

变分量子算法原理和MindQuantum实现

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目录

- 1. 背景介绍
- 2. NISQ的量子算法原理
- 3. MindQuantum入门与实践
- 4. 课后题目

量子计算的颠覆性思想

以0和1作为基础

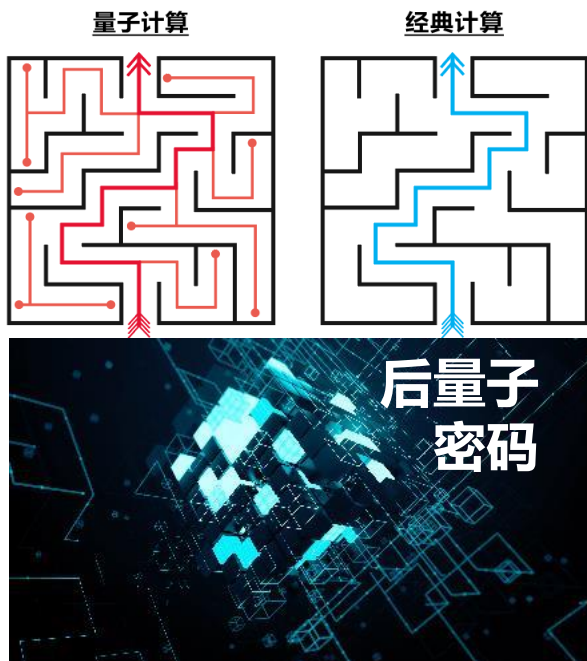
指数空间的操作能力

随机计算

量子计算 = 经典计算 + 量子叠加/纠缠 + 量子并行 + 量子相干 + 量子测量

指数计算空间

波函数（复数）计算



单凭量子计算机存在的可能性，
已经对目前的加密系统造成威胁。

The possibility of quantum
computers alone has already
threatened the current encryption
system.

例子: 计算 $f(x) = x^2$

经典计算机: $f(1), f(2), f(3), \dots$

量子计算机:

$$|1\rangle|f(1)\rangle + |2\rangle|f(2)\rangle + |3\rangle|f(3)\rangle + \dots$$

大数分解问题: $n = p \times q$

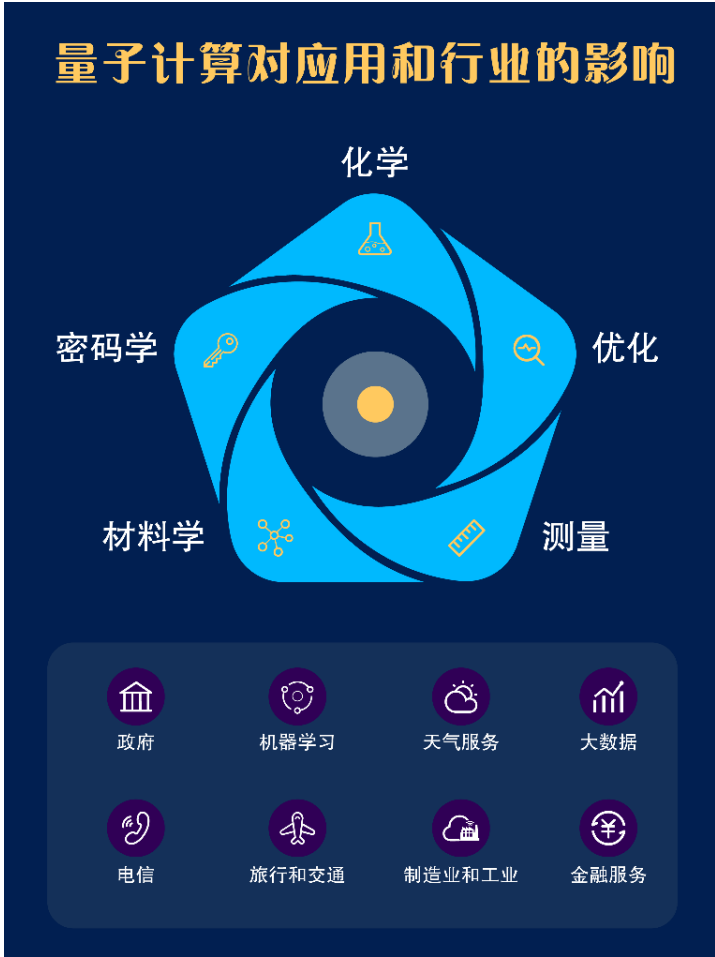
例子:

$$15 = 3 \times 5$$

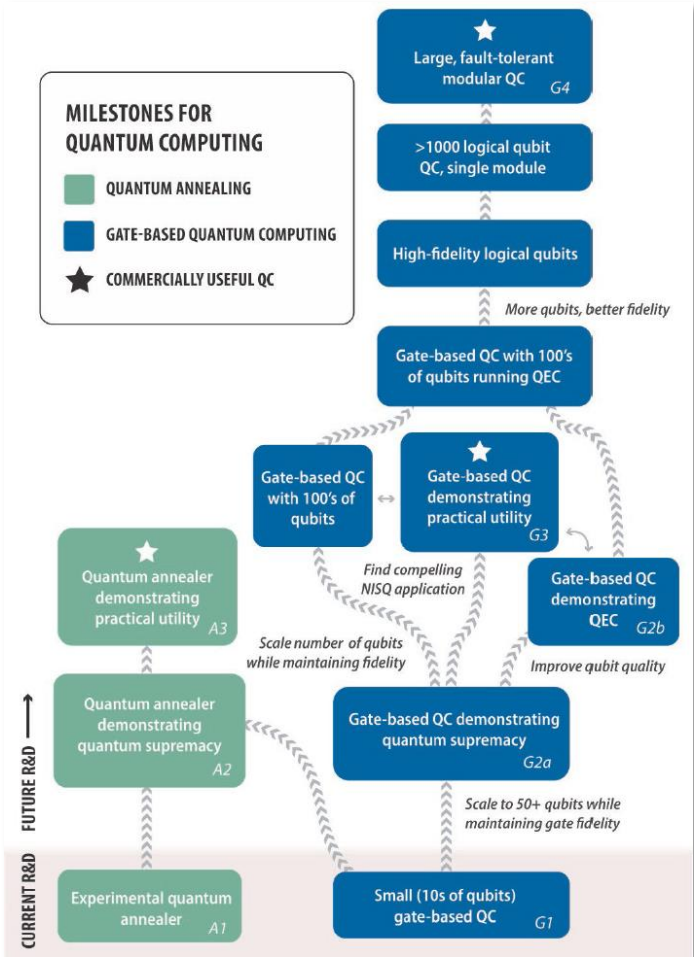
$$21 = 3 \times 7$$

量子计算应用和路线图

量子计算应用

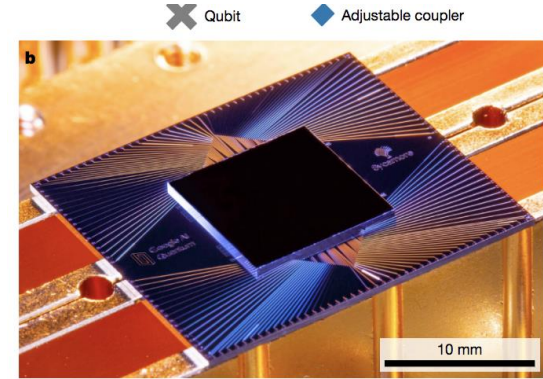


欧盟量子计算路线图



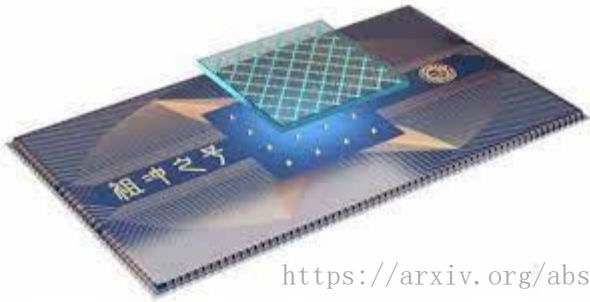
量子计算最新进展

2019 年谷歌宣布利用53超导比特芯片达成量子计算“霸权（优越性）”



<https://doi.org/10.1038/s41586-019-1666-5>

2021 年中科大利用62超导比特芯片达成量子计算优越性

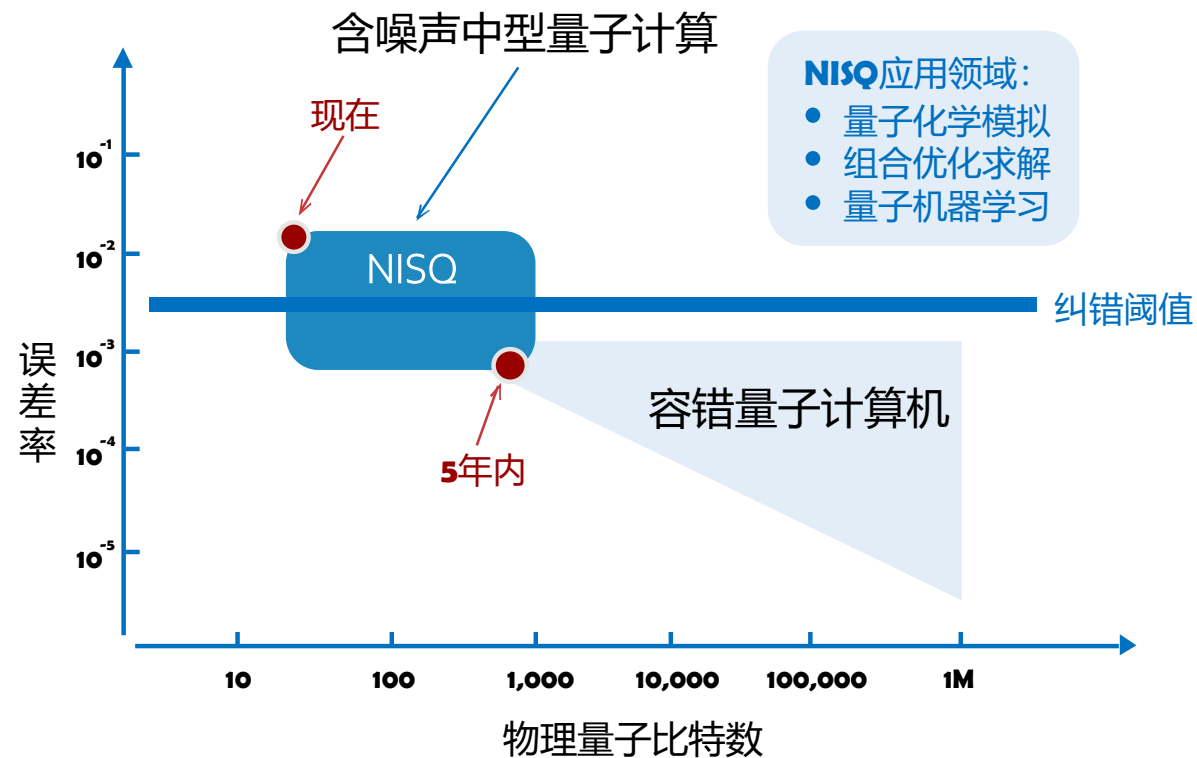
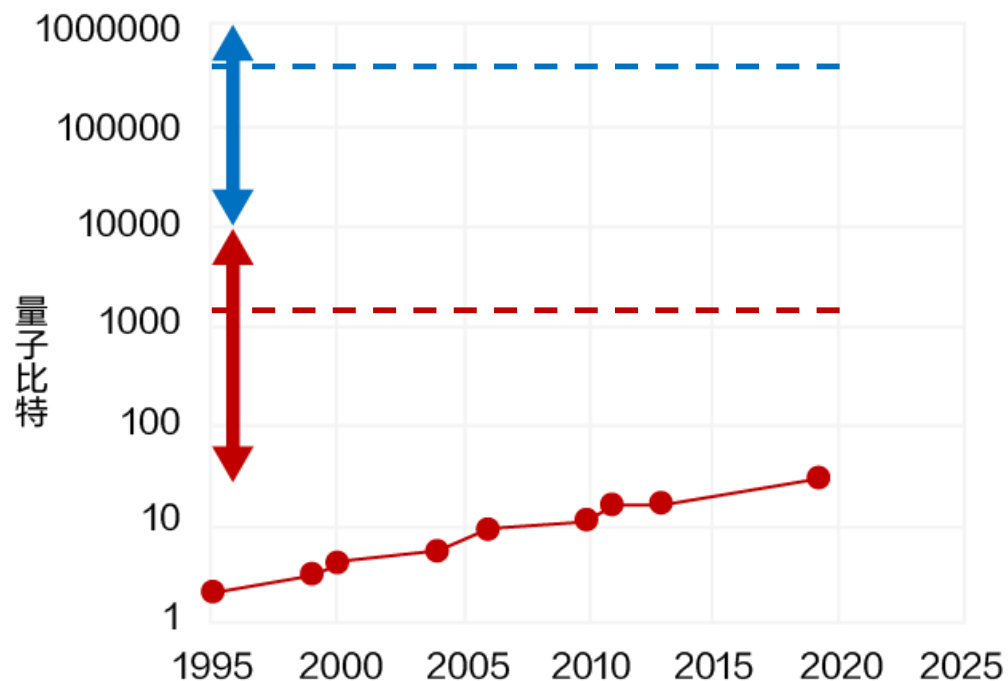


<https://arxiv.org/abs/2106.14734>

NISQ时代

NISQ = Noisy Intermediate-Scale Quantum

通用量子计算




量子算法的简史

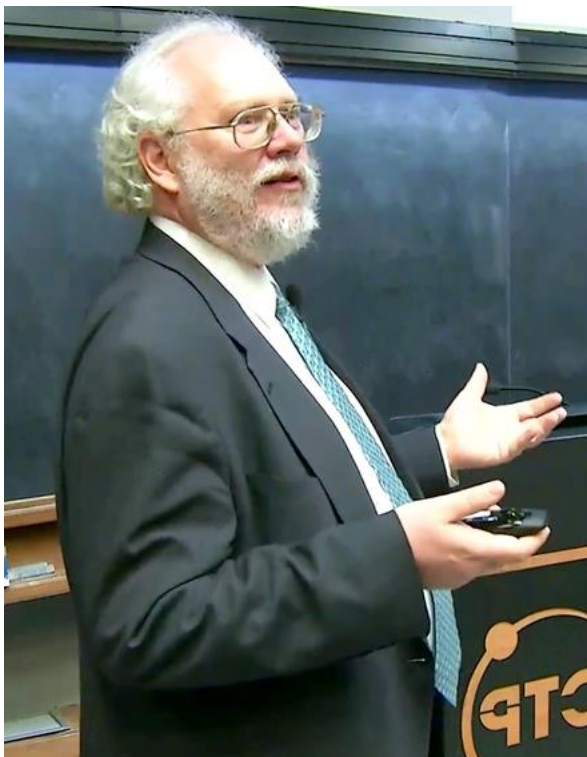
ARTICLE

Why haven't more quantum algorithms been found?



Author:  Peter W. Shor [Authors Info & Affiliations](#)

Publication: Journal of the ACM • January 2003 • <https://doi.org/10.1145/602382.602408>



picture from Wikipedia

13 years

Quantum Algorithms (partial list)

1985
Deutsch

1st quantum algorithm

1992
Deutsch-Jozsa

1st quantum algorithm
with exponential speedup

1994
Shor

exponential speedup
on the factoring problem
Also invented quantum
fourier transform QFT

1996
Hamiltonian Simulation

Suzuki-Trotter-Lloyd
on local Hamiltonians
Zalka on applying
QFT for momentum operator

1996
Grover

quadratic speedup
for database search

1995
Phase estimation

main inventor: Kitaev
Key ingredient for many
quantum algorithms

2009
Harrow-Hassidim-Lloyd
HHL

apply PEA for "solving"
linear systems of equations
many applications in quantum
machine learning

2011
Quantum Neural Networks
QNN

associated with quantum
circuit by Panella and Martinelli
Inspired by earlier works
many different variants

2013
Variational Quantum Eigensolver
VQE

by the Harvard Quantum Chemistry Team
initially applied to molecular structure
Designed for NISQ era

2014
Quantum Approximate Optimization
QAOA

by Farhi, Goldstone, and Gutmann
Variant of VQE for solving
combinatoric optimization problems

Textbook
(math model)

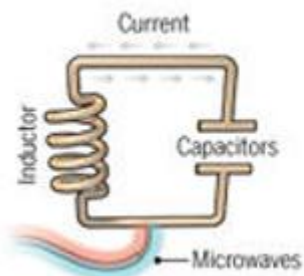
AI

NISQ

量子计算实现路径

超导

Superconducting loops



A resistance-free current oscillates back and forth around a circuit loop. An injected microwave signal excites the current into super-position states.

| | |
|---------------------|---------|
| Longevity (seconds) | 0.00005 |
| Logic success rate | 99.4% |
| Number entangled | 9 |

Company support

Google, IBM, Quantum Circuits

- Pros**
Fast working. Build on existing semiconductor industry.
- Cons**
Collapse easily and must be kept cold.

硅量子点

Silicon quantum dots



These "artificial atoms" are made by adding an electron to a small piece of pure silicon. Microwaves control the electron's quantum state.

| | |
|---------------------|------|
| Longevity (seconds) | 0.03 |
| Logic success rate | ~99% |
| Number entangled | 2 |

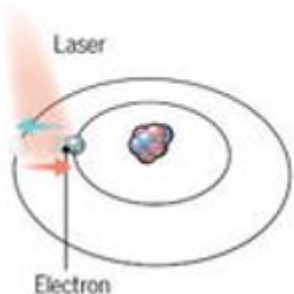
Company support

Intel

- Pros**
Stable. Build on existing semiconductor industry.
- Cons**
Only a few entangled. Must be kept cold.

离子阱

Trapped ions



Electrically charged atoms, or ions, have quantum energies that depend on the location of electrons. Tuned lasers cool and trap the ions, and put them in super-position states.

| | |
|---------------------|-------|
| Longevity (seconds) | >1000 |
| Logic success rate | 99.9% |
| Number entangled | 14 |

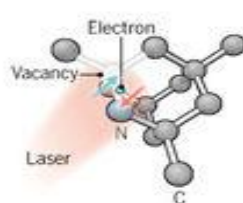
Company support

IonQ

- Pros**
Very stable. Highest achieved gate fidelities.
- Cons**
Slow operation. Many lasers are needed.

金刚石色心

Diamond vacancies



A nitrogen atom and a vacancy add an electron to a diamond lattice. Its quantum spin state, along with those of nearby carbon nuclei, can be controlled with light.

| | |
|---------------------|-------|
| Longevity (seconds) | 10 |
| Logic success rate | 99.2% |
| Number entangled | 6 |

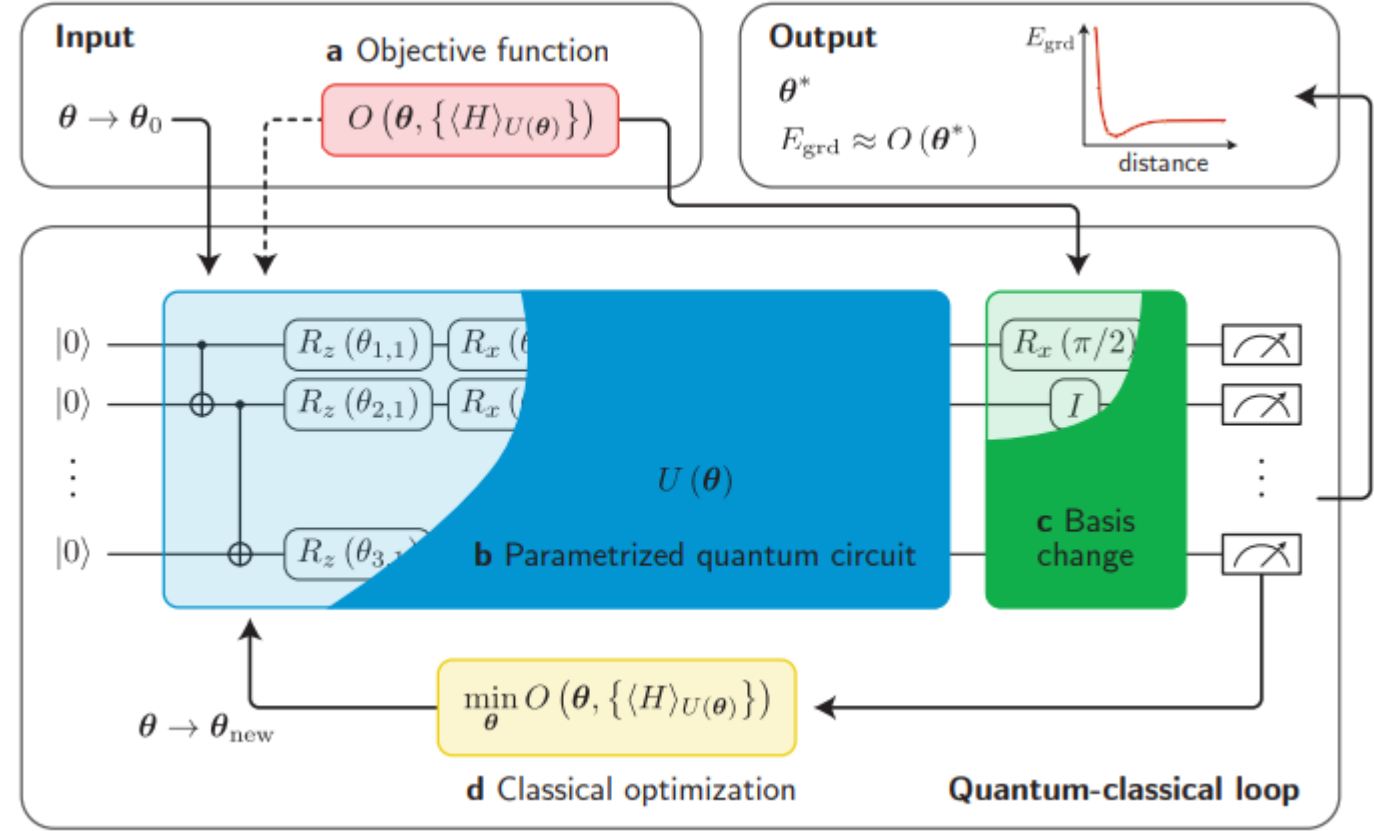
Company support

Quantum Diamond Technologies

- Pros**
Can operate at room temperature.
- Cons**
Difficult to entangle.

Note: Longevity is the record coherence time for a single qubit superposition state, logic success rate is the highest reported gate fidelity for logic operations on two qubits, and number entangled is the maximum number of qubits entangled and capable of performing two-qubit operations.

量子变分算法框架



量子变分算法示意图

a. 目标函数:

$$\langle H \rangle_{U(\theta)} \equiv \langle 0 | U^\dagger(\theta) H U(\theta) | 0 \rangle,$$

b. 参数化量子线路

$$|\Psi(\theta)\rangle = U(\theta) |\Psi_0\rangle,$$

c. 基矢变换

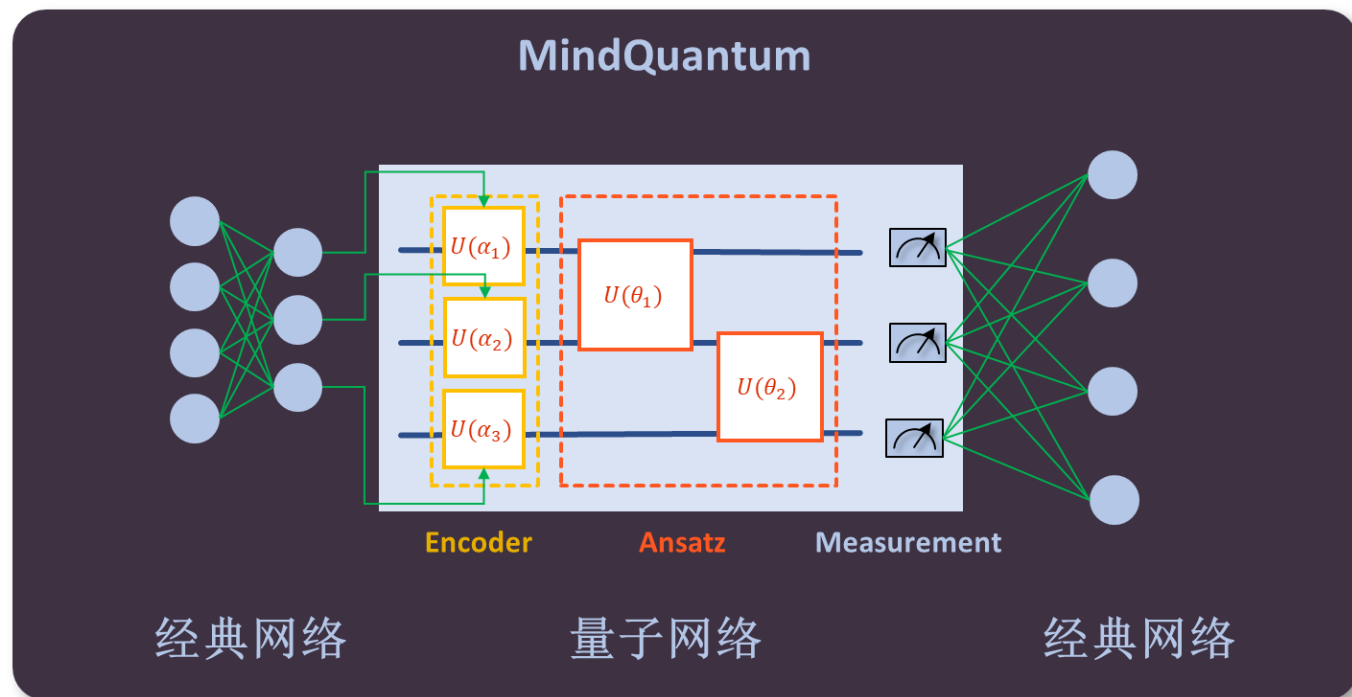
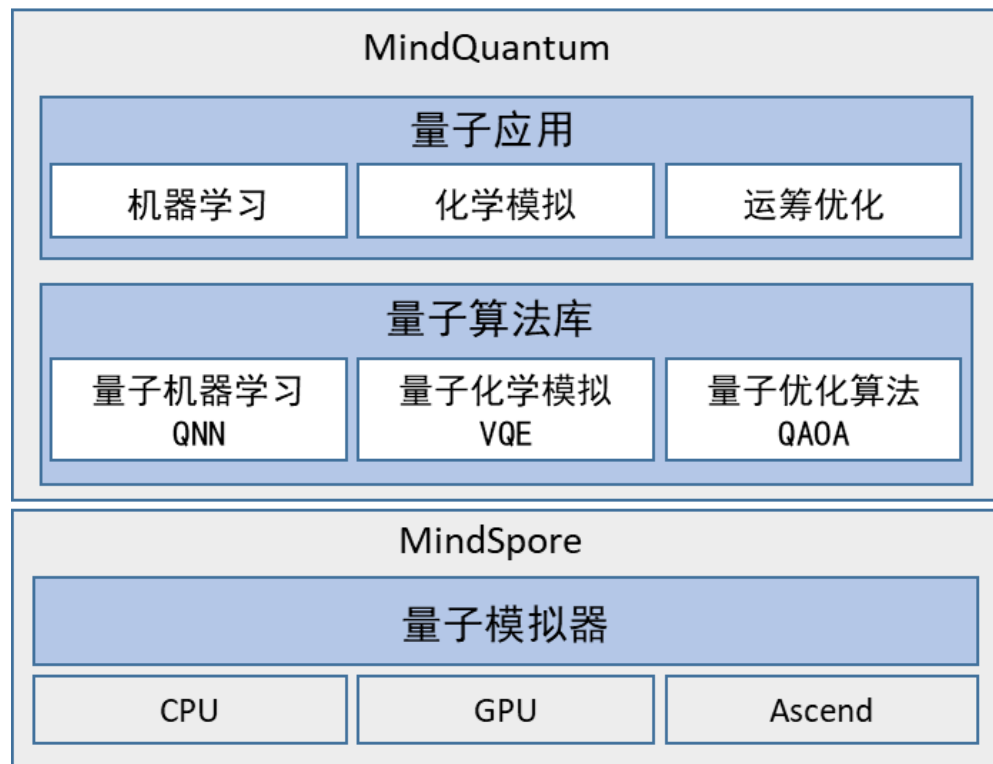
d. 经典优化器

$$\min_{\theta} O(\theta, \{\langle H \rangle_{U(\theta)}\}).$$

用MindQuantum搭建和训练量子神经网络

MindQuantum架构

MindQuantum是结合**MindSpore**和**HiQ**开发的量子机器学习框架，支持多种量子神经网络的训练和推理。得益于华为**HiQ**团队的量子计算模拟器和**MindSpore高性能自动微分能力**，**MindQuantum**能够高效处理量子机器学习、量子化学模拟和量子优化等问题，为广大的科研人员、老师和学生提供了快速设计和验证量子机器学习算法的高效平台。



课上主讲材料：

1.量子逻辑门和量子线路搭建

[https://gitee.com/mindspore/mindquantum/blob/master/tutorials/1.parameterized quantum circuit.ipynb](https://gitee.com/mindspore/mindquantum/blob/master/tutorials/1.parameterized%20quantum%20circuit.ipynb)

2.量子神经网络搭建和训练

[https://gitee.com/mindspore/mindquantum/blob/master/tutorials/2.initial experience of quantum neural network.ipynb](https://gitee.com/mindspore/mindquantum/blob/master/tutorials/2.initial%20experience%20of%20quantum%20neural%20network.ipynb)

3.化学模拟算法原理和实操

[https://gitee.com/mindspore/mindquantum/blob/master/tutorials/7.vqe for quantum chemistry.ipynb](https://gitee.com/mindspore/mindquantum/blob/master/tutorials/7.vqe%20for%20quantum%20chemistry.ipynb)

4.量子近似算法原理和实操

https://gitee.com/mindspore/mindquantum/blob/master/tutorials/5.quantum_approximate_optimization_algorithm.ipynb

5.鸢尾花分类

https://gitee.com/mindspore/mindquantum/blob/master/tutorials/3.classification_of_iris_by_qnn.ipynb

题目：

Bloch球中的点，在**XY**平面上和下分别标记为**0**和**1**， 自己生成数据集利用量子神经网络来进行分类。

提交PR：

<https://gitee.com/mindspore/mindquantum/tree/research/meeting/ustc/1126>