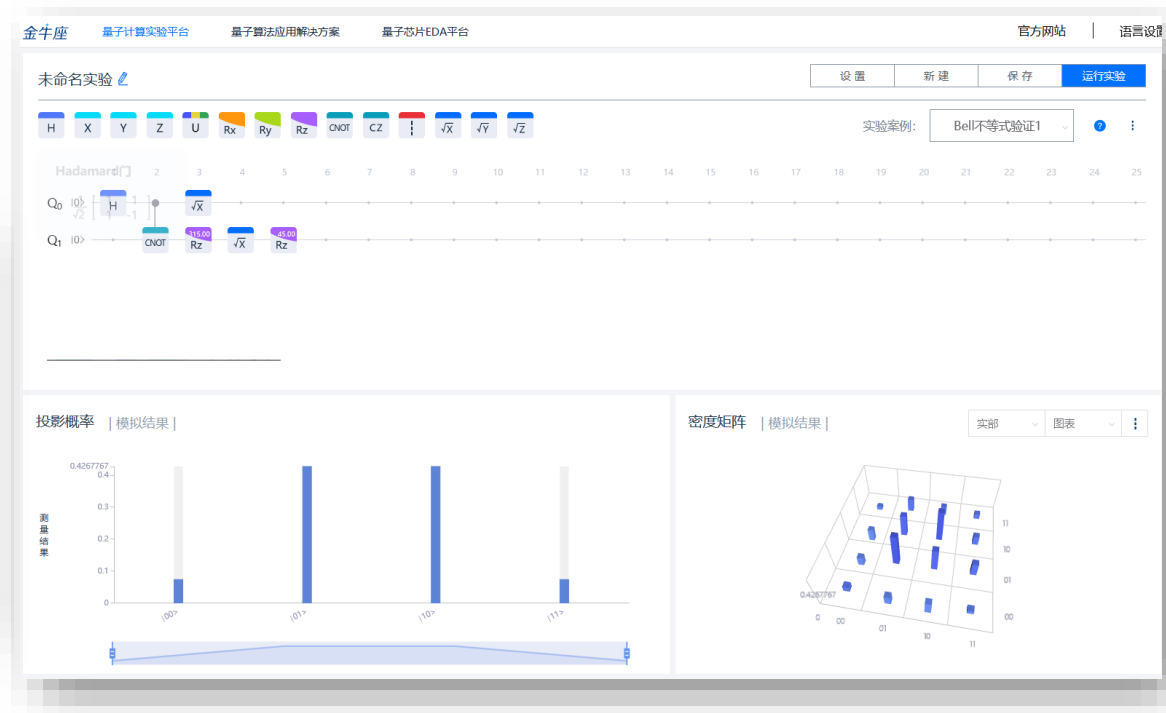# Quantum Basics
for
Game Design

VHAKTYR

2023/9/10

Content

- Quantum Computing Overview
  - state, gate and circuit
  - bloch sphere
  - theoretical: symbolic & matrix form
  - pragmatical: computer device
- Quantum Game Survey
  - gaming category exhibition
  - gameplay design

Toy to play: online quantum circuit simulator

- OriginQ: https://qcloud.originqc.com.cn/zh/computerServies/servies

- SpinQ: https://cloud.spinq.cn/circuitDesign/gemini

- HiQ: https://hiq.huaweicloud.com/portal/programming/hiq-composer?id=UntitledCircuit

- Q-Leaf: https://quantum-hub.baidu.com/services

- wybiral' simulator: https://wybiral.github.io/quantum/

- quirk: https://algassert.com/quirk

未命名实验 ✎

设 置　　新 建　　保 存　　运行实验

H　X　Y　Z　U　Rx　Ry　Rz　CNOT　CZ　⋮　√X　√Y　√Z

实验案例:　Bell不等式验证1

circuit

Hadamard门

| | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |

Q_0 $\frac{|0\rangle}{\sqrt{2}}$ H √X

Q_1 $|0\rangle$ CNOT　315.00 Rz　√X　45.00 Rz

qubit: Q_0

gate: H, CNOT, Rz, ⋯
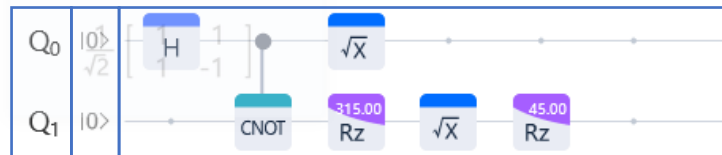
state: $|0\rangle$

unitary evolution

$$\Rightarrow |\psi\rangle = \big(I@\sqrt{X}\big)\big(I@Rz(5.49)\big)\big(\sqrt{X}@Rz(0.78)\big)\,CNOT(H@I)|00\rangle$$
$$= a|00\rangle + b|01\rangle + c|10\rangle + d|11\rangle$$

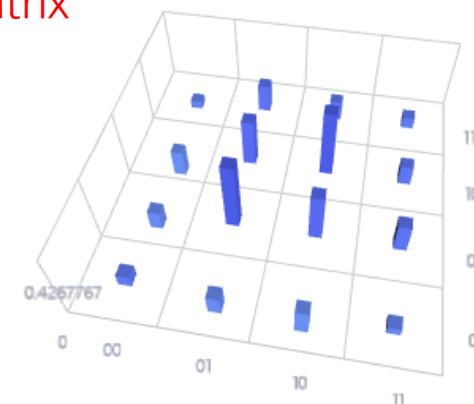When at least two terms are non-zero
It is a superposition state!!

probability distribution
(under projection measure)

measure! $\Rightarrow |01\rangle$

投影概率　｜模拟结果｜
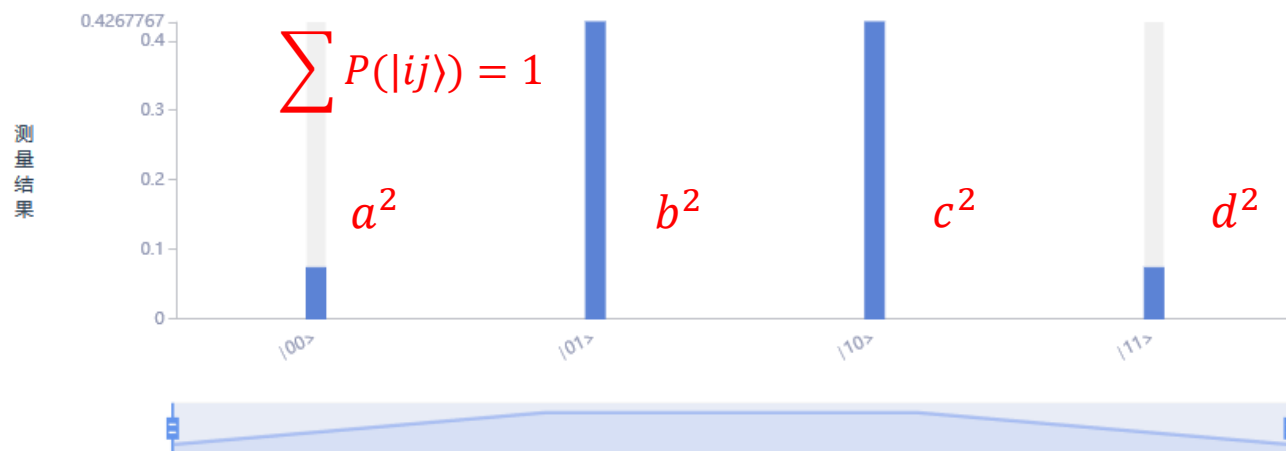
密度矩阵　｜模拟结果｜

实部　图表　⋮

density matrix
$= |\psi\rangle\langle\psi|$

$$\sum P(|ij\rangle) = 1$$

a^2 　 b^2 　 c^2 　 d^2

0.4267767
0.4
0.3
0.2
0.1
0

测量结果

|00⟩　　|01⟩　　|10⟩　　|11⟩

0.4267767

0　00　01　10　11

11
10
01
00

State: the operand

- Classical state: $|\uparrow\rangle$, $|\downarrow\rangle$; $|0\rangle$, $|1\rangle$; $|dead\rangle$, $|alive\rangle$
  - physical phenomenon what we can fully distinguish, diagonal to each other
- Superposition state
  - a single qubit: $|x\rangle$ no certainty
  - state expr can be decomposed into linear sum of classical states
    - $|x\rangle = -\sqrt{0.75}|0\rangle + \sqrt{0.25}i|1\rangle$
- Entangle state
  - two or more qubits: $|xy\rangle$ not independent
  - state expr cannot be decomposed to Cartesian product
    - $|xy\rangle = |00\rangle + |10\rangle = (|0\rangle + |1\rangle)|0\rangle$ ✖
    - $|xy\rangle = |00\rangle + |01\rangle + |11\rangle$ ☑ partial entgl.
   - $|xy\rangle = |00\rangle + |11\rangle$ ☑ max entgl.

Gate: the operator

- Algebraic structure
  - arith: {N; +, −, ∗}, {C; +, −, ∗, /, |·|, phase}, {matrix; +, −, ∗, @, inv, eig/svd}
  - bool: {true, false; &, |, ^, ~, →}
  - com: {0, 1; send, receive, wait, sync}
  - quantum: {$|0\rangle$, $|1\rangle$; I, X, Y, Z, H, RX, RY, RZ, T, S, CNOT, SWAP}
- State + Gate = Circuit / Evolution
  - Algebra
    - expression: $\mathrm{val} = (-1 + 5/2) * 6$
    - function: $f(x, y) = 2 * x - y$
  - Quantum
    - circuit: $|phi\rangle = \mathrm{CNOT}(\mathrm{H@RX}(-0.8))|00\rangle$
    - variational circuit: $\mathrm{U}(\theta)|00\rangle = \mathrm{CRY}(\mathrm{H@RX}(\theta_0), \theta_1)|00\rangle$

init state $|00\rangle$ is not input, it is const

Bloch sphere: visualize a single qubit

- qubit is 4-dim
  - amp: $|0\rangle$ / $|1\rangle$; z-axis
  - sign: $+$ / $-$; x-axis
  - phase: 1 / i; longitude
  - unit mod (constr.)
- state: a unit vector
  - global phase
- gate: rotate the vector
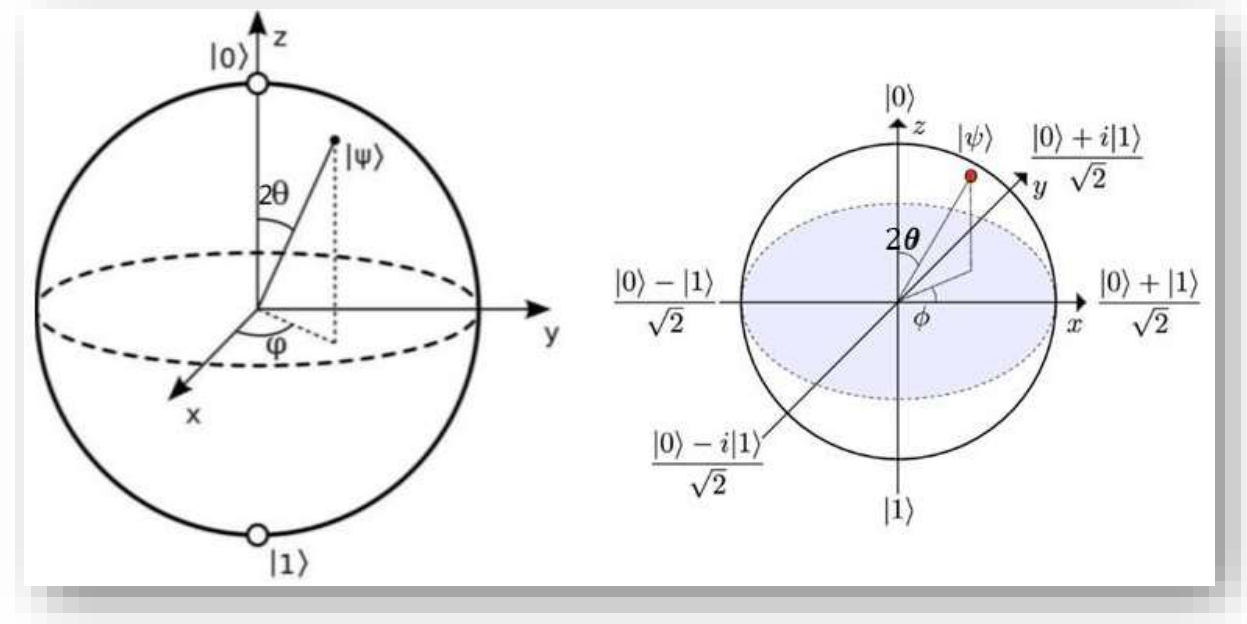 - I, X, Y, Z
  - RX, RY, RZ
  - CNOT, SWAP
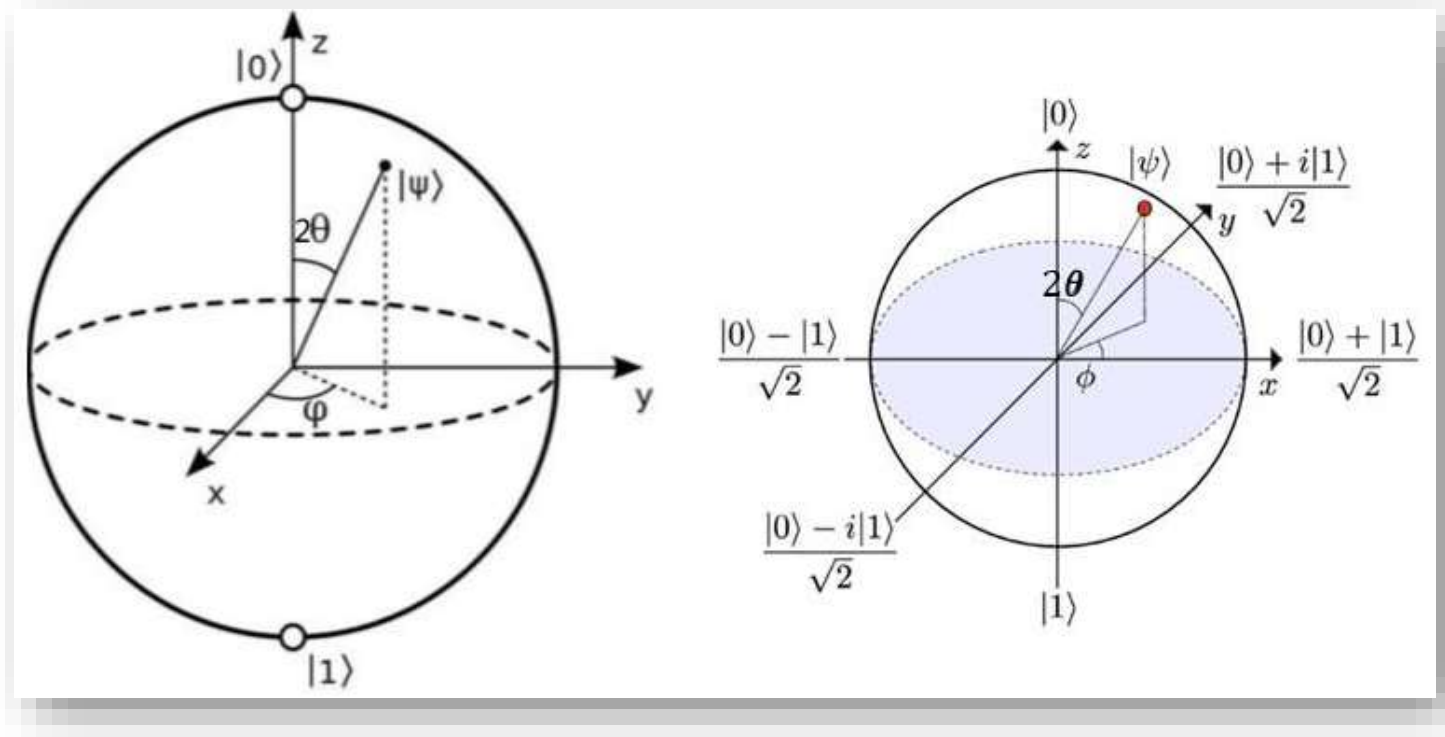
$$|\psi\rangle = (a + bi)|0\rangle + (c + di)|1\rangle$$
$$= \cos(\theta)\,|0\rangle + sin(\theta)e^{i\varphi}|1\rangle$$
(保证在北半球 $|0\rangle$ 前系数为正)
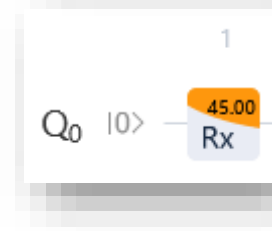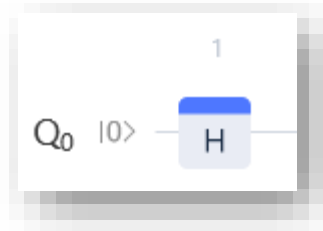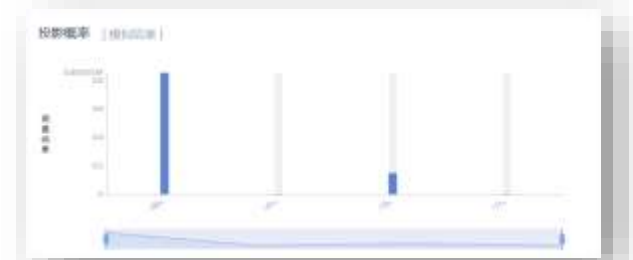
Bloch sphere: what a gate does

- Pauli gates: I, X, Y, Z
  - $X|x\rangle = |\sim x\rangle$
- Hadamard gate: H
  - $X|0\rangle = (|0\rangle + |1\rangle)/\sqrt{2}$
- Phase gate: P, S, T
- Rotation gates: RX, RY, RZ
  - $RX(\theta)|0\rangle = cos(\theta)|0\rangle - isin(\theta)|1\rangle$
- Swap gates: SWAP, iSWAP
  - $SWAP|xy\rangle = |yx\rangle$
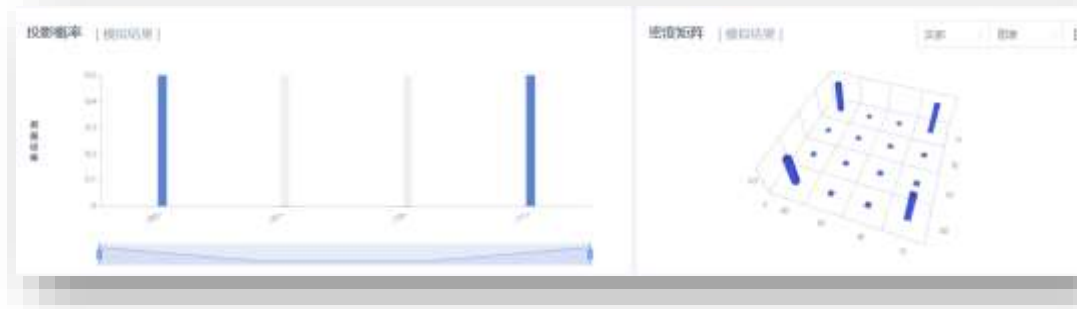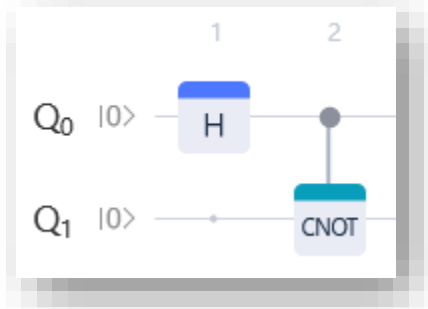- Controlled gates: CNOT/CX, CZ, CRx, CU
  - $CNOT|xy\rangle = |x, x\hat{\ }y\rangle$

Note: rot θ in formula → rot 2*θ on sphere

Write your first Q program 😊 🎉

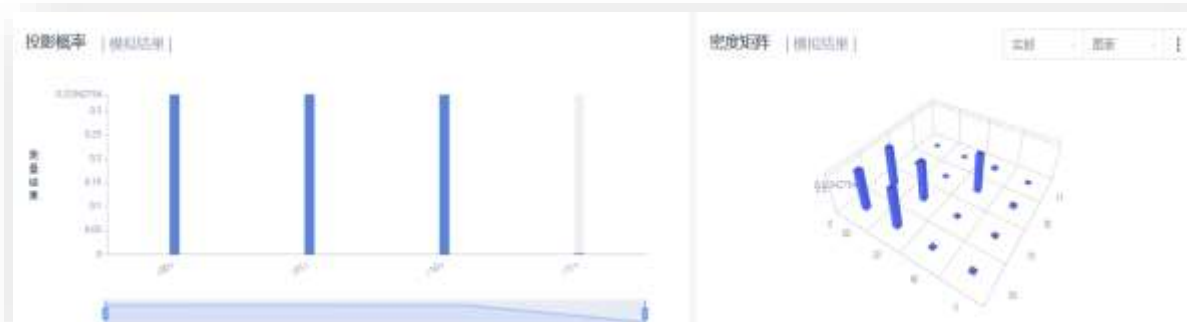- A fair/unfair coin: superposition
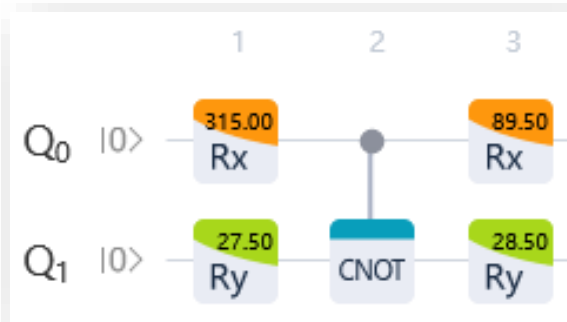- Bell/GHZ state: entanglement


```
1 OPENQASM 2.0;
2 include "qelib1.inc";
3 qreg q[2];
4 rx(pi/4) q[0];
```
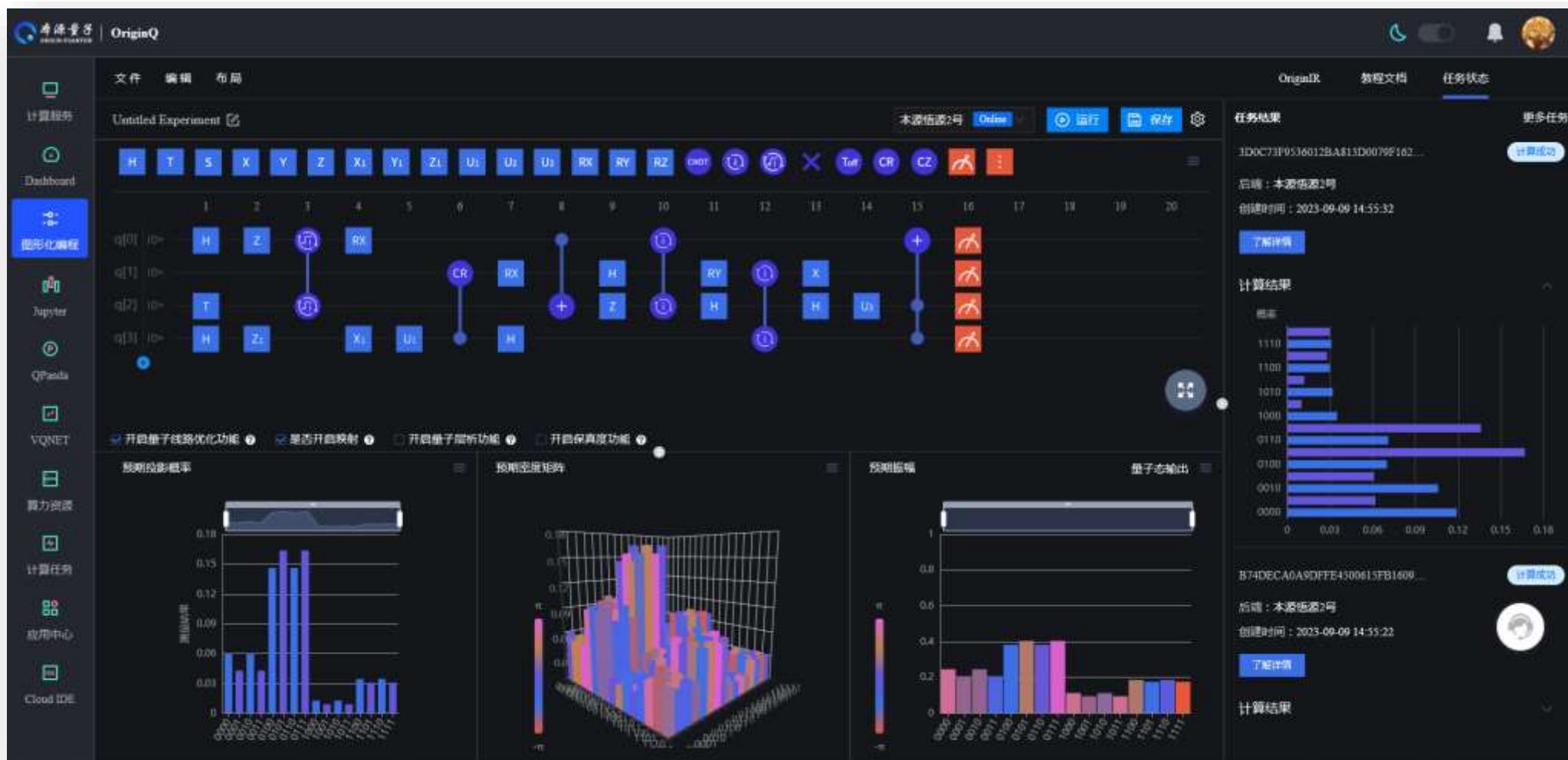
```
1 OPENQASM 2.0;
2 include "qelib1.inc";
3 qreg q[2];
4 h q[0];
5 cx q[0],q[1];
6
```

- A triple-face dice (via vqc)

```
1 OPENQASM 2.0;
2 include "qelib1.inc";
3 qreg q[2];
4 rx(7*pi/4) q[0];
5 ry(0.15278*pi) q[1];
6 cx q[0],q[1];
7 rx(0.49722*pi) q[0];
8 ry(0.15833*pi) q[1];
9
```

Run on a real quantum computer!!

本源量子云平台，注册即可用真机！！

Quantum Computer

- 系统架构
  - 光量子: 光的偏振 ↻ / ↺ 或 + / x
  - 低温超导: 粒子的自旋 ↑ / ↓
- 问题：噪声
  - 门的保真度 fidelity

量旋科技 核磁量子计算机
（教学用）

谷歌 超导量子计算机

	超导	离子阱	光量子	中性原子	硅基半导体
量子比特T2 相干时长	15-120μs	0.2-50s	150μs	0.2-50s	1μs-0.5μs
双量子门 保真度	99%-99.85%	99%-99.9%	98%	99%	98%
门速度 (作用时长)	12-200ns	1μs-3ms	1ns	1μs	0.8--80ns
相干时长/ 门速度	1250-100	1000000-500	150000	1000000-100000	10-50
运行环境	20mK	超高真空	1K-10K（探测器）	超高真空	20mK-1K
已达成 量子比特数	65Q	32Q	12Q	100Q	2Q
2021年预计达成	127Q	50Q	24Q	200Q	6Q
优点	·门速度快 ·可采用现有半导体工业技术	·量子比特相干时间长 ·门保真度高 ·量子比特完全相同，全连接	·光与周围环境相互作用较弱 ·可采用现有半导体工业技术	·量子比特相干时间长 ·天然量子比特，完全相同	·门速度快 ·可采用现有半导体工业技术
缺点	·量子比特相干时间较短 ·必须在极度低温下工作	·门速度慢 ·需要超高真空	·技术不成熟 ·需要在低温下测量	·技术不成熟 ·需要超高真空	·技术不成熟 ·相干时间太短，制作量子比特时，需对硅进行提纯
代表公司	IBM Google rigetti D:WAVE qci intel	IONQ AQT Honeywell	XANADU PsiQuantum	PASQAL ColdQuanta	Silicon Quantum Computing intel

量子计算硬件技术汇总
0K = −273.15℃

Tips: Quantum Computing Simulation
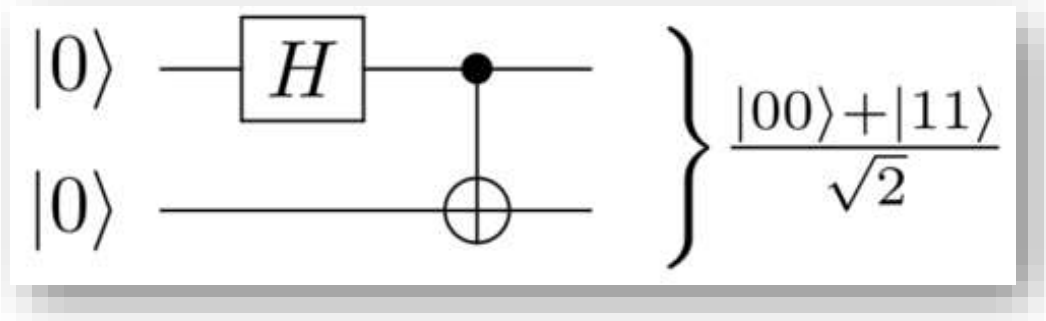
Compute on *matrix form* of the gates & states

$$\text{CNOT}(H \otimes I)|00\rangle = \left(\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \left(\frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \otimes \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \right) \right) \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 0 \\ 0 \\ 1 \end{bmatrix} = \frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

- https://en.wikipedia.org/wiki/Quantum_logic_gate

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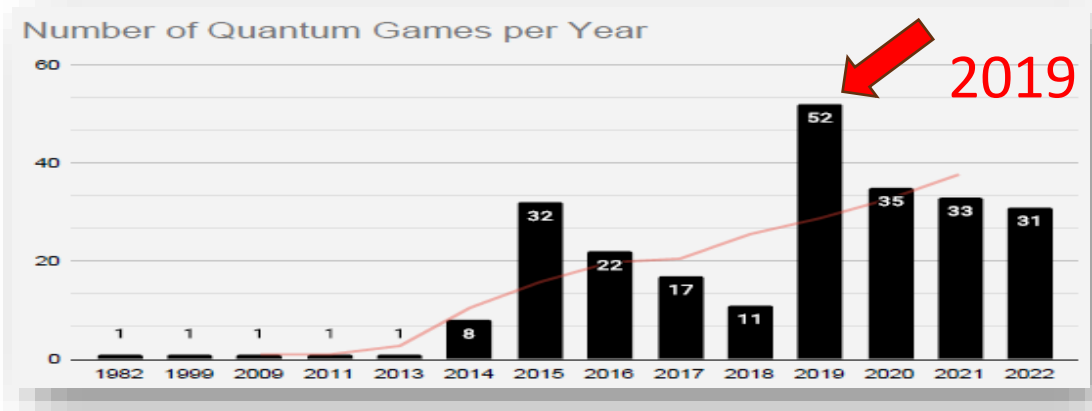 - gaming category exhibition
  - gameplay design

Game Category

- Single player
  - Action / Simulation
  - Adventure / Role-play
  - Tower defense / Rogue-like / Puzzle
- Two players
  - 棋：资源对等、公开，未知的只有对手策略
  - 牌：资源不一定对等、不完全公开， 对手策略和对手私有资源都未知

- Duel goal
  - time racing
  - highest score

Q Game

Number of Quantum Games per Year — 2019

Quantum Wheel game jam
Qiskit 2019 Camps
Qiskit 2019 Hackathons
IBM Q Award 2019
....

- Game list
    - https://github.com/HuangJunye/Awesome-Quantum-Games
    - https://kiedos.art/quantum-games-list

2019

Quantum Wheel game jam

Qubit the Barbarian - You are Qubit the Barbarian on a quest in the Quantum maze. On your quest you navigate through the mysterious changing labyrinth fighting enemies and looking for food to stay alive. (by Henri Sarasvirta, Petri Sarasvirta, Teemu Kivikangas, Henri Lyyra, Leevi Leppäjärvi, Elie Abraham)

Q|Cards⟩ - A quantum card game. (by Oskari Kerppo, Jorden Senior, Sabrina Maniscallo, Guillermo Garcia-Perez, Samuli Jääskeläinen, Sylvia Smatanova, Krista Erkkilä, Elie Abraham)

Quantum Socket - Quantum Socket is a game where you try to insert a USB cable the "right" way into a USB socket. (by Jere Sanisalo, Antti Svenn, Jaakko Iisalo)

h a m s t e r w a v e - Hamsterwave is a game where you use the quantum black box to move the hamster. (by Elie Abraham, Bjorn Lindholm, Sebastian Laitila, Thekids Laitila, Sun Park, Laura Piispanen, Julia Rassa, Igor Sokolov, Sabrina Maniscalco)

Schrödinger's Livingroom - All the stuff in Erwin Schrödinger's living room is |dead⟩+|alive⟩ simultaneously! (by Adelina Lintuluoto, Daria Anttila, Matt Bengston, Sabine Harrer, Simon Nielsen, Reetu Kontio, Vasili Sevriuk)

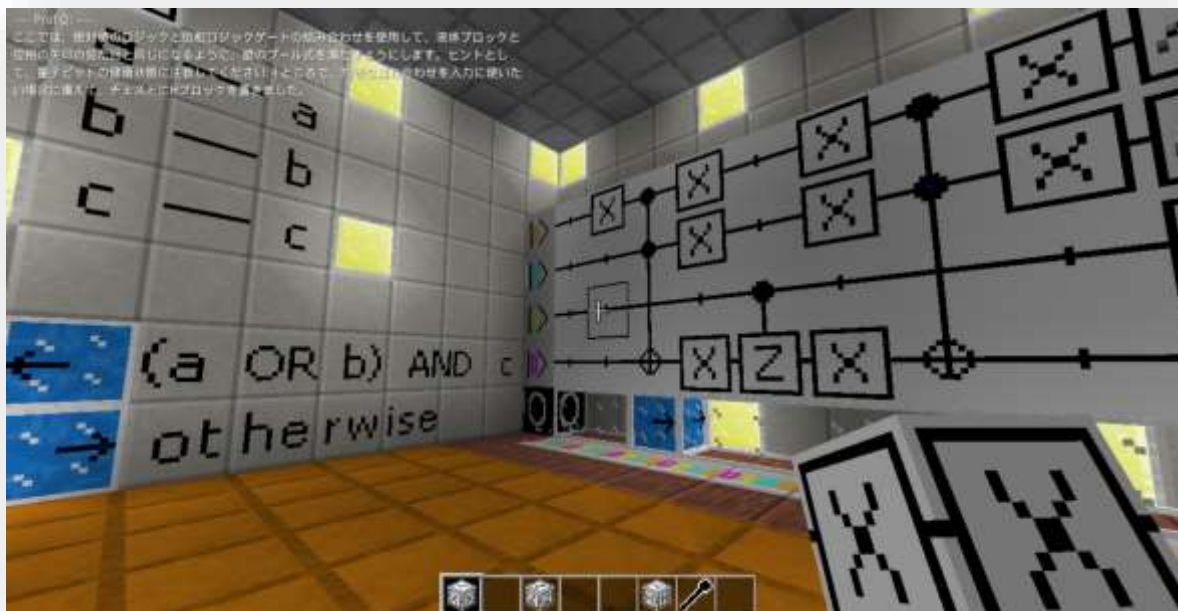Quantum Fruit - A game about quantum black box. (by Jaakko Sirén, Arvi Teikari, Rosanna Micieli, Nicola Lo Gullo)

SneaQysnake - A strange adventure of the snake in the "quantum world". (by Vasilii Sevriuk, Ivan Yamshchikov)

List of Quantum Games : QGames

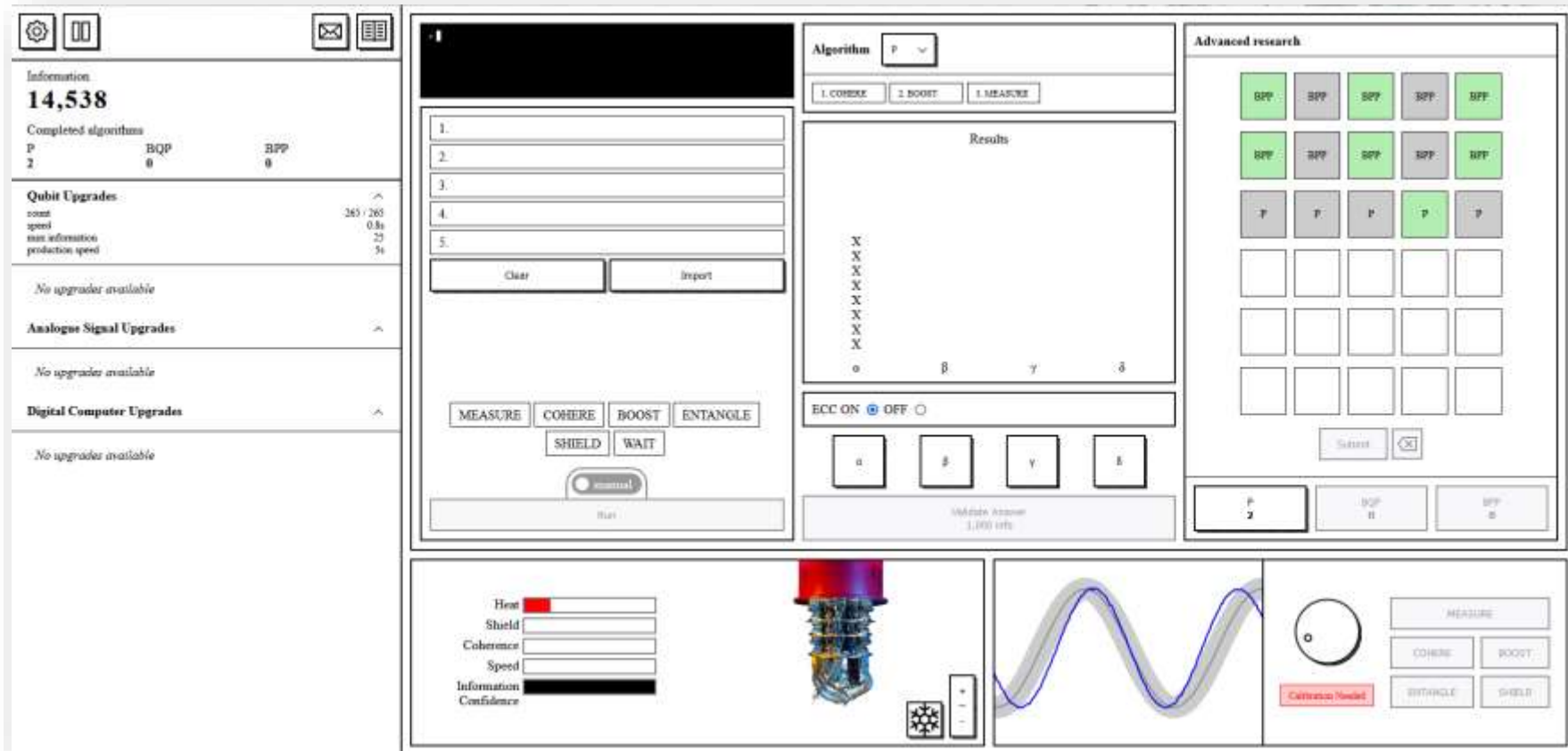|					
7	Battleships with complem	https://decodo	James Wootton	Windows, Mac, Linux-Jupyte	
8	Battleships with partial NC	https://medium	James Wootton	Windows, Mac	
9	BB84	https://github.c	Alberto Sebastian et al.		
10	Beach Buddy Diet	https://quantun	Teemu Kokkonen, Noora Heiskar	Windows, Mac	
11	Bean Jam	https://itch.io/ja	vvenomsnake		
12	Beat the Dome!	https://itch.io/ja	Julio Garcia, Carlos Vieira	Windows	
13	Benji the Blob	https://decodo	James Wootton	Browser	
14	Black Box Toys	https://exca.itcl	Henri Sarasvirta	Windows, Linu	Educational
15	Bloch duel	https://gitlab.cc			
16	Bloch duel v2	https://gitlab.cc			
17	Bloqit	https://github.c	Thomas Storwick, Kelly Zheng, J	Windows, Mac, Linux, Andro	
18	Body Scrubber	https://itch.io/ja	Mika Kar	Browser	
19	C.L.A.Y.	https://medium	MiTale Games		
20	CatBoxScissors	https://decodo	James Wootton	Windows, Mac	
21	Catris	https://www.fin	Victor Matsuguma, Vinícius Pimentel, Francelino Carvalho, J		
22	Cats	https://docs.mi			
23	chaos-of-the-b2	https://shelegic	Giorgi Shelegia, David Jimshelaq	Windows	
24	Circuits	https://chord.cs	Quantum Realm Games / Quantin	Browser	Educational
25	Cold to GO	https://itch.io/ja	Ida Aho, Miika Saunavaara, Ville Simontaival		Educational
26	Cool the Quantum	https://quantun	Sebastian C., Yasmine	VR	

QGames

Circuit Puzzle

- Qiskit Blocks
  - https://github.com/JavaFXpert/QiskitBlocks
- Quantum Flytrap
  - https://lab.quantumflytrap.com/game

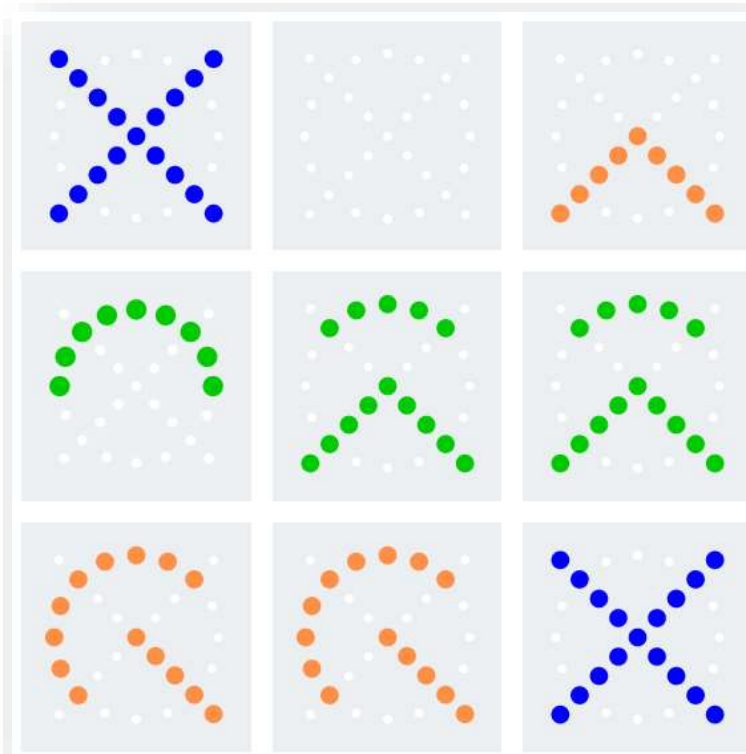# Q Computer Simulation

- The qubit game
  - https://quantumai.google/education/thequbitgame

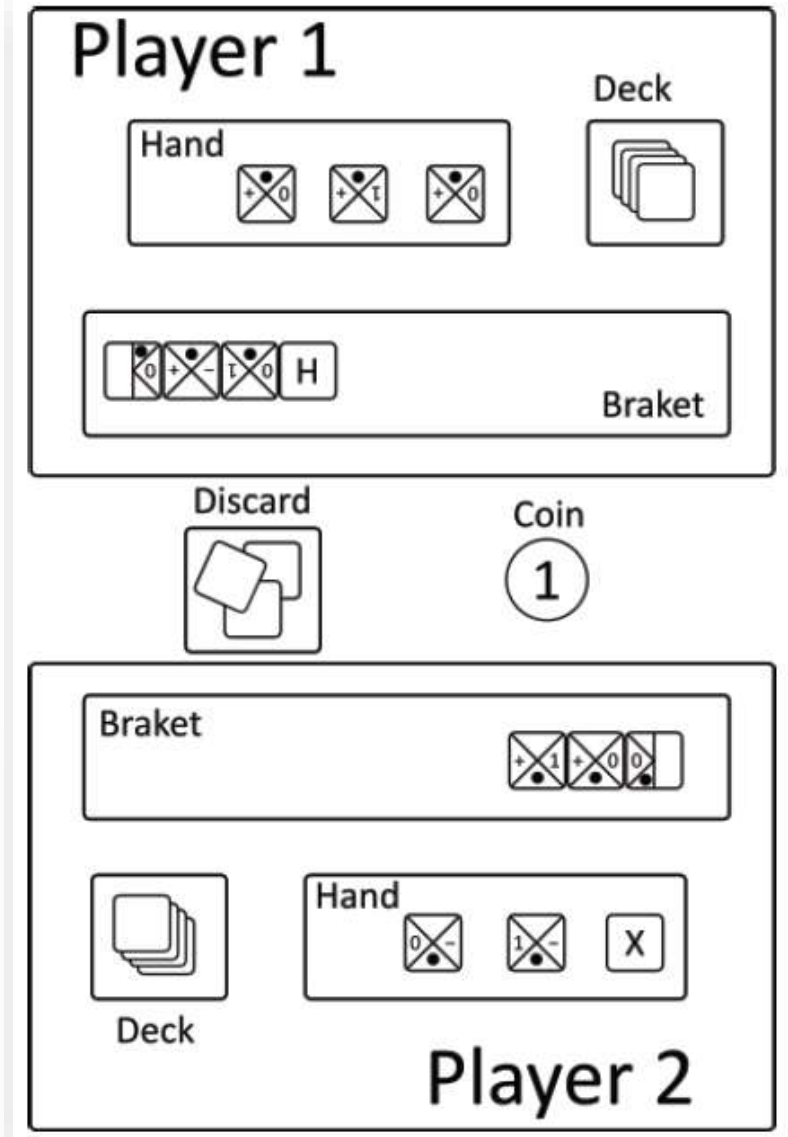# Chess

- Quantum Chess
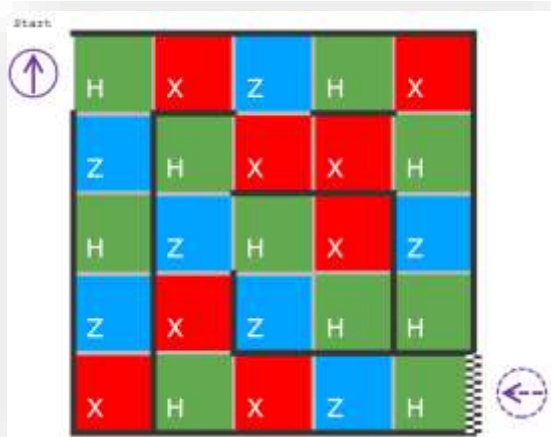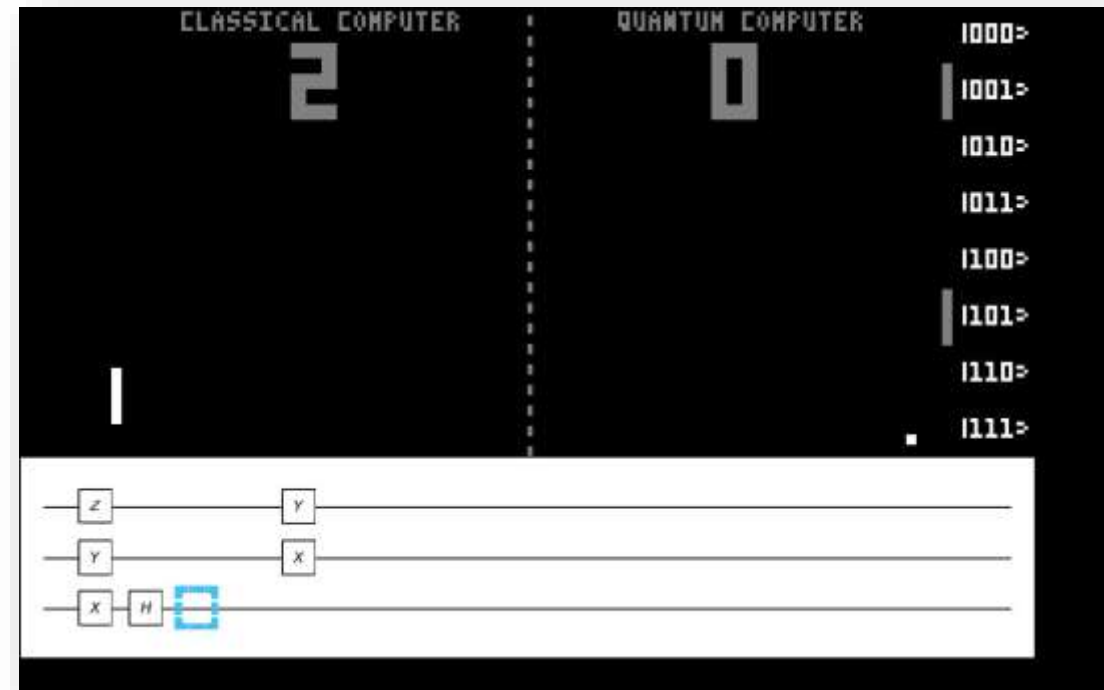 - https://store.steampowered.com/app/453870/Quantum_Chess/
- Quantum Tiq-Taq-Toe
  - https://tiqtaqtoe.com/start

Cards

- QuantumCards
  - https://github.com/SamuliJaaskelainen/QuantumCards
- Brackets
  - https://github.com/csferrie/Brakets

More Toys…

- https://enibolas.itch.io/schrdingers-livingroom
- https://qorsairs.github.io/Quaze/quaze.html
- https://quander.cs.uchicago.edu/
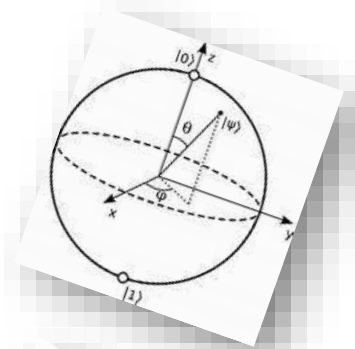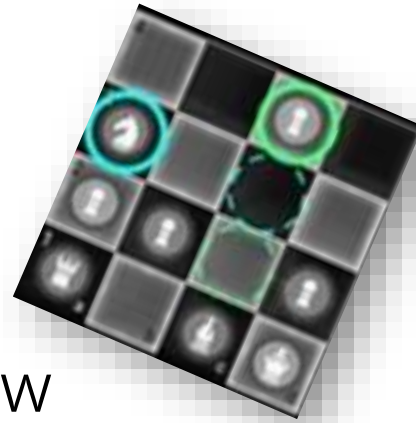- https://github.com/QPong/QPong-Unity

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$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$

$P(\varphi) = \begin{bmatrix} 1 & 0 \\ 0 & e^{i\varphi} \end{bmatrix}$