Quantum Computing Summative Assignment

hzwr87

1. Quantum States

   (a) $i|0\rangle$ and $\frac{1+i}{\sqrt{2}}|0\rangle$ are in the same quantum state, as the direction, $|0\rangle$, is common to both.

   (b) $\frac{1}{\sqrt{2}}(|1\rangle - |0\rangle)$ and $\frac{1}{\sqrt{2}}(|+\rangle - |-\rangle)$ are not in the same quantum state, as converting $\frac{1}{\sqrt{2}}(|+\rangle - |-\rangle)$ into the standard basis gives $|1\rangle$, as shown below, which is not in the same state as $\frac{1}{\sqrt{2}}(|1\rangle - |0\rangle)$.

$$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$

$$|-\rangle = \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle)$$

$$\frac{1}{\sqrt{2}}(|+\rangle - |-\rangle) = \frac{1}{\sqrt{2}}(\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) - \frac{1}{\sqrt{2}}(|0\rangle - |1\rangle))$$

$$\frac{1}{\sqrt{2}}(|+\rangle - |-\rangle) = \frac{1}{2}(|0\rangle + |1\rangle) - \frac{1}{2}(|0\rangle - |1\rangle)$$

$$\frac{1}{\sqrt{2}}(|+\rangle - |-\rangle) = \frac{1}{2}|0\rangle + \frac{1}{2}|1\rangle - \frac{1}{2}|0\rangle + \frac{1}{2}|1\rangle$$

$$\frac{1}{\sqrt{2}}(|+\rangle - |-\rangle) = |1\rangle$$

   (c) $(\frac{\sqrt{3}}{2}|0\rangle + \frac{1}{2}|1\rangle)$ and $(\frac{\sqrt{6}+\sqrt{2}}{4}|+\rangle + \frac{\sqrt{6}-\sqrt{2}}{4}|-\rangle)$ are in the same quantum state as converting $(\frac{\sqrt{6}+\sqrt{2}}{4}|+\rangle + \frac{\sqrt{6}-\sqrt{2}}{4}|-\rangle)$ to the standard basis gives $(\frac{\sqrt{3}}{2}|0\rangle + \frac{1}{2}|1\rangle)$.

$$(\frac{\sqrt{6}+\sqrt{2}}{4}|+\rangle + \frac{\sqrt{6}-\sqrt{2}}{4}|-\rangle) = (\frac{\sqrt{6}+\sqrt{2}}{4\sqrt{2}}(|0\rangle + |1\rangle)) + \frac{\sqrt{6}-\sqrt{2}}{4\sqrt{2}}(|0\rangle - |1\rangle))$$

$$(\frac{\sqrt{6}+\sqrt{2}}{4}|+\rangle + \frac{\sqrt{6}-\sqrt{2}}{4}|-\rangle) = (\frac{2\sqrt{6}}{4\sqrt{2}}|0\rangle + \frac{2\sqrt{2}}{4\sqrt{2}}|1\rangle)$$

$$(\frac{\sqrt{6}+\sqrt{2}}{4}|+\rangle + \frac{\sqrt{6}-\sqrt{2}}{4}|-\rangle) = (\frac{\sqrt{6}}{2\sqrt{2}}|0\rangle + \frac{1}{2}|1\rangle)$$

$$(\frac{\sqrt{6}+\sqrt{2}}{4}|+\rangle + \frac{\sqrt{6}-\sqrt{2}}{4}|-\rangle) = (\frac{\sqrt{3}}{2}|0\rangle + \frac{1}{2}|1\rangle)$$

2. State Measurements

   (a) Given that $\frac{1}{2}|0\rangle - \frac{\sqrt{3}}{2}|1\rangle$ is being measured in the standard basis, the probability of measuring a $|0\rangle$ is $\frac{1}{2}^2 = \frac{1}{4}$, while the probability of measuring a $|1\rangle$ is $\frac{\sqrt{3}}{2}^2 = \frac{3}{4}$. These are the only two possible measured states as measurement is being done relative to the standard basis, and their probability is given by the square of the magnitude of the direction of each possible state.

(b) Given that $\frac{3i}{4}|+\rangle - \frac{\sqrt{7}}{4}|-\rangle$ is being measured in the standard basis, the probability of measuring a $|0\rangle$ is $|\frac{3i-7}{4\sqrt{2}}| = \frac{1}{2}$, while the probability of measuring a $|1\rangle$ is $|\frac{3i+7}{4\sqrt{2}}| = \frac{1}{2}$.

$$\frac{3i}{4}|+\rangle - \frac{\sqrt{7}}{4}|-\rangle = \frac{3i}{4\sqrt{2}}(|0\rangle + |1\rangle) - \frac{\sqrt{7}}{4\sqrt{2}}(|0\rangle - |1\rangle)$$

$$\frac{3i}{4}|+\rangle - \frac{\sqrt{7}}{4}|-\rangle = \frac{3i}{4\sqrt{2}}(|0\rangle + |1\rangle) - \frac{\sqrt{7}}{4\sqrt{2}}(|0\rangle - |1\rangle)$$

$$\frac{3i}{4}|+\rangle - \frac{\sqrt{7}}{4}|-\rangle = \frac{3i-\sqrt{7}}{4\sqrt{2}}|0\rangle + \frac{3i+\sqrt{7}}{4\sqrt{2}}|1\rangle$$

$$|\frac{3i-\sqrt{7}}{4\sqrt{2}}|^2 = (\frac{-\sqrt{7}}{4\sqrt{2}})^2 + (\frac{3}{4\sqrt{2}})^2 = \frac{7}{32} + \frac{9}{32} = \frac{1}{2}$$

$$|\frac{3i+\sqrt{7}}{4\sqrt{2}}|^2 = (\frac{\sqrt{7}}{4\sqrt{2}})^2 + (\frac{3}{4\sqrt{2}})^2 = \frac{7}{32} + \frac{9}{32} = \frac{1}{2}$$

(c) Given that $\frac{1}{\sqrt{2}}(|1\rangle - |0\rangle)$ is being measured in the Hadamard basis, the probability of a $|+\rangle$ is 0, and the probability of a $|-\rangle$ is 1.

$$|0\rangle = \frac{1}{\sqrt{2}}(|+\rangle + |-\rangle)$$

$$|1\rangle = \frac{1}{\sqrt{2}}(|+\rangle - |-\rangle)$$

$$\frac{1}{\sqrt{2}}(|1\rangle - |0\rangle) = \frac{1}{2}(|+\rangle - |-\rangle - |+\rangle - |-\rangle)$$

$$\frac{1}{\sqrt{2}}(|1\rangle - |0\rangle) = \frac{1}{2}(-2|-\rangle)$$

$$\frac{1}{\sqrt{2}}(|1\rangle - |0\rangle) = -|-\rangle$$

3. Key Exchange - in this question qubits presented in the form $\binom{+}{-}$ have a probability of 50% of being a $|+\rangle$ and a probability of 50% of being a $|-\rangle$. The same applies for the standard basis.

(a) Steps:

i. Alice generates random string 0101 1101 0100 1110
ii. Alice chooses bases SHHH SHSS HSHS HHSH
iii. Alice encodes and sends message $|0-+-\rangle|1-01\rangle|+1+0\rangle|--1+\rangle$
iv. Bob chooses bases HHSH HSSS HSHS SSSH
v. Bob receives message and decodes it$|\binom{+}{-} - \binom{0}{1}-\rangle|\binom{+}{-}\binom{0}{1}01\rangle|+1+0\rangle|\binom{0}{1}\binom{0}{1}1+\rangle$
vi. Bob announces that he has received and decoded the message, and announces what bases he used to decode.
vii. Alice sends the bases she used to encode.
viii. Alice and Bob agree on the string for which they have used the same bases - in this case this is xHxH xxSS HSHS xxSH, (where x means that the bit has been discarded), which gives the qubits$|--01+1+01+\rangle$
ix. They compare the last 4 bits as check bits $|+01+\rangle$ to check for tampering, and will find none in this case. This string will be 0010.
x. Their shared secret key with then be 110101.

(b) Steps:

i. Alice generates random string 0101 1101 0100 1110
ii. Alice chooses bases SHHH SHSS HSHS HHSH
iii. Alice encodes and sends message $|0-+-\rangle|1-01\rangle|+1+0\rangle|--1+\rangle$

iv. Eve chooses bases SHSS HHSH HHHH SHSS

v. Eve measures the message as$|0 - \binom{0}{1}\binom{0}{1}\rangle|\binom{+}{-} - 0\binom{+}{-}\rangle|+\binom{+}{-} + \binom{+}{-}\rangle|\binom{0}{1} - 1\binom{0}{1}\rangle$ and sends on to Bob

vi. Bob chooses bases HHSH HSSS HSHS SSSH

vii. Bob decodes the message as $|\binom{+}{-} - \binom{0}{1}\binom{+}{-}\rangle|\binom{+}{-}\binom{0}{1}0\binom{0}{1}\rangle|+\binom{0}{1} + \binom{0}{1}\rangle|\binom{0}{1}\binom{0}{1}1\binom{+}{-}\rangle$

viii. Alice and Bob agree on the string for which they have used the same bases - in this case this is xHxH xxSS HSHS xxSH, (where x means that the bit has been discarded), which gives the qubits $|-\binom{+}{-}0\binom{0}{1} + \binom{0}{1} + \binom{0}{1}1\binom{0}{1}\rangle$, and the string $1\binom{0}{1}0\binom{0}{1}0\binom{0}{1}0\binom{0}{1}1\binom{0}{1}$

ix. Alice and Bob compare the last 4 bits as check bits $|+\binom{0}{1}1\binom{0}{1}\rangle$, or string $0\binom{0}{1}1\binom{0}{1}$, to check for tampering. In this case 2 of the qubits could be different, and we know which bases Eve has used and what the check bits were, so the probability she is not detected in this particular case is $\frac{1}{2}\times\frac{1}{2} = \frac{1}{4}$, so the probability she is detected is $\frac{3}{4}$. In a more general case , if we did not know what the check bits would be, then the probability of Eve getting away with it is ${\frac{3}{4}}^4 = \frac{81}{256}$, meaning that the probability of her being detected would be $\frac{175}{256}$.

x. If she was detected then they start again, if she was not then the shared secret key will also be different with probability $\frac{7}{8}$, so communication is unlikely to be successful.

4. Polaroid Filters on Single Photon

(a) As this does not require a change in basis, the probabilities of P and A are simply the squares of the magnitudes of the amplitudes in each direction, so Probability P is ${\frac{1}{\sqrt{2}}}^2 = \frac{1}{2}$, whereas the Probability A is ${\frac{1}{\sqrt{2}}}^2 = \frac{1}{2}$.

(b) We must first determine what $|0\rangle$ and $|1\rangle$ in terms of the basis $\{|u\rangle, |u\rangle^{\perp}\}$, and then apply this conversion to the original vector $\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$ to get the probabilities of pass through and absorbed. Probability P $(\frac{1+\sqrt{3}}{2\sqrt{2}})^2 = 0.933$, Probability A $(\frac{1-\sqrt{3}}{2\sqrt{2}})^2 = 0.067$. The calculations for this have been done using the numerical values of sin and cos, as shown below.

$$|0\rangle = \frac{1}{2}|u\rangle - \frac{\sqrt{3}}{2}|u^{\perp}\rangle$$

$$|1\rangle = \frac{\sqrt{3}}{2}|u\rangle + \frac{1}{2}|u^{\perp}\rangle$$

$$\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) = \frac{1}{\sqrt{2}}(\frac{1}{2}|u\rangle - \frac{\sqrt{3}}{2}|u^{\perp}\rangle + \frac{\sqrt{3}}{2}|u\rangle + \frac{1}{2}|u^{\perp}\rangle)$$

$$\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) = \frac{1+\sqrt{3}}{2\sqrt{2}}|u\rangle + \frac{1-\sqrt{3}}{2\sqrt{2}}|u^{\perp}\rangle$$

(c) Here, we apply the same method as (b), but to the basis$\{|w\rangle, |w\rangle^{\perp}\}$. Probability P $(\frac{-1+\sqrt{3}}{2\sqrt{2}})^2 = 0.067$, Probability A $(\frac{1+\sqrt{3}}{2\sqrt{2}})^2 = 0.933$.

$$|0\rangle = -\frac{1}{2}|u\rangle + \frac{\sqrt{3}}{2}|u^{\perp}\rangle$$

$$|1\rangle = \frac{\sqrt{3}}{2}|u\rangle + \frac{1}{2}|u^{\perp}\rangle$$

$$\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) = \frac{1}{\sqrt{2}}(-\frac{1}{2}|u\rangle + \frac{\sqrt{3}}{2}|u^{\perp}\rangle + \frac{\sqrt{3}}{2}|u\rangle + \frac{1}{2}|u^{\perp}\rangle)$$

$$\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) = \frac{-1+\sqrt{3}}{2\sqrt{2}}|u\rangle + \frac{1+\sqrt{3}}{2\sqrt{2}}|u^{\perp}\rangle$$

5. Polaroid filters on EPR pairs. In this question $|v\rangle = \frac{1}{2}(|00\rangle + |11\rangle)$

(a) Probability P is $\frac{1}{2}$, Probability A is $\frac{1}{2}$

$$Proj(|v\rangle \to S1) = \frac{1}{\sqrt{2}}|00\rangle$$

$$Prob(P) = \frac{1}{\sqrt{2}}^{2} = \frac{1}{2}$$

$$Proj(|v\rangle \to S2) = \frac{1}{\sqrt{2}}|11\rangle$$

$$Prob(A) = \frac{1}{\sqrt{2}}^{2} = \frac{1}{2}$$

(b) Probability P is $\frac{1}{2}$, Probability A is $\frac{1}{2}$

$$Proj(|v\rangle \to S1) = \frac{cos60}{\sqrt{2}}|u0\rangle + \frac{sin60}{\sqrt{2}}|u1\rangle$$

$$Prob(P) = |\sqrt{\frac{cos60}{\sqrt{2}}^{2} + \frac{sin60}{\sqrt{2}}^{2}}|^{2} = \frac{1}{2}$$

$$Proj(|v\rangle \to S2) = \frac{-cos30}{\sqrt{2}}|u^{\perp}0\rangle + \frac{sin30}{\sqrt{2}}|u^{\perp}1\rangle$$

$$Prob(A) = |\sqrt{\frac{-cos30}{\sqrt{2}}^{2} + \frac{sin30}{\sqrt{2}}^{2}}|^{2} = \frac{1}{2}$$

(c) Probability P is $\frac{1}{2}$, Probability A is $\frac{1}{2}$

$$Proj(|v\rangle \to S1) = \frac{-cos60}{\sqrt{2}}|w0\rangle + \frac{sin60}{\sqrt{2}}|w1\rangle$$

$$Prob(P) = |\sqrt{\frac{-cos60}{\sqrt{2}}^{2} + \frac{sin60}{\sqrt{2}}^{2}}|^{2} = \frac{1}{2}$$

$$Proj(|v\rangle \to S2) = \frac{cos30}{\sqrt{2}}|w^{\perp}0\rangle + \frac{sin30}{\sqrt{2}}|w^{\perp}1\rangle$$

$$Prob(A) = |\sqrt{\frac{cos30}{\sqrt{2}}^{2} + \frac{sin30}{\sqrt{2}}^{2}}|^{2} = \frac{1}{2}$$

(d) When we are measuring both photons, we must consider the outcomes PP, PA, AP and AA. The respective probabilities of these outcomes are $\frac{1}{2}, 0, 0, \frac{1}{2}$.

i. $PP = S1 = |u\rangle \otimes |u\rangle$

$$|PP\rangle = cos60|0\rangle + sin60|1\rangle \otimes cos60|0\rangle + sin60|1\rangle$$

$$|PP\rangle = cos^{2}60|00\rangle + cos60sin60|01\rangle + cos60sin60|10\rangle + sin^{2}60|11\rangle$$

$$Proj(|v\rangle \to S1) = |v\rangle.|PP\rangle|PP\rangle$$

$$Prob(PP) = ||v\rangle.|PP\rangle|^{2} = |\frac{cos^{2}60|00\rangle + sin^{2}60|11\rangle}{\sqrt{2}}|^{2}$$

$$Prob(PP) = \frac{1}{2}$$

ii. $PA = S2 = |u\rangle \otimes |u^{\perp}\rangle$

$$|PA\rangle = cos60|0\rangle + sin60|1\rangle \otimes -cos30|0\rangle + sin30|1\rangle$$

$$|PA\rangle = -cos60cos30|00\rangle + cos60sin30|01\rangle - cos30sin60|10\rangle + sin60sin30|11\rangle$$

$$Proj(|v\rangle \to S2) = |v\rangle.|PA\rangle|PA\rangle$$

$$Prob(PA) = ||v\rangle.|PA\rangle|^2 = |\frac{-cos60cos30|00\rangle + sin60sin30|11\rangle}{\sqrt{2}}|^2$$

$$Prob(PA) = 0$$

iii. $AP = S3 = |u^{\perp}\rangle \otimes |u\rangle$

$$|AP\rangle = -cos30|0\rangle + sin30|1\rangle \otimes cos60|0\rangle + sin60|1\rangle$$

$$|AP\rangle = -cos30cos60|00\rangle - cos30sin60|01\rangle + cos60sin30|10\rangle + sin30sin60|11\rangle$$

$$Proj(|v\rangle \to S3) = |v\rangle.|AP\rangle|AP\rangle$$

$$Prob(AP) = ||v\rangle.|AP\rangle|^2 = |\frac{-cos30cos60|00\rangle + sin30sin60|11\rangle}{\sqrt{2}}|^2$$

$$Prob(AP) = 0$$

iv. $AA = S4 = |u^{\perp}\rangle \otimes |u^{\perp}\rangle$

$$|AA\rangle = -cos30|0\rangle + sin30|1\rangle \otimes -cos30|0\rangle + sin30|1\rangle$$

$$|AA\rangle = cos^2 30|00\rangle - cos30sin30|01\rangle - cos30sin30|10\rangle + sin^2 30|11\rangle$$

$$Proj(|v\rangle \to S4) = |v\rangle.|AA\rangle|AA\rangle$$

$$Prob(AA) = ||v\rangle.|AA\rangle|^2 = |\frac{cos^2 30|00\rangle + sin^2 30|11\rangle}{\sqrt{2}}|^2$$

$$Prob(AA) = \frac{1}{2}$$

(e) When we are measuring both photons, we must consider the outcomes PP, PA, AP and AA. The respective probabilities of these outcomes are $\frac{1}{8}, \frac{3}{8}, \frac{3}{8}, \frac{1}{8}$.

i. $PP = S1 = |u\rangle \otimes |0\rangle$

$$|PP\rangle = cos60|00\rangle + sin60|10\rangle$$

$$Proj(|v\rangle \to S1) = |v\rangle.|PP\rangle|PP\rangle$$

$$Prob(PP) = ||v\rangle.|PP\rangle|^2 = |\frac{cos60|00\rangle}{\sqrt{2}}|^2$$

$$Prob(PP) = \frac{1}{8}$$

ii. $PA = S2 = |u\rangle \otimes |1\rangle$

$$|PA\rangle = cos60|01\rangle + sin60|11\rangle$$

$$Proj(|v\rangle \to S2) = |v\rangle.|PA\rangle|PA\rangle$$

$$Prob(PA) = ||v\rangle.|PA\rangle|^2 = |\frac{sin60|00\rangle}{\sqrt{2}}|^2$$

$$Prob(PA) = \frac{3}{8}$$

iii. $AP = S3 = |u^{\perp}\rangle \otimes |0\rangle$

$$|AP\rangle = -cos30|00\rangle + sin30|10\rangle$$

$$Proj(|v\rangle \to S3) = |v\rangle.|AP\rangle|AP\rangle$$

$$Prob(AP) = ||v\rangle.|AP\rangle|^2 = |\frac{-cos30|00\rangle}{\sqrt{2}}|^2$$

$$Prob(AP) = \frac{3}{8}$$

iv. $AA = S4 = |u^{\perp}\rangle \otimes |1\rangle$

$$|AA\rangle = -cos30|01\rangle + sin30|11\rangle$$

$$Proj(|v\rangle \rightarrow S4) = |v\rangle.|AA\rangle|AA\rangle$$

$$Prob(AA) = ||v\rangle.|AA\rangle|^2 = |\frac{sin30|11\rangle}{\sqrt{2}}|^2$$

$$Prob(AA) = \frac{1}{8}$$

6. Quantum Supremacy

Quantum supremacy refers to the ability of quantum computers to outperform classical computers and perform incredibly complex calculations. Physicists have predicted that a quantum computer with 50 qubits would be able to outperform the world's most powerful supercomputers. However, this is a very difficult thing to achieve, as quantum states are incredible delicate objects, and one of the key challenges associated with quantum computer development is the isolation of quantum computers and their associated quantum processing machinery from the outside world. This has not yet been properly solved, so it would seem that an effective demonstration of quantum supremacy is still some distance in the future. However, Charles Neill at the University of California Santa Barbara and Pedram Roushan at Google claim to know how a demonstration of quantum supremacy can be achieved[5, 2], by shifting focus away from a general purpose quantum computer, and towards one the is built to solve one very specific problem. If it can provably solve this better than a classical computer can, then they will be able to achieve the first demonstration of quantum supremacy.

Before moving on to examine the suggested machine for demonstrating quantum supremacy, we must establish why quantum computers should have an advantage over conventional computers. The advantage of qubits is that they can be both representing a 0 and a 1 at the same time, as they exist in a superposition of the two states. This means that 2 qubits can represent 4 numbers at the same time, 3 qubits can represent 8 numbers and 4 qubits can represent 16 numbers. This trend continues exponentially, and the 50 qubit system that physicists predict will outperform classical computers can represent 10,000,000,000,000,000 numbers at the same time, which would require petabyte scale memory to store in a classical computer.[2]

This is how Neill and Roushan [5, 2] plan to demonstrate quantum supremacy, by creating a system that can support 49 qubits in superposition. For this proposed system, the ability to perform calculations is not necessary, it simply needs to be able to reliably explore the space of the 49 qubit superposition. The quantum system being proposed for use here is based on a superconducting qubit. This is a loop of metal that has been cooled to a low temperature, and if a current is made to flow through this loop it will then flow forever. This is the quantum phenomenon of superconductivity, and it allows the current to flow in one direction and the other at the same time, which is what enables this superconducting loop to act as a qubit and simultaneously represent 0 and 1.

There are other ways of creating qubits that are currently being experimented with by physicists, such as the polarisation of photons vertically and horizontally, spinning atomic nuclei up and down at the same time or sending electrons along two separate paths at the same time. The advantage of using the superconductivity method is that they are comparatively easy to control and measure, and can also be linked to their neighbours if they are put into a sufficiently high energy state. This interaction enables the creation of much larger superpositions. A proof of concept chip has been constructed with nine neighbouring superconducting loops, and it has been proven that this can represent 512 numbers simultaneously[5]. This chip is shown in the figure below.

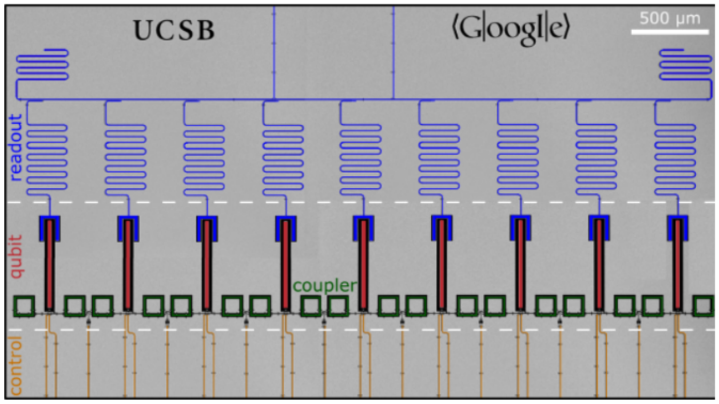

Figure 1: “Device: nine-qubit array. Optical micrograph of the device. Gray regions are aluminum, dark regions are where the aluminum has been etched away to define features. Colours have been added to distinguish readout circuitry, qubits, couplers and control wiring.”[5]

This is far from sufficient levels of complexity to be a proof of quantum supremacy, but it does give promising indications of things to come, as the team performing the experiments in [5] showed that the errors do not scale rapidly in these superconducting chips, which was the fear among theoretical physicists, who predicted that the errors would increase exponentially in quantum systems as well as the quantity of numbers that they will be able to simultaneously represent. The authors of [5] claim that this design will enable meaningful superposition of up to 60 qubits. This work seems to be our best hope for a demonstration of quantum supremacy in the near future, as if this claim holds, we can expect a demonstration of quantum supremacy in the near future, but if it does not, then it may be the case that a proof of effective quantum supremacy is still a very long way off.

References

[1] Sergio Boixo, Sergei V Isakov, Vadim N Smelyanskiy, Ryan Babbush, Nan Ding, Zhang Jiang, Michael J Bremner, John M Martinis, and Hartmut Neven. Characterizing Quantum Supremacy in Near-Term Devices. 2016.

[2] Emerging Technology from the arXiv. Google Reveals Blueprint for Quantum Supremacy, 2017.

[3] Jeremy Kahn. Google’s Quantum Supremacy Moment May Not Mean What You Think - Bloomberg, 2017.

[4] Karla Lant. Google Just Revealed How They’ll Build Quantum Computers, 2017.

[5] C Neill, P Roushan, K Kechedzhi, S Boixo, S V Isakov, V Smelyanskiy, R Barends, B Burkett, Y. Chen, Z Chen, B Chiaro, A Dunsworth, A Fowler, B Foxen, R Graff, E Jeffrey, J Kelly, E Lucero, A Megrant, J Mutus, M Neeley, C Quintana, D Sank, A Vainsencher, J Wenner, T C White, H Neven, and J M Martinis. A blueprint for demonstrating quantum supremacy with superconducting qubits. 2017.

[6] Science Alert. We’re About to Cross the "Quantum Supremacy" Limit in Computing, 2017.