Generative Modeling Using Quantum Computers

Quantum Advantage and Training of the Ising Born Machine for Machine Learning

arXiv:1904.02214 - Brian Coyle, **Daniel Mills**, Vincent Danos, Elham Kashefi

Mission

Investigate tasks for which current and near term quantum devices can be useful and can even demonstrate the supremacy of quantum over classical computing.

Specifically

Develop tools to utilise quantum computers in generative modeling and explore the Ising Born Machine for this purpose.

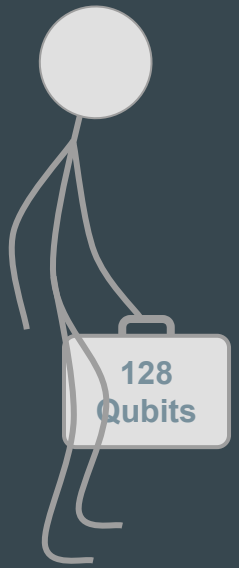
Breakdown of the Mission

What is:

- a near term device?
- generative modeling?
- quantum supremacy?
- the Ising Born Machine?

Noisy Intermediate Scale Quantum Technologies

An Application



Factoring

An Application

4000 Qubits

Factoring

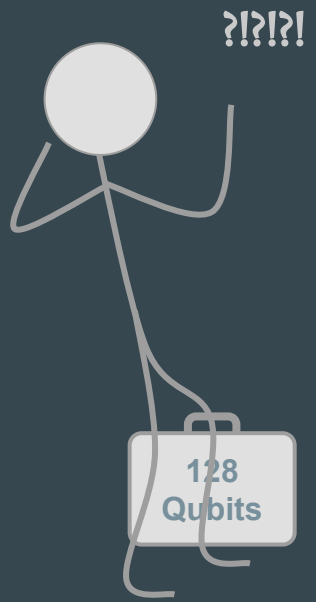
An Application

10^9 Gates

4000 Qubits

Factoring

An Application



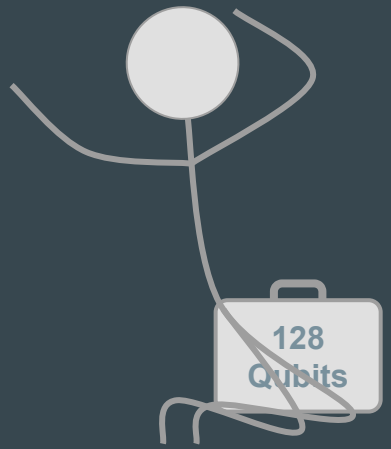
Fault Tolerance

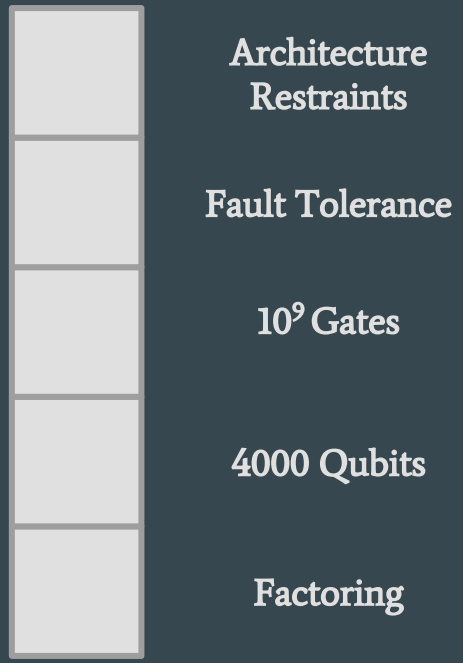
10^9 Gates

4000 Qubits

Factoring

An Application





Restrictions on Applications

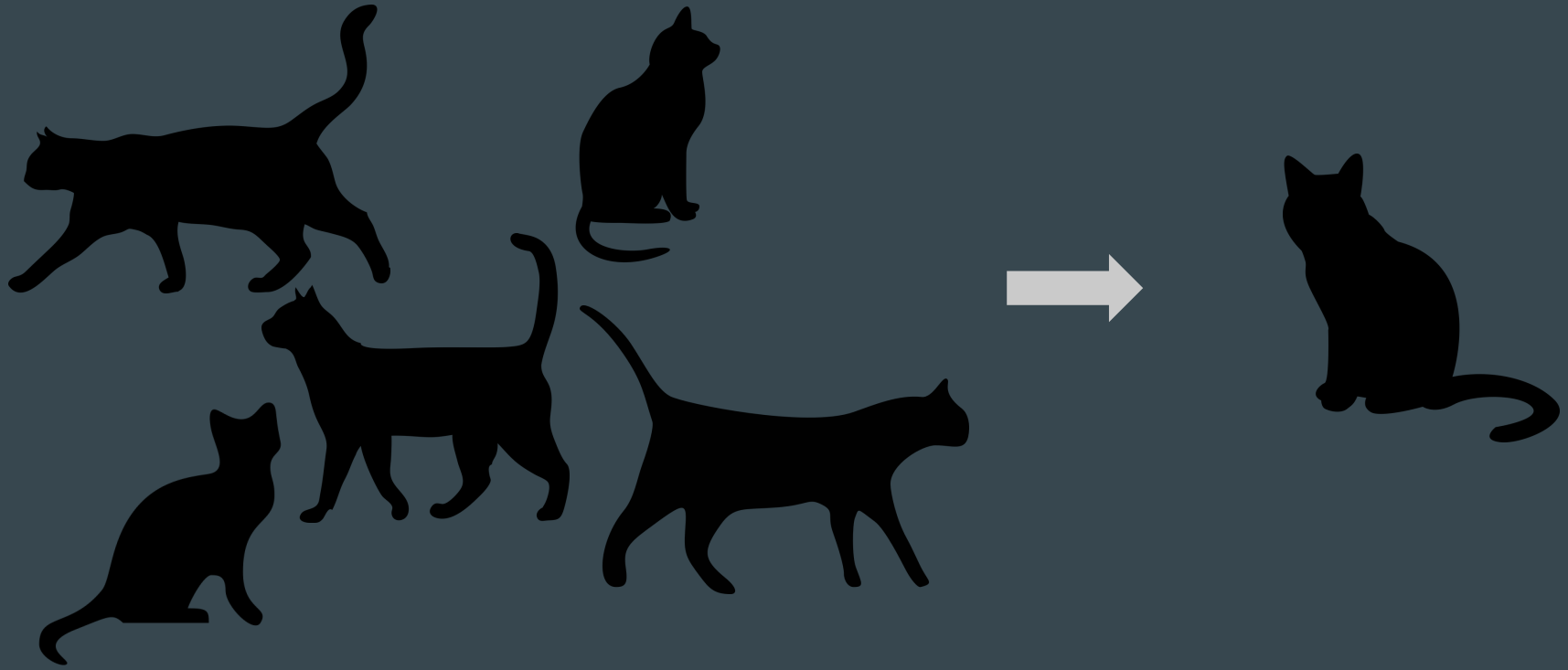
- Should require few qubits
- Ideally there would be intrinsic “fault tolerance”
- Guided by available architecture

Possible Applications

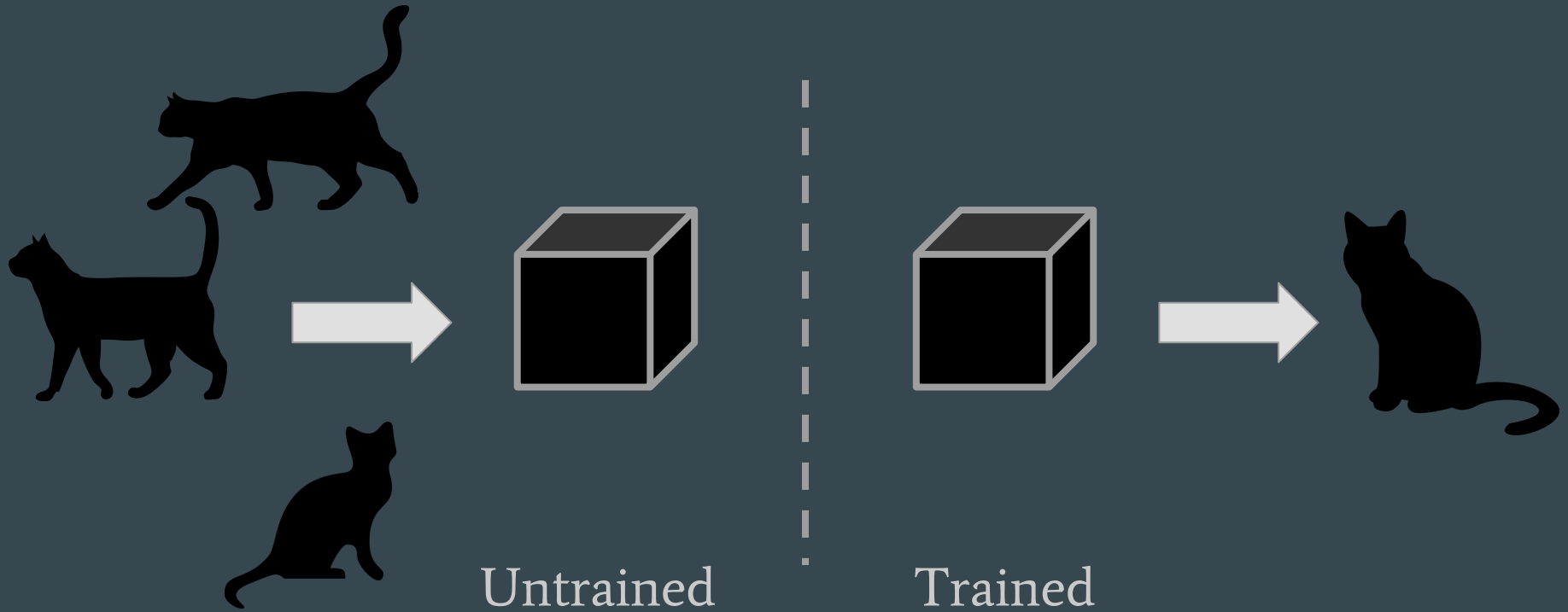
- Circuit classes that are simpler than universal
  - IQP, Boson Sampling, Random Circuits, ...
  - All shown to be better than classical but are simpler than a fully quantum device
- Simulate quantum mechanical systems
  - A very natural application where noise is a property of the simulation
- Proof of principle
  - If we do not target real word problems we can save qubits

Generative Modeling

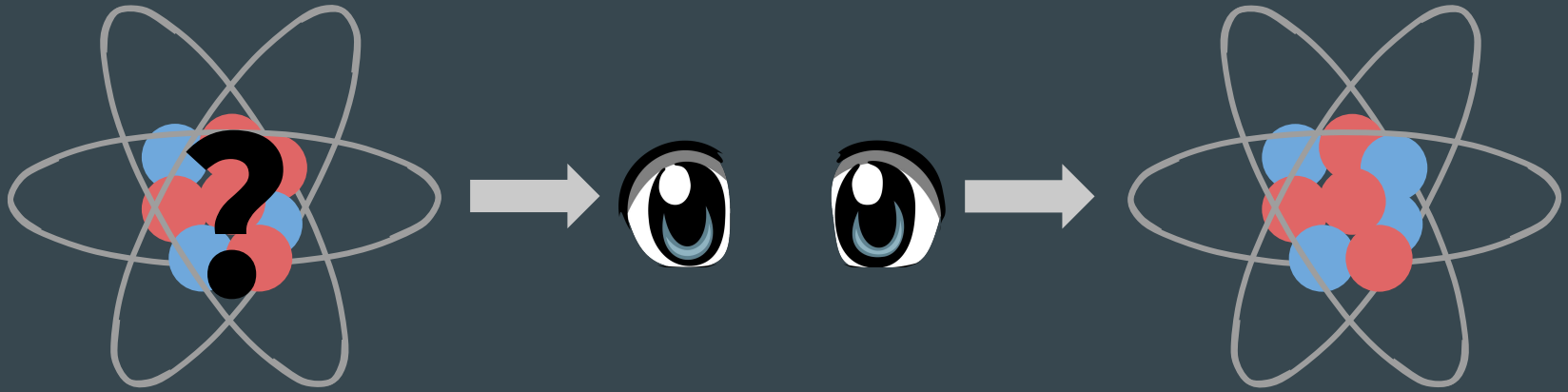
Reproduce New From Old



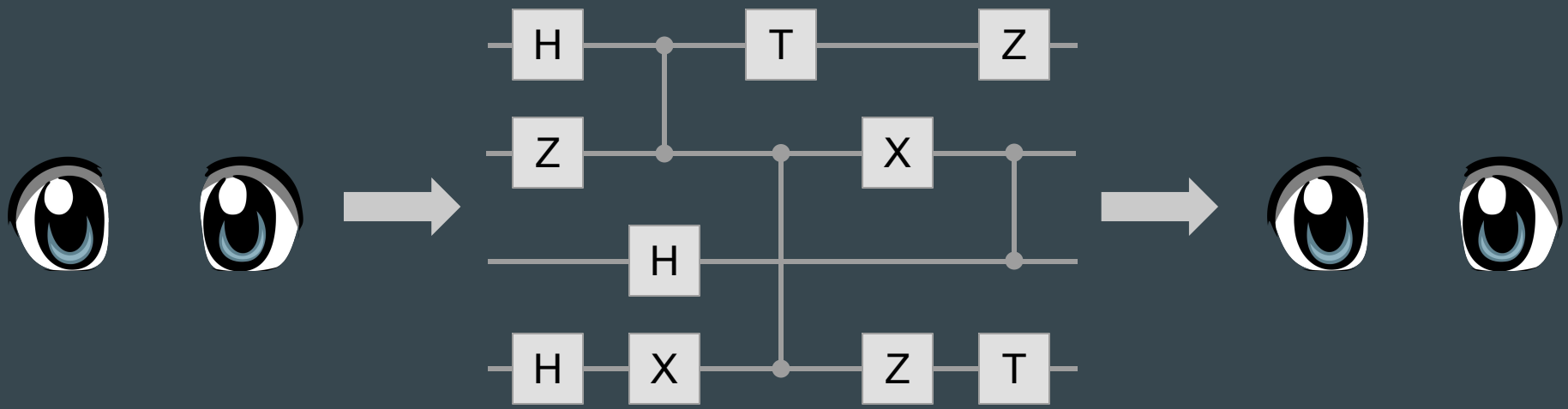
A Black Box



And in Quantum Computing?



More Precisely



Quantum Learning Supremacy

The Order of Definitions

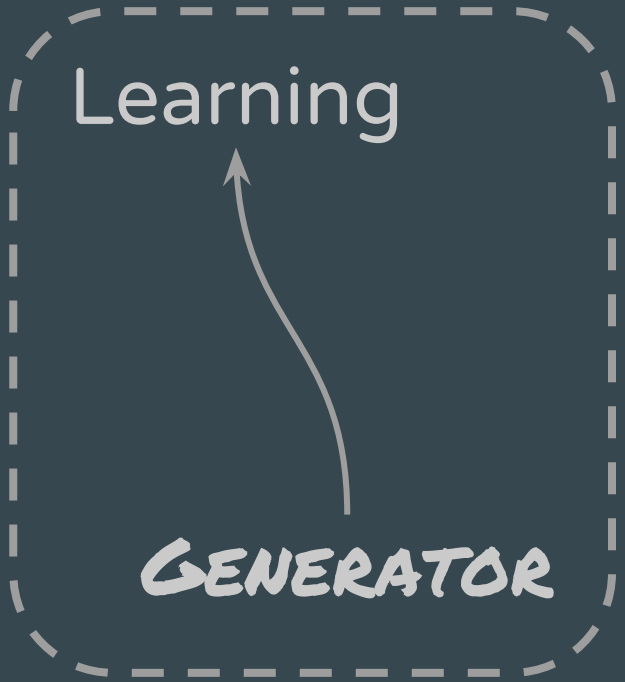
Supremacy

The Order of Definitions

Learning

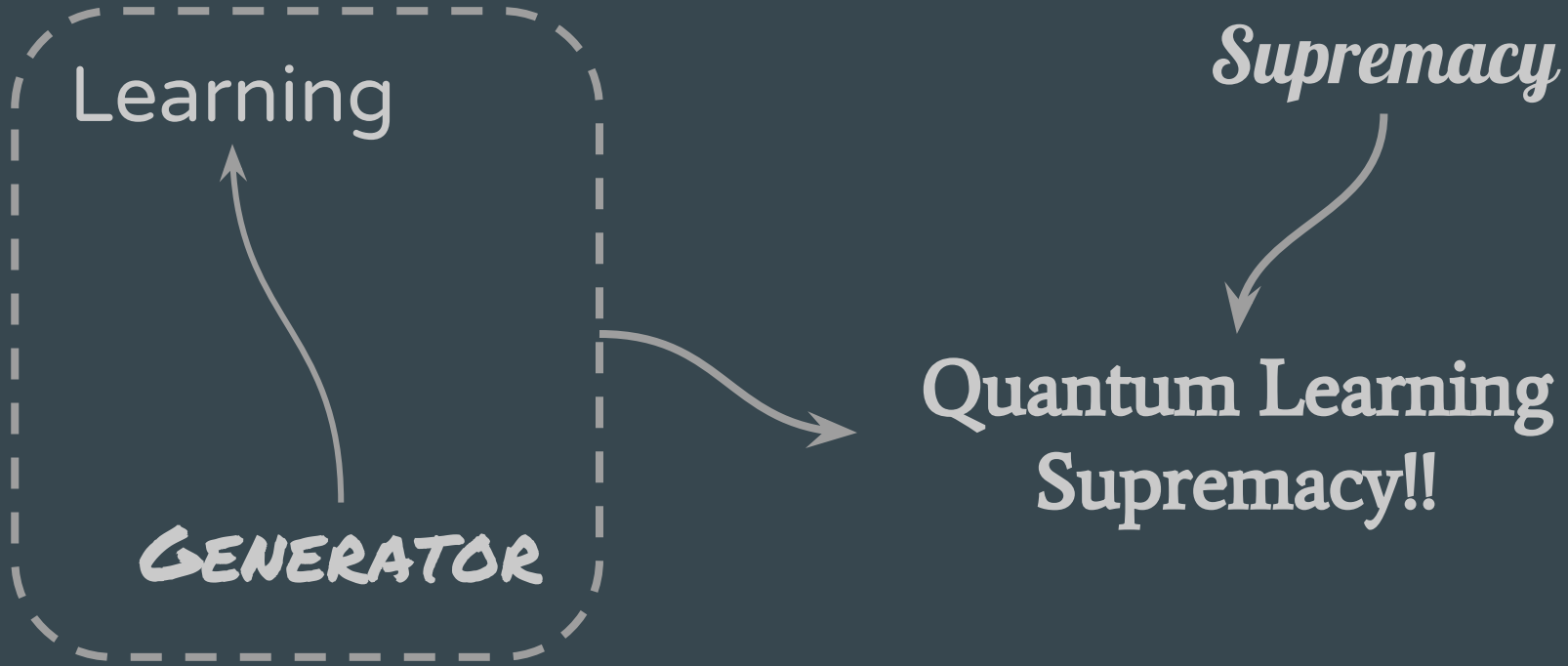
Supremacy

The Order of Definitions

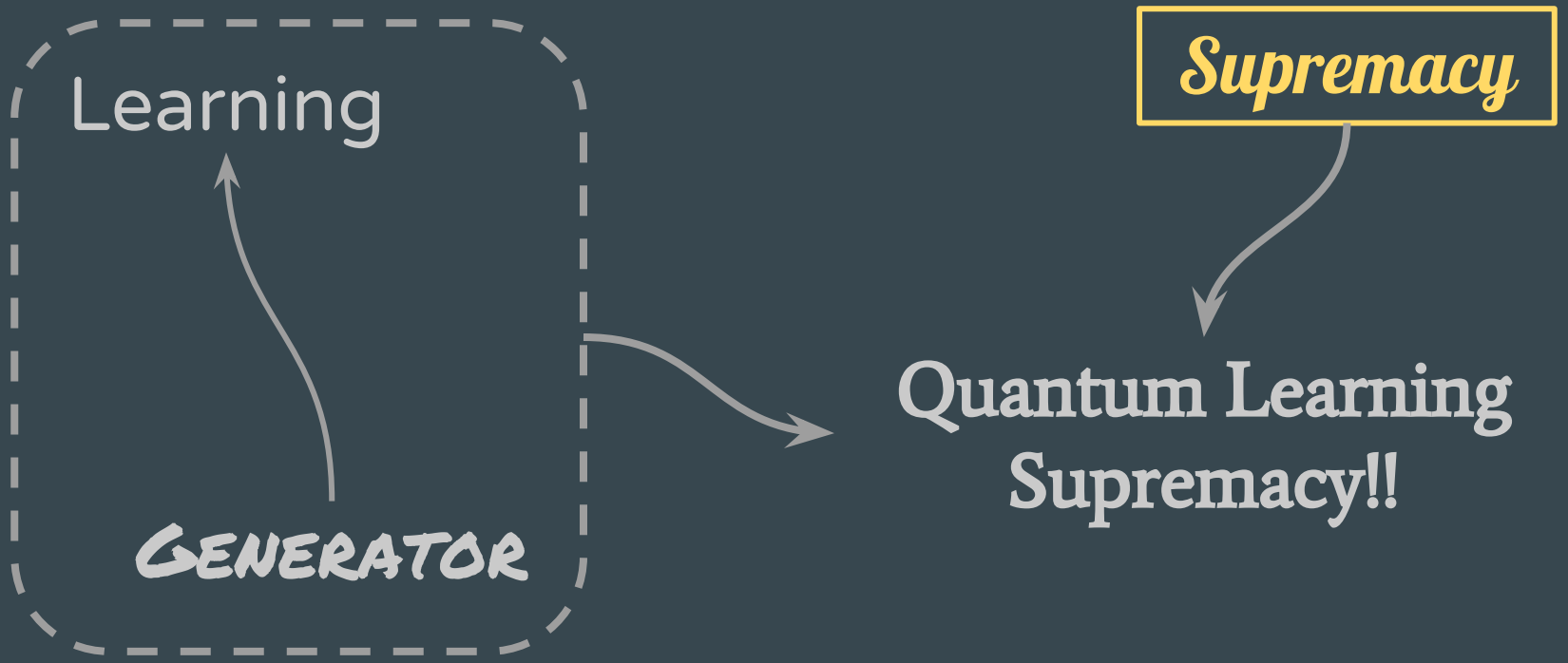


Supremacy

The Order of Definitions



The Order of Definitions

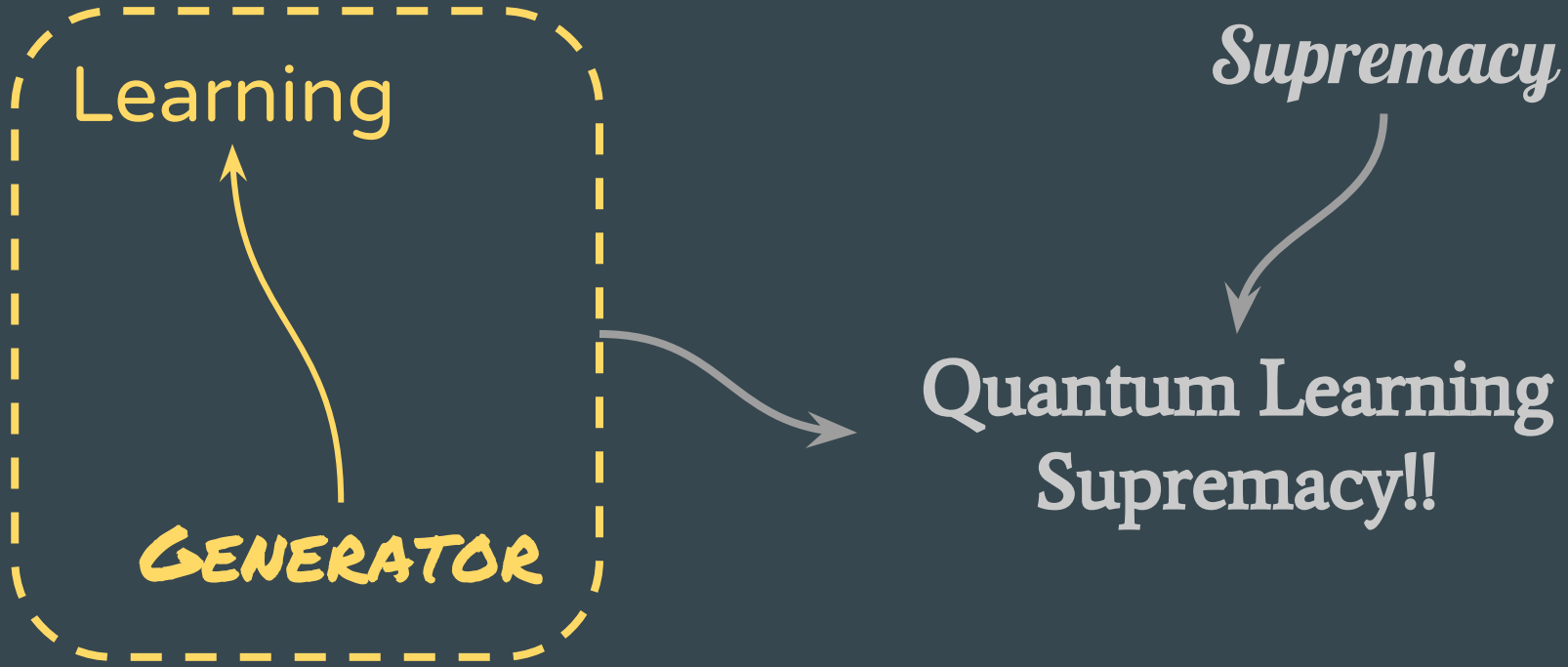


Supremacy

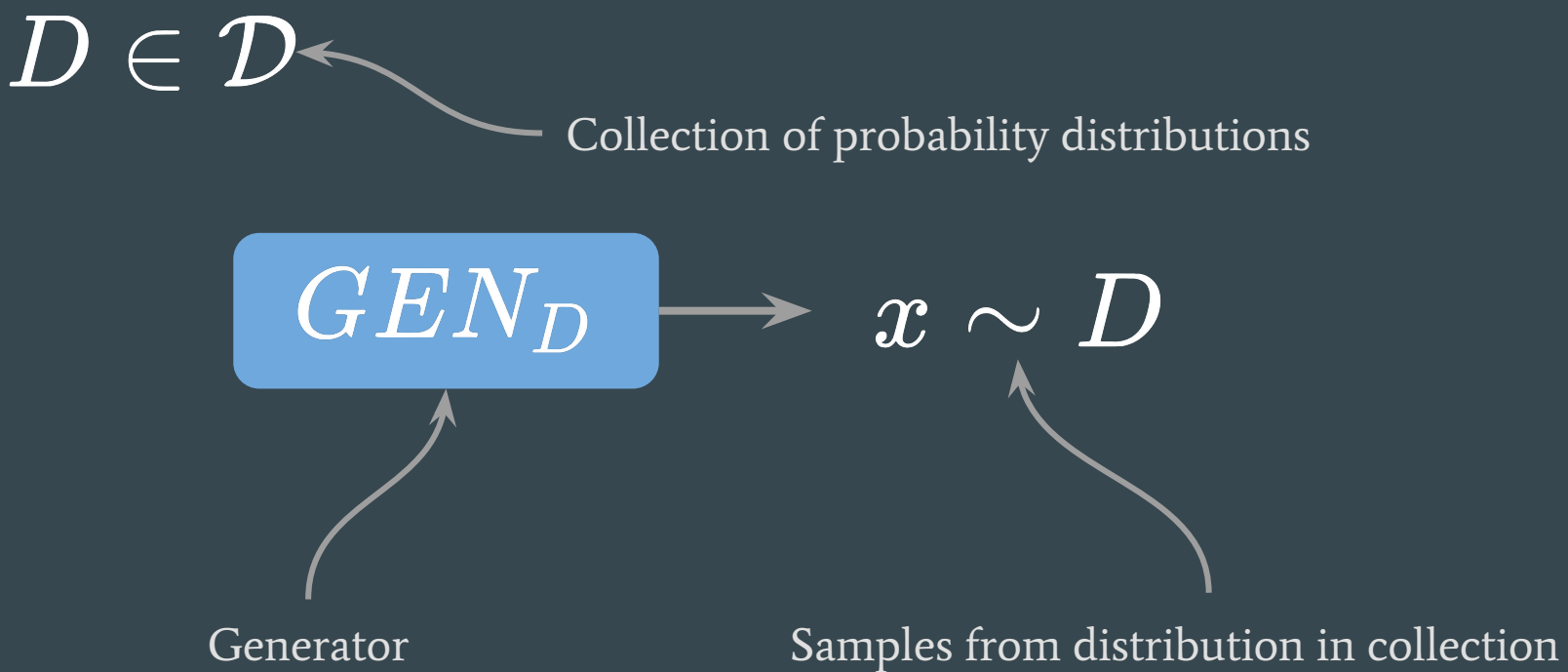
Supremacy null hypothesis:

The output of this computation was arrived at by a classical computer

The Order of Definitions

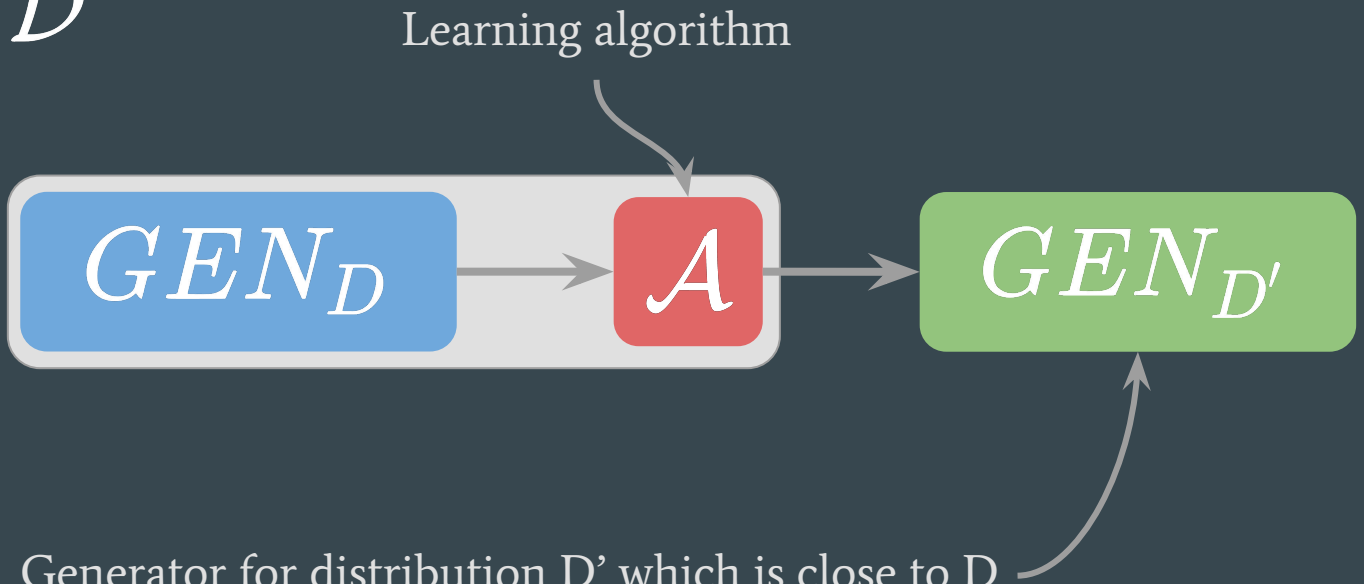


Generator

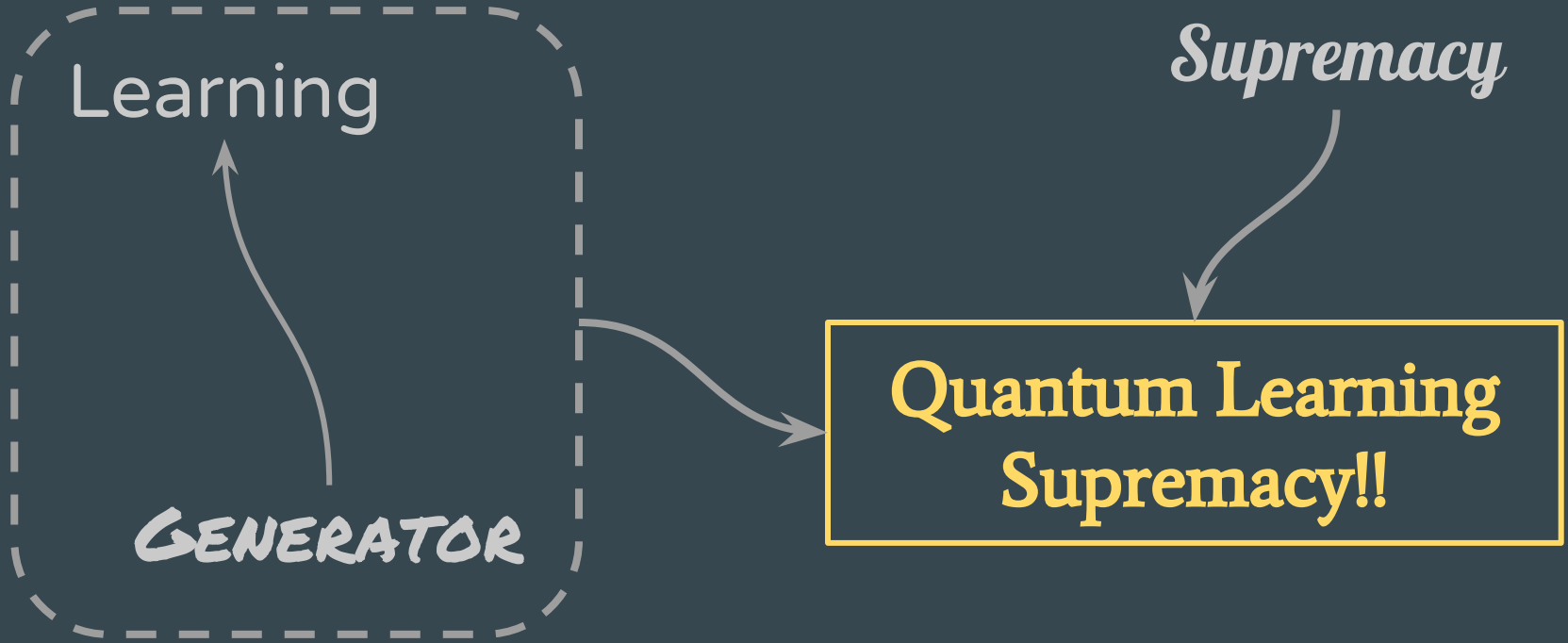

$D \in \mathcal{D}$
Collection of probability distributions
GEN_D
$x \sim D$
Generator
Samples from distribution in collection

Learning

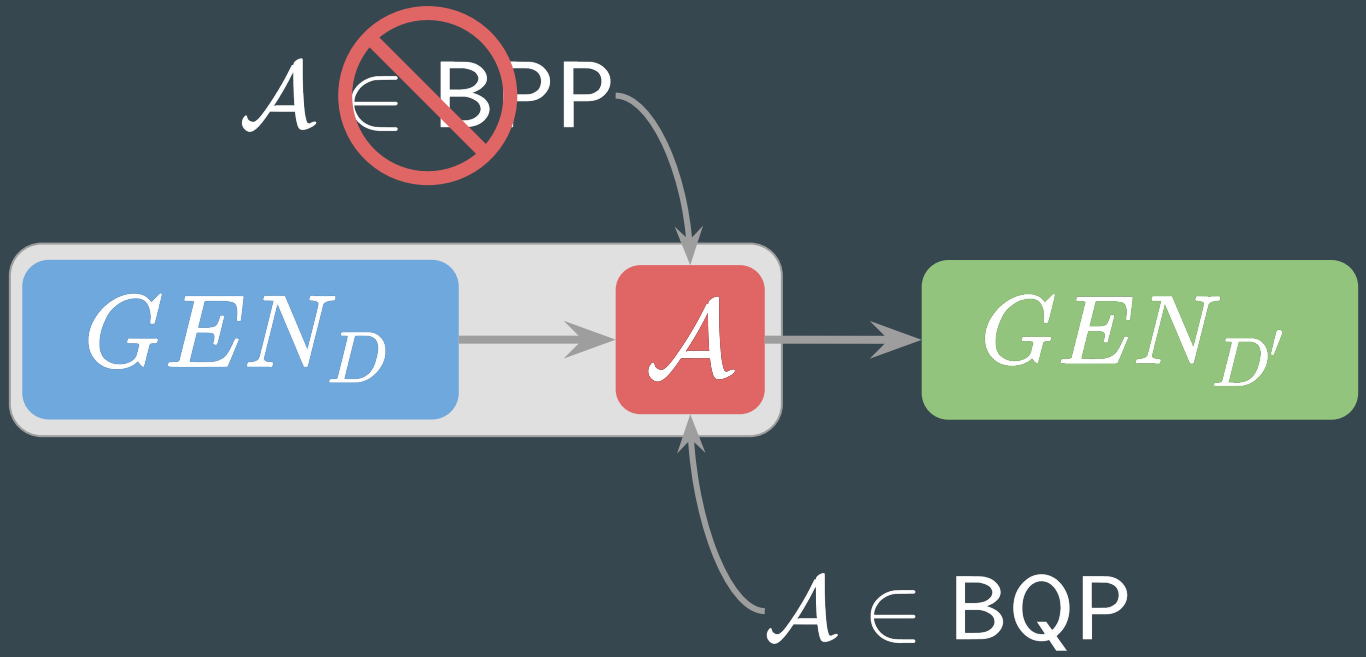
$D \in \mathcal{D}$



The Order of Definitions



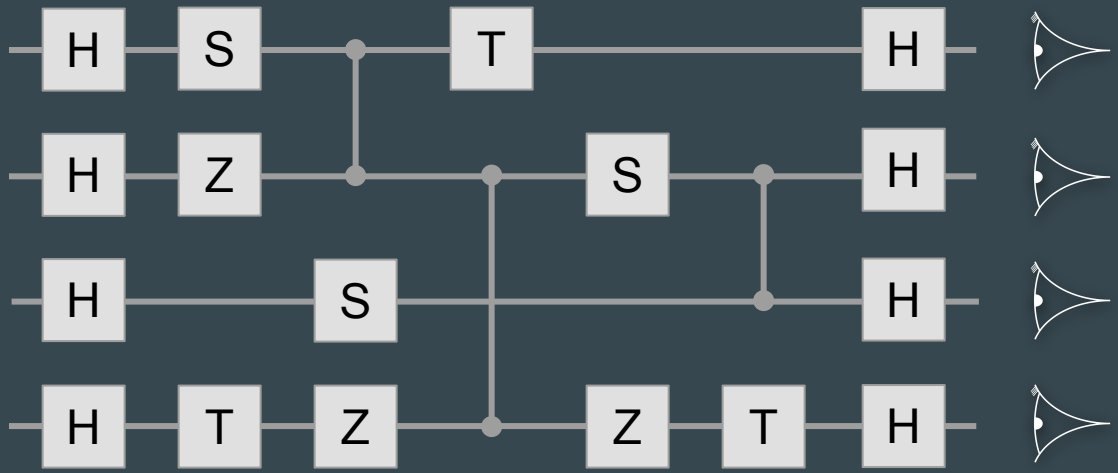
Quantum Learning Supremacy



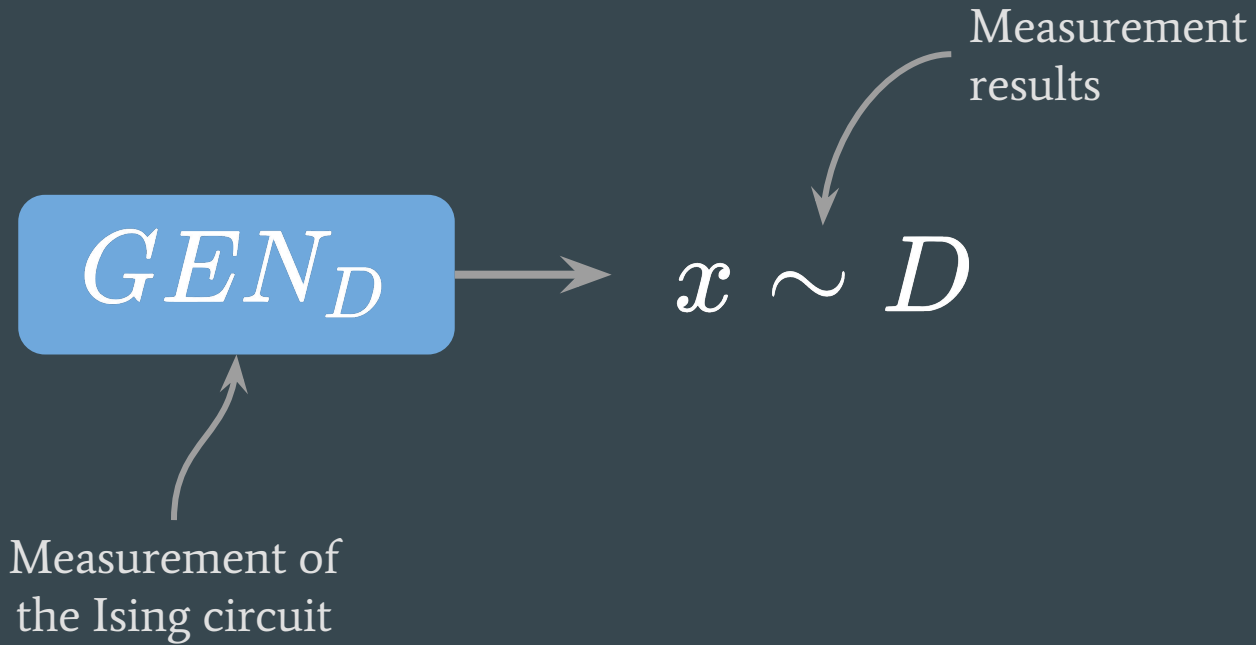
The Ising Born Machine

Ising Born Machine Definition

- Ising - Use Ising circuits
- Born - Outputs probabilities determined by Born rule



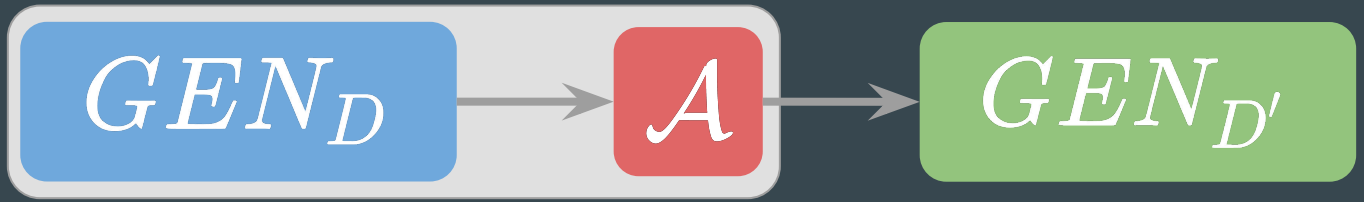
Generator


Measurement
results
GEN_D
$x \sim D$
Measurement of
the Ising circuit

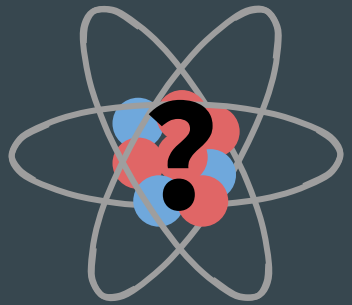
NISQ? Generative Model? Supremacy?

- NISQ - Can be implemented in one time step saving on memory
- Supremacy - The circuit class is shown to exhibit supremacy

Training



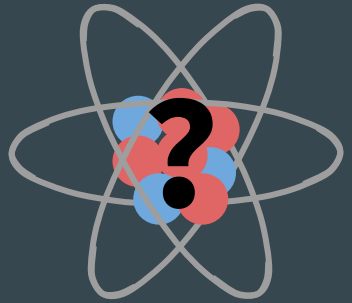
Training

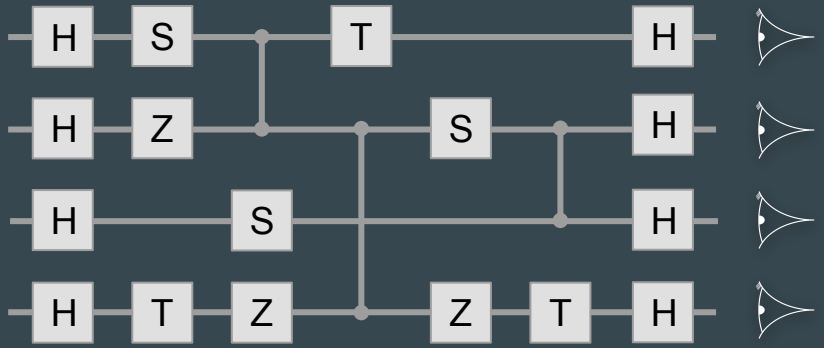


$=$

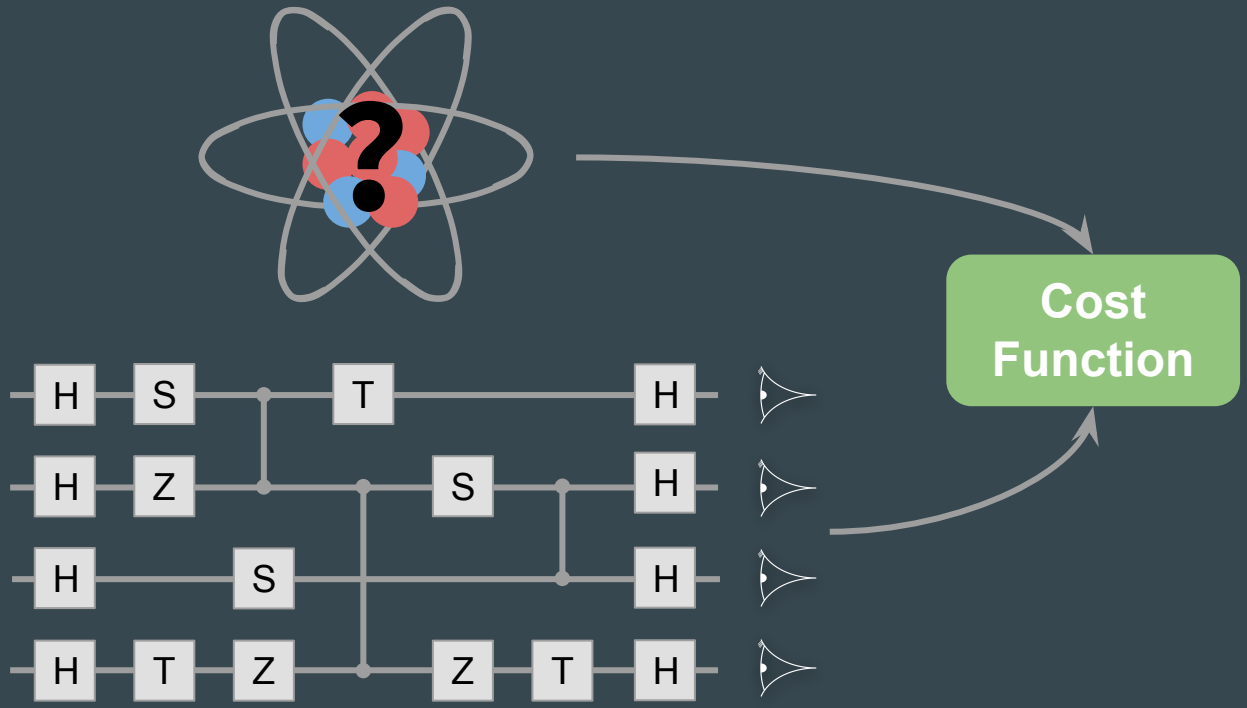
GEN_D

Training

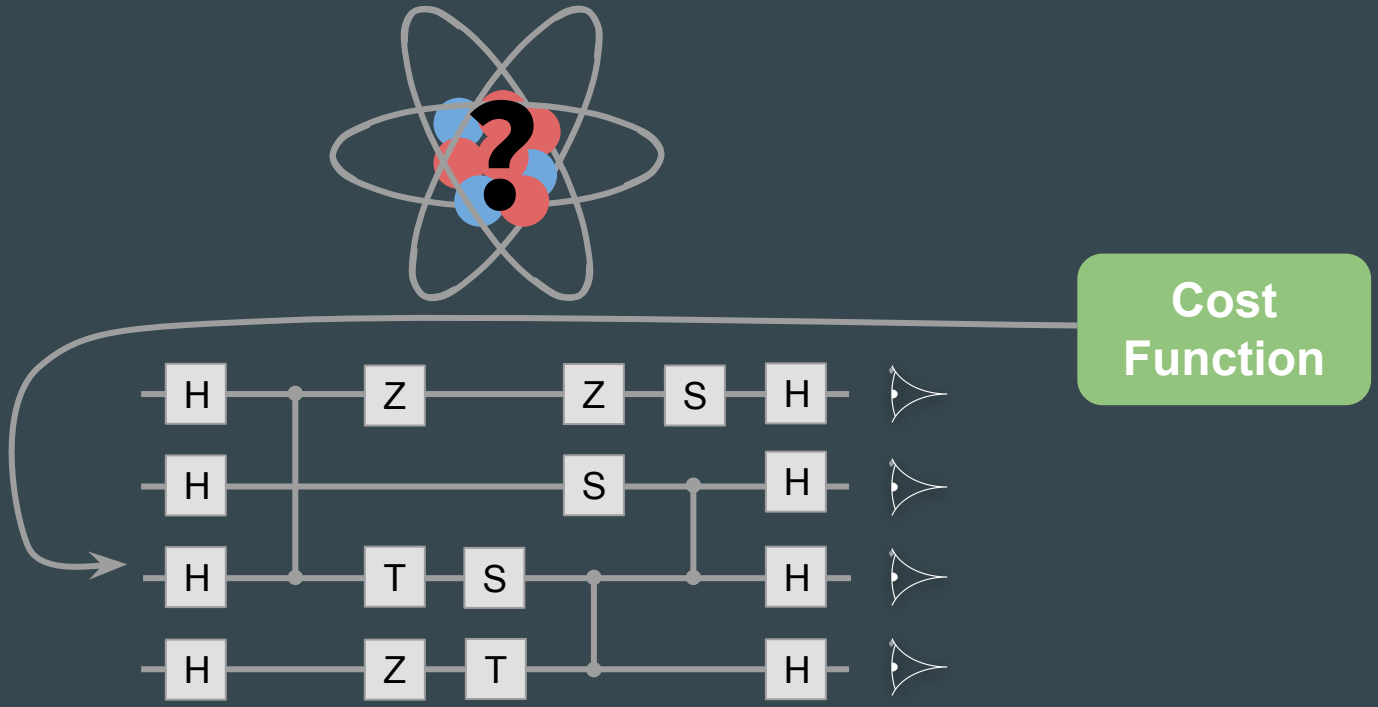




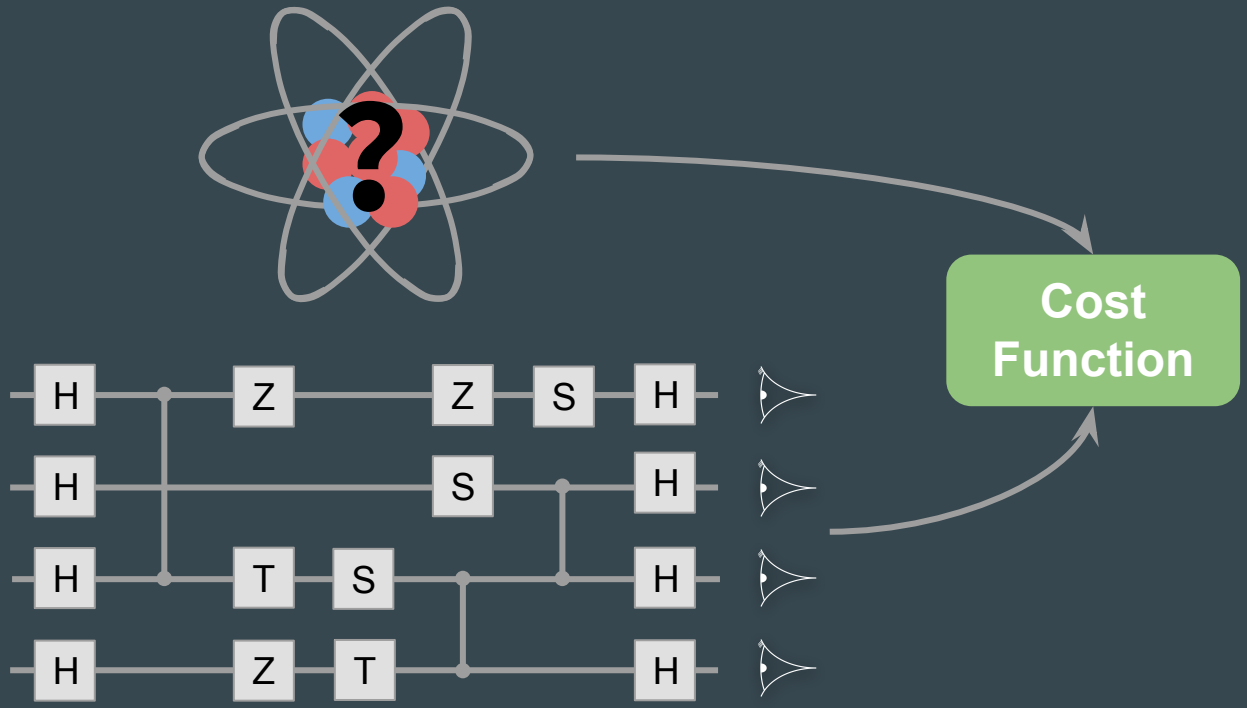
Training



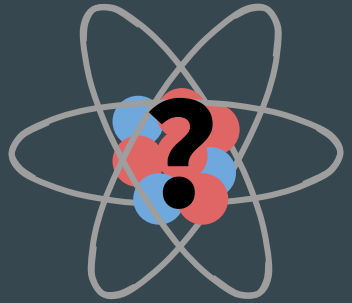
Training



Training

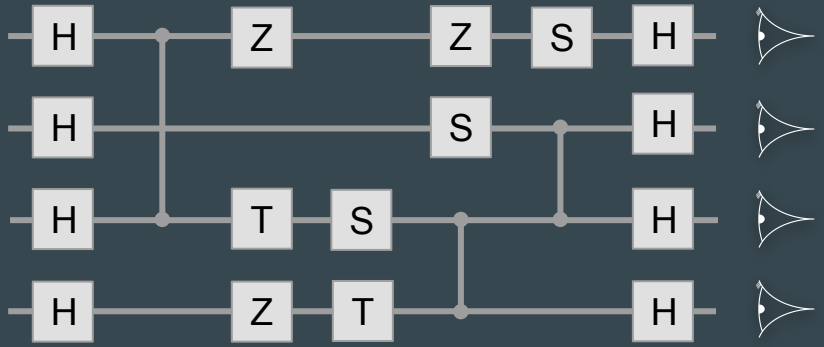


Training



=

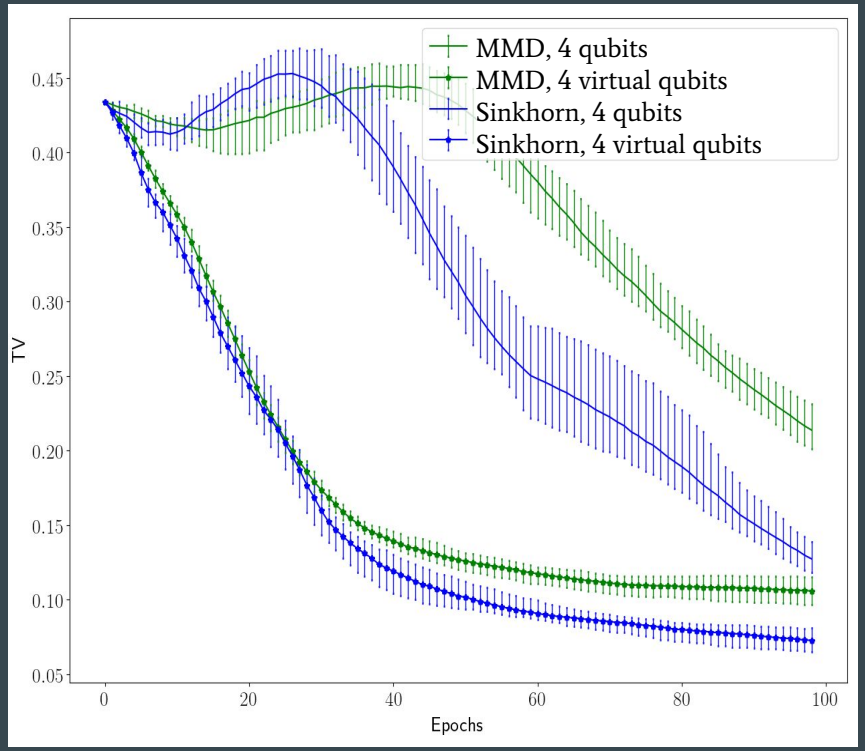
GEN_D

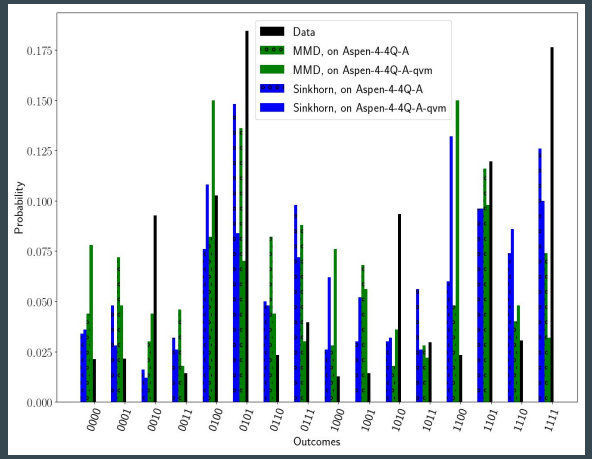


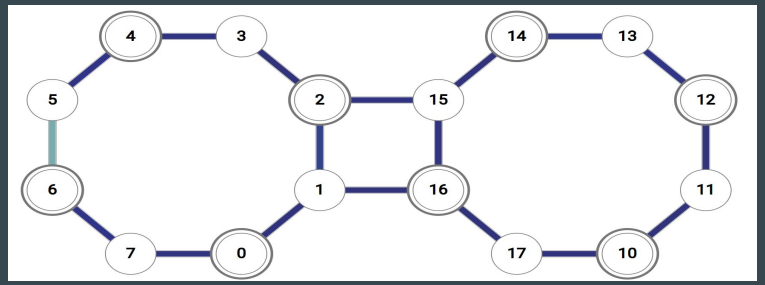
=

$GEN_{D'}$

Results


MMD, 4 qubits
MMD, 4 virtual qubits
Sinkhorn, 4 qubits
Sinkhorn, 4 virtual qubits
TV
Epochs
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
20
40
60
80
100


Data
MMD, on Aspen-4-4Q-A
MMD, on Aspen-4-4Q-A-qvm
Sinkhorn, on Aspen-4-4Q-A
Sinkhorn, on Aspen-4-4Q-A-qvm
Probability
Outcomes
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0000
0001
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111


4
3
14
13
5
2
15
12
6
1
16
11
7
0
17
10

Conclusion

- NISQ devices can be very exciting
- Learning using generative modeling is one possible application
- It may be possible to demonstrate quantum superiority using this problem