Quantum Computing and Blockchain

What is the connection and why is it interesting?

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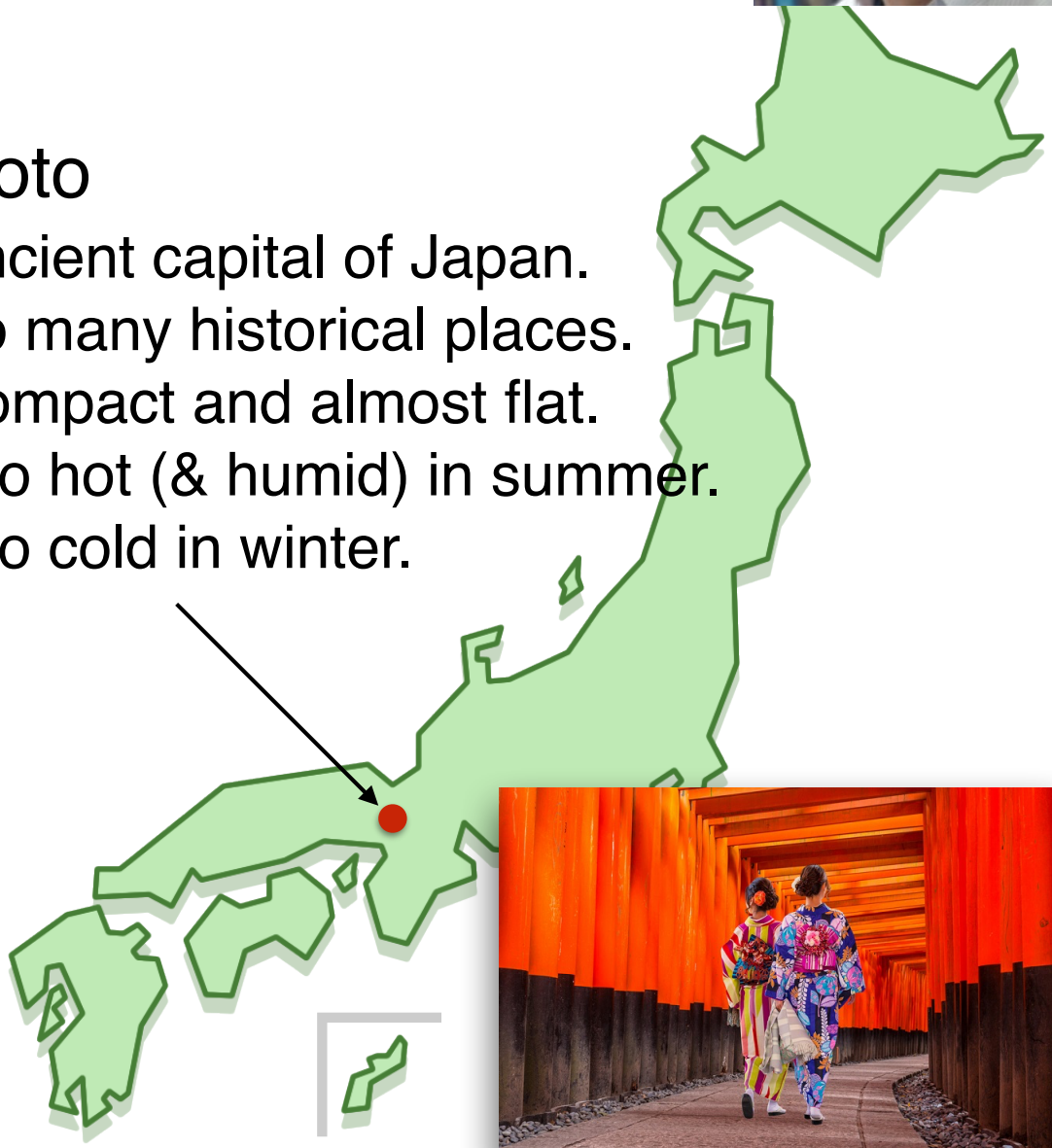
Kyoto

-Ancient capital of Japan.
-So many historical places.
-Compact and almost flat.
-Too hot (& humid) in summer.
-Too cold in winter.



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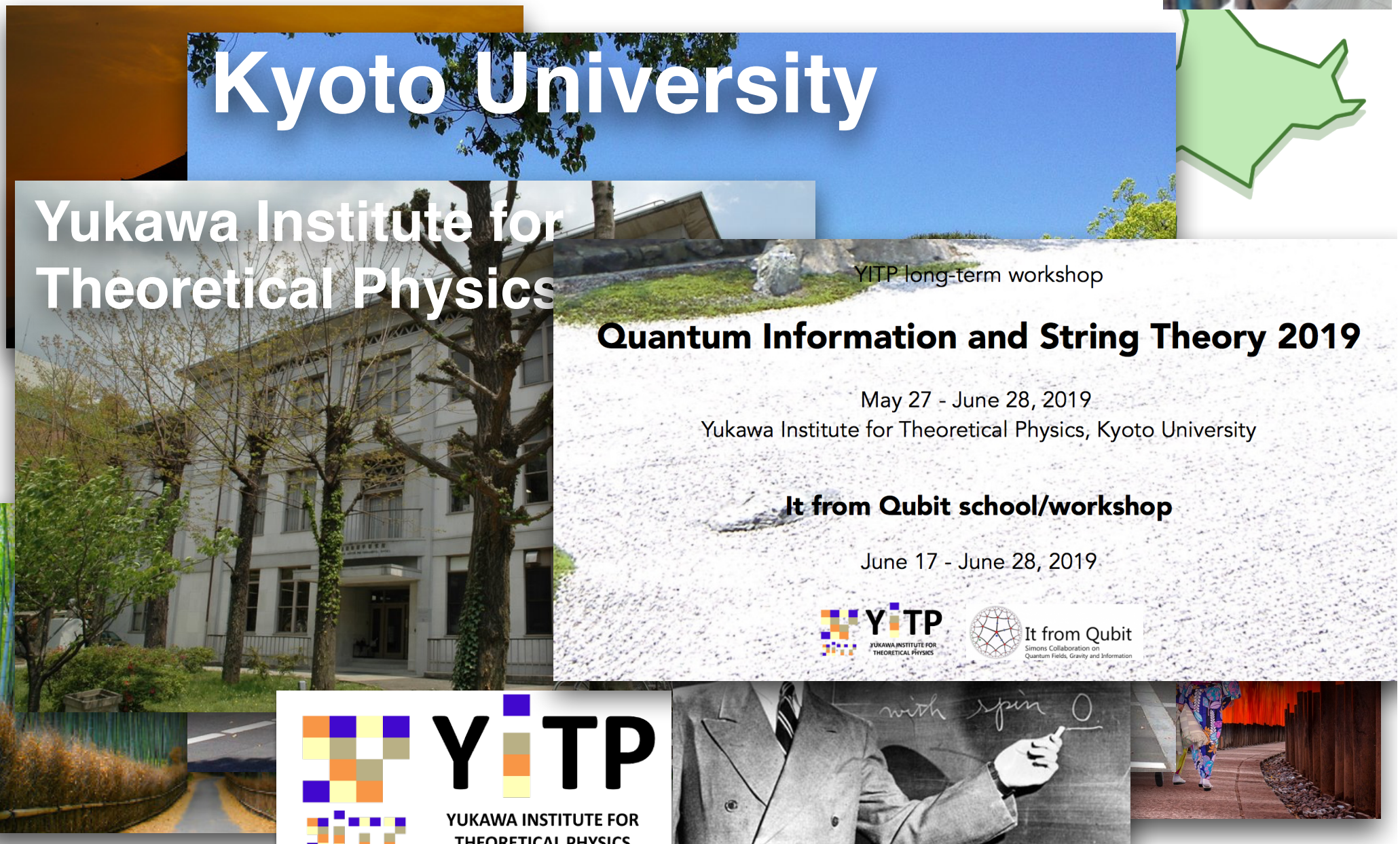
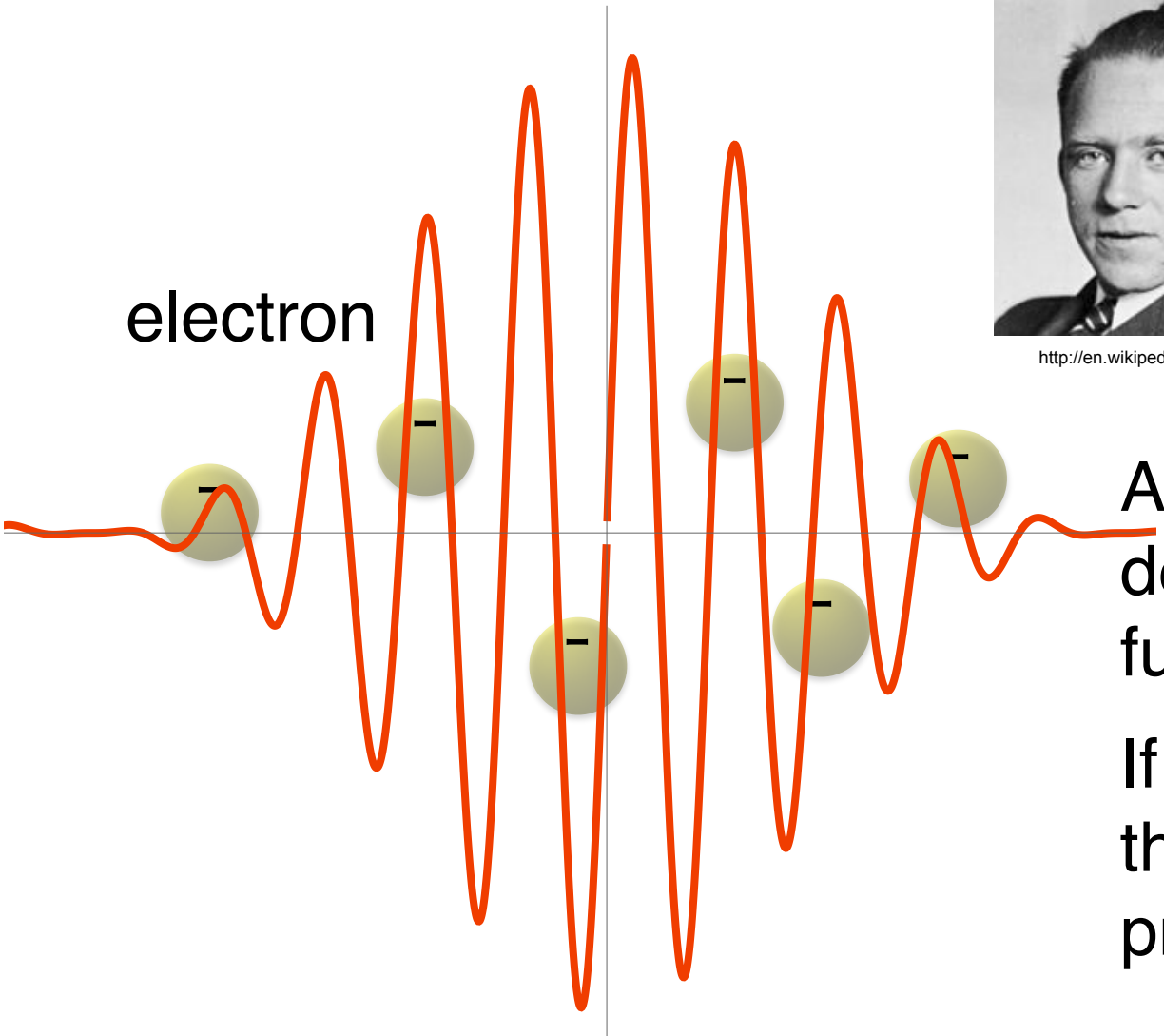


Outline

- Quantum physics and information
- How quantum computers work
- Industrial approaches to quantum computers
- Quantum computer and blockchain
- Summary

Quantum physics

Wave & particle duality



Werner K Heisenberg (1901-1976)

http://en.wikipedia.org/wiki/Werner_Heisenberg

Erwin Schrödinger (1887-1961)

http://www.owlnet.rice.edu/~mishat/1933-5.html

An electron is described by **wave**-function, and can interfere.

If we do a measurement, the **position** is determined probabilistically.

Quantum physics

Wave & particle duality

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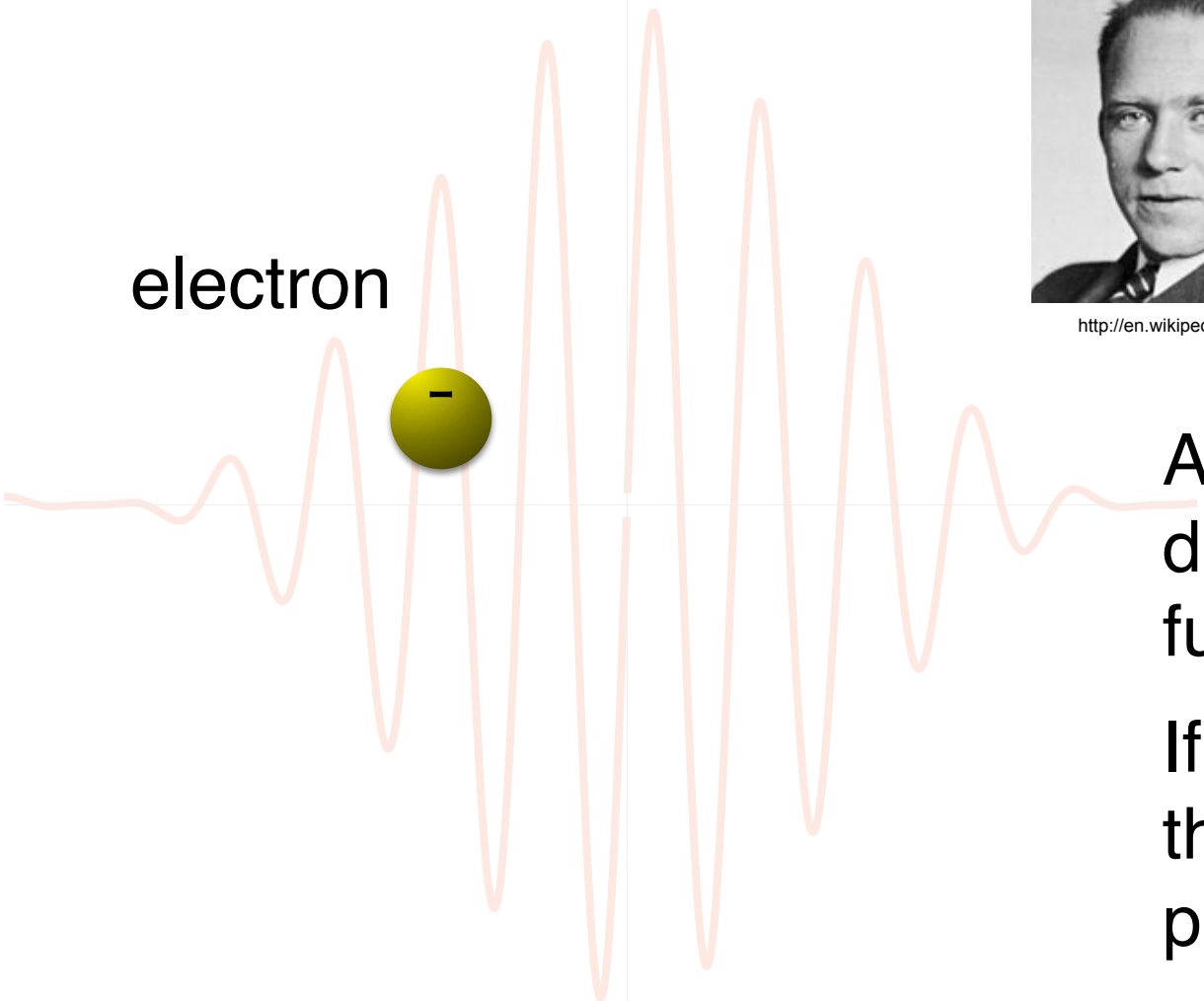
electron



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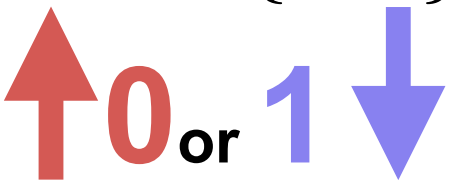
Quantum information

classical bit:

$$x \in \{0, 1\}$$



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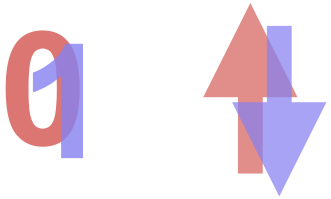
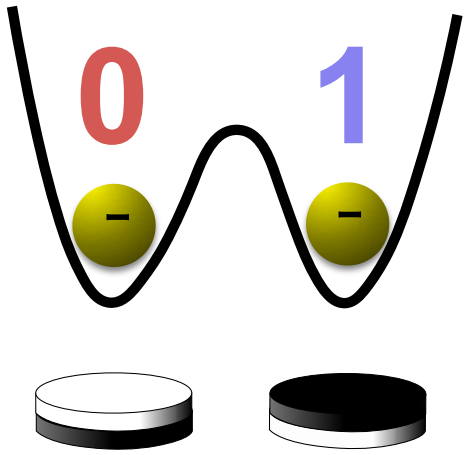
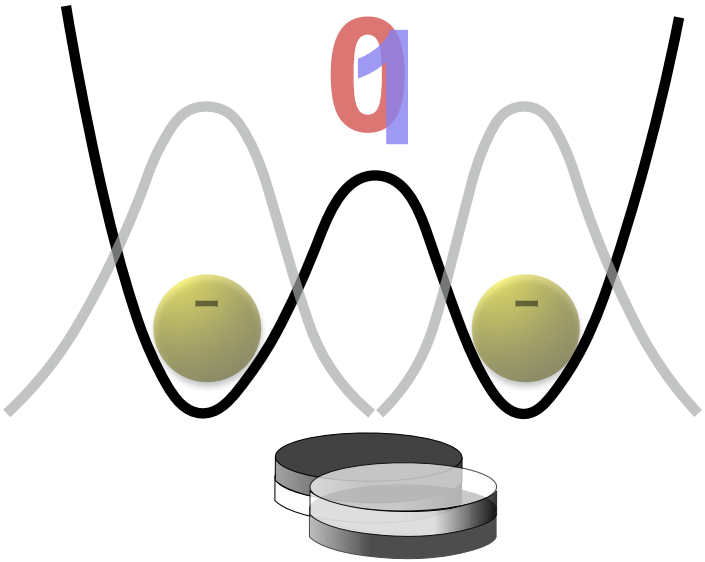




superposition of 0 and 1



complex
vector space

$$|\psi\rangle = \begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

Quantum information

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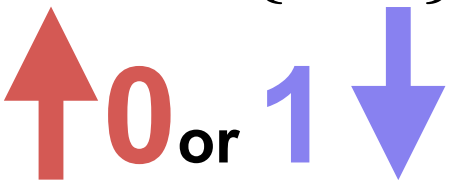
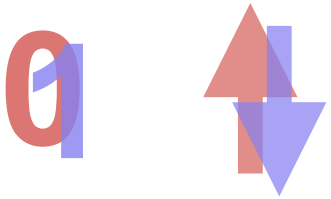
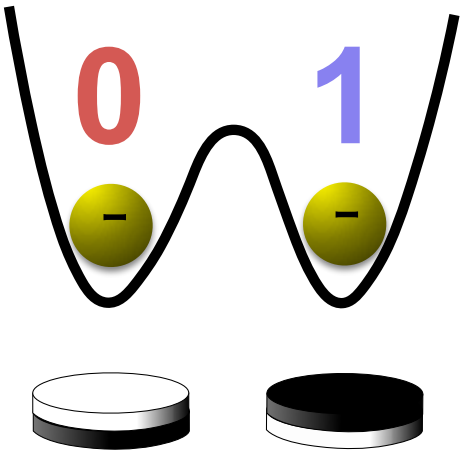


quantum bit:





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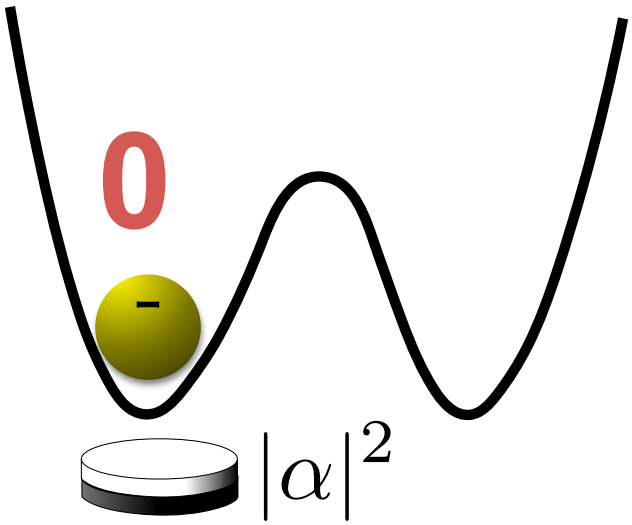

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Quantum information

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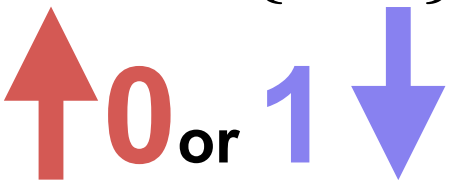

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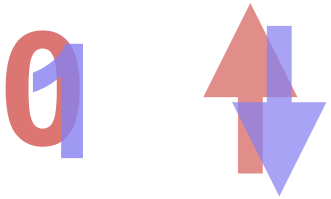

superposition of 0 and 1

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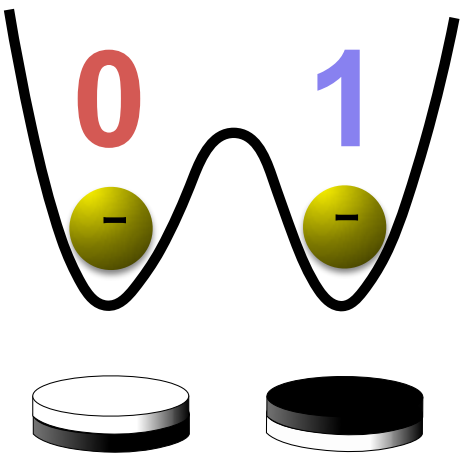
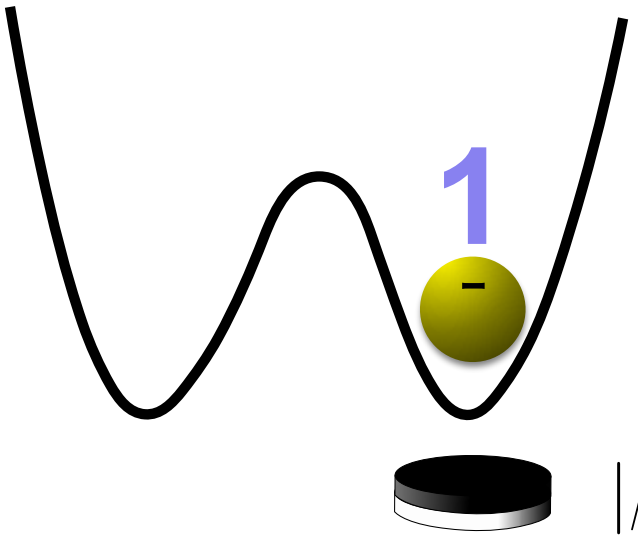


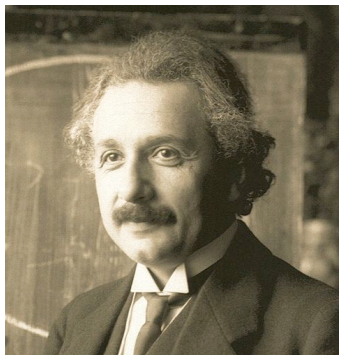


$$|\psi\rangle = \begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

If you do a measurement, 0 or 1 is determined probabilistically.

Bell's inequality

Einstein's letter to M. Born (1926):
"I, at any rate, am convinced that He (God) does not throw dice"



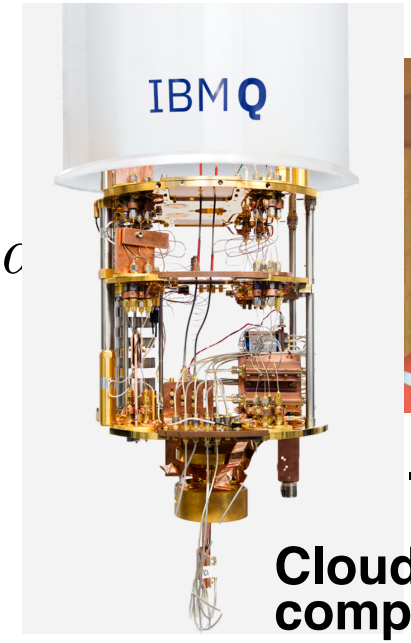
A. Einstein

In the Einstein-Podolsky-Rosen paper:
"elements of physical reality (= hidden variable) must be added to quantum mechanics to restore the theory causality and locality"

Bell's inequality (1964):
Any local hidden variable theory satisfies

$$E(a_x, b_x) + E(a_x, b_z) + E(a_z, b_x) + E(a_z, b_z) \leq 2$$

But quantum mechanics provides $2\sqrt{2}$!



Cloud quantum computer (IBM Q)

. S. Bell

Aspect's experiment (RPL 1981):

A. Aspect

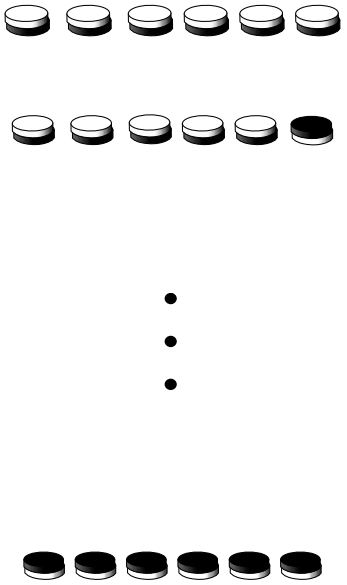
How quantum computer works

multiple classical bit (*n-dimensional vector space over GF(2)****):***

$$(x_1, x_2, x_3, x_4, x_5, x_6) = (0,\quad 0,\quad 1,\quad 0,\quad 0,\quad 1)$$

multiple quantum bit:

$$|\psi\rangle = \begin{pmatrix} c_{00\ldots0} \\ c_{00\ldots1} \\ \vdots \\ c_{11\ldots1} \end{pmatrix} \begin{matrix} |00\ldots0\rangle \\ |00\ldots1\rangle \\ \vdots \\ |11\ldots1\rangle \end{matrix}$$



superposition of all possible patterns

2^n-dimensional complex vector space!

How quantum computer works

1981(MIT) "1st Symposium on Physics and Computation"

Richard P Feynman
(1918-1988)

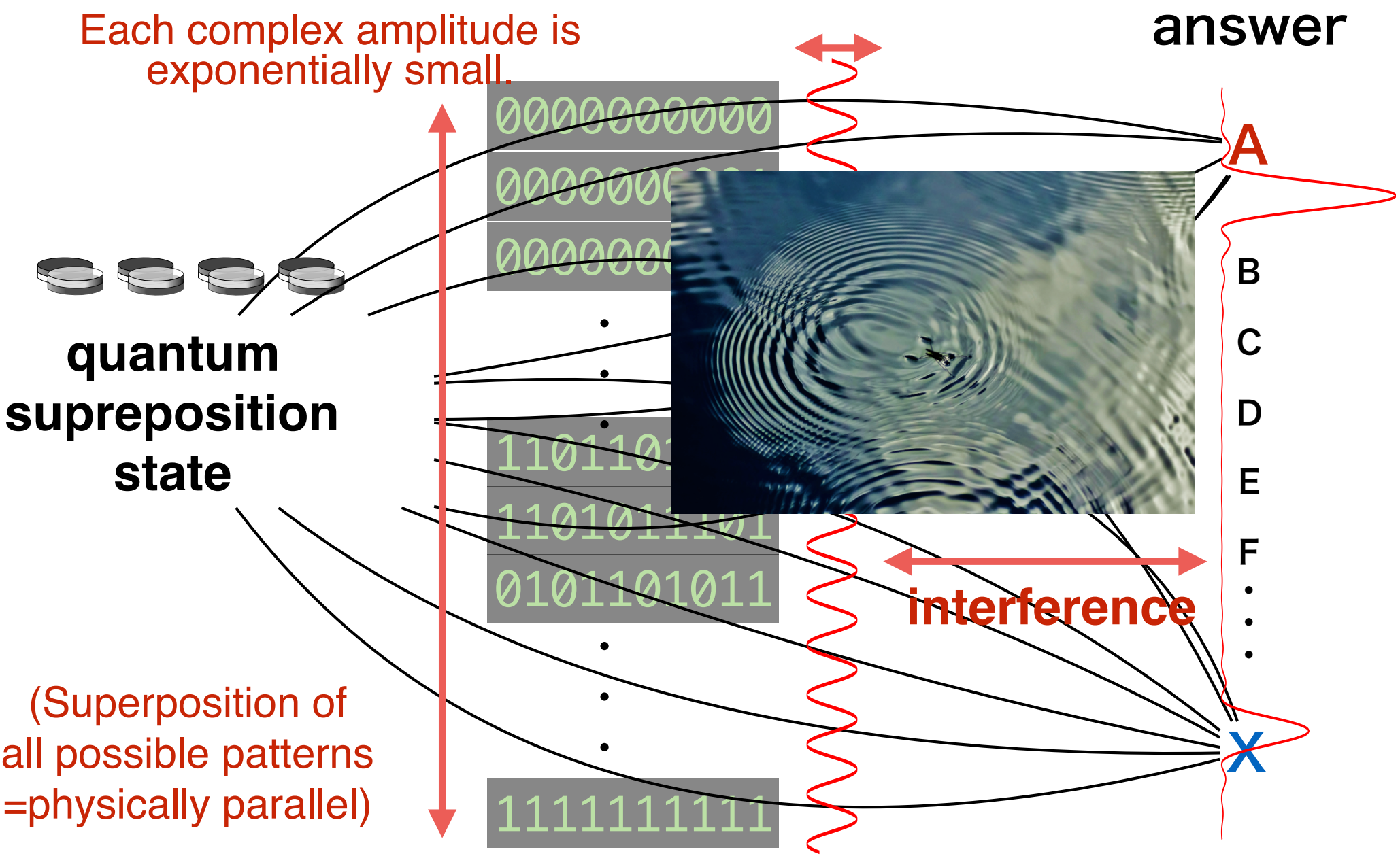
http://www.nobelprize.org/nobel_prizes/physics/laureates/1965/feynman-bio.html

*"I'm not happy with all the analyses that go with just the classical theory, **because nature isn't classical**. If you want to make a **simulation of nature** you'd better make it quantum mechanical"*

1981(Texas) "Physics and Computation"
Then you guys are using wrong physics….
*→**universal quantum computer 1985***

http://www.daviddeutsch.org.uk
David Deutsch (1953-)

How quantum computer works

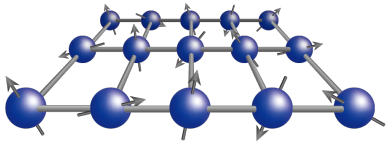


Quantum easy problems

- Intrinsically quantum related problems:

  Quantum chemistry · quantum material science

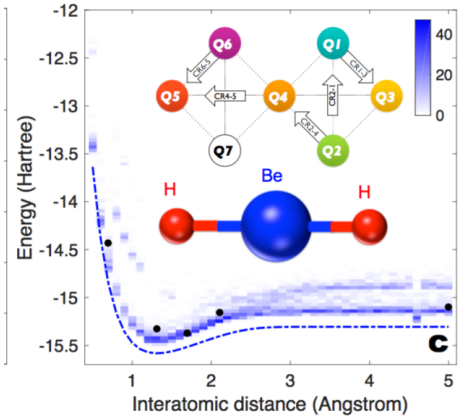
  → Quantum speedup is ubiquitous!



Nature **549**, 242–246 (14 September 2017) | doi:10.1038/nature23879

Hardware-efficient variational quantum eigensolver for small molecules and quantum magnets

Abhinav Kandala , Antonio Mezzacapo , Kristan Temme , Maika Takita , Markus Brink , Jerry M. Chow & Jay M. Gambetta



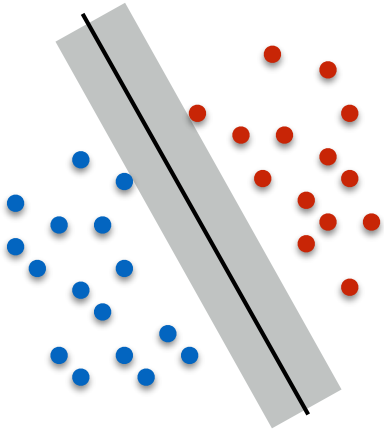
- Not intrinsically quantum but has a nice structure

  Factoring · PCA · SVM · Clustering ·

  (sparse, data encoded quantum state)

  recommendation system (Amazon, Netflix)

  → Calculation of eigenvalue & singular value using the linear algebraic structure of quantum systems.



QSVM

Rebentrost-Mohseni-Lloyd, PRL **113**, 130503 (2014)

Quantum industries

Microsoft

QuArC, StationQ etc…

豊田通商 DENSO Crafting the Core RECRUIT

1QBit QC WARE The Quantum Computing Company™ D-Wave

Quantum annealing（Ising problem）

IBM

intel

QUTech

QuTech@Delft

QuSoft

QuSoft@Delft

Google

+UCSB(Martinis)

qci

Quantum circuit inc.
@Yale University
(Schoelkopf, Devoret)

Quantum Native Systems QunaSys

IONQ

Univ. (Monroe)

20 qubits systems are already reached.
>**50 qubits** (1Peta dimensions) systems are already fabricated and would work in the near future.

NVIDIA

中国科学院 CHINESE ACADEMY OF SCIENCES

(A16Z: Andreessen Horowitz)

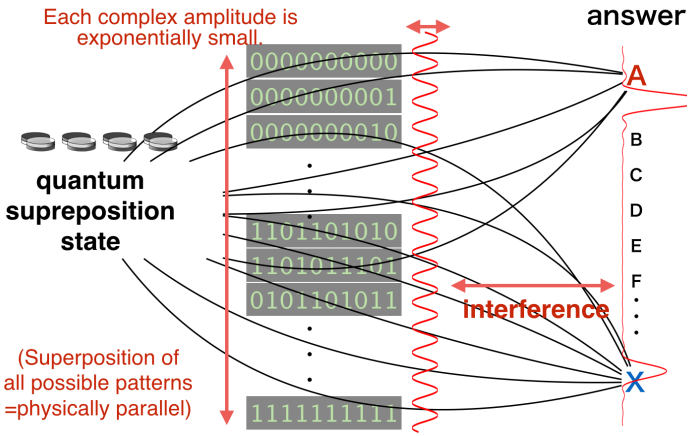
Silicon Quantum Computing Pty
(UNSW)

Quantum computer and blockchain

Proof of Work: computationally costly part

01011011 ⟵ h(?????) = 000101
preimage

→ *Grover's quantum search*
(only quadratic speedup, less impact)



Digital signature: Public-key cryptography, RSA, ECDSA ..

Sig(message, private_key) = signature

computationally hard

Verification(message, signature, public_key) = true/false

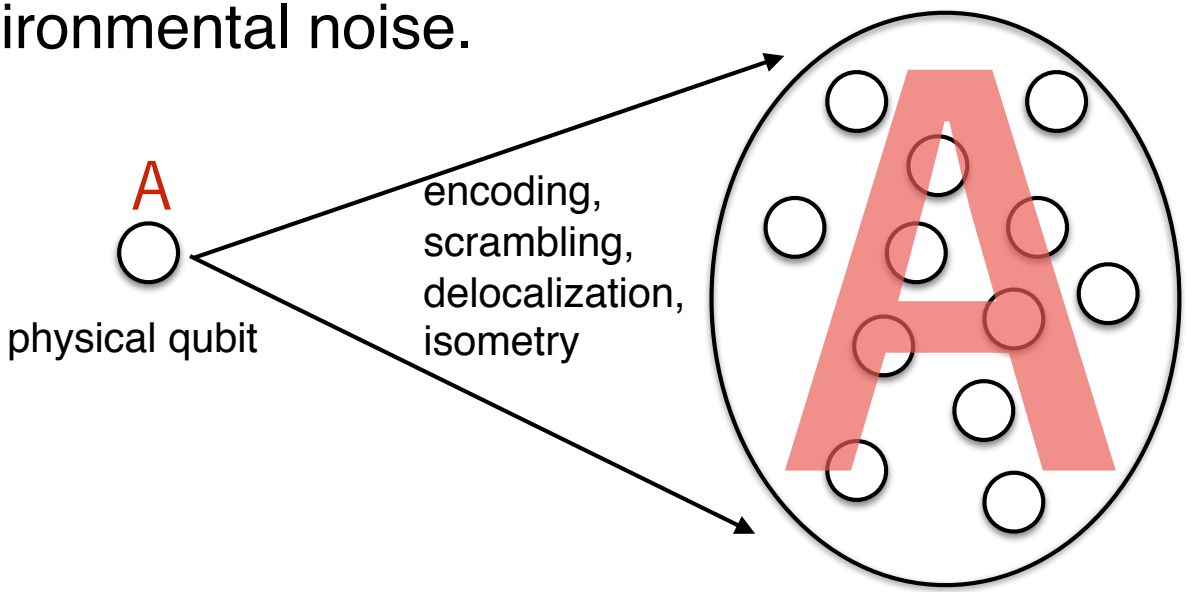
hardness of factoring, discrete logarithm → Shor's quantum algorithm

Summary

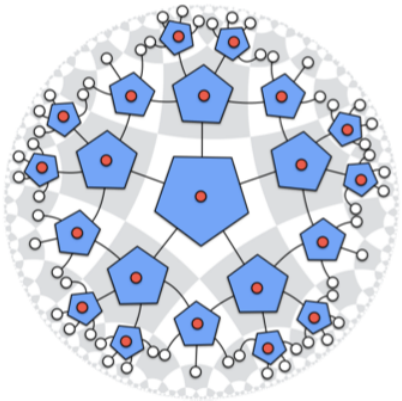
- Quantum computer: a computer that works under quantum mechanical law, and hence can efficiently simulate nature.
- IT giants are currently heavily engaged in developing quantum computers and exploring complex quantum frontier.
- Hacking a quantum computer provides us a deep insight about quantum physics, topological order, holographic principle, black hole etc…
- Potentially, quantum algorithms are effective on blockchain (PoW, DSA), but there would be no threat in a near feature.
- It would be interesting to explore blockchain for quantum computing and quantum computing for blockchain.

Quantum computer and high energy physics

Quantum error correction:
protection of quantum information from environmental noise.



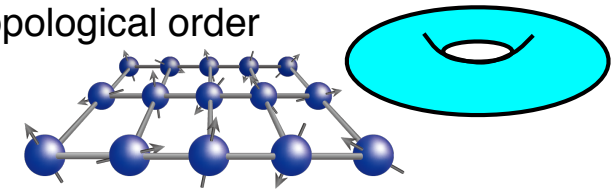
Holographic principle



(b) Holographic pentagon code

[Pastawski et al., JHEP '15]

Topological order



[Kitaev. Ann. Phys. '03]

Blackhole information paradox:
quantum information solution → fast scrambling: Blackhole is the fastest quantum computer in universe!