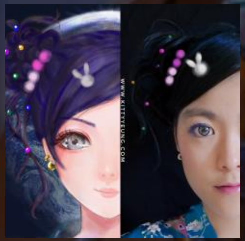
Introduction to Quantum Computing



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Microsoft

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May 17, 2020
Hackaday, session 8

Class structure

- Comics on Hackaday – Introduction to Quantum Computing every Wed & Sun

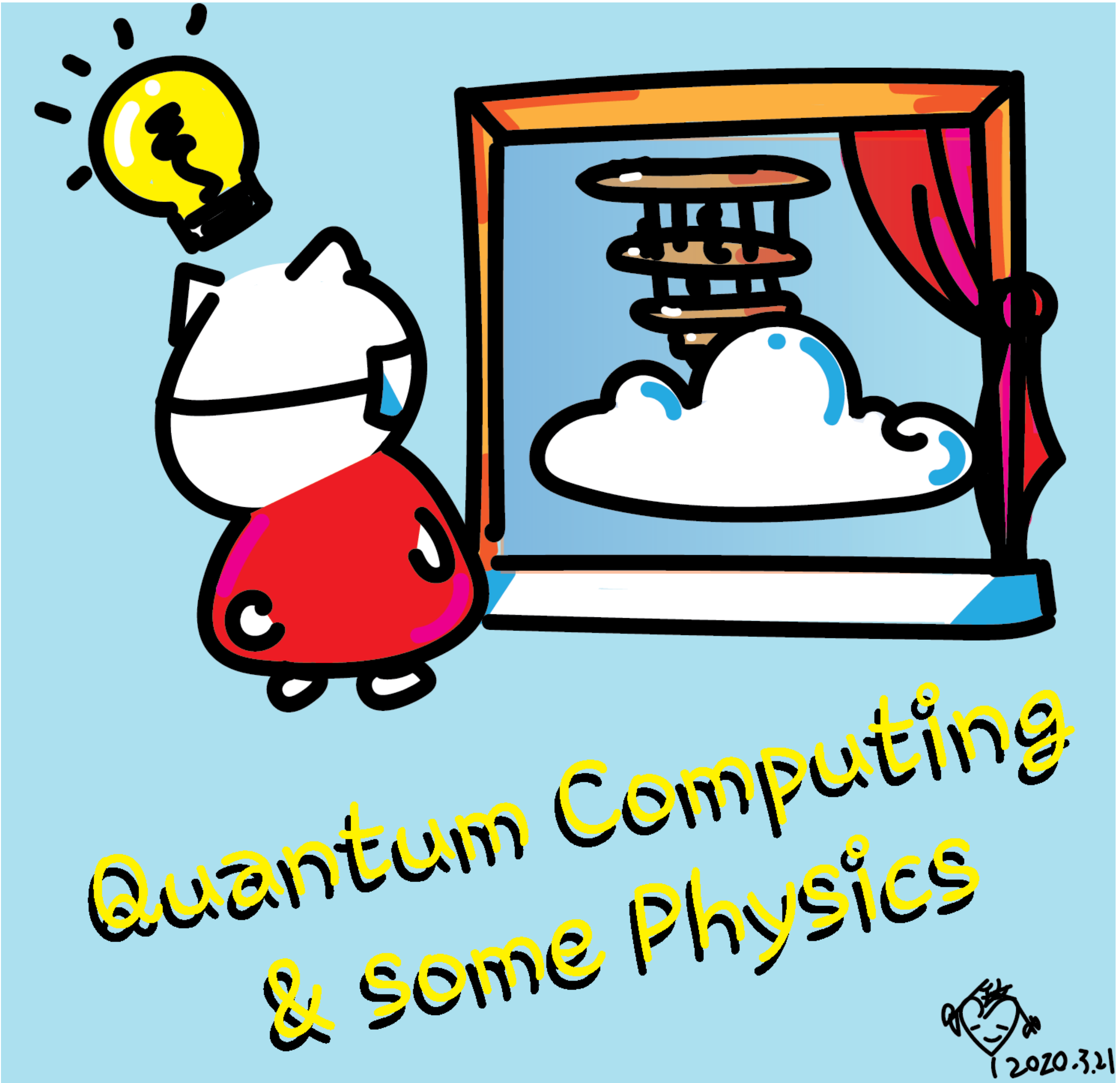
- 30 mins every Sun, one concept (theory, hardware, programming), Q&A

- Contribute to Q# documentation http://docs.microsoft.com/quantum

- Coding through Quantum Katas https://github.com/Microsoft/QuantumKatas/

- Discuss in Hackaday project comments throughout the week

- Take notes



Next class

Recap of past topics

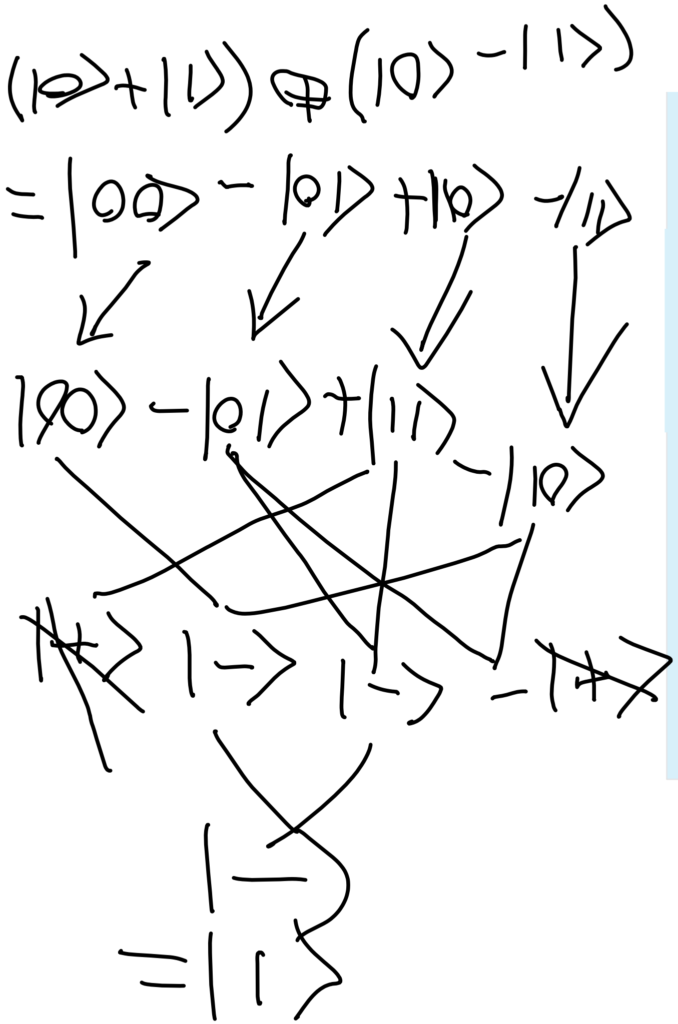
1 hour

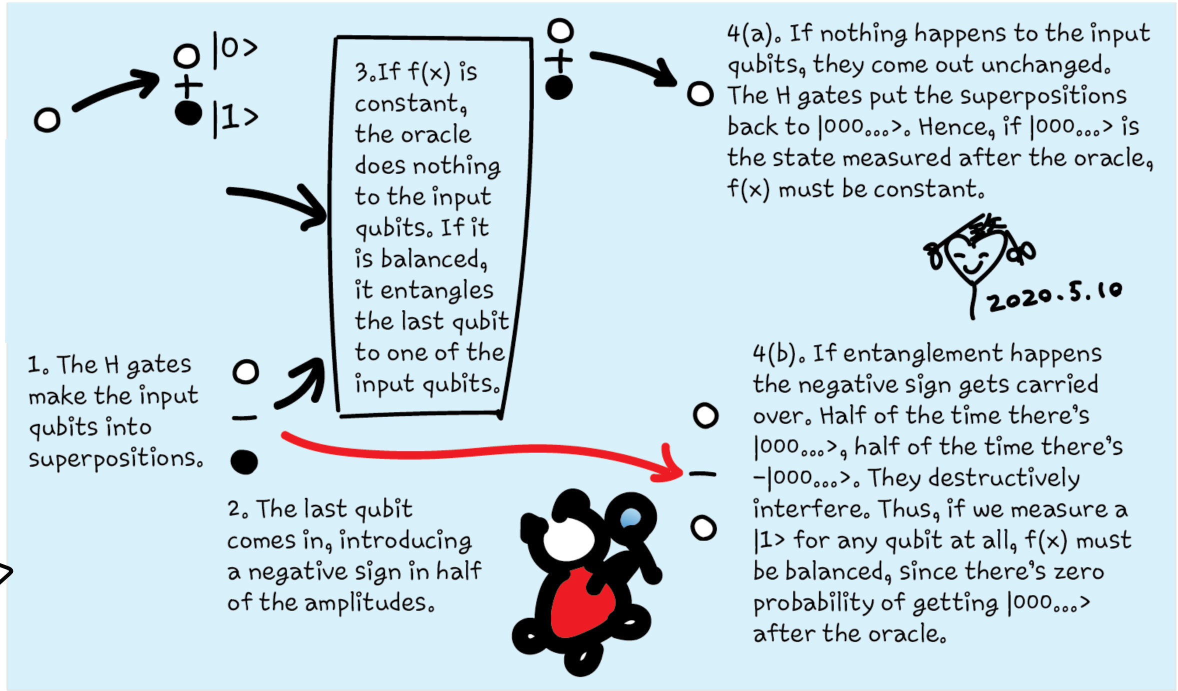
Quantum Algorithms

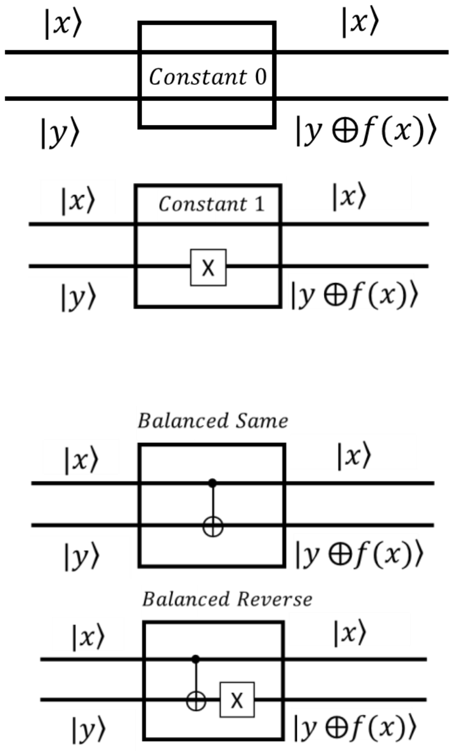
- Deutsch's: determines if a function $f(x)$ is *Balanced* ($f(0) \neq f(1)$, which is 1-to-1) or
- *Constant* ($f(0) = f(1)$, which is 2-to-1)
- Deutsch-Jozsa: a general case of Deutsch's algorithm for n-qubits
- Grover's: search for an item in an unordered list
- Simon's: query complexity, solves the problem exponentially faster than any deterministic or probabilistic classical algorithm, finds repeats in a list
- Shor's: given an integer N, find its prime factors

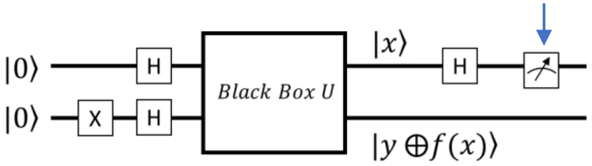
Can you come up with more useful algorithms?

- http://quantumalgorithmzoo.org/





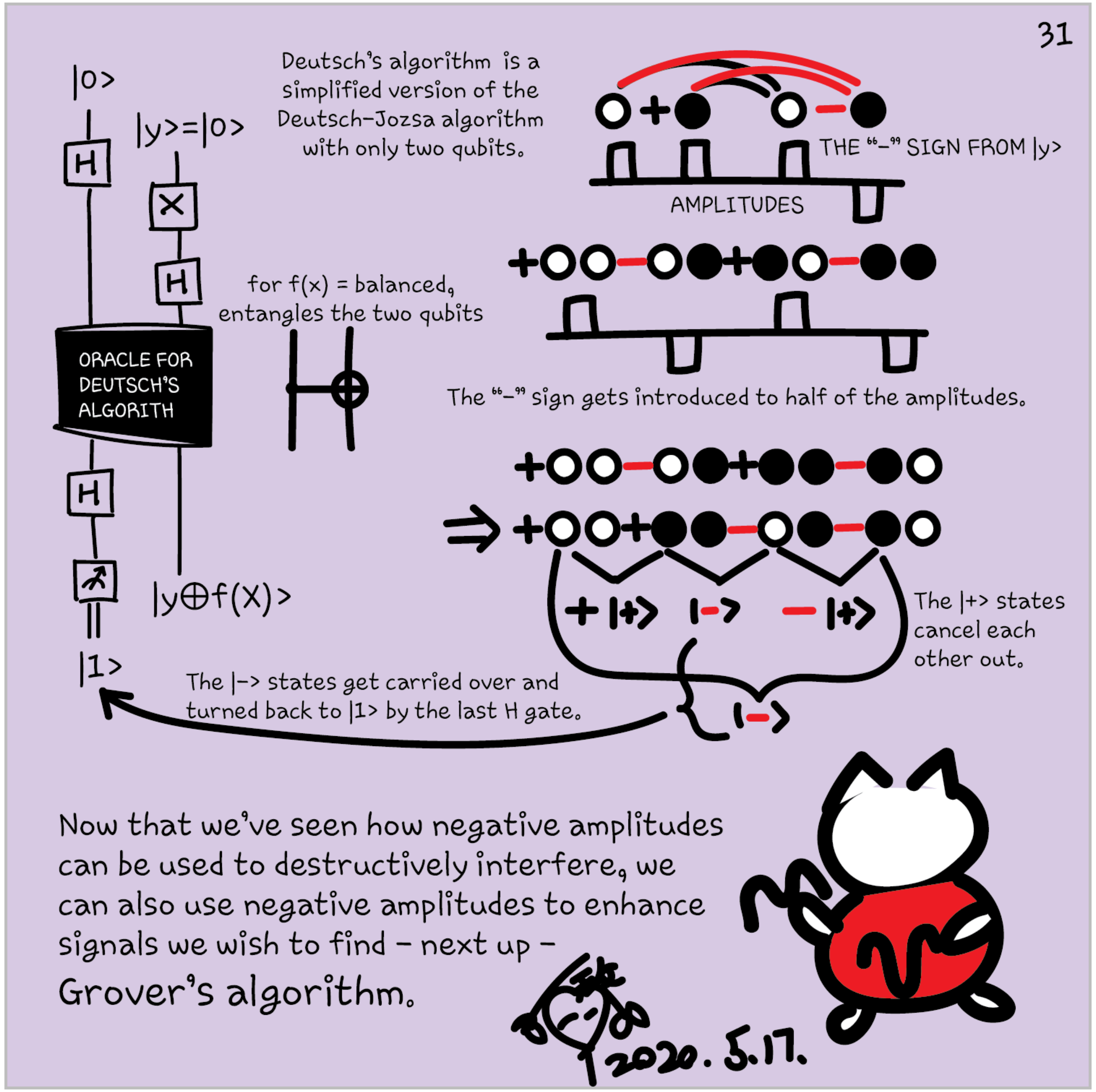


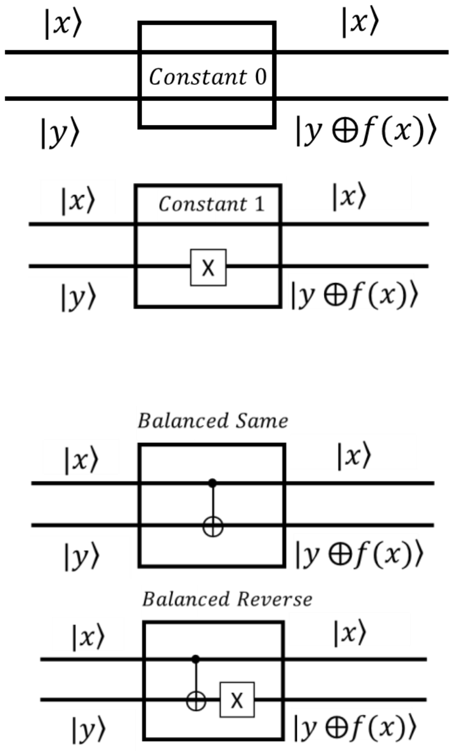


Obtains result with corresponding probability

0 means *Constant*

1 means *Balanced*

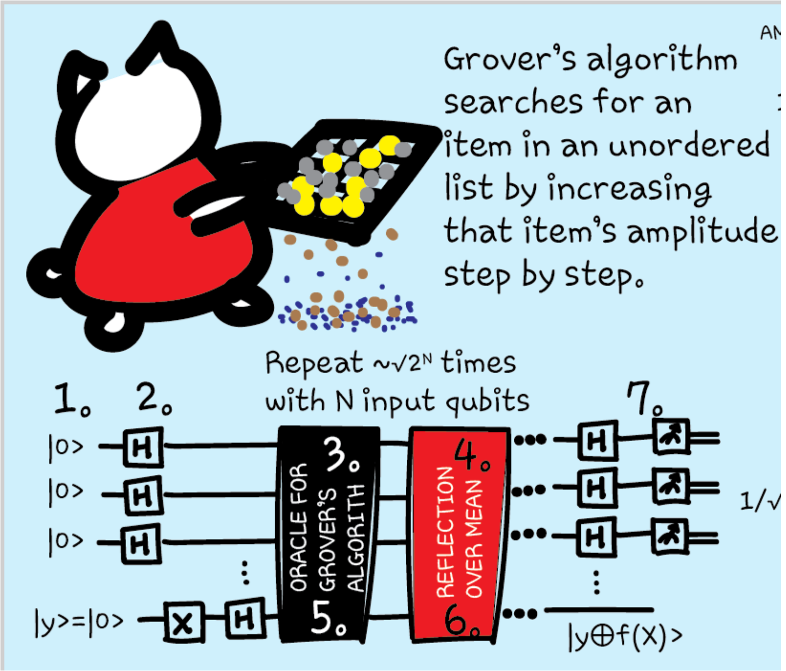

31
|0>
|y>=|0>
Deutsch's algorithm is a simplified version of the Deutsch-Jozsa algorithm with only two qubits.
THE "–" SIGN FROM |y>
AMPLITUDES
H
X
H
for f(x) = balanced, entangles the two qubits
ORACLE FOR DEUTSCH'S ALGORITH
The "–" sign gets introduced to half of the amplitudes.
H
|y⊕f(X)>
|1>
The |+> states cancel each other out.
The |–> states get carried over and turned back to |1> by the last H gate.
|–>
Now that we've seen how negative amplitudes can be used to destructively interfere, we can also use negative amplitudes to enhance signals we wish to find – next up –
Grover's algorithm.
2020. 5.17.

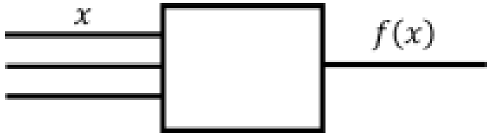

|x⟩
Constant 0
|y⟩
|x⟩
|y ⊕f(x)⟩
|x⟩
Constant 1
X
|y⟩
|x⟩
|y ⊕f(x)⟩
Balanced Same
|x⟩
|y⟩
|x⟩
|y ⊕f(x)⟩
Balanced Reverse
|x⟩
X
|y⟩
|x⟩
|y ⊕f(x)⟩

Grover's algorithm

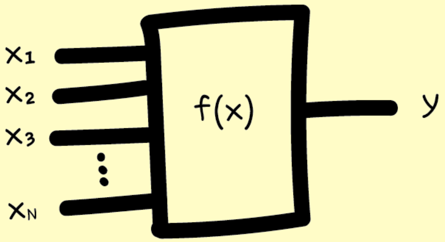
https://en.wikipedia.org/wiki/Grover%27s_algorithm

Lov Kumar Grover (* 1960 in Merath, India) is an Indian-American computer scientist





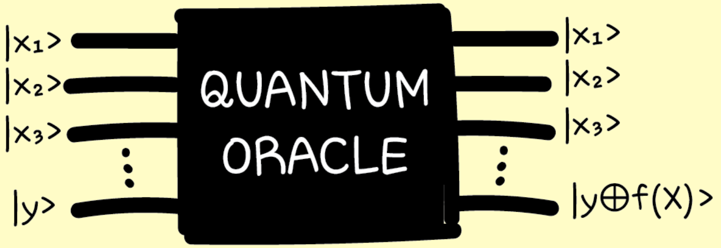
x	$y = f(x)$
000	0
001	0
010	0
011	0
100	0
101	0
110	1
111	0



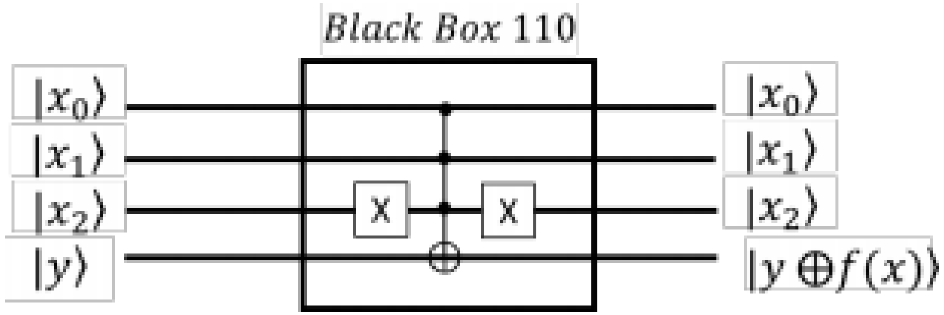
A classical algorithm takes inputs and produces an output. This algorithm is a function, f(x).

(This construction is not possible for a quantum algorithm, as f(x) can not guarantee to be a reversible.)

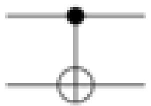
In many quantum algorithms, we put both the inputs and the output through a black box – a quantum **oracle**. The classical function f(x) is used to construct the black box.



x	$y = f(x)$
000	0
001	0
010	0
011	0
100	0
101	0
110	1
111	0

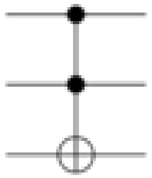


Controlled Not
(CNOT, CX)



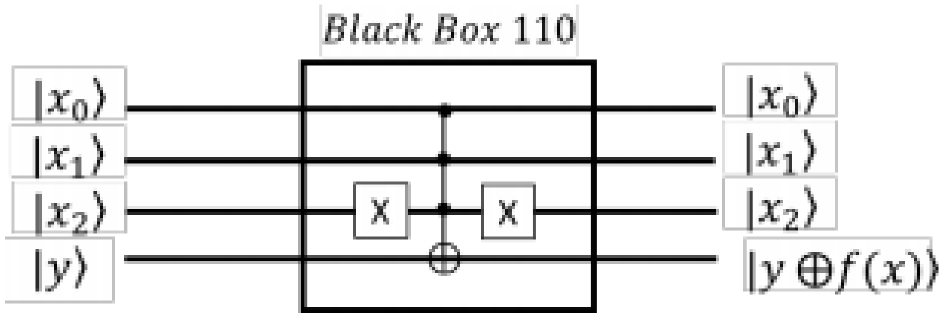
$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Toffoli
(CCNOT,
CCX, TOFF)

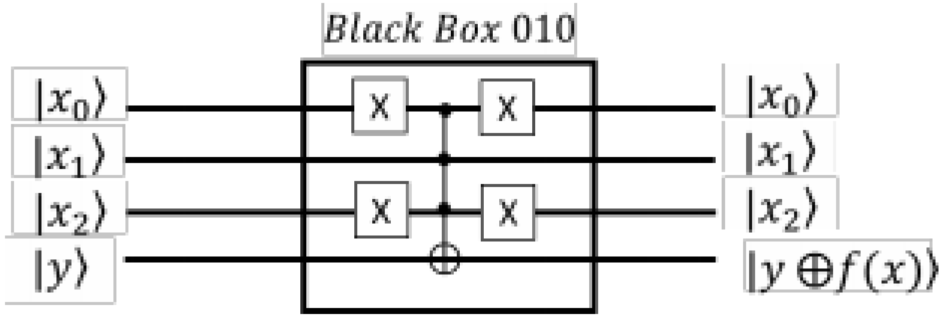


$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

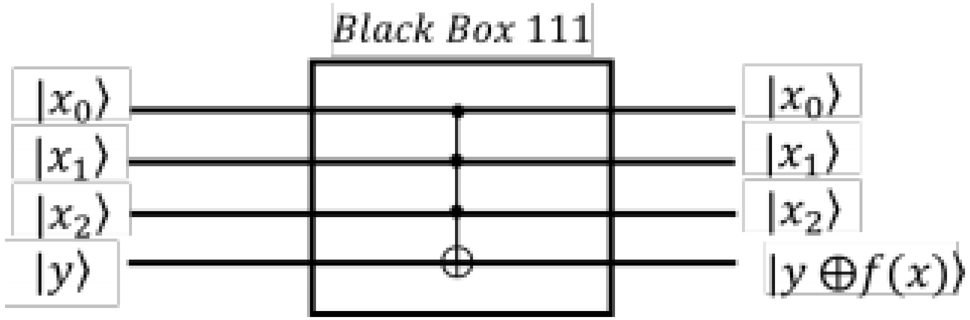
x	$y = f(x)$
000	0
001	0
010	0
011	0
100	0
101	0
110	1
111	0

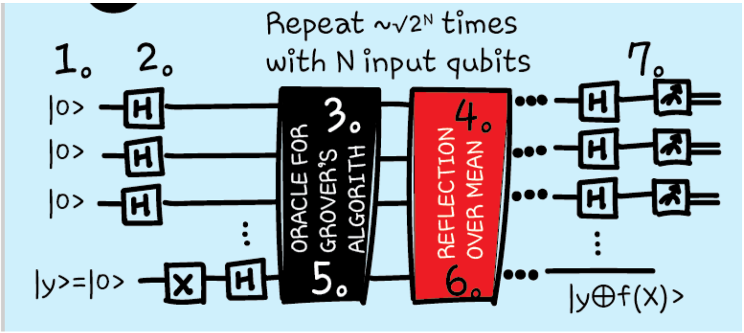


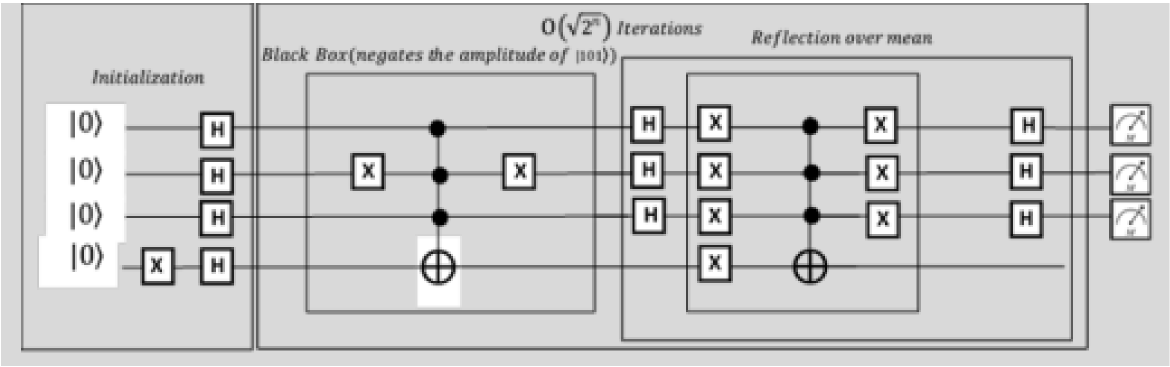
x	$y = f(x)$
000	0
001	0
010	1
011	0
100	0
101	0
110	0
111	0

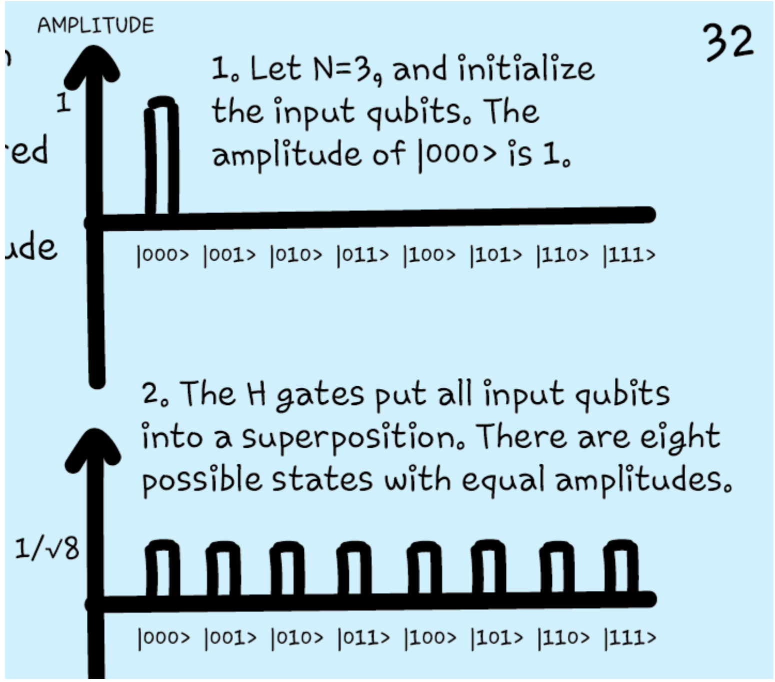


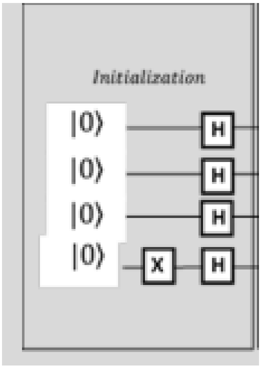
x	$y = f(x)$
000	0
001	0
010	0
011	0
100	0
101	0
110	0
111	1

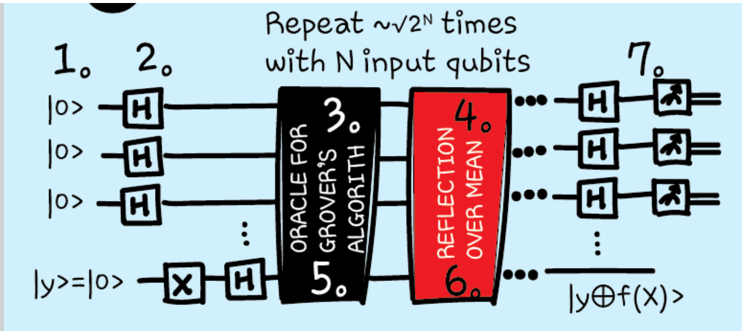


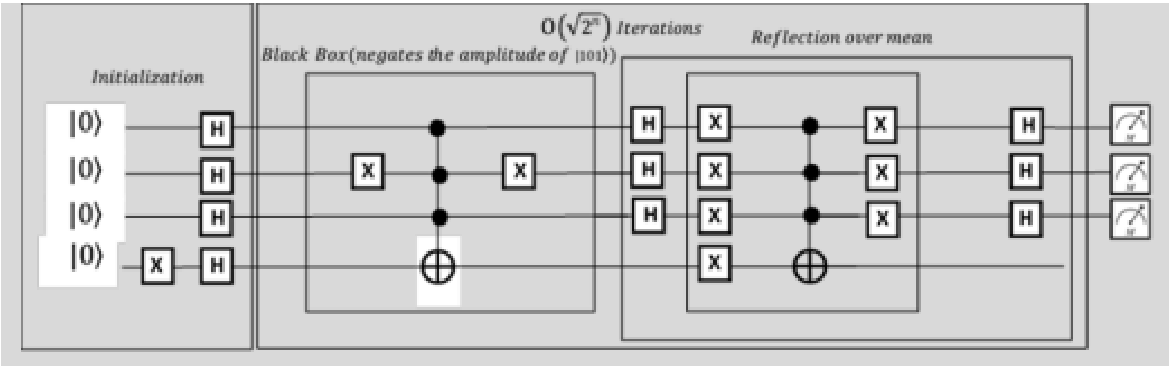

Repeat ~√2^N times
with N input qubits
1.
2.
3.
4.
5.
6.
7.
|0>
|0>
|0>
|y>=|0>
ORACLE FOR GROVER'S ALGORITH
REFLECTION OVER MEAN
|y⊕f(x)>

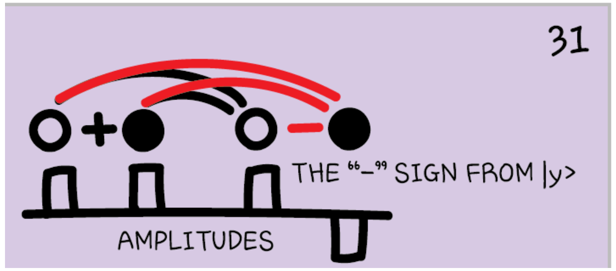

Initialization
O(√2^n) Iterations
Black Box(negates the amplitude of |101⟩)
Reflection over mean
|0⟩
|0⟩
|0⟩
|0⟩

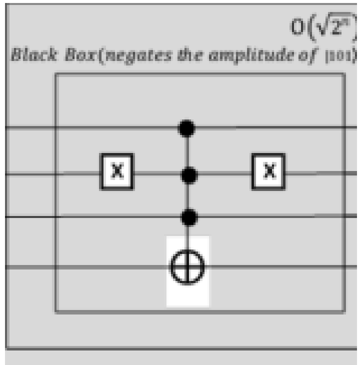

AMPLITUDE
32
1
1. Let N=3, and initialize the input qubits. The amplitude of |000> is 1.
|000> |001> |010> |011> |100> |101> |110> |111>
2. The H gates put all input qubits into a superposition. There are eight possible states with equal amplitudes.
1/√8
|000> |001> |010> |011> |100> |101> |110> |111>

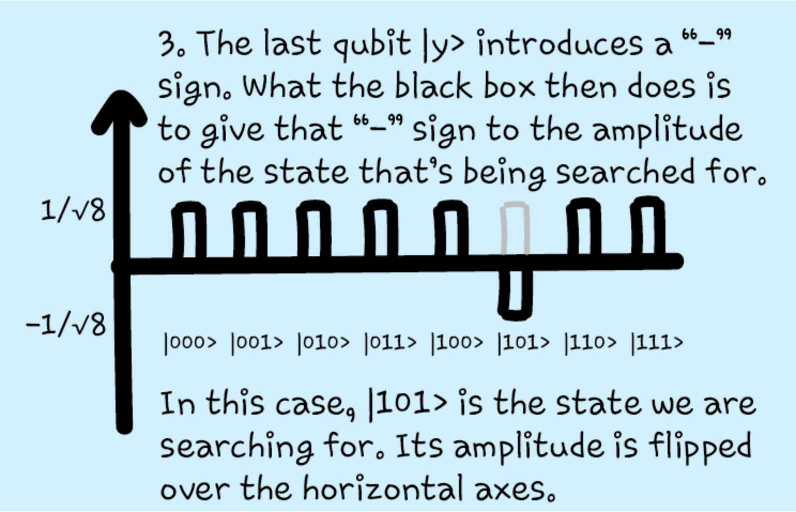

Initialization
|0⟩
|0⟩
|0⟩
|0⟩



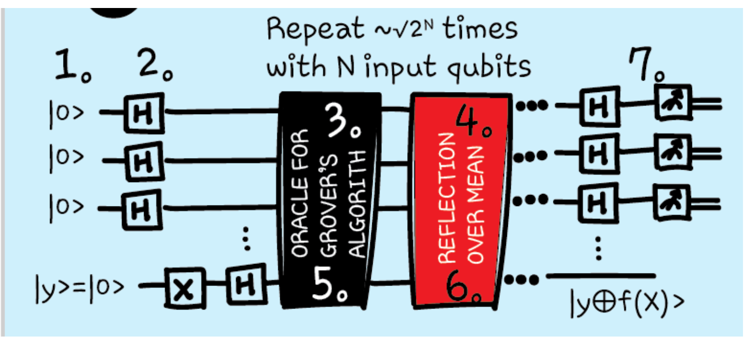


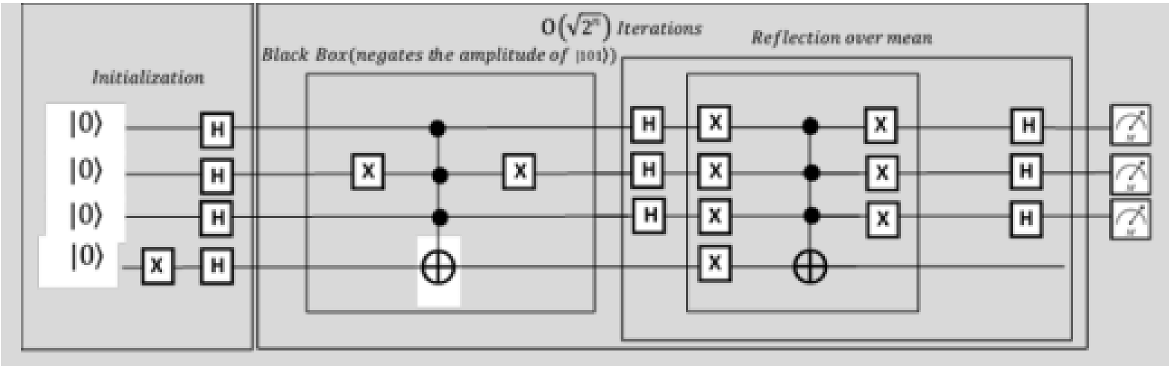


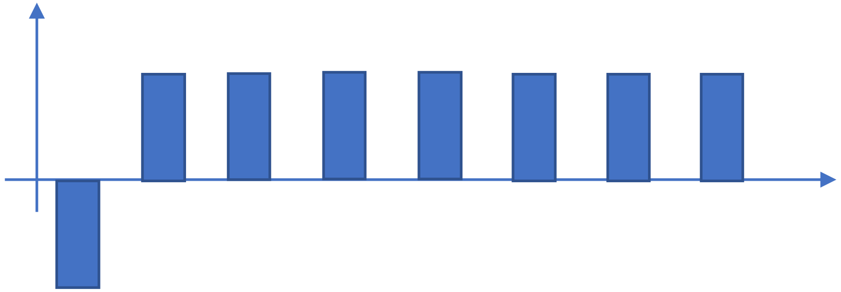


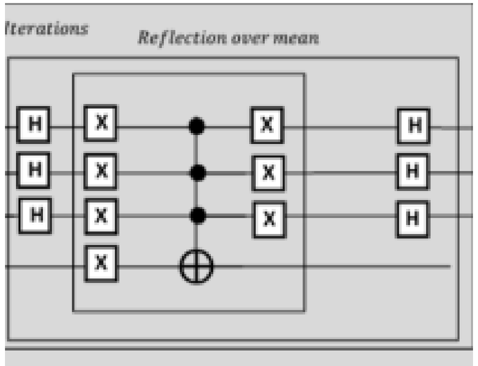


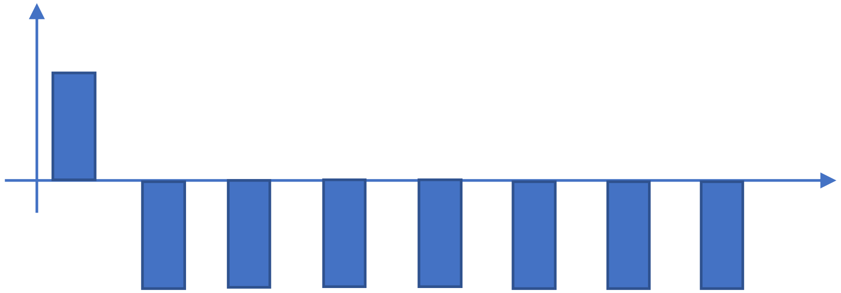
x	$y = f(x)$
000	0
001	0
010	0
011	0
100	0
101	1
110	0
111	0





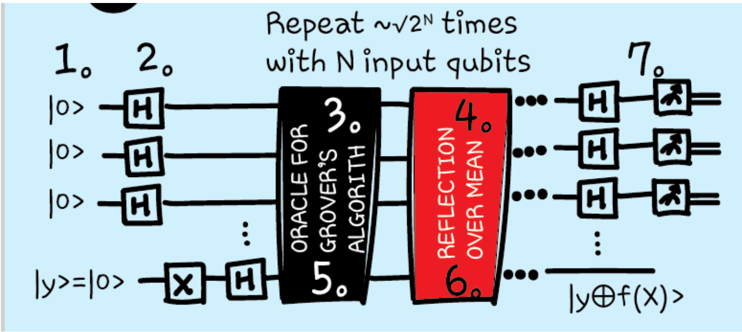


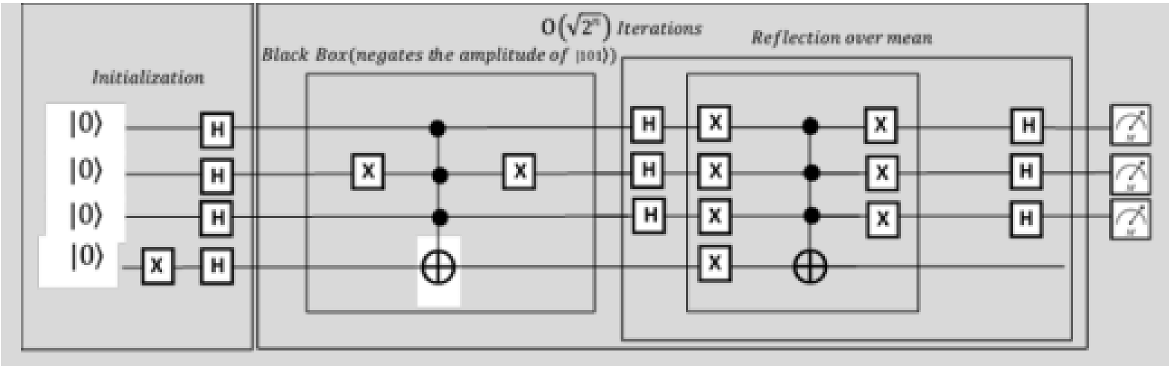


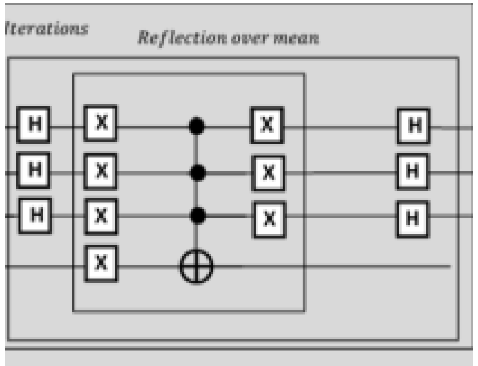


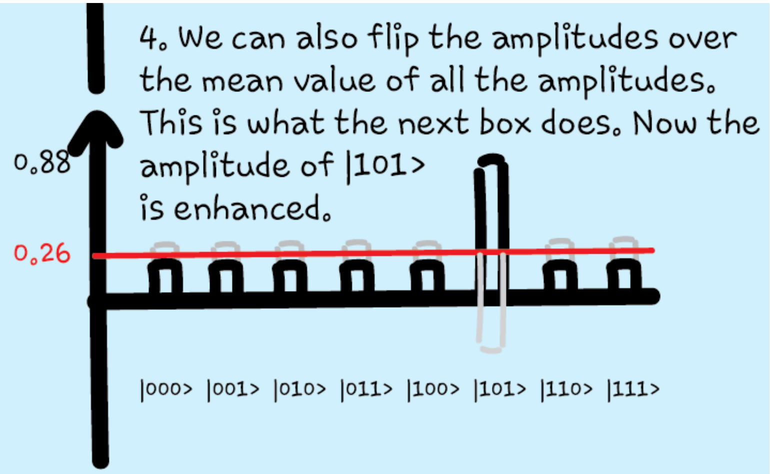
$$-a_0\,|000\rangle \otimes \left(-\frac{|0\rangle}{\sqrt{2}} + \frac{|1\rangle}{\sqrt{2}}\right) - a_1|001\rangle \otimes \left(\frac{|0\rangle}{\sqrt{2}} - \frac{|1\rangle}{\sqrt{2}}\right) - a_2|010\rangle \otimes \left(\frac{|0\rangle}{\sqrt{2}} - \frac{|1\rangle}{\sqrt{2}}\right) - a_3|011\rangle \otimes \left(\frac{|0\rangle}{\sqrt{2}} - \frac{|1\rangle}{\sqrt{2}}\right) - a_4|100\rangle \otimes \left(\frac{|0\rangle}{\sqrt{2}} - \frac{|1\rangle}{\sqrt{2}}\right) - a_5|101\rangle \otimes \left(\frac{|0\rangle}{\sqrt{2}} - \frac{|1\rangle}{\sqrt{2}}\right) - a_6|110\rangle \otimes \left(\frac{|0\rangle}{\sqrt{2}} - \frac{|1\rangle}{\sqrt{2}}\right) - a_7|111\rangle \otimes \left(\frac{|0\rangle}{\sqrt{2}} - \frac{|1\rangle}{\sqrt{2}}\right)$$

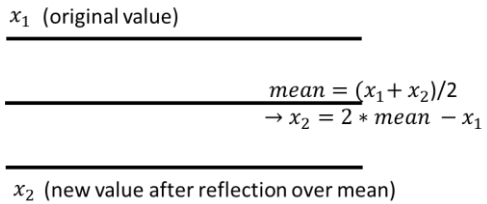
$$= (a_0|000\rangle - a_1|001\rangle - a_2|010\rangle - a_3|011\rangle - a_4|100\rangle - a_5|101\rangle - a_6|110\rangle - a_7|111\rangle) \otimes \left(\frac{|0\rangle}{\sqrt{2}} - \frac{|1\rangle}{\sqrt{2}}\right)$$

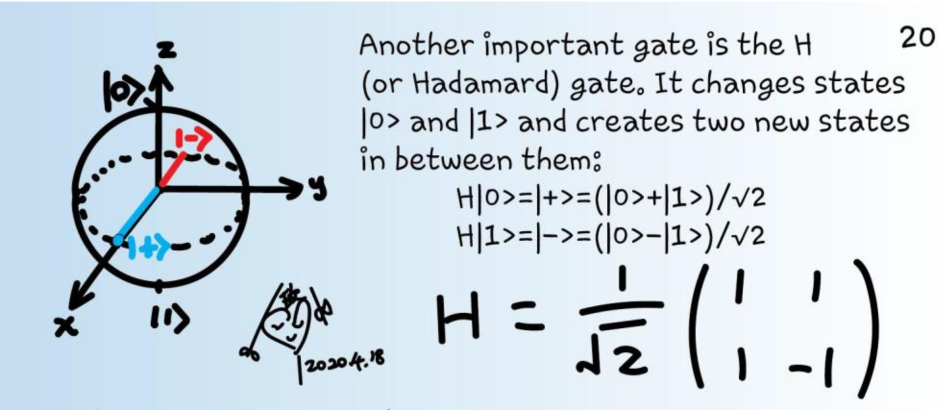

Repeat ~√2^N times
with N input qubits
1.
2.
7.
|0>
|0>
|0>
|y>=|0>
H
X
3.
ORACLE FOR GROVER'S ALGORITH
5.
4.
REFLECTION OVER MEAN
6.
|y⊕f(x)>

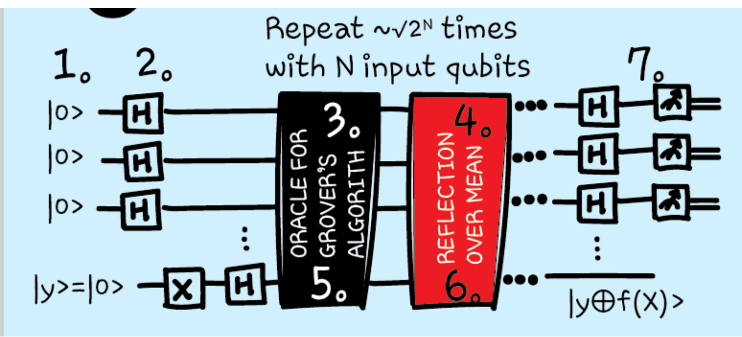

Initialization
O(√2^n) Iterations
Black Box(negates the amplitude of |101⟩)
Reflection over mean
|0⟩
|0⟩
|0⟩
|0⟩
H
X

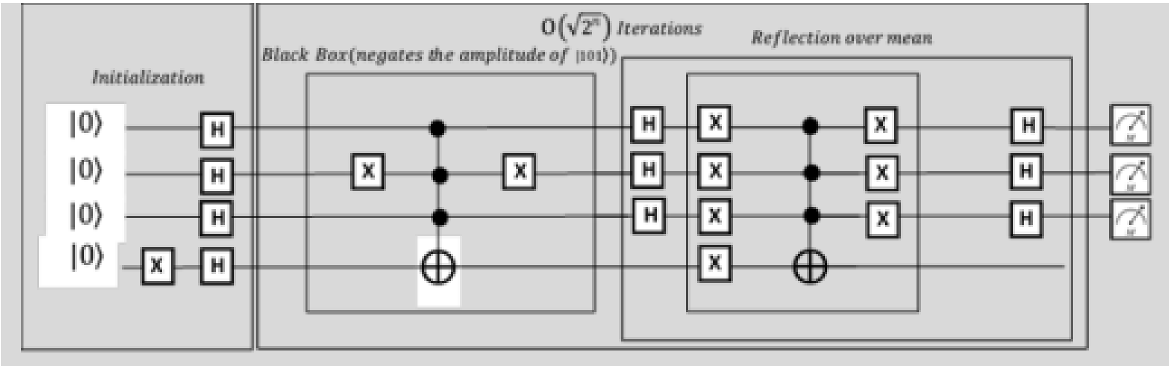

Iterations
Reflection over mean
H
X

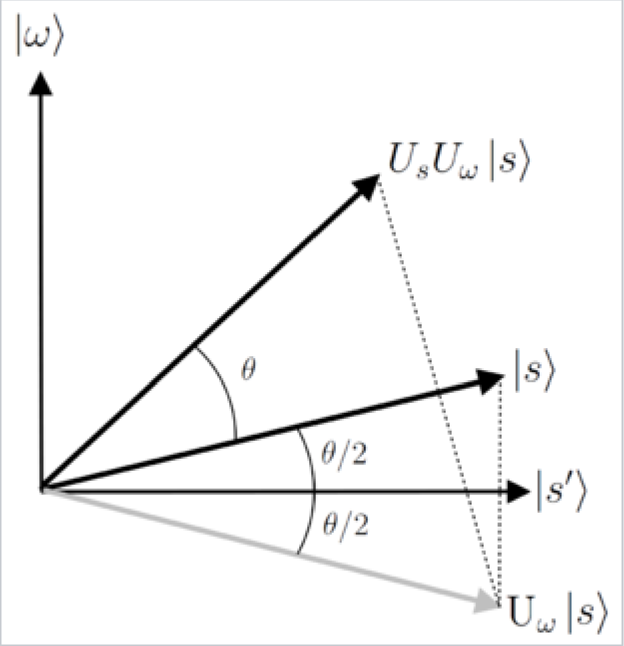

4. We can also flip the amplitudes over
the mean value of all the amplitudes.
This is what the next box does. Now the
amplitude of |101>
is enhanced.
0.88
0.26
|000> |001> |010> |011> |100> |101> |110> |111>


x_1 (original value)
$mean = (x_1 + x_2)/2$
$\rightarrow x_2 = 2 * mean - x_1$
x_2 (new value after reflection over mean)

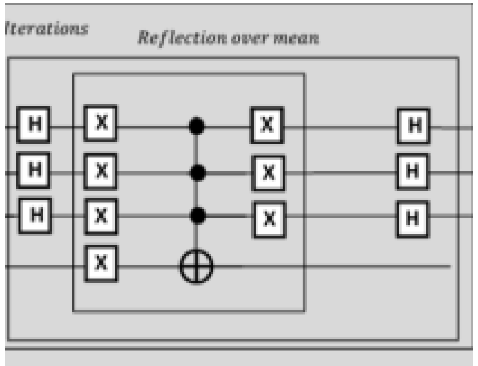

Another important gate is the H
20
(or Hadamard) gate. It changes states
|0> and |1> and creates two new states
in between them:
H|0>=|+>=(|0>+|1>)/√2
H|1>=|−>=(|0>−|1>)/√2
$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$
z
|0>
y
x
|1>
|−>
|+>
2020.4.18

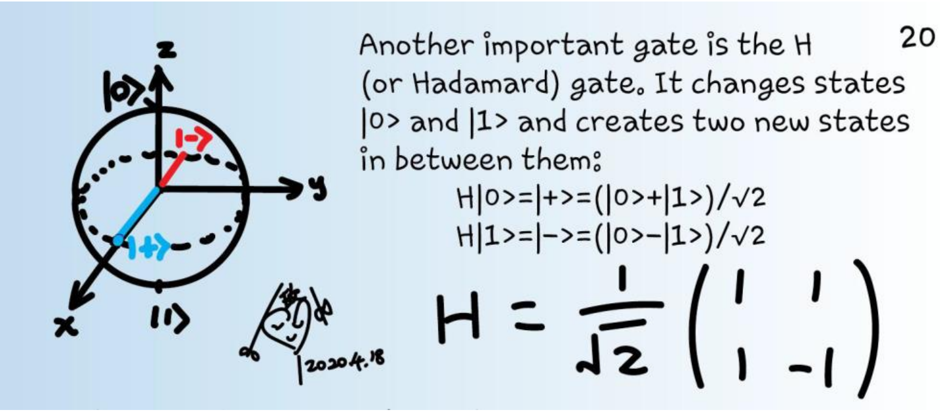


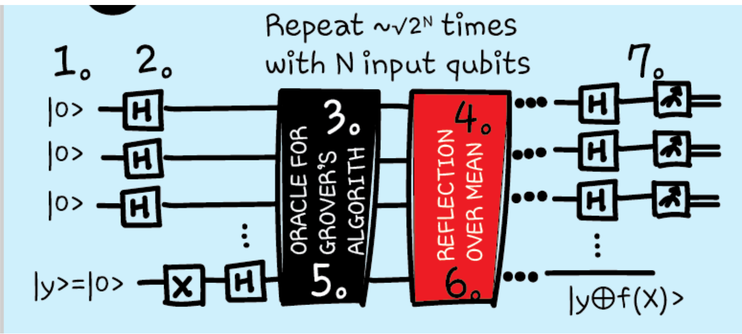


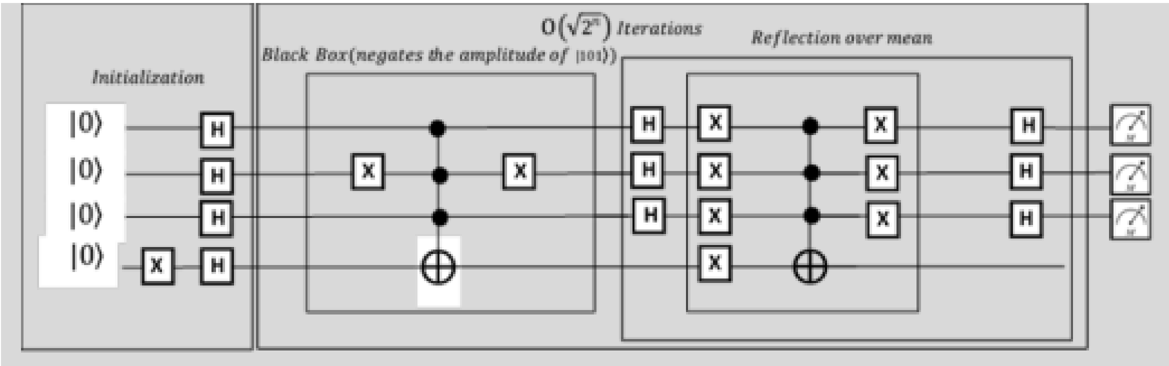


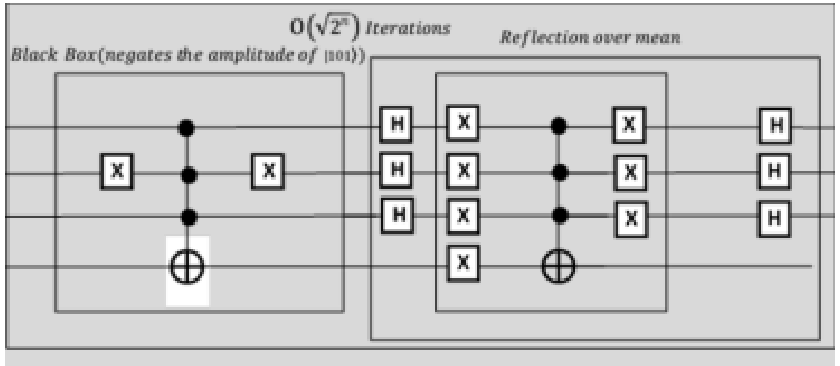
Picture showing the geometric interpretation of the first iteration of Grover's algorithm. The state vector $|s\rangle$ is rotated towards the target vector $|\omega\rangle$ as shown.

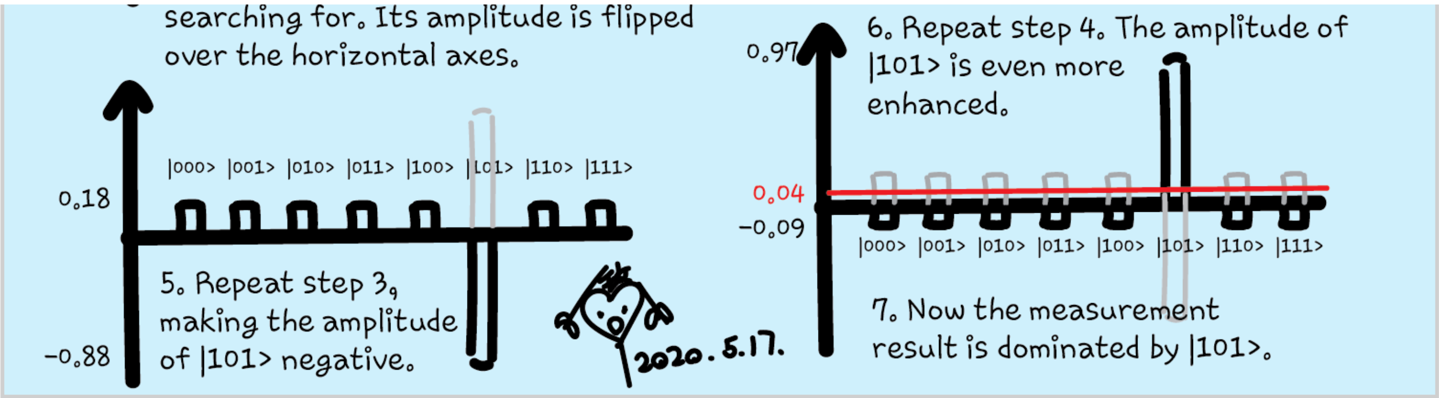


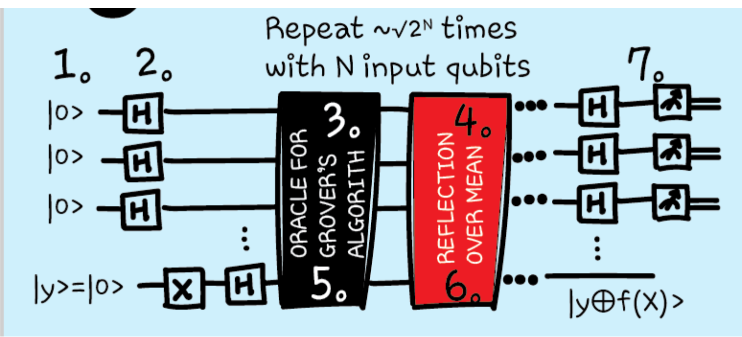


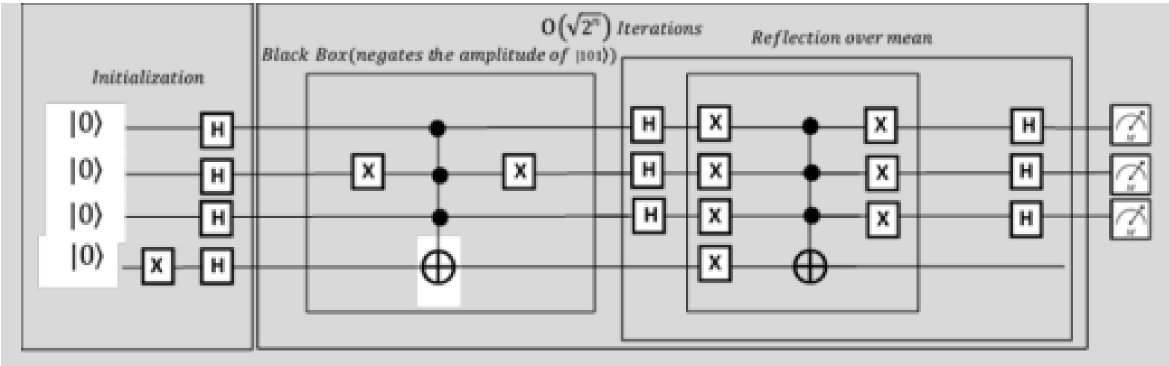

Repeat ~√2^N times with N input qubits
1.
2.
|0>
|0>
|0>
|y>=|0>
ORACLE FOR GROVER'S ALGORITH
3.
5.
REFLECTION OVER MEAN
4.
6.
7.
|y⊕f(X)>

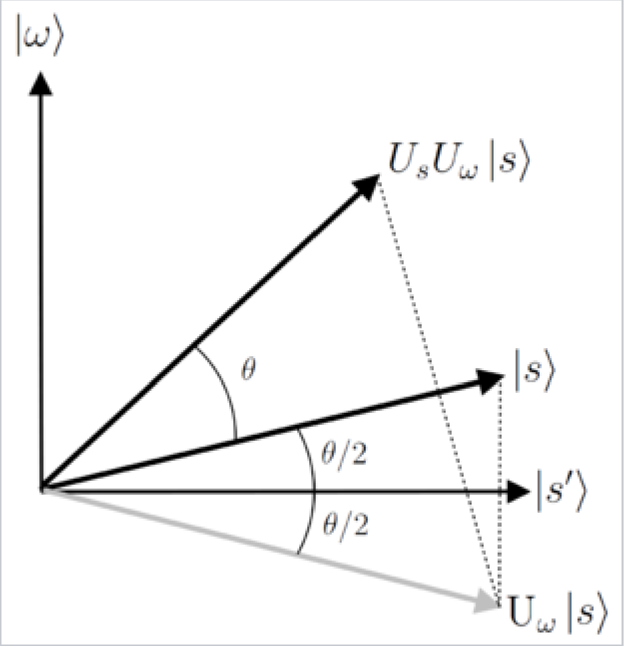

Initialization
|0⟩
|0⟩
|0⟩
|0⟩
O(√2^n) Iterations
Black Box(negates the amplitude of |101⟩)
Reflection over mean


O(√2^n) Iterations
Black Box(negates the amplitude of |101⟩)
Reflection over mean

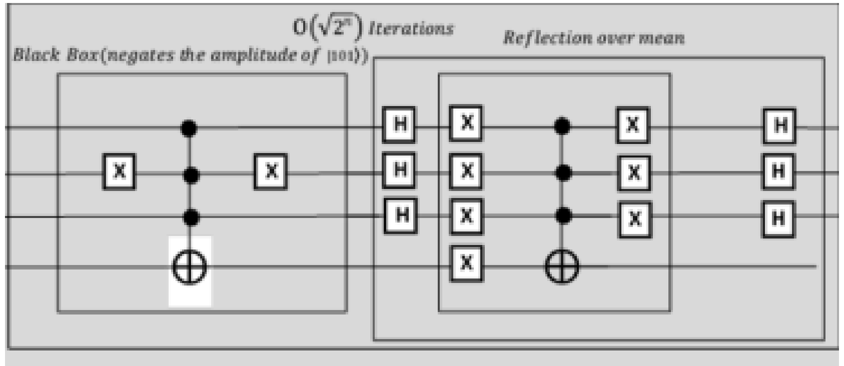

searching for. Its amplitude is flipped over the horizontal axes.
0.18
-0.88
|000> |001> |010> |011> |100> |101> |110> |111>
5. Repeat step 3, making the amplitude of |101> negative.
2020.5.17.
0.97
0.04
-0.09
6. Repeat step 4. The amplitude of |101> is even more enhanced.
|000> |001> |010> |011> |100> |101> |110> |111>
7. Now the measurement result is dominated by |101>.







Picture showing the geometric interpretation of the first iteration of Grover's algorithm. The state vector $|s\rangle$ is rotated towards the target vector $|\omega\rangle$ as shown.



x	$y = f(x)$
000	0
001	0
010	0
011	0
100	0
101	1
110	0
111	0

Classically on the order of 2^N times
Grover’s on the order of sqrt(2^N) times

Quantum katas

Set up Grover's algorithm from scratch	https://github.com/microsoft/QuantumKatas/tree/master/GroversAlgorithm
Use Grover's algorithm	https://github.com/microsoft/QuantumKatas/tree/master/tutorials/ExploringGroversAlgorithm
Visualize Grover's algorithm	https://github.com/microsoft/QuantumKatas/tree/master/GraphColoring
Decorating the Christmas tree using Grover's search	https://github.com/tcNickolas/MiscQSharp/tree/master/DecoratingTheTree

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Let's Talk Quantum — May 21 12:45 pm-1:00 pm CEST

Speakers: Amy Boyd; Microsoft, Anita Ramanan; Microsoft

Ever wondered how a quantum computer works? Or what we'd use them for? Join Anita Ramanan, Senior Quantum Software Engineer at Microsoft, to learn all this and more

Building on Azure Quantum — May 21 2:30 pm-3:00 pm CEST

Speaker: Anita Ramanan; Microsoft

Quantum computing continues to evolve and mature, driving real impact today for organizations around the world. Azure Quantum extends the scalability, security and reliability of Azure into the quantum computing world, providing access to a diverse set of quantum services, ranging from pre-built solutions to software and quantum hardware. Azure Quantum enables multiple paths for developers to prepare, explore and build apps to solve their most complex problems. Hear about the latest progress as Azure Quantum reaches important release milestones and learn about new Microsoft Learn resources

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Building on Azure Quantum — May 20 8:30 am – 9:00 am CEST

Speaker: Bettina Heim

Quantum computing continues to evolve and mature, driving real impact today for organizations around the world. Azure Quantum extends the scalability, security and reliability of Azure into the quantum computing world, providing access to a diverse set of quantum services, ranging from pre-built solutions to software and quantum hardware. Azure Quantum enables multiple paths for developers to prepare, explore and build apps to solve their most complex problems. Hear about the latest progress as Azure Quantum reaches important release milestones and learn about new Microsoft Learn resources

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Building on Azure Quantum — May 20 11:45 pm – 12:15 pm CEST

Speaker: Bettina Heim

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For certificate 1

- Complete any one quantum kata
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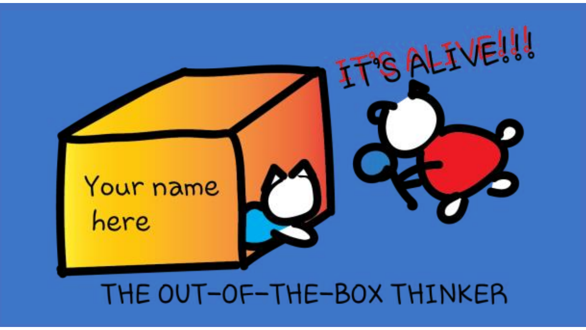
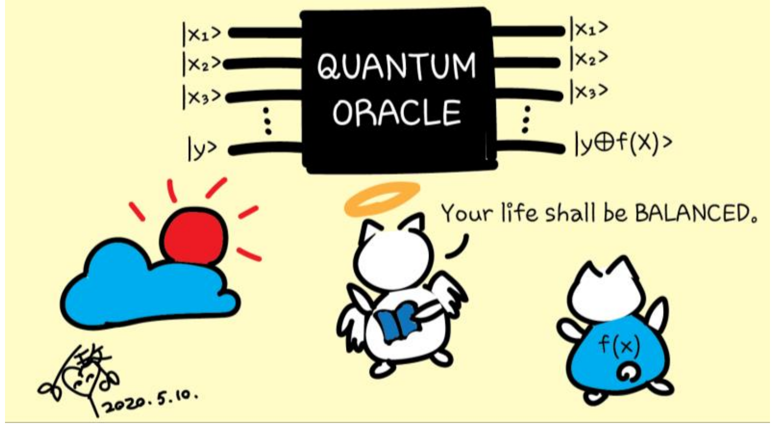
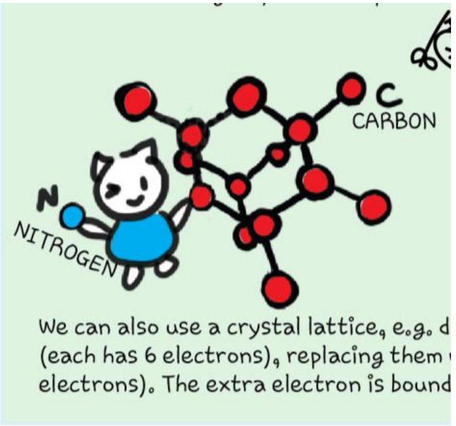
For certificate 2



- 1. Who came up with the term "Quantum Oracle"?
- 2. Who is this on page 6?
- 3. Who is this on page 26?





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