this noise? (**Mitigation)**

Noise characterisation and mitigation



Randomised benchmarking: a standard tool

$p(m) = \mathbb{E}_{U_1,\ldots,U_m}$

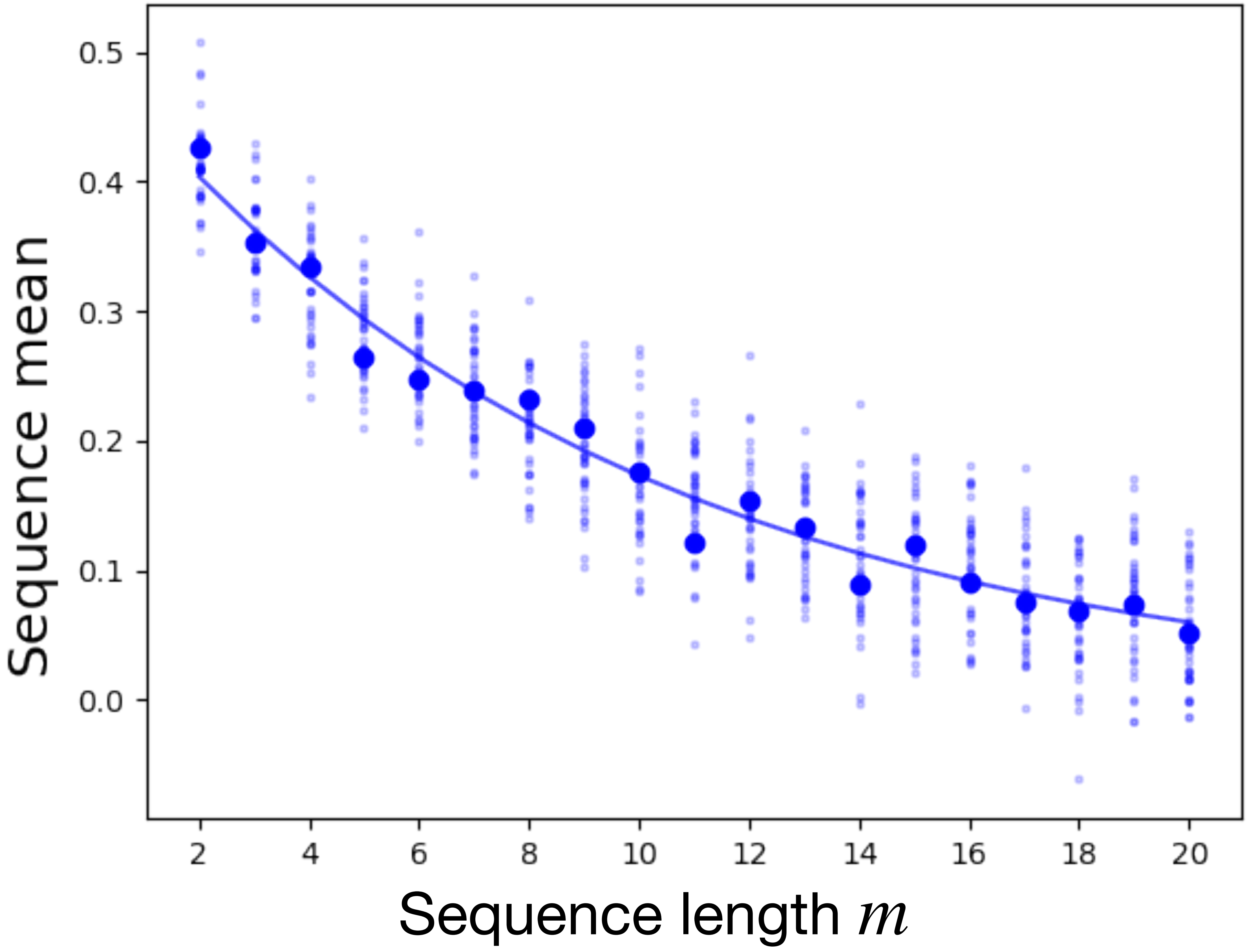


Randomized benchmarking

- Apply sequence of **random** quantum circuits
- Compile such that overall circuit is **identity**
- Vary sequence length and fit to exponential
- Decay rate estimates gate fidelity

$$p(m) \approx A f^m$$

f is a measure of (average) gate quality



Randomised benchmarking: math problems

How do we go from specification to predictable behaviour?

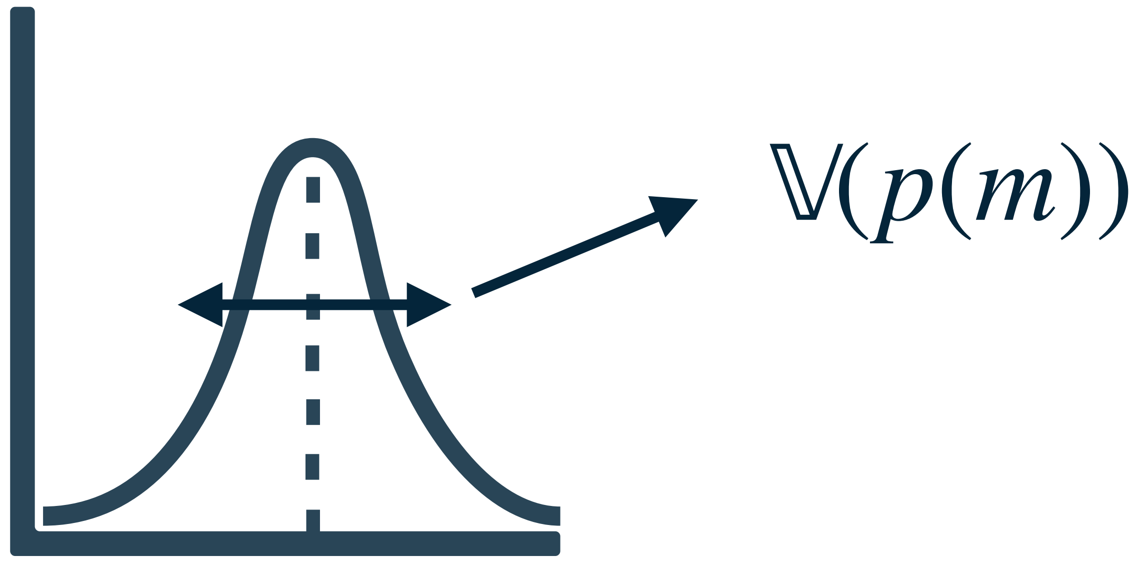
Questions

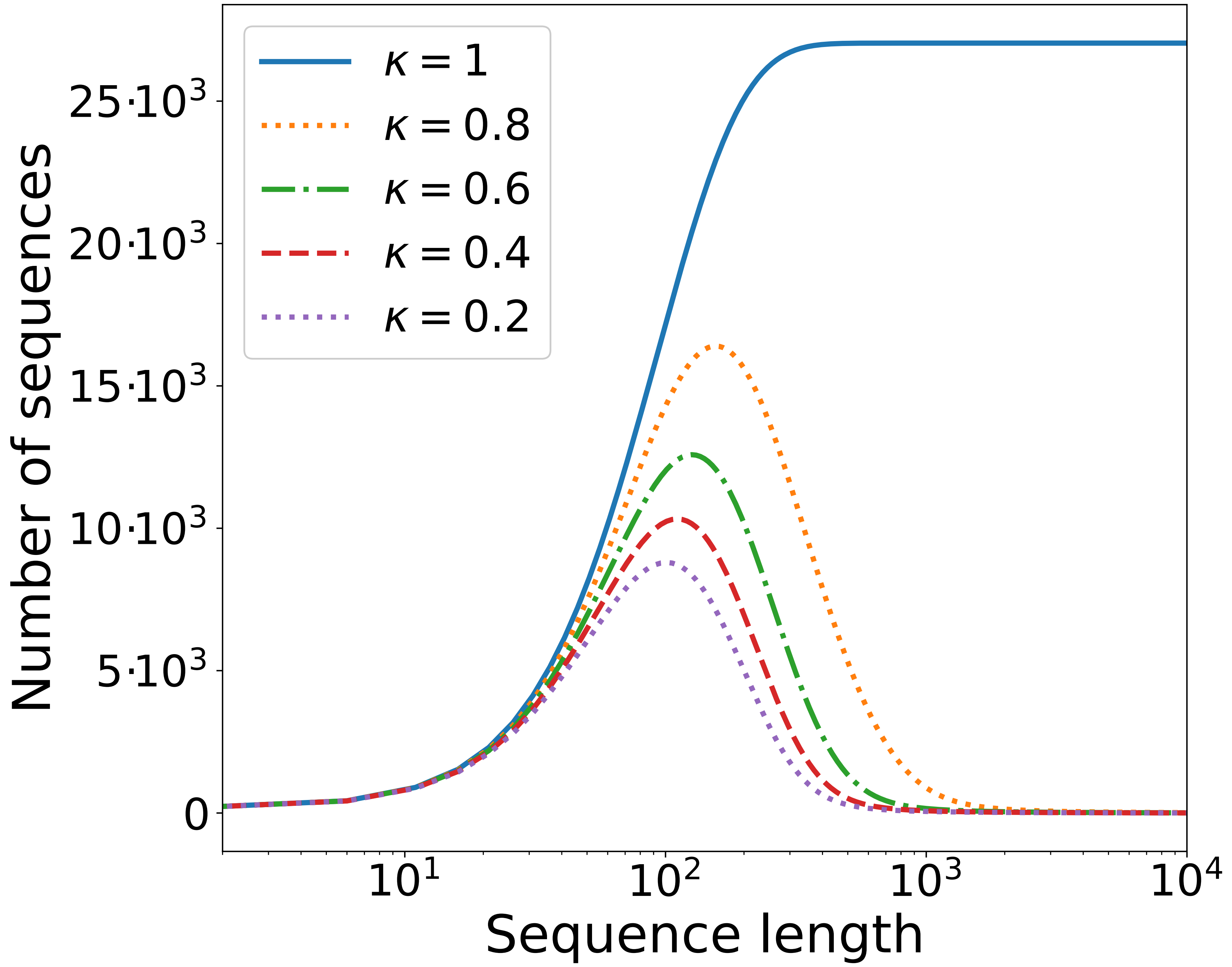
- What sets of circuits are useful/practical?
- What assumptions must be made on device physics?
- What is is the sample complexity? Can we lower it?

Theory of randomised benchmarking

Statistics of randomised benchmarking

How many random sequences are needed?





- Compute variance of $p(m)$
- Representation theory of the Clifford group
- <100 sequences suffices in many cases (independent of qubit number!)
- Number of sequences depends on coherence of noise

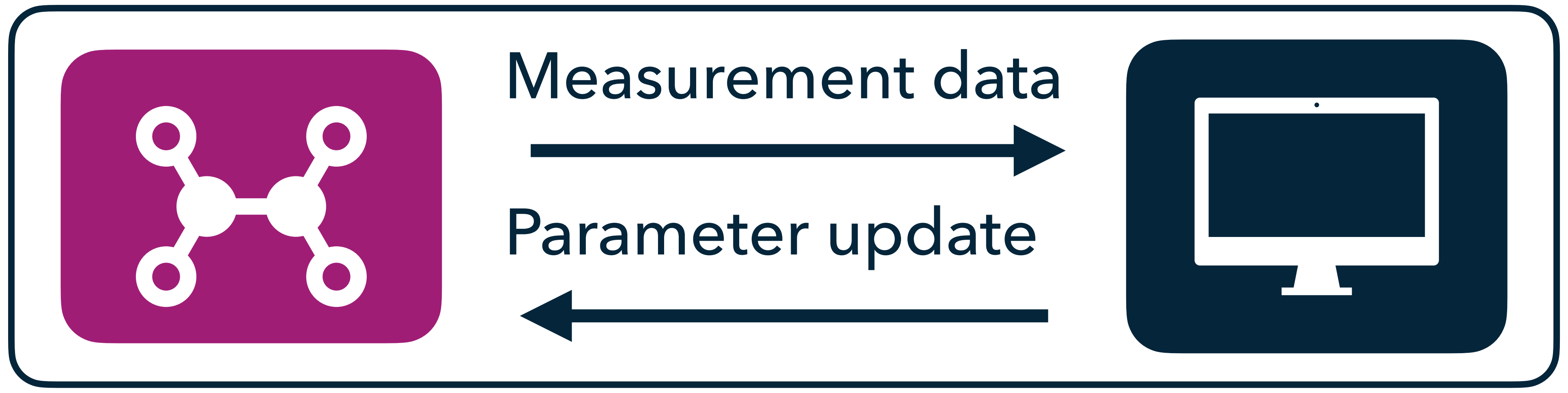
Helsen et al. Phys Rev A 100 (3), 032304 (2019) & Helsen et al. Jour. Math. Phys. 59 (072201) (2018)

Noise in quantum computers: into the future

What do I want to do?

Error mitigation: focus on variational algorithms

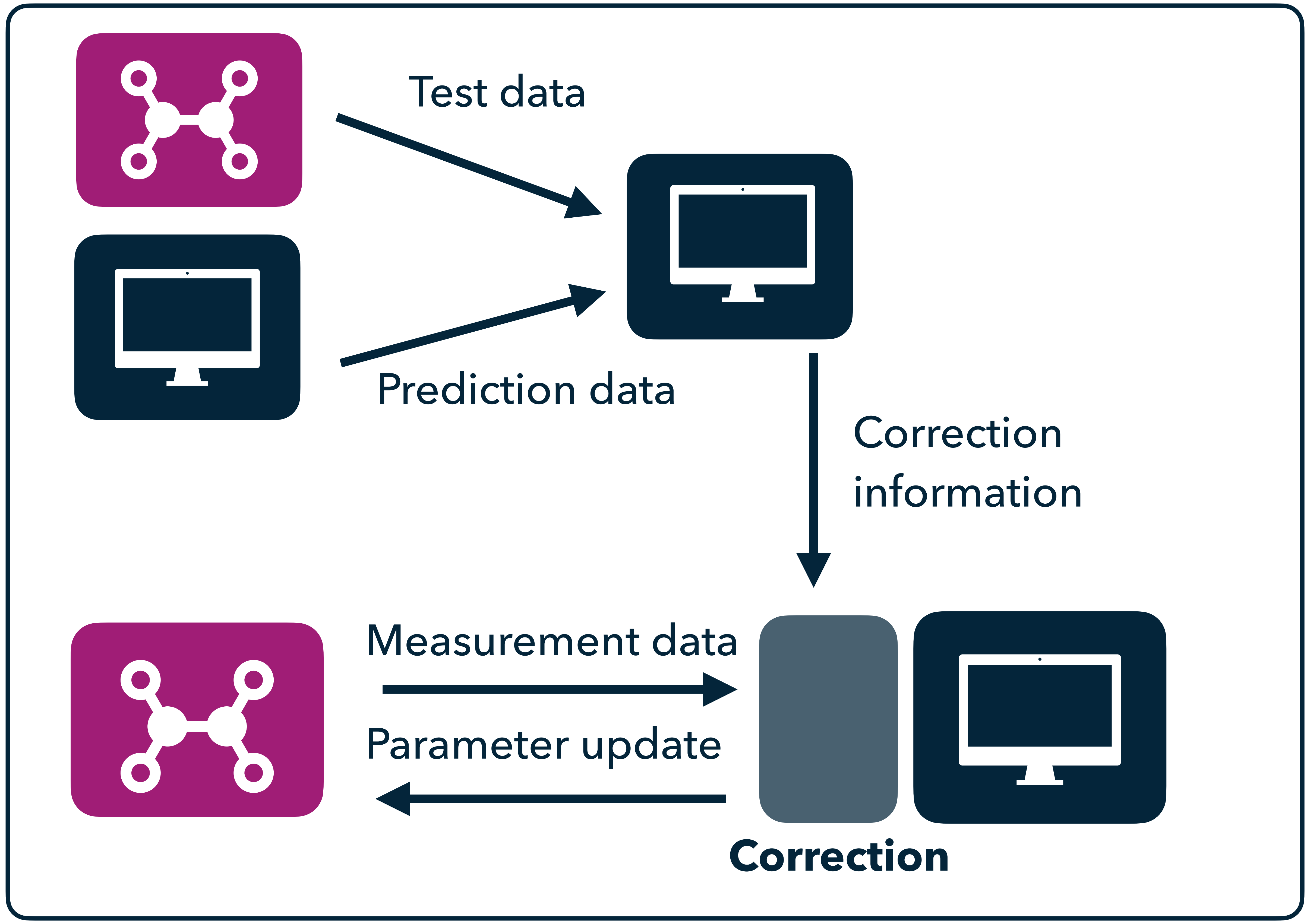
Variational algorithms



Different types of correction

- Learn effect of noise on test circuits
  - (mitigation by learning)
- Artificially induce noise
  - (zero noise extrapolation)

Error mitigation cycle



See e.g. Montanaro & Stanisic, arXiv 2102.02120

Learning a noise model -> characterisation procedures

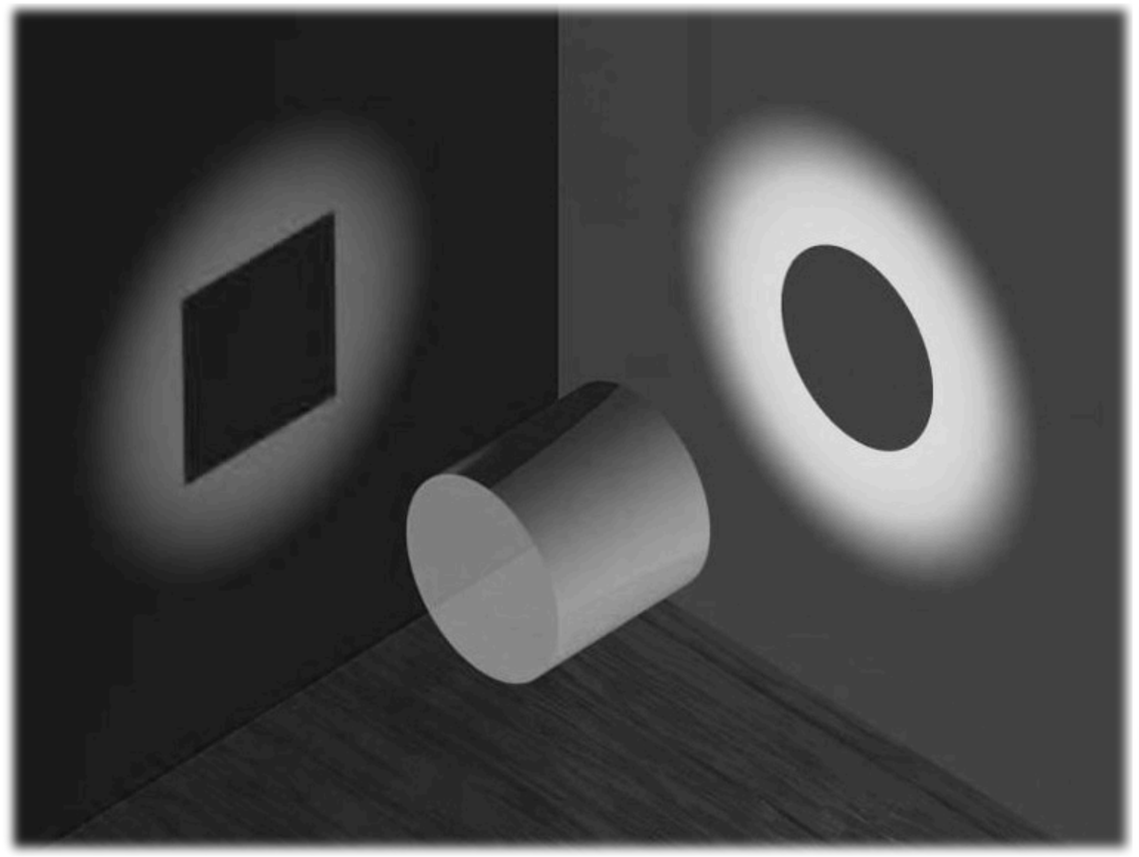
Optimisation models vary a lot -> characterisation must be **versatile & efficient**

Characterisation: more and better

Goal: Mitigation focused characterisation

Tool: “Shadow Tomography”

Aaronson, STOC18-368 (2018)
Huang et al. Nat Phys 16, (2020)



Classical shadows
of a quantum state

- Observe a quantum object from many (random) angles -> classical “shadows”
- Post-hoc reconstruction of large sets of observables
  - With explicit reconstruction guarantees
- Very versatile and efficient!

Current goals

1. Use shadow techniques to improve mitigation strategies
2. Connect randomised benchmarking to shadow tomography
   -> Is RB “self-randomising shadow process tomography”?

Take home messages

- Characterisation and mitigation are a fundamental part of near term quantum computing
- Characterisation tools are interesting in their own right
- Characterisation and mitigation can inform each other