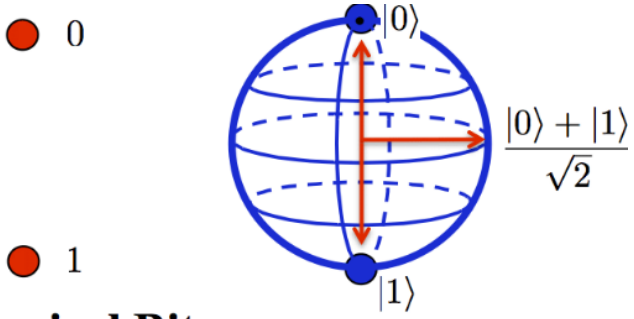
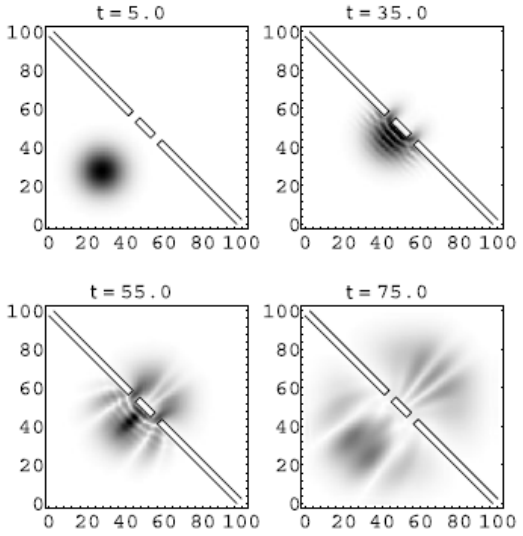
Kuantum Hesaplama ve Teknolojileri Çalıştayı

Gürültülü Bölgede Kuantum Hesaplama

Deniz Türkpençe

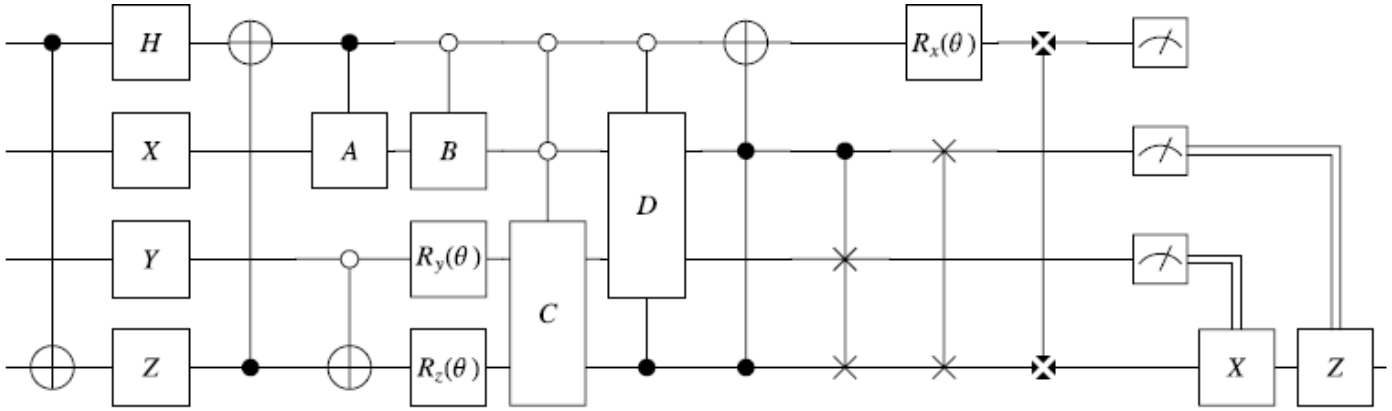
Klasik bit, Kubit





A particle impinging on a double slit seen at four different times $t = 5.0, 35.0, 55.0$ and 75.0.

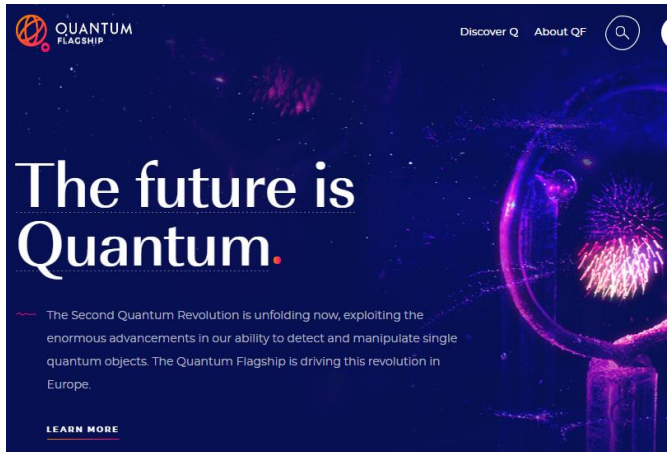
Klasik : 0 ya da 1
Kuantum : 0 ya da 1 ya da **her ikisi**



Kuantum teknolojileri kuantum mekaniğinin kendine has özellikleri kullanarak klasik olasılık ve istatistik kavramlarının izin vermediği bazı olanakları kullanabilme yetisine dayanan kaynaklarla geliştirilen kritik bir teknolojidir.

Kuantum kaynaklar:

Kuantum eşevrelilik : (Kuantum algoritmalar, kuantum termodinamik)
Kuantum dolanıklık : (Kuantum güvenli haberleşme, kuantum anahtar dağıtımı, Kuantum internet, kuantum ağ, kuantum algılama/radar)
Kuantum çökme : Kuantum kriptoloji, kuantum rassal sayı üreteçleri
Kopyalama yasağı : Kuantum güvenli haberleşme, Kuantum kriptoloji



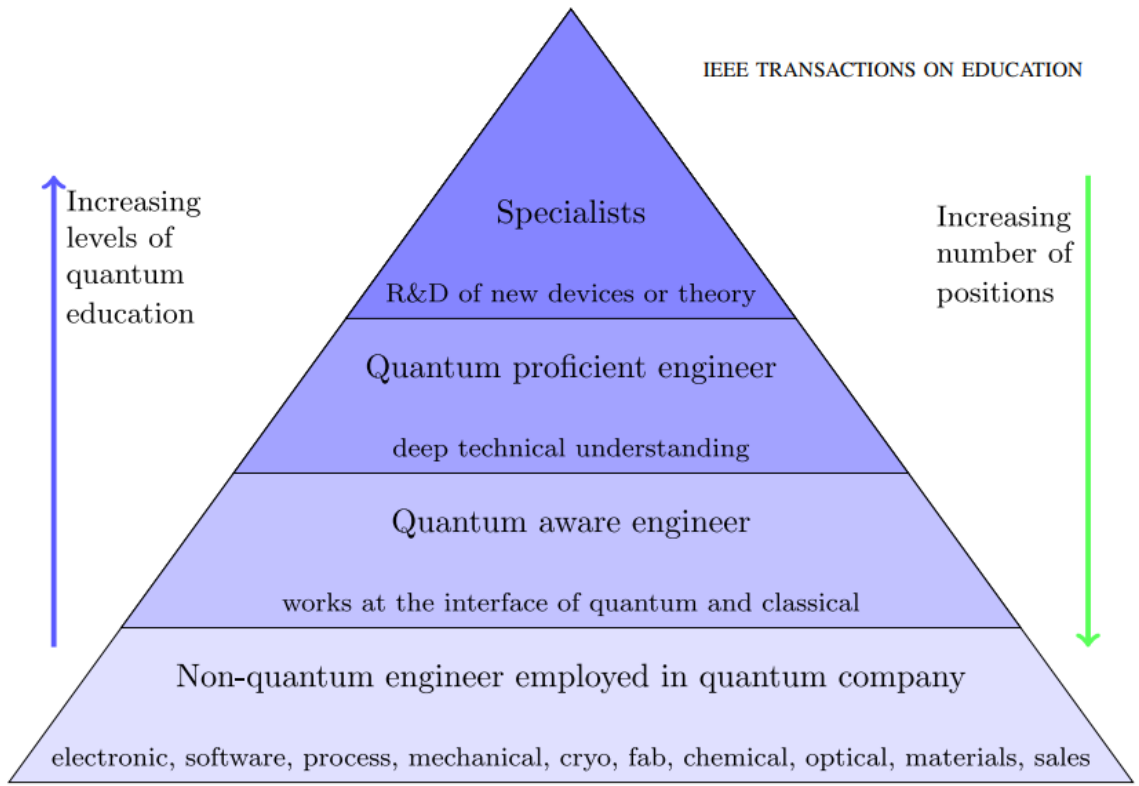
İlk defa Ekim 2018'de toplanan kuantum amiral gemisi adlı AB girişimi kuantum teknolojilerini aşağıdaki başlıklar altında toplamıştır.

List of contents

qt.eu/app/uploads/2018/04/QT-Roadmap-2016.pdf

Building a Quantum Engineering Undergraduate Program

Abraham Asfaw, Alexandre Blais, Kenneth R. Brown, Jonathan Candelaria, Christopher Cantwell, Lincoln D. Carr, *Senior Member, IEEE*, Joshua Combes, Dripto M. Debroy, John M. Donohue, Sophia E. Economou, Emily Edwards, Michael F. J. Fox, Steven M. Girvin, Alan Ho, Hilary M. Hurst, Zubin Jacob, Blake R. Johnson, Ezekiel Johnston-Halperin, Robert Joynt, Eliot Kapit, Judith Klein-Seetharaman, Martin Laforest, H. J. Lewandowski, Theresa W. Lynn, Corey Rae H. McRae, Celia Merzbacher, Spyridon Michalakis, Prineha Narang, William D. Oliver, Jens Palsberg, David P. Pappas, Michael G. Raymer, David J. Reilly, Mark Saffman, Thomas A. Searles, Jeffrey H. Shapiro, and Chandralekha Singh

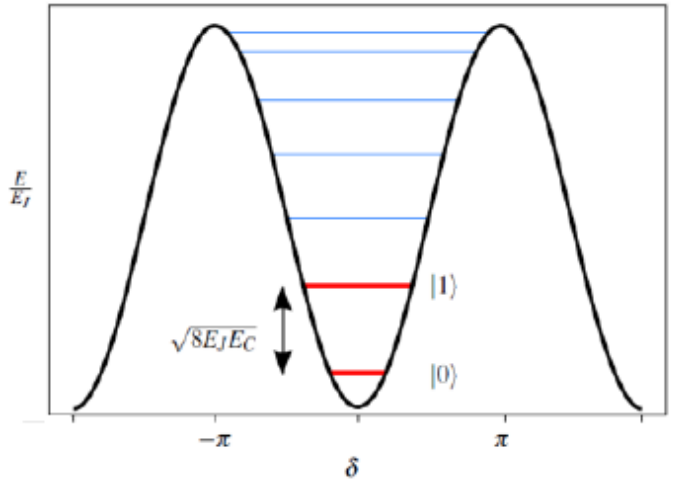


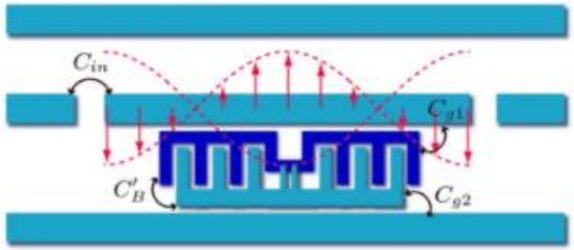
Material System	$\|0\rangle$	$\|1\rangle$
Ion traps		
Defects in solids		
Semiconductor quantum dot		
Superconducting		
Topological nanowire		

Material systems used to build qubits. Source: Levy Research 2013.*

devopedia.org/quantum-computing#Gumann-2019

- (Süperiletken transmon kubitler)

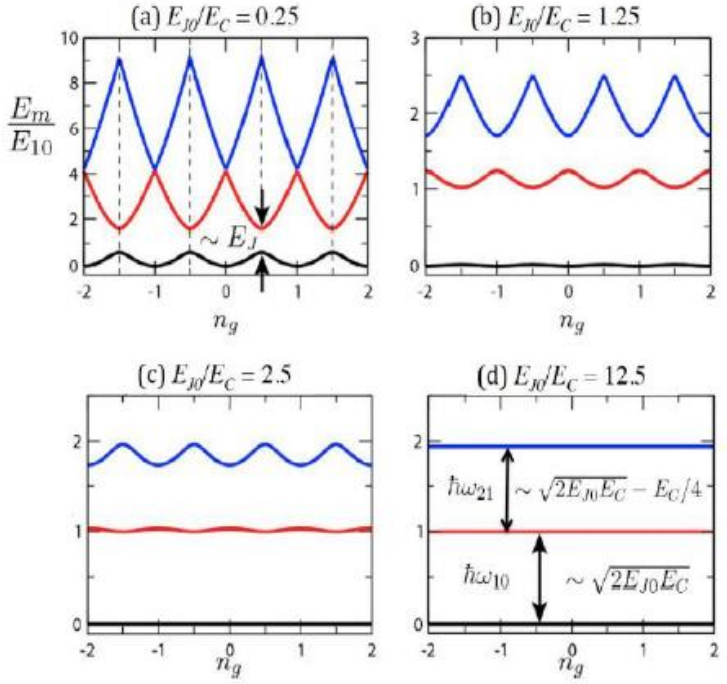




[Nakahara M., Ohmi T.Quantum Computing from linear algebra to physical realizations, 1st ed., Taylor &Francis, Osaka,2008.]

$$H = 4E_C(\hat{n} - n_g)^2 - E_J cos\hat{\phi}$$

$$H = \sqrt{8E_CE_J}b^\dagger b - \frac{E_C}{2}(b^\dagger b^\dagger bb + 2b^\dagger b)$$



J. Koch, T. M. Yu, J. M. Gambetta, A. A. Houck, D. I. Schuster, J. Majer, A. Blais, M. H. Devoret, S. M. Girvin, and R. J. Schoelkopf, Charge Insensitive Qubit Design from Optimizing the Cooper-Pair Box, Phys. Rev. A **76**, 042319 (2007).

DIVINCENZO CRITERIA

REQUIREMENTS FOR THE PHYSICAL IMPLEMENTATION OF QUANTUM COMPUTATION	
D1: Scalable qubits	Scalable physical system of well-defined, characterized qubits
D2: Initialization	Prepare a simple, fiducial input state
D3: Measurement	Measure the qubit state
D4: Universal gate set	Perform a universal set of gate operations with high fidelity
D5: Coherence	Robustly represent quantum information (long coherence times)
REQUIREMENTS FOR ROUTING QUANTUM INFORMATION	
D6: Interconversion	Ability to interconvert stationary and flying qubits
D7: Communication	Ability to transmit flying qubits faithfully between two locations

arXiv:2006.02799v1 [quant-ph] 4 Jun 2020

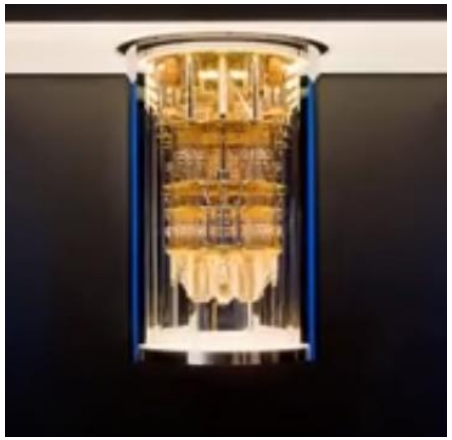
D. P. Divincenzo, “Two-Bit Gates are Universal for Quantum Computation,” Physical Review A, vol. 51, no. 2, pp. 1015–1022, Feb. 1995. [Online]. Available: http://arxiv.org/abs/cond-mat/9407022

Quantum Computing in the NISQ era and beyond

John Preskill

Institute for Quantum Information and Matter and Walter Burke Institute for Theoretical Physics,
California Institute of Technology, Pasadena CA 91125, USA
30 July 2018

Noisy Intermediate-Scale Quantum (NISQ) technology will be available in the near future. Quantum computers with 50-100 qubits may be able to perform tasks which surpass the capabilities of today's classical digital computers, but noise in quantum gates will limit the size of quantum circuits that can be executed reliably. NISQ devices will be useful tools for exploring many-body quantum physics, and may have other useful applications, but the 100-qubit quantum computer will not change the world right away — we should regard it as a significant step toward the more powerful quantum technologies of the future. Quantum technologists should continue to strive for more accurate quantum gates and, eventually, fully fault-tolerant quantum computing.



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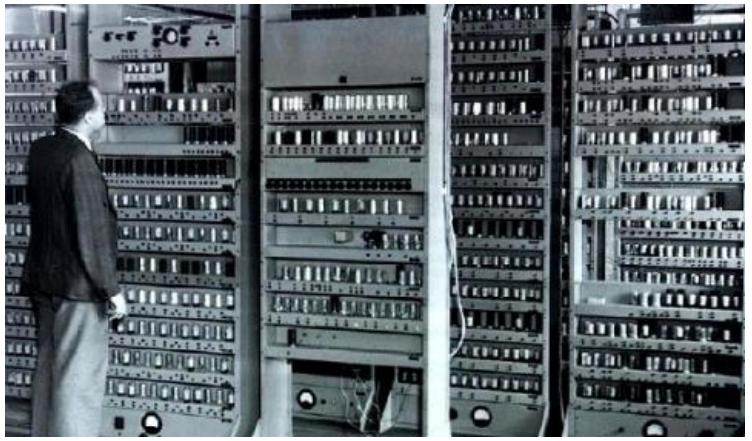
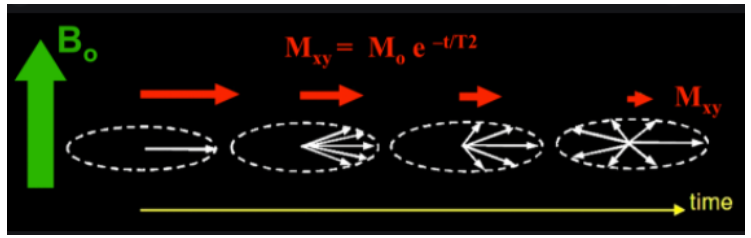
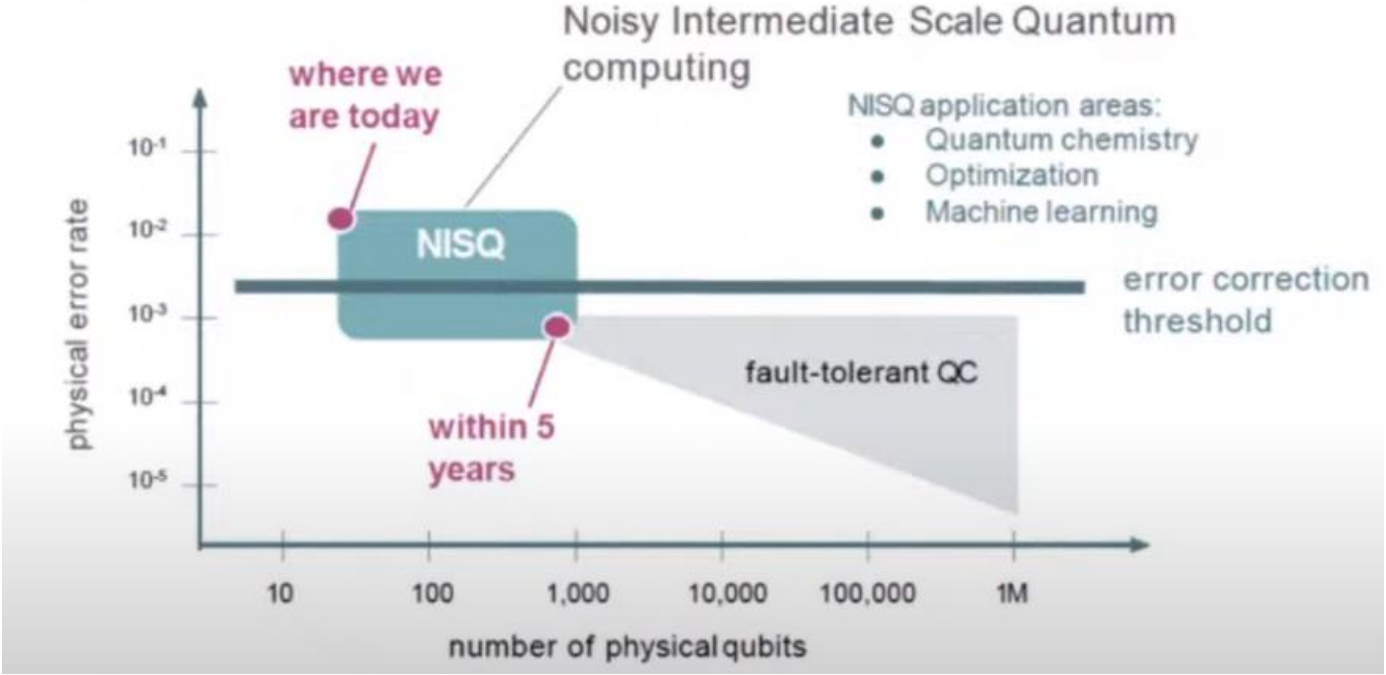




Eşevresizlik (decoherence) kuantum donamımın verimliliğini sınırlamaktadır.

Günümüzdeki kuantum bilgisayarların ‘Gürültülü ara ölçek’te yer aldığı varsayılmakta ve bilgisayarların ilk zamanlarındaki vakum tüplü hallerine benzetilmektedir.

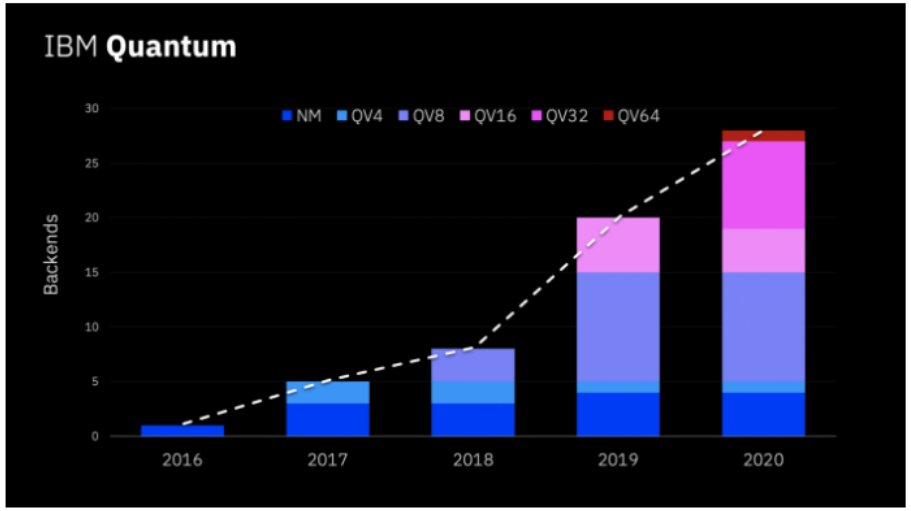


Main Sources of Error in QIP devices

Gate decomposition errors (Trotterization)
Environmental noise , decoherence, dissipation
Single qubit rotation errors
Cross talk (Unwanted interactions in multi-qubit gates)
1/f noise (phenomenon of the spectral density of a stochastic process)

Kuantum derinliği, kuantum hacmi

What Is Quantum Volume, Anyway?



A graph showing the number of IBM backends over time. Each bar is broken into the number of backends achieving each given Quantum Volume.

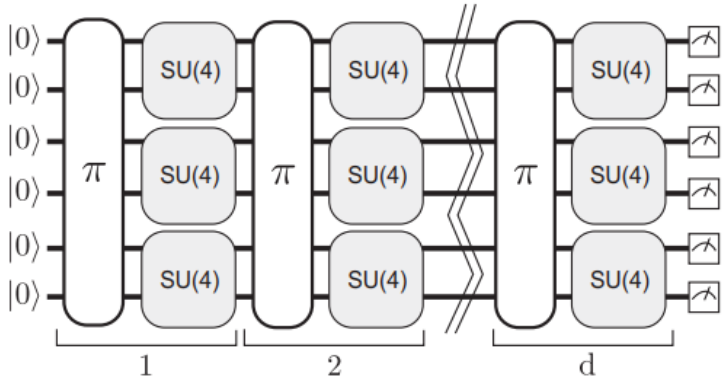
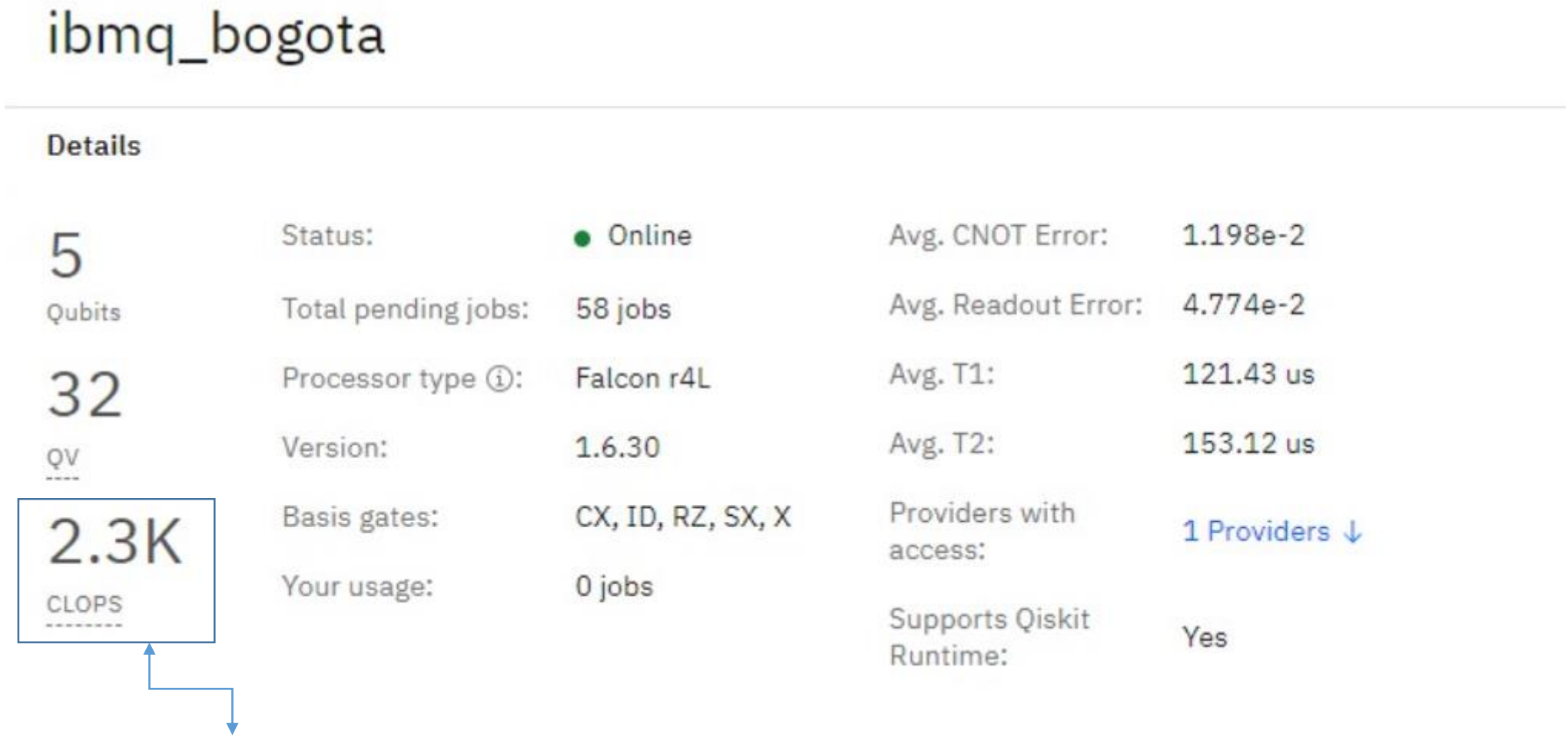


FIG. 1. Model circuit. A model circuit consists of d layers of random permutations of the qubit labels, followed by random two-qubit gates. When the circuit width m is odd, one of the qubits is idle in each layer. A final permutation can be applied to the labels of the measurement outcomes.

Kuantum Hacmi protokolü, bir kuantum bilgisayarın, cihazın kubitlerinin bir alt kümesi üzerinde paralel olarak hareket eden rastgele iki kubitlik kapılardan oluşan bir devreyi ne kadar iyi çalıştırabileceğini test eder. Bu devreler, kaç tane kubitin dahil olduğu anlamına gelen bir genişliğe ve bir derinliğe, yani kubitler eşevresizliğe uğramadan önce devrenin kapıları çalıştırabileceği ayrık zaman adımlarının sayısı anlamına gelir.

$$\log_2 V_Q = \underset{m}{\operatorname{argmax}} \min\left(m, d(m)\right)$$

https://www.ibm.com/quantum-computing/

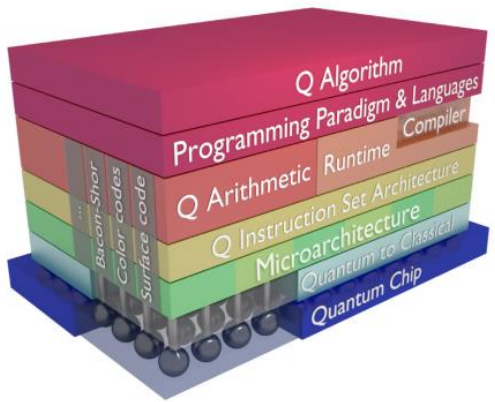


The new metric focuses on Circuit Layer Operations per Second (CLOPS-Nov-2021)

Towards a Scalable Quantum Computer

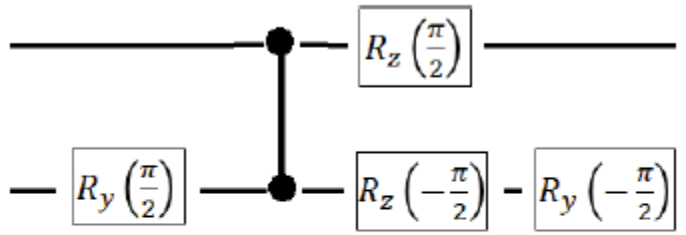
C. G. Almudever*, N. Khammassi*, L Hutin. †, M.Vinet †,
M. Babaie*, F. Sebastiano*, E. Charbon*, K. Bertels*

* Department of Quantum and Computer Engineering and QuTech, Delft University of Technology
† CEA-LETI



Overview of the quantum computer system stack.

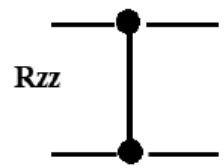
C-NOT =



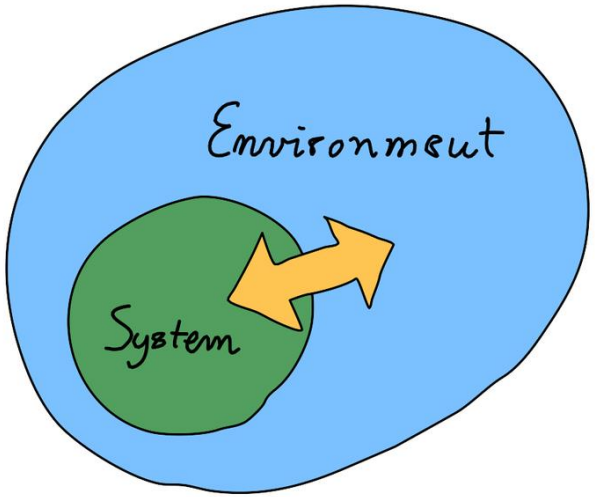
$$CNOT = (\mathbb{1} \otimes Y)(Rzz)(Z \otimes \bar{Z})(\mathbb{1} \otimes \bar{Y})$$

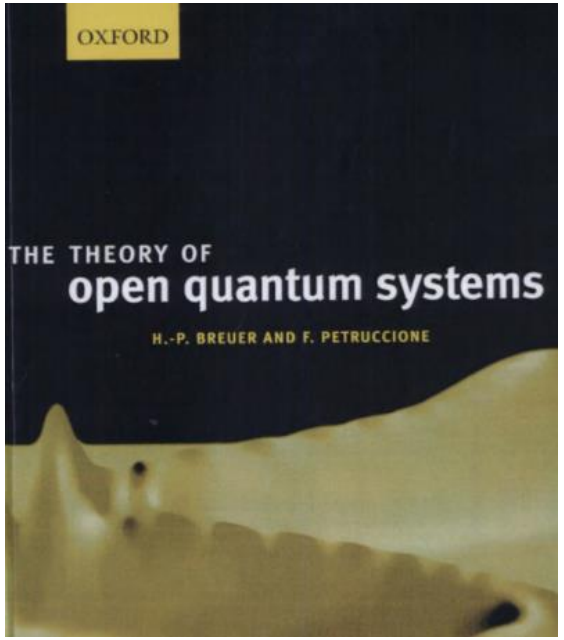
Rzz Gate:

$$R_{zz} = e^{-i\frac{\pi}{4}\sigma_z\sigma_z} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1-i & & & \\ & 1+i & & \\ & & 1+i & \\ & & & 1-i \end{pmatrix}$$



Open Quantum Systems





the *quantum master equation*

$$\frac{\mathrm{d}\hat{\rho}_{\mathrm{S}}(t)}{\mathrm{d}t} = \mathbb{L}_t[\hat{\rho}_{\mathrm{S}}(t)].$$

$$\begin{array}{ccc} \hat{\rho}_{\mathrm{SE}} & \xrightarrow[\hat{\mathcal{U}}_t]{\text{unitary evolution}} & \hat{\rho}_{\mathrm{SE}}(t) = \hat{\mathcal{U}}_t \hat{\rho}_{\mathrm{SE}} \hat{\mathcal{U}}_t^\dagger \\ \Big\downarrow \mathrm{Tr}^{(\mathrm{E})} & & \Big\downarrow \mathrm{Tr}^{(\mathrm{E})} \\ \hat{\rho}_{\mathrm{S}} & \xrightarrow[\text{reduced evolution}]{\hat{\Phi}_t} & \hat{\rho}_{\mathrm{S}}(t) = \mathrm{Tr}^{(\mathrm{E})}\left[\hat{\mathcal{U}}_t \hat{\rho}_{\mathrm{SE}} \hat{\mathcal{U}}_t^\dagger\right]. \end{array}$$

Lindblad equation

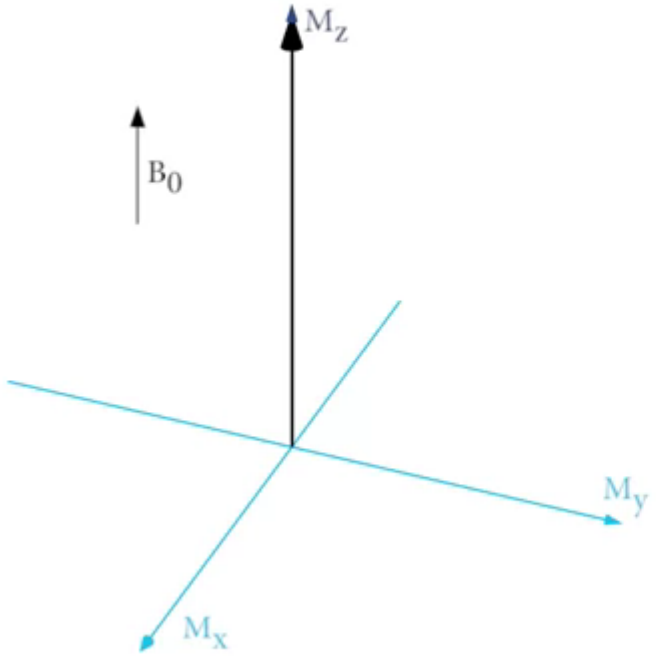
$$\mathbb{L}\left[\hat{\rho}_{\mathrm{S}}(t)\right] = -\frac{i}{\hbar}\left[\hat{H}_{\mathrm{S}}, \hat{\rho}_{\mathrm{S}}(t)\right] - \frac{i}{\hbar}\left[\Delta\hat{H}, \hat{\rho}_{\mathrm{S}}(t)\right]$$

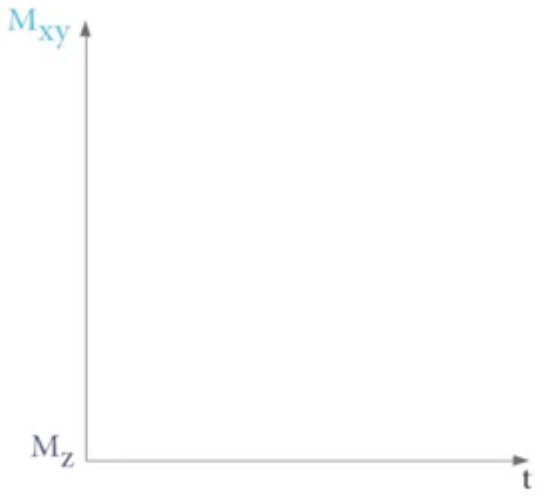
$$+ \sum_{a,b=1}^{N^2-1} K_{ab}\left[\hat{L}_a \hat{\rho}_{\mathrm{S}}(t) \hat{L}_b^\dagger - \frac{1}{2}\left\{\hat{L}_b^\dagger \hat{L}_a, \hat{\rho}_{\mathrm{S}}(t)\right\}\right]$$

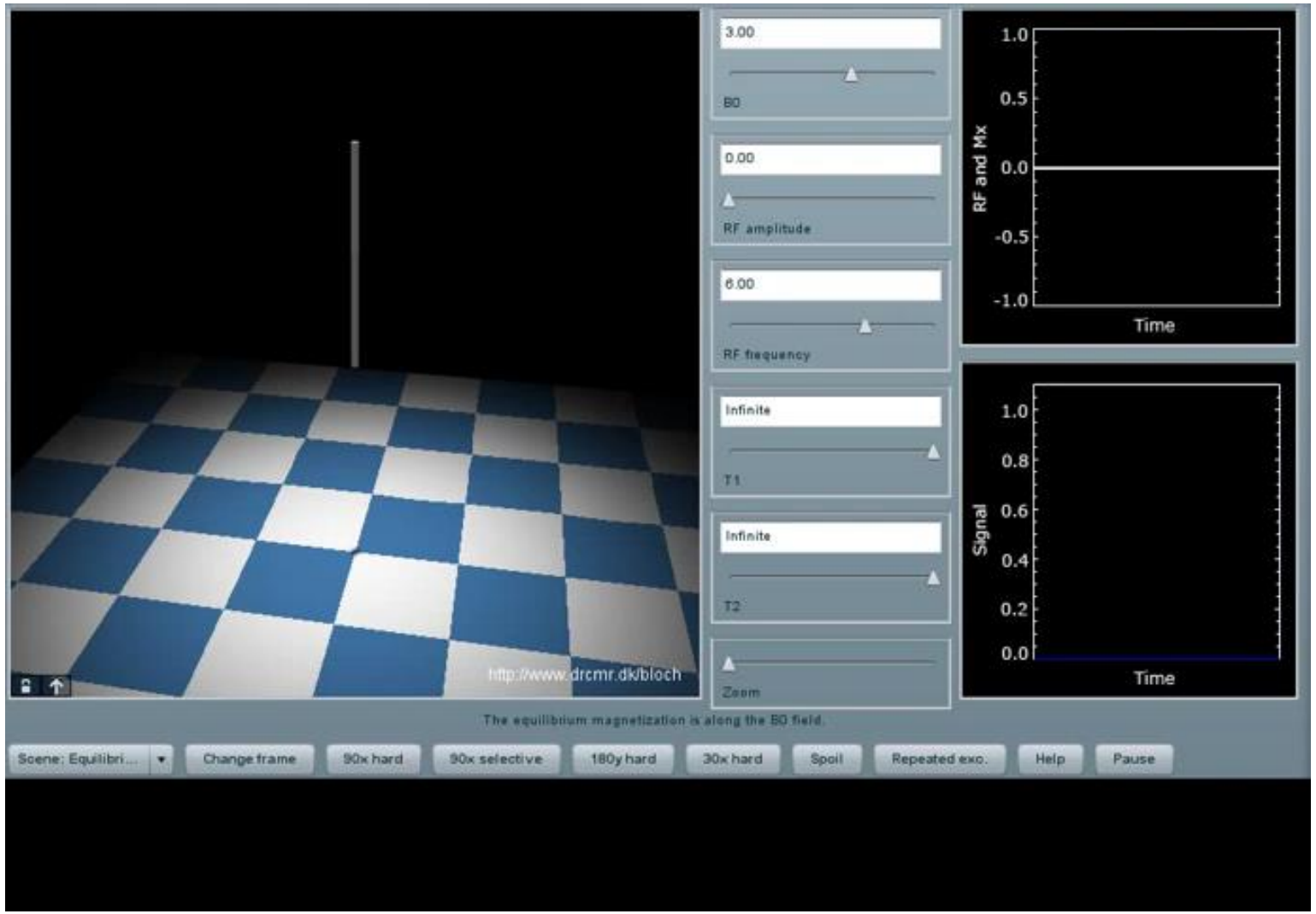
Dinamik metotlar

$$M_z(t) = M_{z,\mathrm{eq}}\left(1 - e^{-t/T_1}\right)$$

$$M_{xy}(t) = M_{xy}(0)e^{-t/T_2}$$

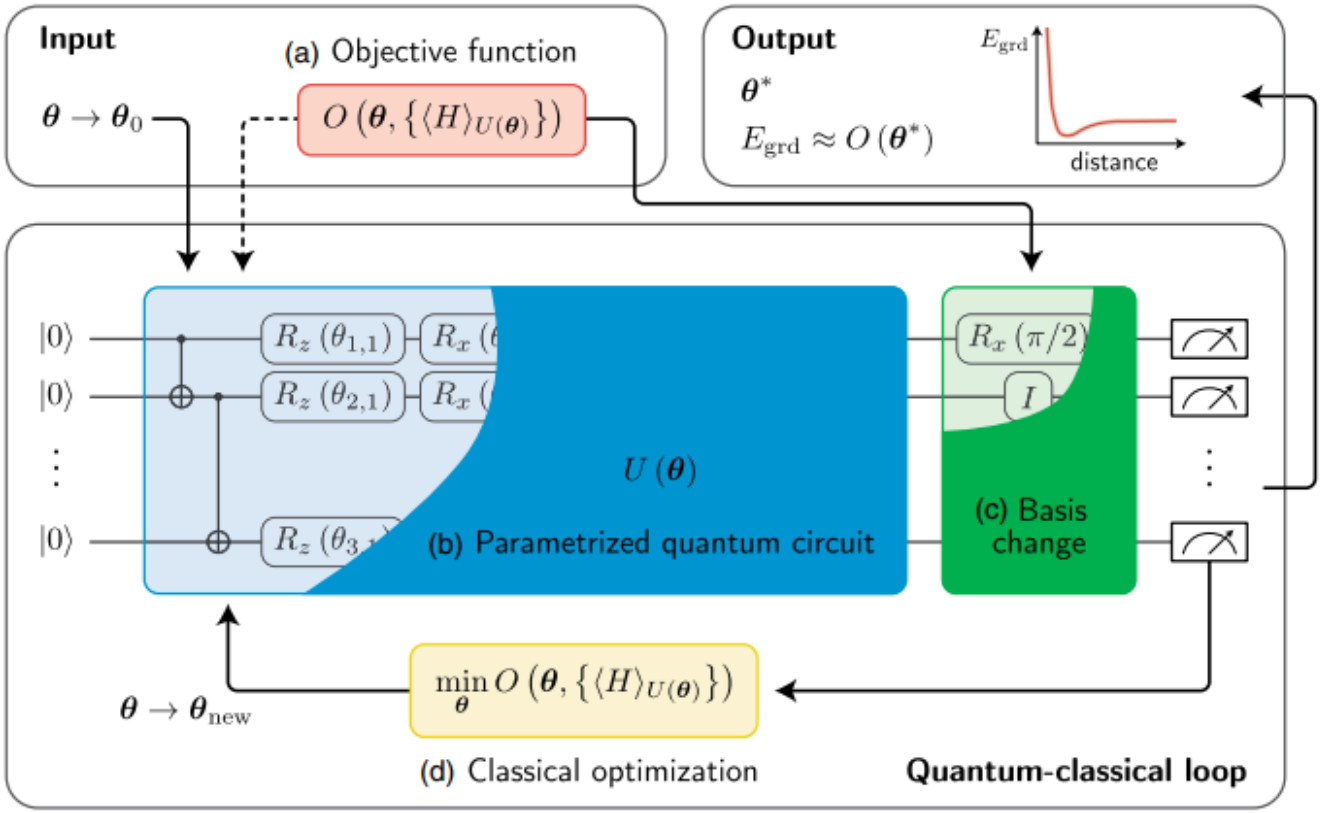





3.00
B0
0.00
RF amplitude
6.00
RF frequency
Infinite
T1
Infinite
T2
Zoom
RF and Mx
1.0
0.5
0.0
-0.5
-1.0
Time
Signal
1.0
0.8
0.6
0.4
0.2
0.0
Time
http://www.drcmr.dk/bloch
The equilibrium magnetization is along the B0 field.
Scene: Equilibri...
Change frame
90x hard
90x selective
180y hard
30x hard
Spoil
Repeated exc.
Help
Pause

Kishor Bharti *et al.*: Noisy intermediate-scale quantum algorithms

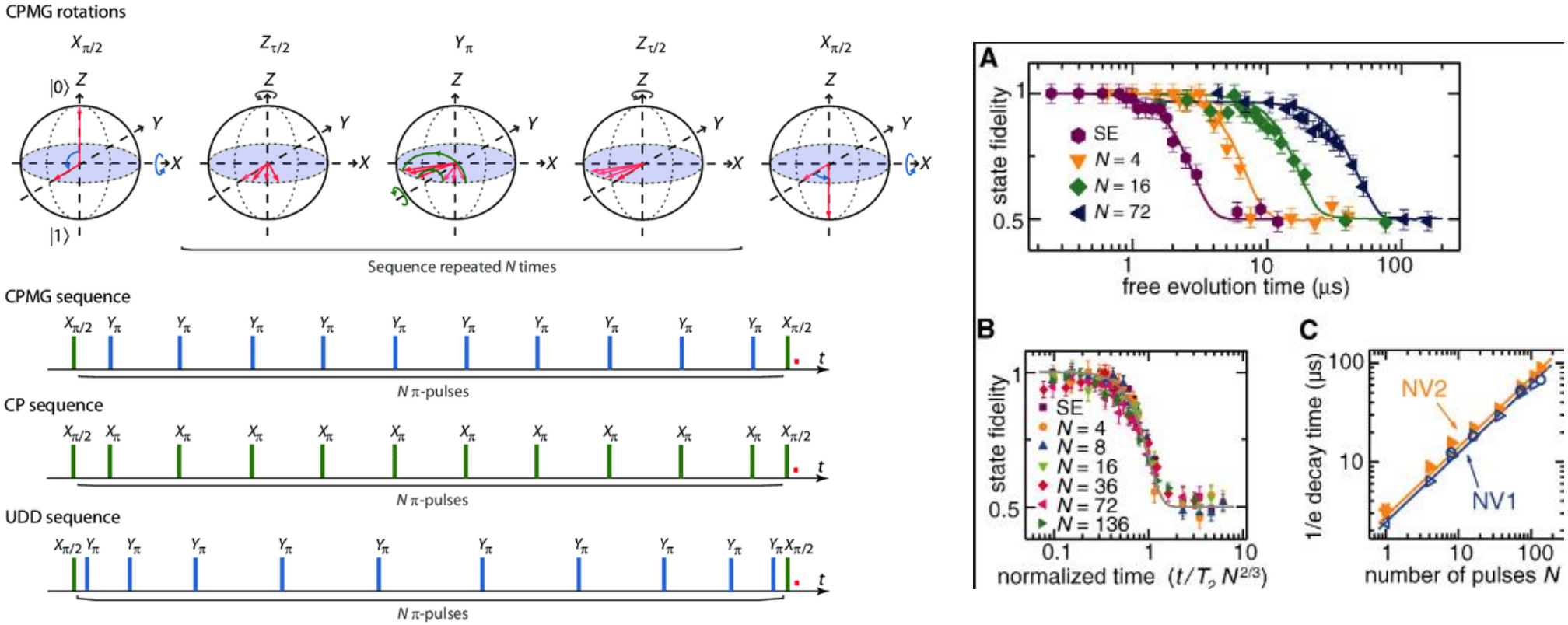
Rev. Mod. Phys., Vol. 94, No. 1, January–March 2022



Diagrammatic representation of a variational quantum algorithm (VQA). A VQA workflow can be divided into four main components:

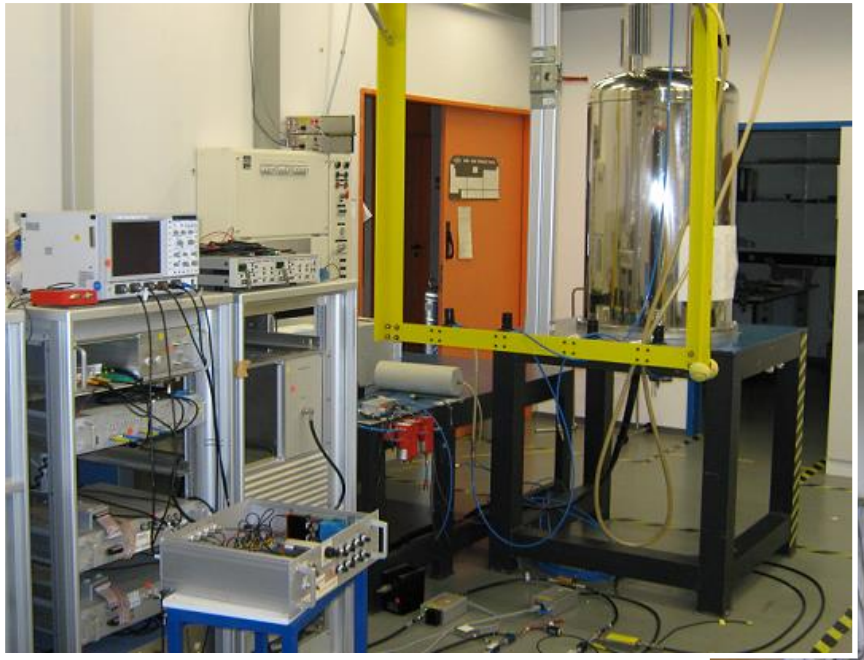
İteratif çözüm gerektiren algoritmalar NISQ hesaplamada perfomans sorunu yaşayabilir.

❑ Gürültü baskılayıcı dinamik metotlar



[Universal Dynamical Decoupling of a Single Solid-State Spin from a Spin Bath
G. de Lange, Z. H. Wang, D. Ristè, V. V. Dobrovitski, R. Hanson,Science , Vol. 330, Issue 6000, pp. 60-63.]

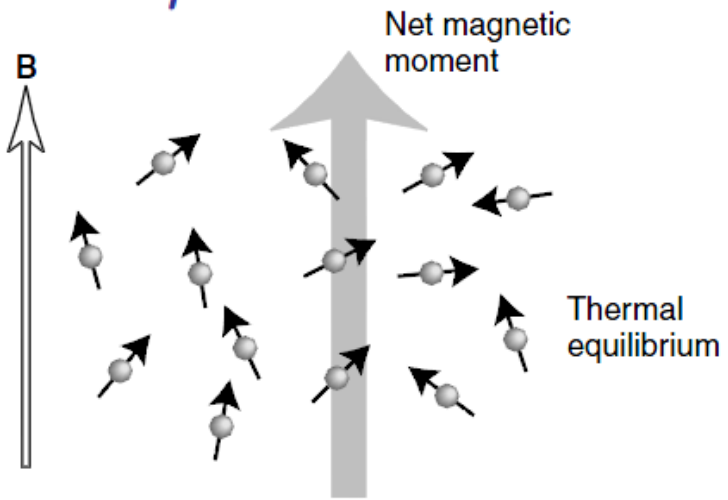
Oda sıcaklığı Kuantum hesaplama – NMR -QIP

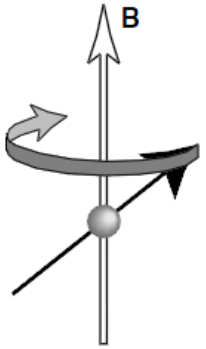


Dortmund Teknik Üniversitesi Fizik fakültesi e-3 lab.

NMR systems

$$H = \vec{\mu} \cdot \vec{B}$$

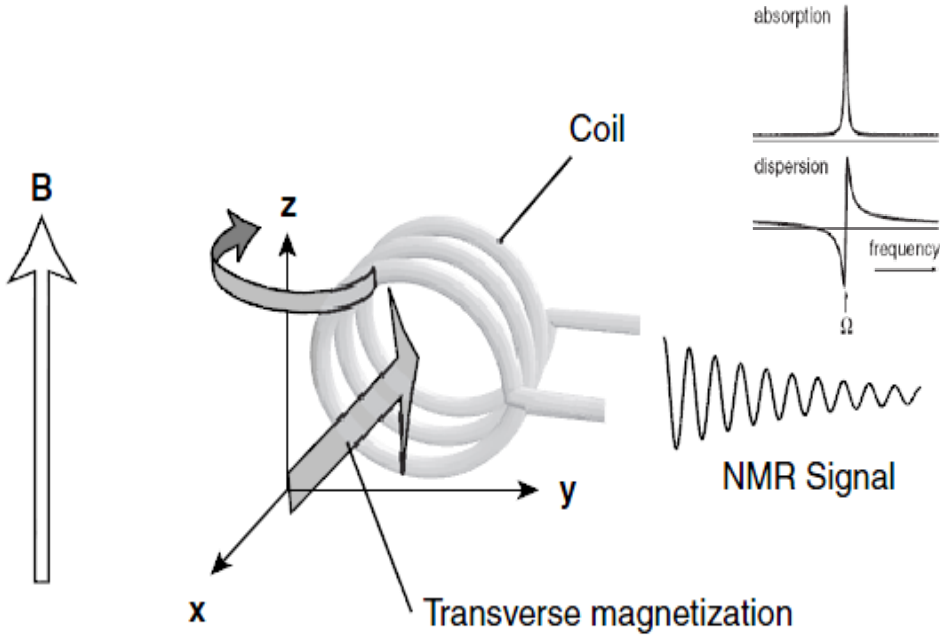




$$\omega_o = -\gamma B_o$$

$$|\psi\rangle = \begin{pmatrix} c_\alpha \\ c_\beta \end{pmatrix} \qquad \hat{\rho} = \overline{|\psi\rangle\langle\psi|}$$

$$|\overline{\rho}| = \begin{pmatrix} c_\alpha \\ c_\beta \end{pmatrix} \begin{pmatrix} c_\alpha^* & c_\beta^* \end{pmatrix} = \begin{pmatrix} \overline{c_\alpha c_\alpha^*} & \overline{c_\alpha c_\beta^*} \\ \overline{c_\beta c_\alpha^*} & \overline{c_\beta c_\beta^*} \end{pmatrix}$$



IBM Quantum launches accelerator for enterprise

New program offers resources to businesses at any point on their journey to quantum readiness.

Mevcut NISQ algoritmalarının çoğu, kuantum bilgisayarların gücünü hibrit bir kuantum-klasik düzenlemede kullanır.

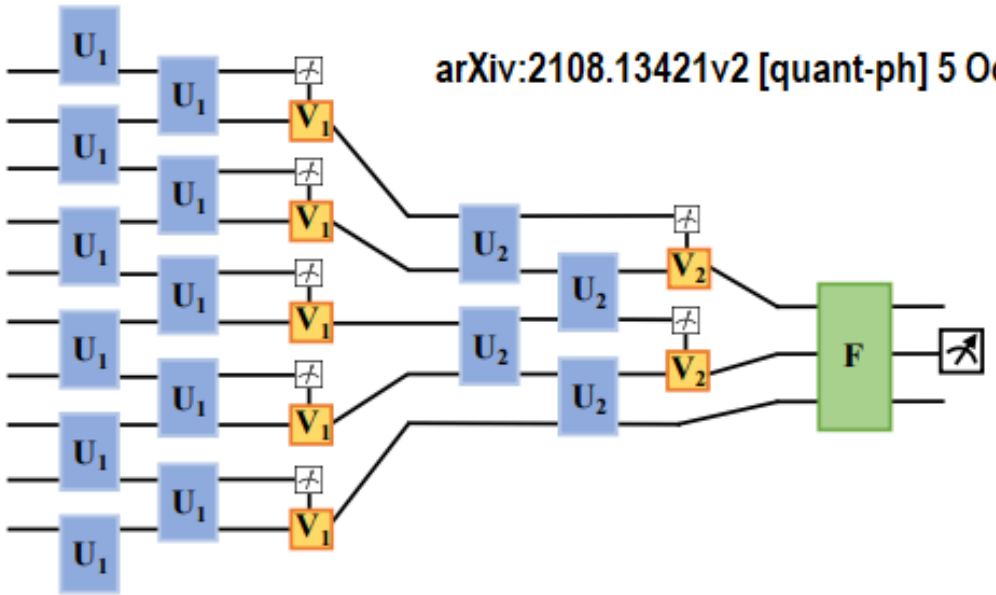


FIG. 7. A schematic illustration of the quantum convolutional neural networks, where the U_i, V_i, and F are unitary blocks and the V_i is controlled by some measurement outcomes.

Kuantum sınıflayıcılar

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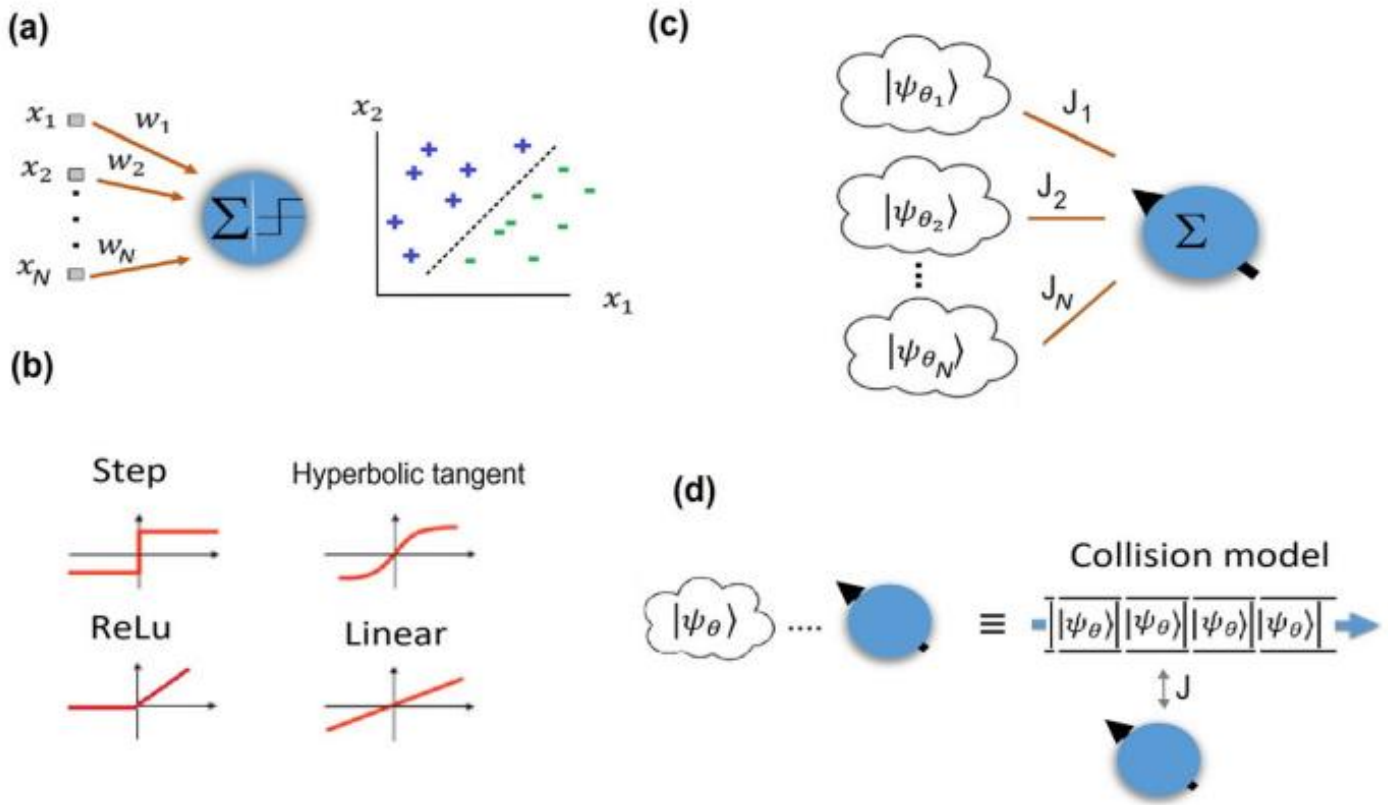
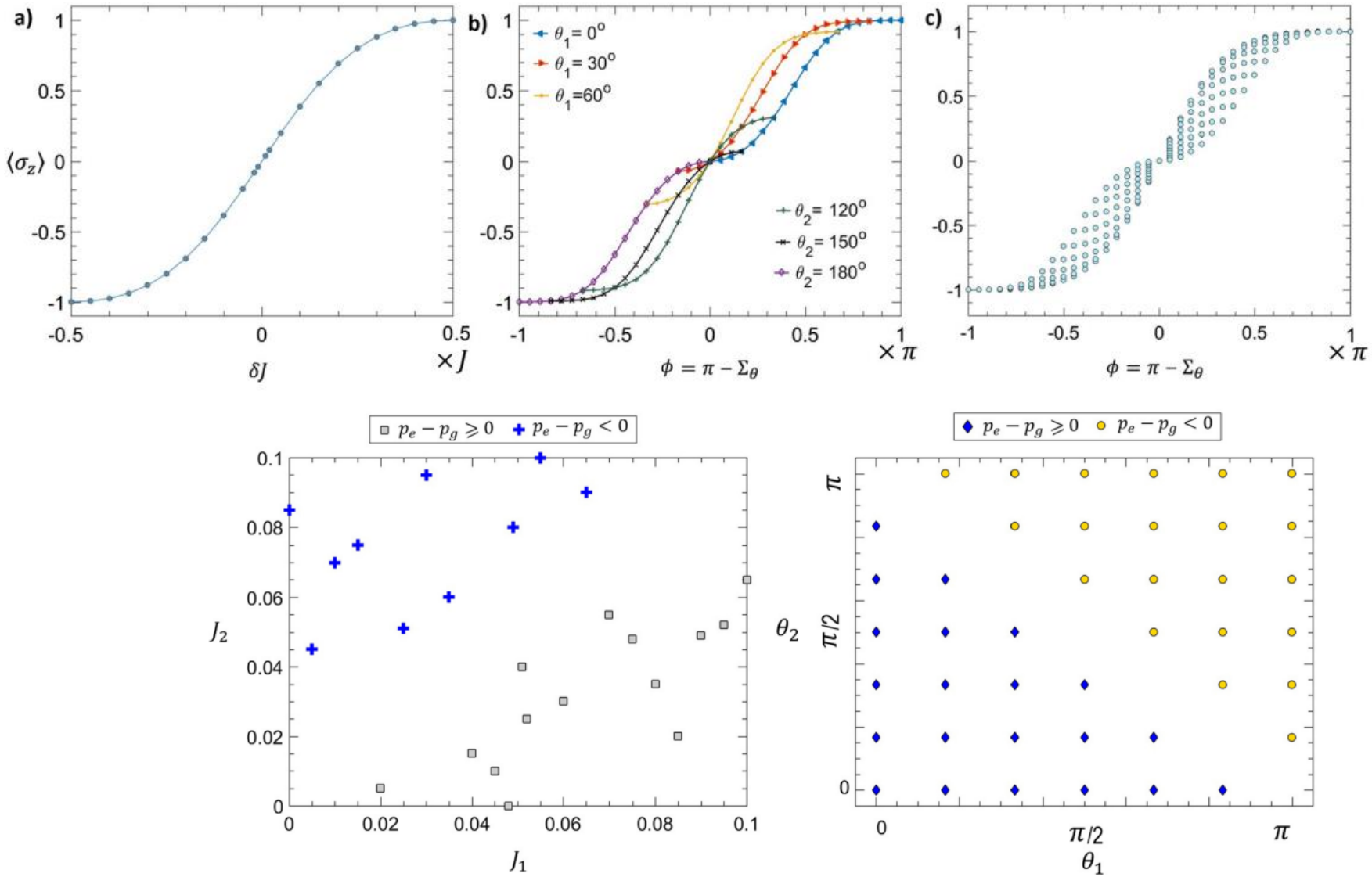


TÜBİTAK

KARİYER GELİŞTİRME PROGRAMI

PROJE ADI: KONTROL EDİLEBİLİR AKTİVASYONLU BİR KUANTUM SINIFLAYICI MODELİ GELİŞTİRİLMESİ

Benzer bir yaklaşımı kendi çalışmalarımızda kullandık.



Benzer bir yaklaşımı kendi çalışmalarımızda kullandık.

Transfer of quantum information via a dissipative protocol for data classification

Ufuk Korkmaz, Deniz Türkpençe *

Department of Electrical Engineering, İstanbul Technical University, 34469 İstanbul, Turkey

Physics Letters A 426 (2022) 127887

$$\Phi_t^{(i)}[\varrho_0] = \mathrm{Tr}_{\mathcal{R}_i}\{U_t(\varrho_0 \otimes \rho_{\mathcal{R}_i})U_t^\dagger\}$$

$$\rho_{\mathcal{R}_i} = \bigotimes_{k=1}^{n} \rho_k(\theta_i, \phi_i),$$

$$\mathcal{H}_0 = \frac{\hbar\omega_0}{2}\sigma_0^z + \frac{\hbar\omega_i}{2}\sum_{k=1}^{n}\sigma_{k_i}^z$$

$$\mathcal{H}_{int} = \hbar\sum_{k=1}^{n} g_i(\sigma_0^+\sigma_{k_i}^- + \mathrm{H.c.}),$$

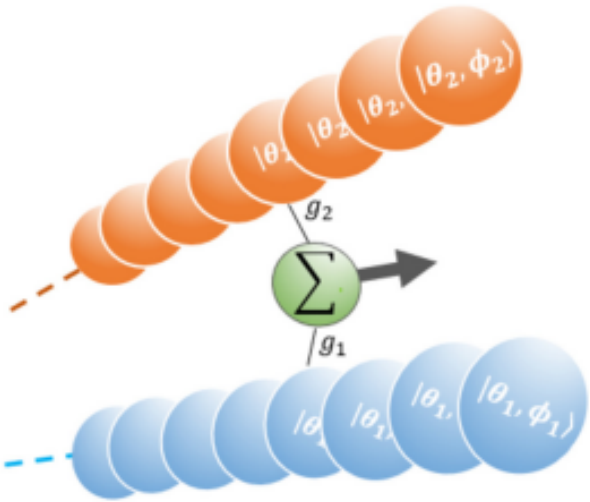
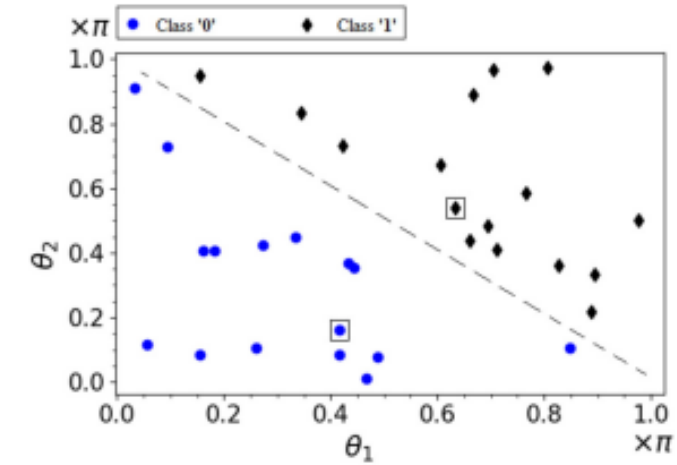


Fig. 1. (Colour online.) Schematical illustration of the proposed model. A probe qubit sequentially interacts with the identical units of two information reservoirs with coupling strengths g_i. Binary classification result in terms of weighted combination of reservoir parameters is encoded in the steady-state.



$$\textit{Decision}: \begin{cases} 0, & \langle\sigma_z^0\rangle^{ss} = \frac{1}{g_\Sigma}\sum_i^N g_i^2\langle\sigma_z\rangle_i \geq 0 \\ 1, & \text{else} \end{cases}$$

Teşekkürler