Quantum Software

@ Quantinuum

CQ

Ross Duncan
ACT Industry Session
21 July 2022

QUANTINUUM

CQ

Quantum Software

Honeywell

Quantum Solutions

Quantum Hardware

Quantum Software?

System Software

- Compiler / optimiser
- Programming system and runtime
- Online services
- Quantum Error Correction

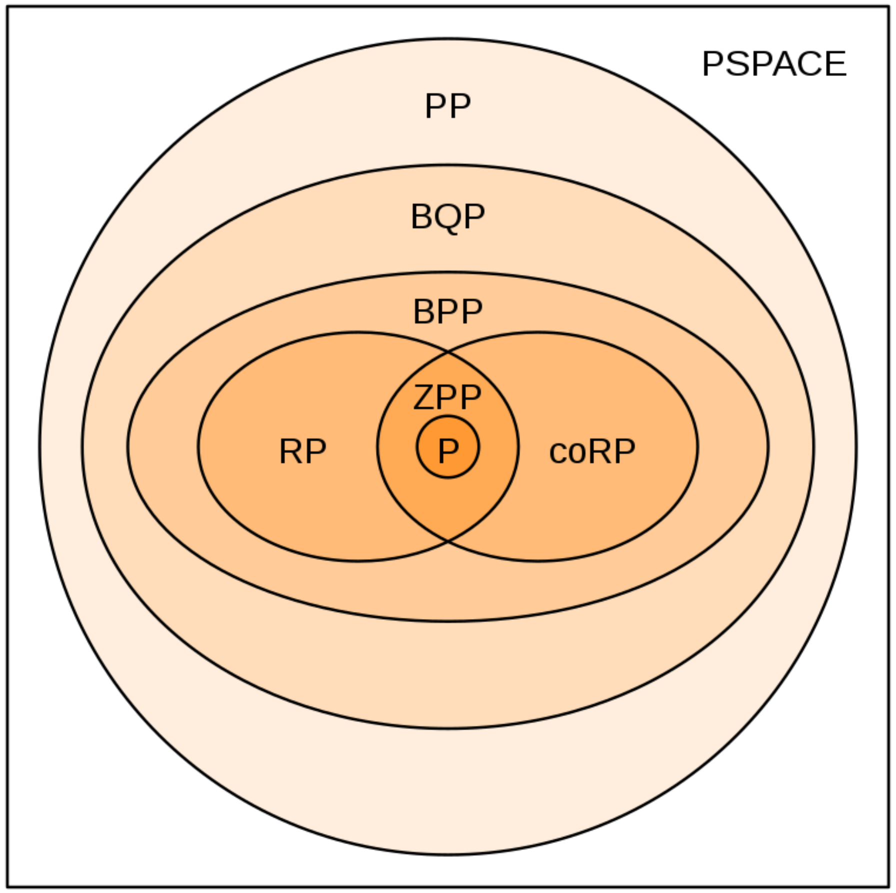
Applications

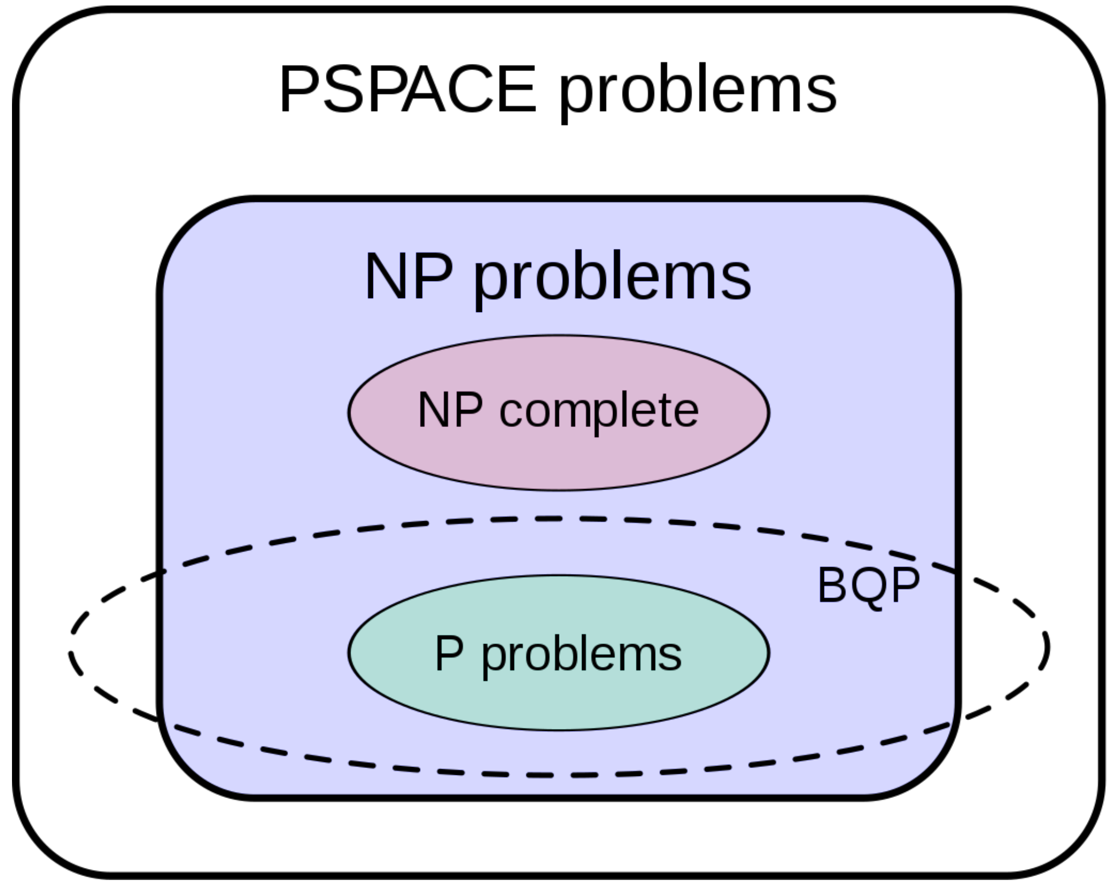
- Computational chemistry and materials science
- Machine learning
- Monte Carlo methods
- Natural language processing

Security / Crypto

Make a quantum computer do something **useful**

The Complexity Theory

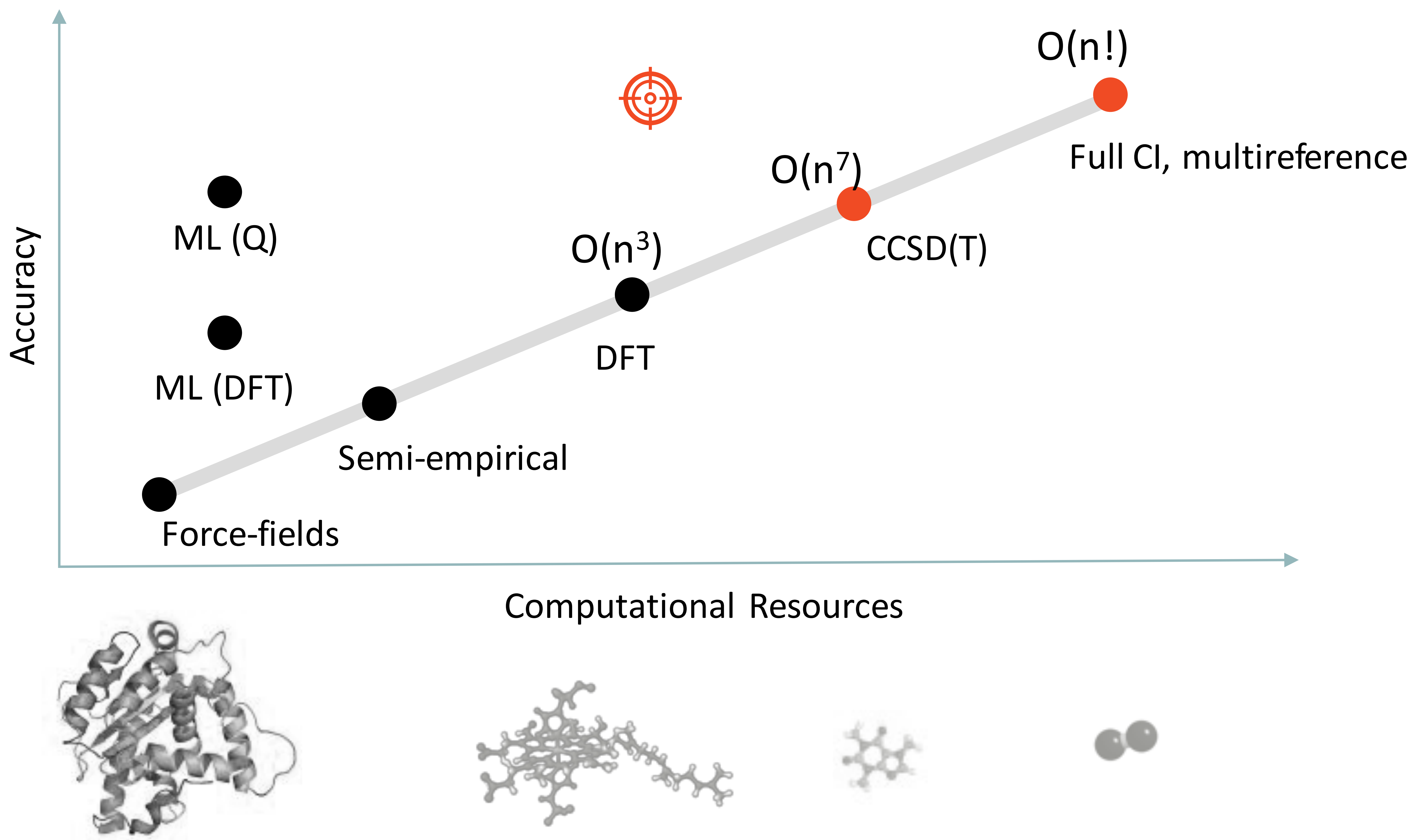




- Examples of quadratic speed up widespread
- Poly-time quantum vs best known classical exp-time

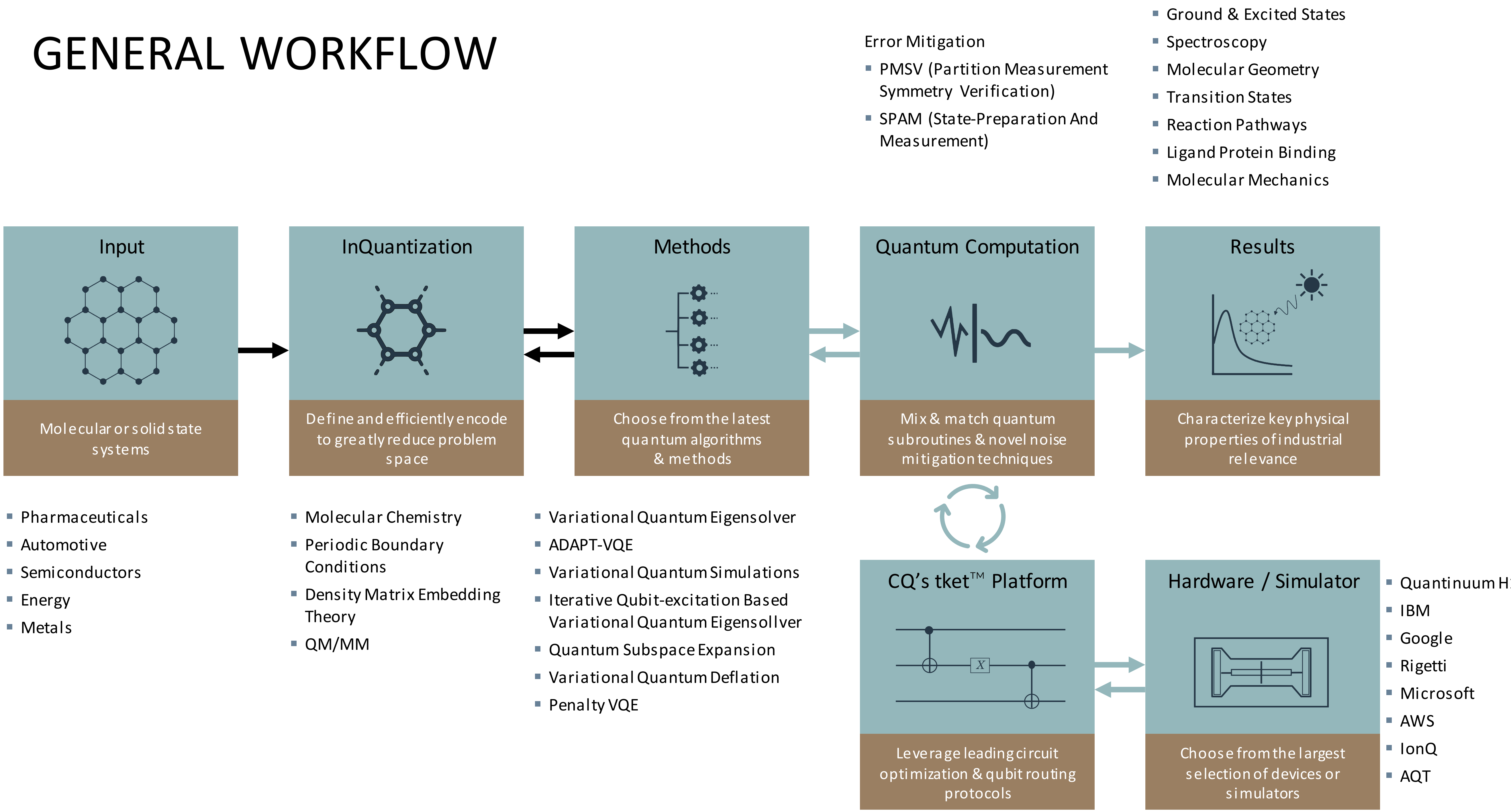
- Contrived/restricted problems with an exponential speed up
- Exponential speed-up conjectured for some quantum simulation problems


QUANTINUUM
INQUANTO
Computational
Chemistry



O(n!)
Full CI, multireference
O(n^7)
CCSD(T)
ML (Q)
O(n^3)
DFT
ML (DFT)
Semi-empirical
Force-fields
Accuracy
Computational Resources

GENERAL WORKFLOW



Irfan

Molecules,
Spin orbitals,
Energy levels,

Circuits

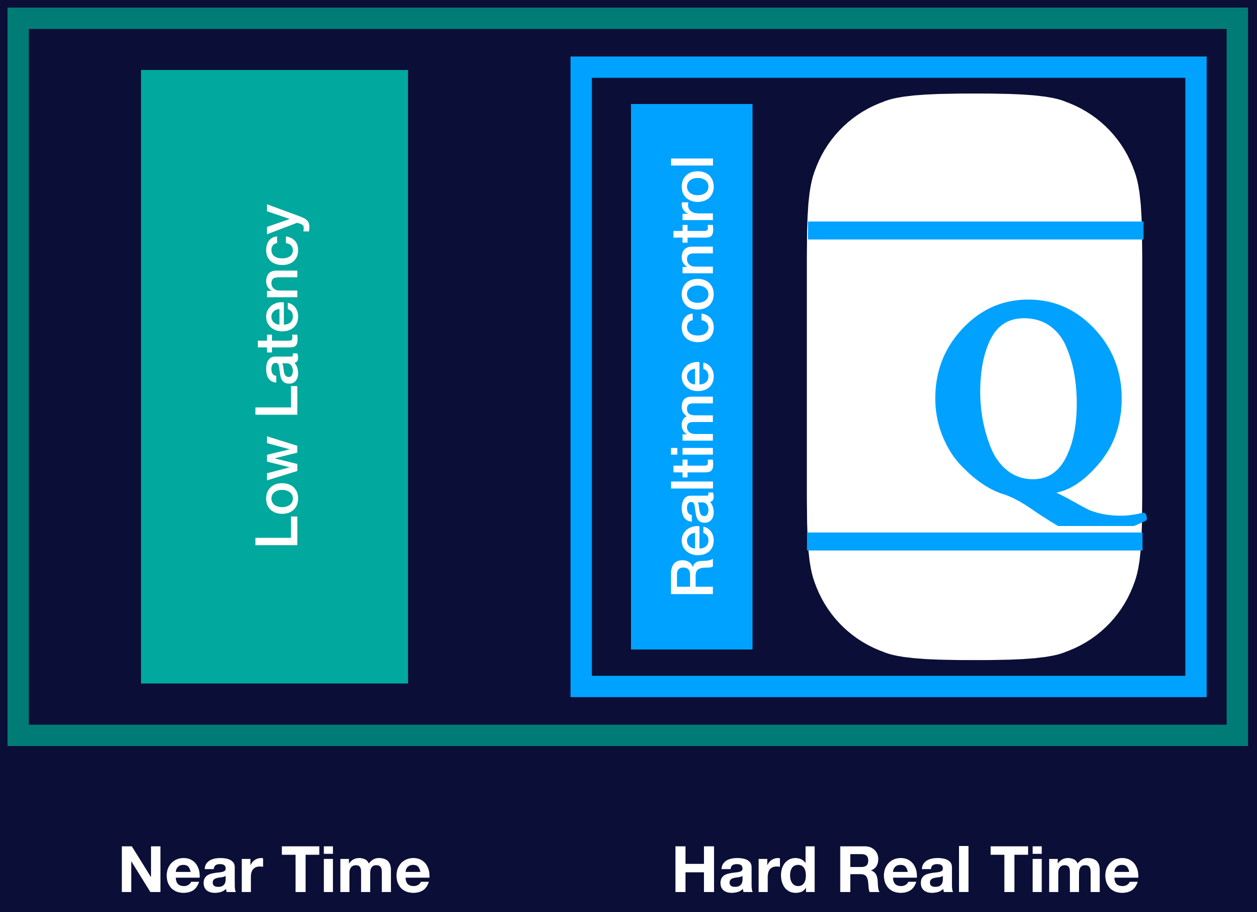
Counts

Research Software Engineer
Quantum Chemistry

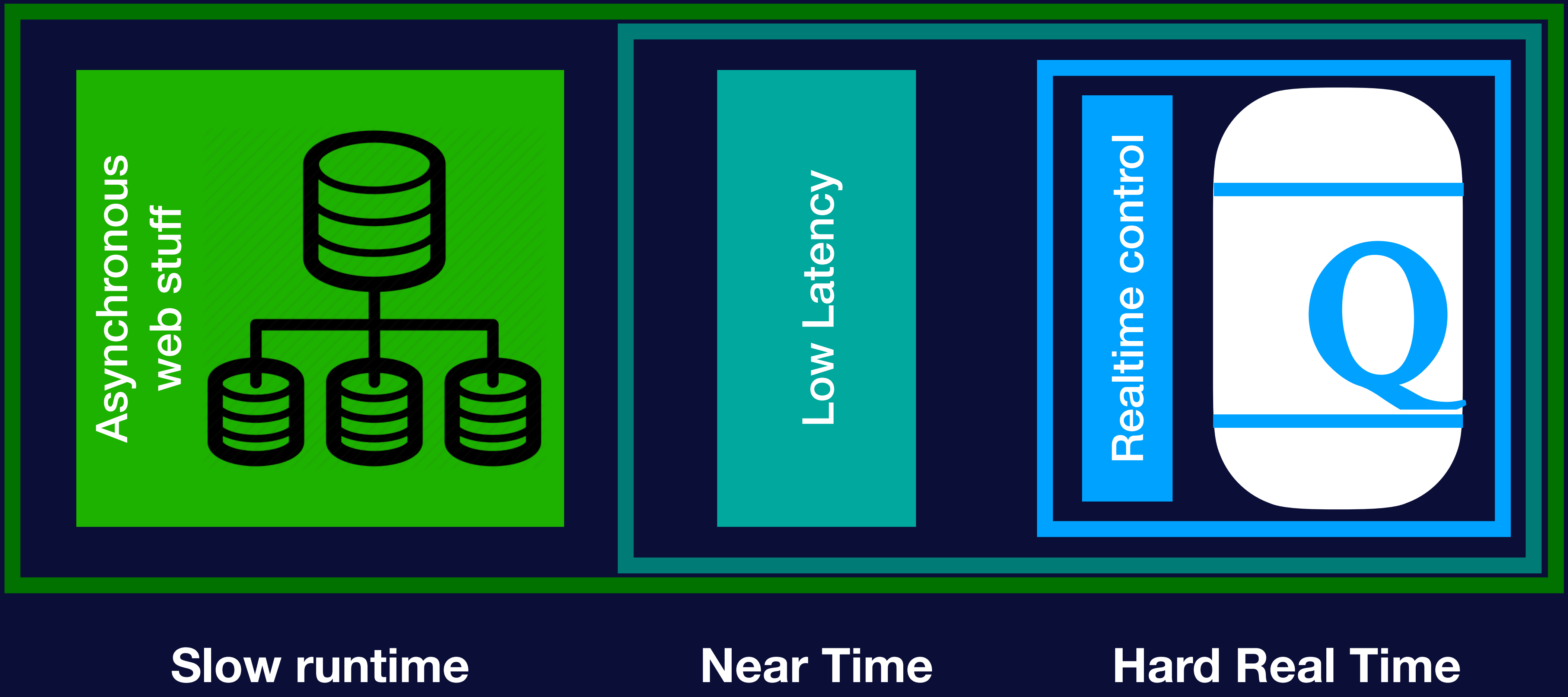
Realtime control

Hard Real Time

Irfan



Irfan


Asynchronous web stuff
Low Latency
Realtime control
Q
Slow runtime
Near Time
Hard Real Time

Irfan

Compile time **Slow runtime** **Near Time** **Hard Real Time**

Irfan

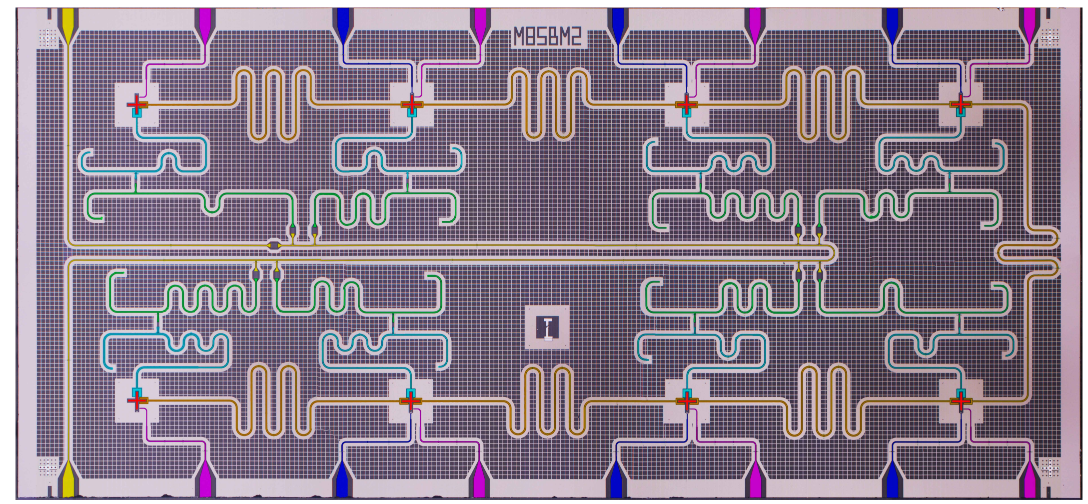
Each box is :

- a different *time regime*
- a different set of *capabilities*
- a different *scope*

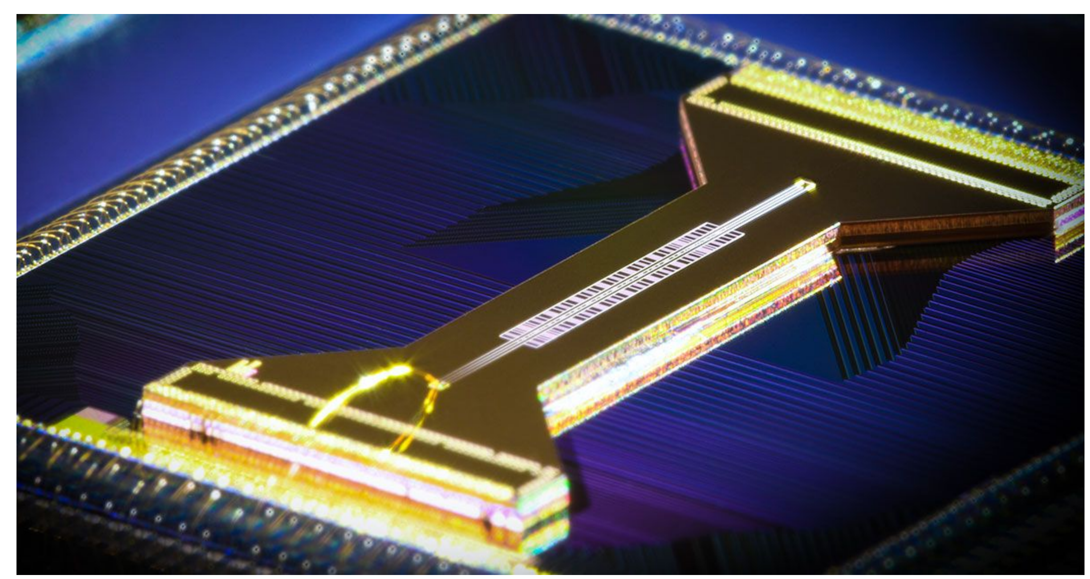
The program *as a whole* must be correctly distributed between them

Quantum Computers

- Superconducting
  IBM, Google, Rigetti, OQC...
- Ion traps
  Quantinuum, IonQ, AQT, ...
- Cold atoms
  Cold Quanta, Pasqal, ...
- Photonic
  Psi Quantum, Quandela, ORCA ..
- Semiconductors
  Intel, Quantum Motion, ...



ETH Zürich



Quantinuum

ibm_**washington** Exploratory

System status: Online - Queue paused *maintenance*

Processor type: Eagle r1

Qubits	QV	CLOPS
127	64	850

ibmq_**brooklyn** Exploratory

System status: Online

Processor type: Hummingbird r2

Qubits	QV	CLOPS
65	32	1.5K

ibmq_**kolkata**

System status: Online

Processor type: Falcon r5.11

Qubits	QV	CLOPS
27	128	2K

ibmq_**montreal**

System status: Online

Processor type: Falcon r4

Qubits	QV	CLOPS
27	128	2K

ibmq_**mumbai** Exploratory

System status: Online

Processor type: Falcon r5.1

Qubits	QV	CLOPS
27	128	1.8K

ibm_**cairo**

System status: Online - Queue paused *maintenance*

Processor type: Falcon r5.11

Qubits	QV	CLOPS
27	64	2.4K

ibm_**auckland** Exploratory

System status: Online

Processor type: Falcon r5.11

Qubits	QV	CLOPS
27	64	2.4K

ibm_**hanoi**

System status: Online

Processor type: Falcon r5.11

Qubits	QV	CLOPS
27	64	2.3K

ibmq_**toronto**

System status: Online

Processor type: Falcon r4

Qubits	QV	CLOPS
27	32	1.8K

ibm_**peekskill** Exploratory

System status: Online

Processor type: Falcon r8

Qubits	QV
27	1

ibmq_**guadalupe**

System status: Online

Processor type: Falcon r4P

Qubits	QV	CLOPS
16	32	2.4K

ibm_**perth**

System status: Online

Processor type: Falcon r5.11H

Qubits	QV	CLOPS
7	32	2.9K

ibm_**lagos**

System status: Online

Processor type: Falcon r5.11H

Qubits	QV	CLOPS
7	32	2.7K

ibm_**nairobi**

System status: Online

Processor type: Falcon r5.11H

Qubits	QV	CLOPS
7	32	2.6K

ibmq_**jakarta**

System status: Online

Processor type: Falcon r5.11H

Qubits	QV	CLOPS
7	16	2.4K

ibmq_**manila**

System status: Online

Processor type: Falcon r5.11L

Qubits	QV	CLOPS
5	32	2.8K

ibmq_**bogota**

System status: Online

Processor type: Falcon r4L

Qubits	QV	CLOPS
5	32	2.3K

ibmq_**santiago**

System status: Online

Processor type: Falcon r4L

Qubits	QV
5	32

ibmq_**quito**

System status: Online

Processor type: Falcon r4T

Qubits	QV	CLOPS
5	16	2.5K

ibmq_**belem**

System status: Online

Processor type: Falcon r4T

Qubits	QV	CLOPS
5	16	2.5K

“NISQ”

Noisy Intermediate-Scale Quantum

"NISQ"

Noisy Intermediate-Scale Quantum

“NISQ”

Noisy Intermediate-Scale Quantum

- 50—100 qubits
- Enough to be hard to simulate
- Not enough for error correction

“NISQ”

Noisy Intermediate-Scale Quantum

"NISQ"

Noisy Intermediate-Scale Quantum

Everything has a limited fidelity
Qubits have finite coherence time
Errors can vary across the machine
Errors can vary across time
Errors are correlated, non-markovian
Errors are not always well understood

“NISQ”

Noisy ~~Intermediate-Scale~~ Quantum

- Noise implies scale limitations
- There will be errors
- Whole stack must actively work to manage noise
- Not all interesting algorithms are possible
- The quantities we are computing are statistical

Quantum Compilation

Now Open Source!

t|ket⟩

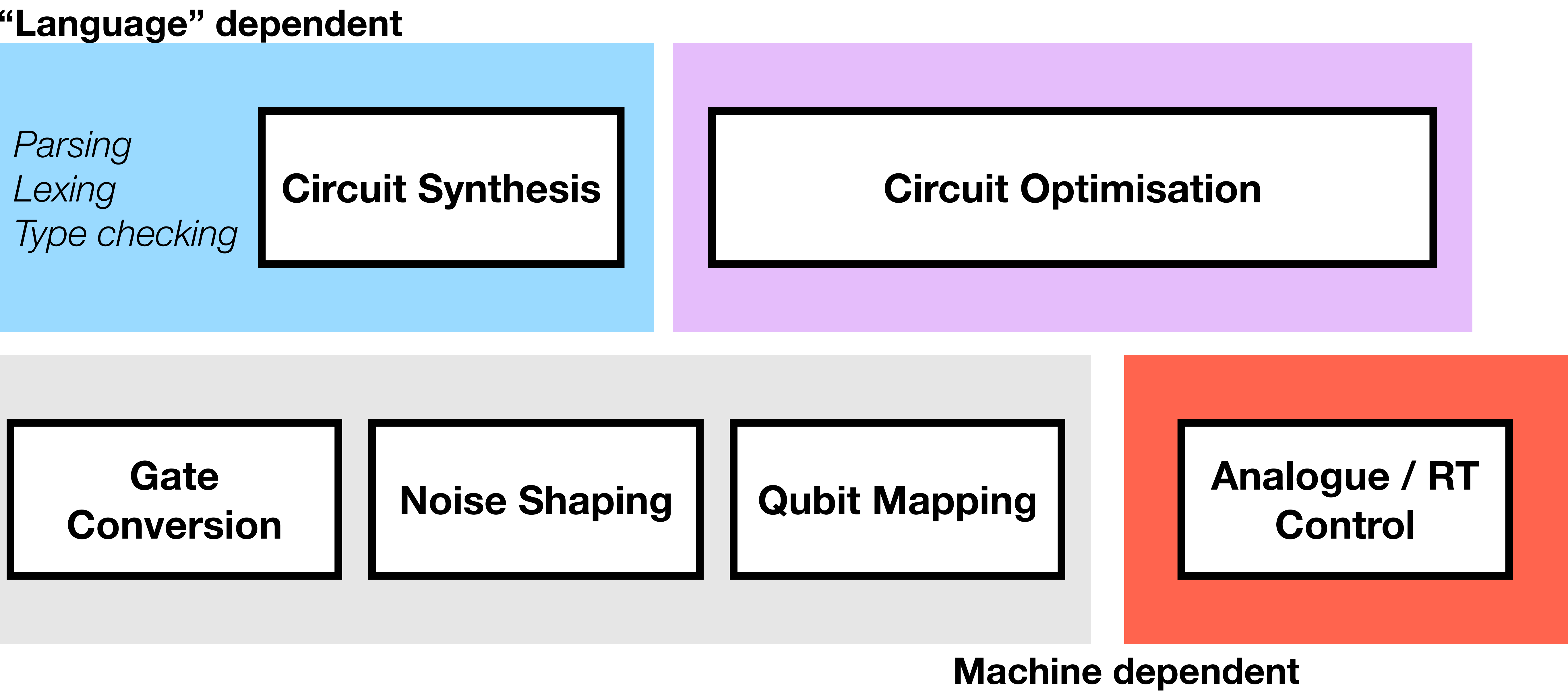
A **language and platform agnostic**
retargetable compiler for **NISQ** devices

```
pip install pytket
```

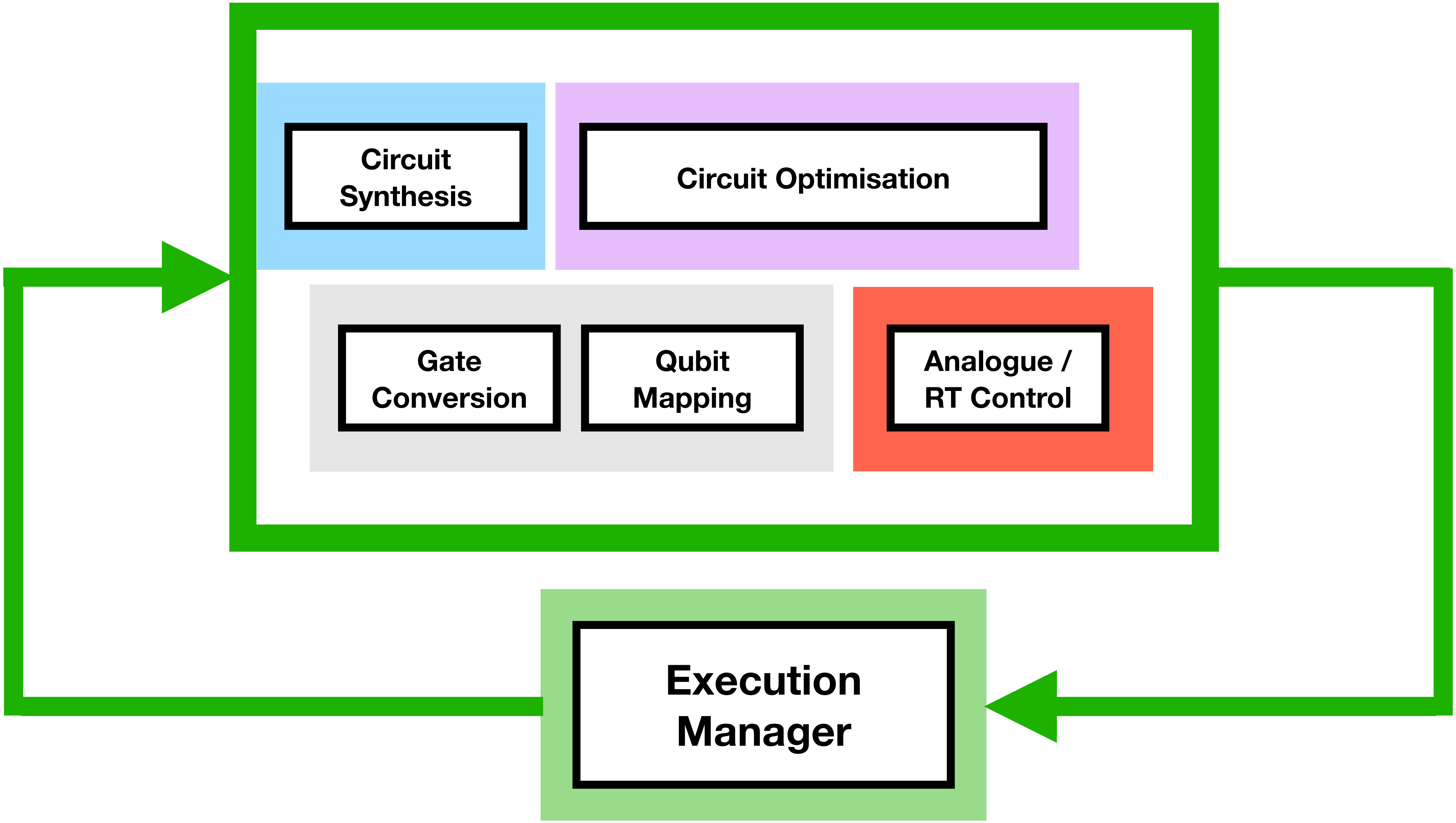
TKET


Qiskit
Cirq
rigetti
QUANTINUUM
pytket-qiskit
Qiskit
IBM-Q, Aer
pytket-cirq
Cirq
pytket-pyquil
pyquil
QCS, QVM
pytket-qsharp
Azure Quantum
pytket-quantinuum
Quantinuum H-series
pytket
Compiler
C++ Library

Quantum Compiler Phases



Quantum Compiler Phases



Compiler Passes

- Synthesise many qubit operations to 1-, 2-qubit gates
- Symbolic expression optimisation
- Resynthesise sub-circuits via special representations
  - ZX-terms, Clifford tableaux, Phase-polynomials
- Exact and approximate synthesis of unitaries
- Architecture aware synthesis
- Mapping to chosen gate basis
- Allocating “virtual” qubits to physical qubits
- Mapping and routing circuits to fixed architectures
- .... more!

Composable

Error Mitigation

Mitigation vs Correction

Error Correction

- Map "logical" qubits into a larger code space of many physical qubits and perform encoded operations on code space
- Frequently measure ancillary qubits to detect errors
- Intervene in circuit to correct observed errors
- Every circuit evaluation is "correct"
- Terrifyingly high resource overheads (x10000s of qubits)

Error Mitigation

- Accept the statistical nature of the results and try to improve the accuracy of the final output.
- Generally aim to extract more signal from noise
- Typically involves computing many variations of the desired circuit and combining them with classical side processing
- Can intervene at almost any point of the overall computation
- Can also involve high overheads in terms of circuit executions

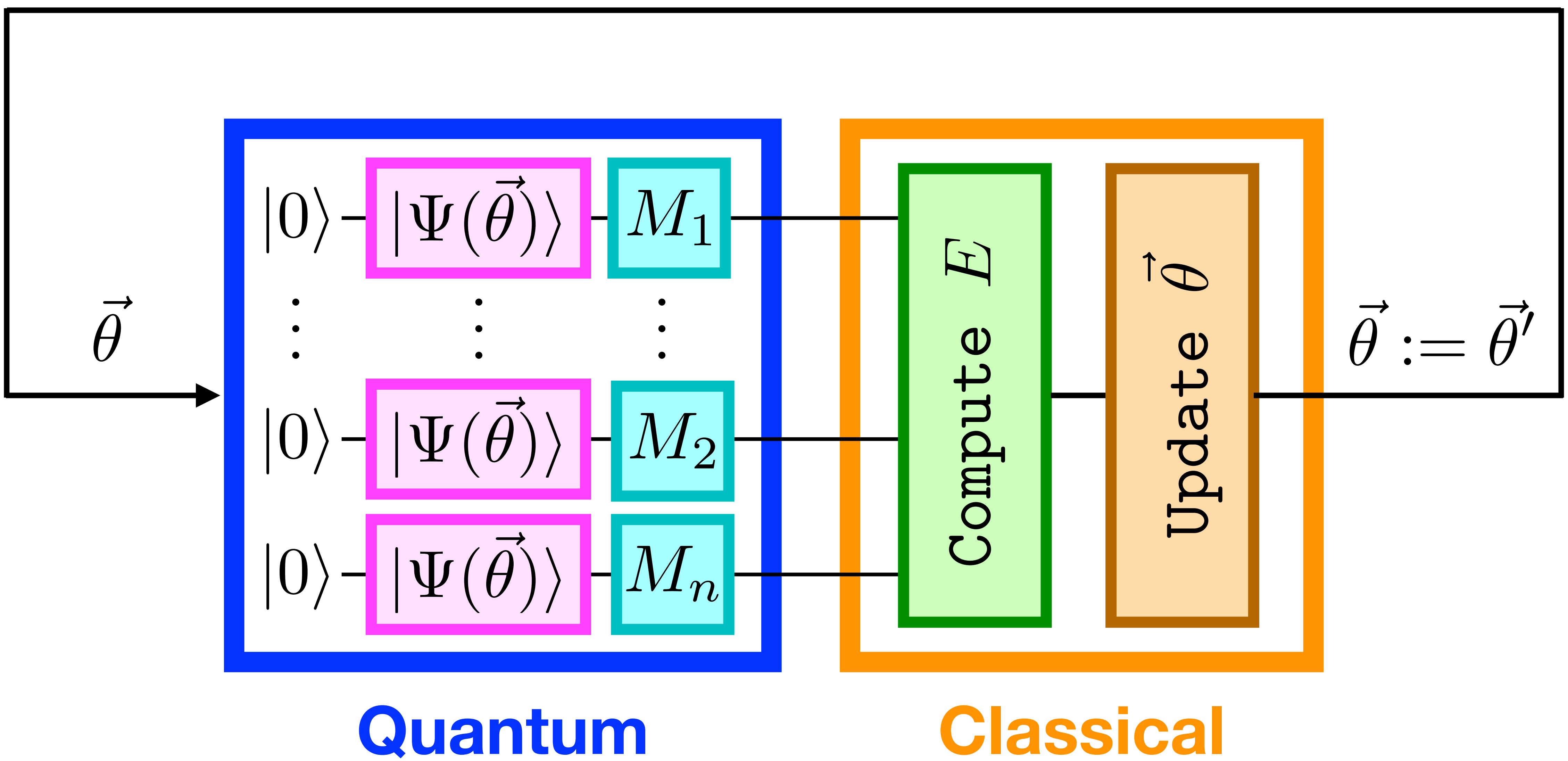
Introducing....

QERMIT

- Fully compositional Quantum Error Mitigation toolkit
- Extensible and open source
- Many error mitigation methods implemented and benchmarked

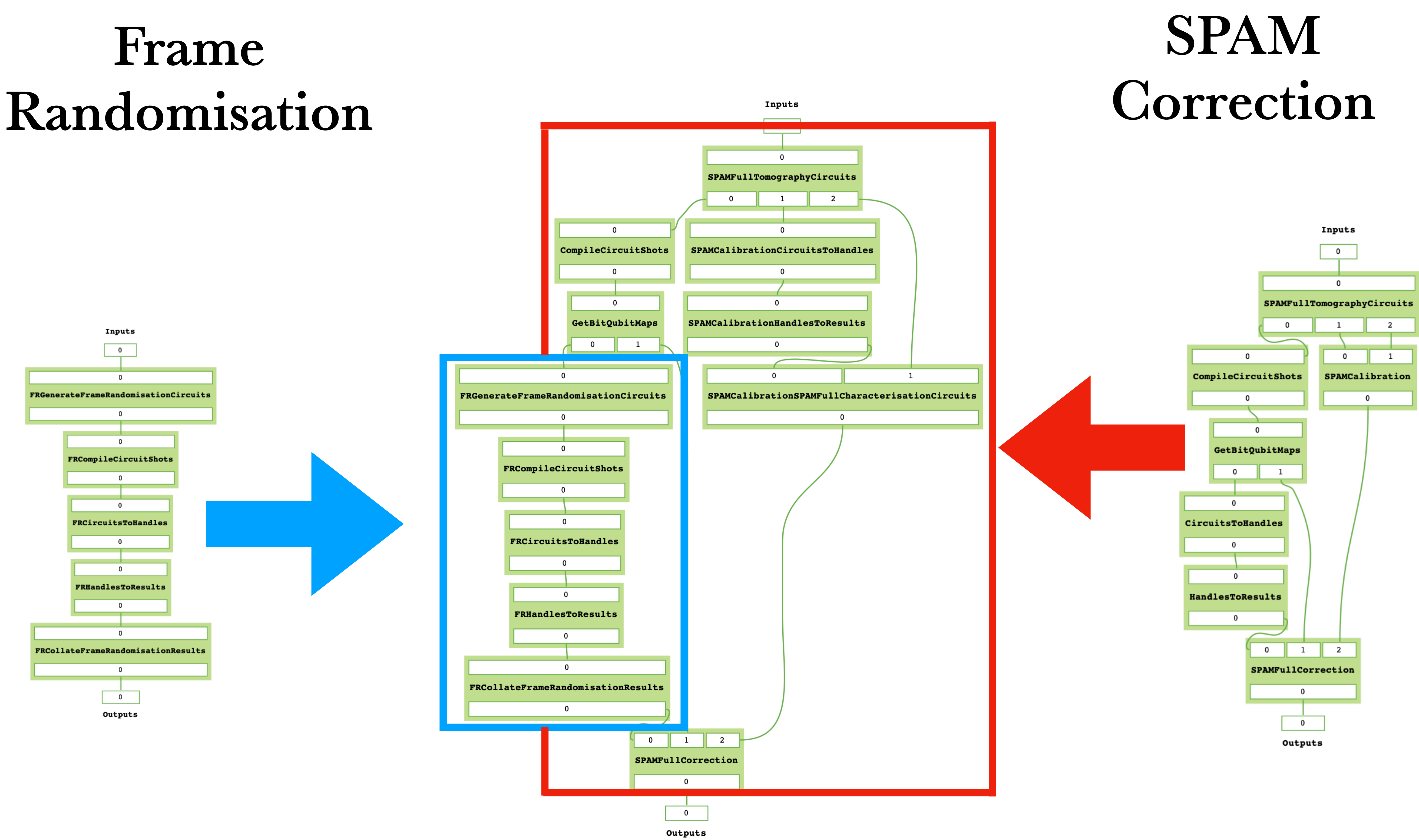
```
pip install qermit
```

Variational Quantum Algorithms



Kinds of Mitigation

- "**MitRes**" :
  transform the **distribution** of **results** of a circuit
- "**MitEx**" :
  transform the **expectation** of some computed **quantity**


Frame Randomisation
SPAM Correction
Inputs
FRGenerateFrameRandomisationCircuits
FRCompileCircuitShots
FRCircuitsToHandles
FRHandlesToResults
FRCollateFrameRandomisationResults
Outputs
Inputs
SPAMFullTomographyCircuits
CompileCircuitShots
SPAMCalibrationCircuitsToHandles
GetBitQubitMaps
SPAMCalibrationHandlesToResults
FRGenerateFrameRandomisationCircuits
SPAMCalibrationSPAMFullCharacterisationCircuits
FRCompileCircuitShots
FRCircuitsToHandles
FRHandlesToResults
FRCollateFrameRandomisationResults
SPAMFullCorrection
Outputs
Inputs
SPAMFullTomographyCircuits
CompileCircuitShots
SPAMCalibration
GetBitQubitMaps
CircuitsToHandles
HandlesToResults
SPAMFullCorrection
Outputs

Academic Collaborations

Chalmers
Resources for Quantum Chemistry

Tokyo
Distributed QC

UCL
MBQC

ULB
Device Independent Crypto

Cambridge
Quantum Chemistry Algorithms

Edinburgh / NPL
Noise at large scale

Strathclyde
Quantum PL

NPL
Noise-resilient algorithms

MPQ / TUM
Condensed Matter Simulations

Thanks!

If you are looking for a job or an internship email
careers@cambridgequantum.com