Quantum information processing, quantum communication and quantum Artificial Intelligence in semiconductor quantum computer

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New Scientist,23.09.2019:
Google claims it has finally reached quantum supremacy

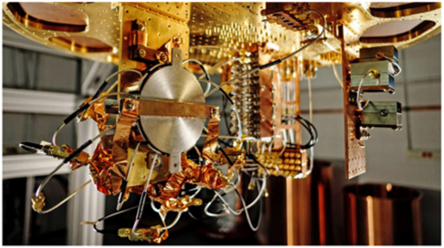
"Google's quantum processor tackled a random sampling problem … Although one of its qubits didn't work, the remaining 53 were quantum entangled with one another and used to generate a set of binary digits and check their distribution was truly random. The paper calculates the task would have taken Summit, the world's best supercomputer, 10,000 years – but Sycamore did it in 3 minutes and 20 seconds."

ScienceNews
INDEPENDENT JOURNALISM SINCE 1921

NEWS QUANTUM PHYSICS

Rumors hint that Google has accomplished quantum supremacy

Reports suggest a quantum computer has surpassed standard computers on a specific type of calculation



Google may have created the first quantum computer that can perform a calculation impossible on classical computers. A dilution refrigerator (shown) is used to cool quantum processors.
ERIK LUCERO/GOOGLE

Source: https://www.sciencenews.org/article/rumors-hint-that-google-has-accomplished-quantum-supremacy

IBM: the future is quantum

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

- **Learn**
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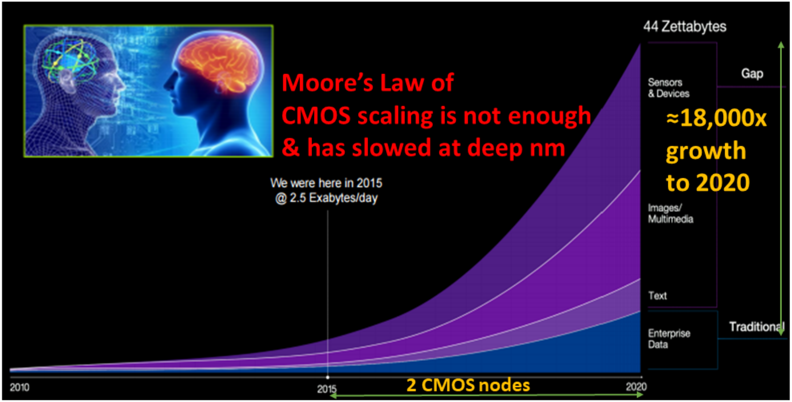
IBM 50Q System: a cryostat wired for a 50 qubit system.

Source:
https://www.ibm.com/blogs/research/2017/11/the-future-is-quantum/

Why Quantum Computing?



- Cognitive computing (see T.J.Watson presentation @ GTC2016)
- Machine learning will dominate the compute infrastructure

Bits and Qubits

Classical bit:

0 or 1

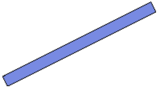
Coin on table

Digital: self-correcting

Quantum bit:

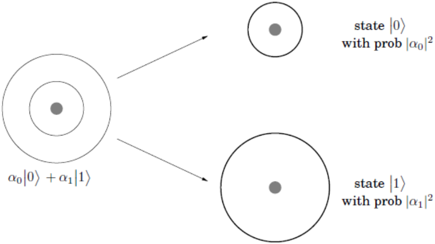
$$\psi = \cos\theta\,|0\rangle + \sin\theta\, e^{i\phi}\,|1\rangle$$

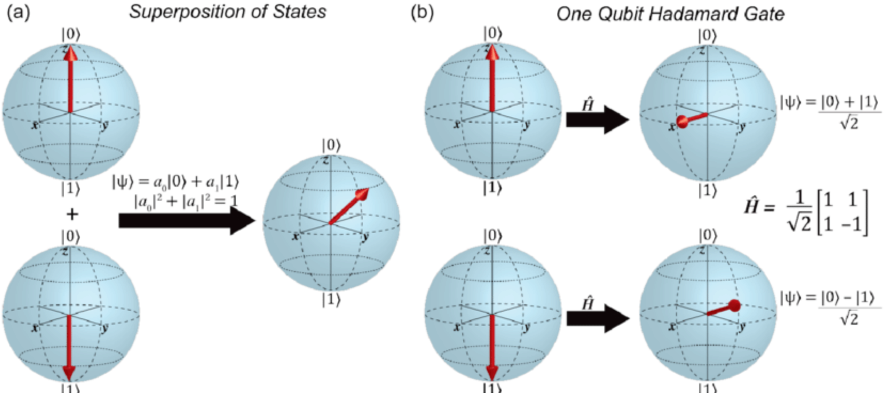
Coin in space



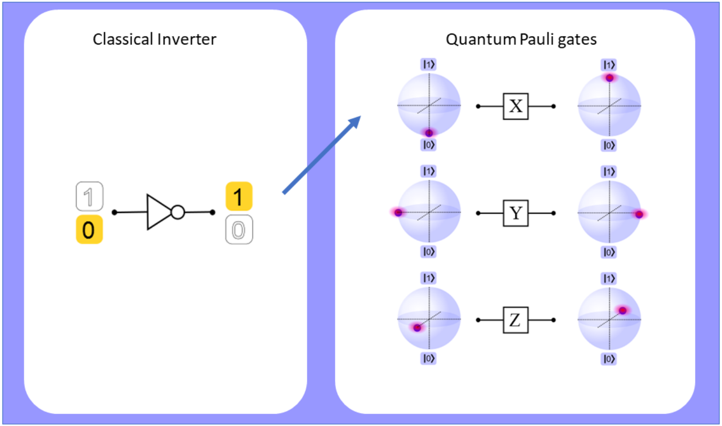
Analog: sensitive to small errors

Measurement of a superposition has the effect of forcing the system to decide on a particular state, with probabilities determined by the amplitudes.




(a)
Superposition of States
$|0\rangle$
$|1\rangle$
+
$|\psi\rangle = a_0|0\rangle + a_1|1\rangle$
$|a_0|^2 + |a_1|^2 = 1$
(b)
One Qubit Hadamard Gate
$\hat{H}$
$|\psi\rangle = \frac{|0\rangle + |1\rangle}{\sqrt{2}}$
$\hat{H} = \frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ 1 & -1\end{bmatrix}$
$|\psi\rangle = \frac{|0\rangle - |1\rangle}{\sqrt{2}}$

Qubit Inverter Gates



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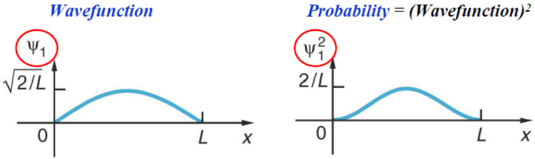
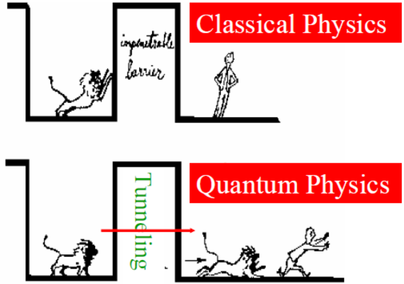
Interpreting the wavefunction

- Probability interpretation

  The square magnitude of the wavefunction $|\Psi|^2$ gives the probability of finding the particle at a particular spatial location





The difference between classical theory and quantum theory, illustrating tunneling through potential barrier. This illustration was used by Van Vleck in his last publication, the Julian E. Mack Lecture at his Alma Mater, the University of Wisconsin, in 1979. (After B. Bleaney, Contemp. Phys. 25 (1984) 320.)

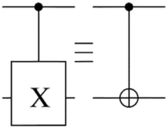
X Gate, Bit–flip, Not:
$$X \equiv \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \end{bmatrix} = \beta|0\rangle + \alpha|1\rangle$$

Z Gate, Phase–flip:
$$Z \equiv \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \end{bmatrix} = \alpha|0\rangle - \beta|1\rangle$$

H Gate, Hadamard:
$$H \equiv \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \end{bmatrix} = \frac{\alpha+\beta|0\rangle + \alpha-\beta|1\rangle}{\sqrt{2}}$$

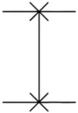
T Gate:
$$T \equiv \begin{bmatrix} 1 & 0 \\ 0 & e^{i\pi/4} \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \end{bmatrix} = \alpha|0\rangle + e^{i\pi/4}\beta|1\rangle$$

Controlled Not, Controlled X, CNot:



$$\equiv \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} = a|00\rangle + b|01\rangle + d|10\rangle + c|11\rangle$$

Swap:



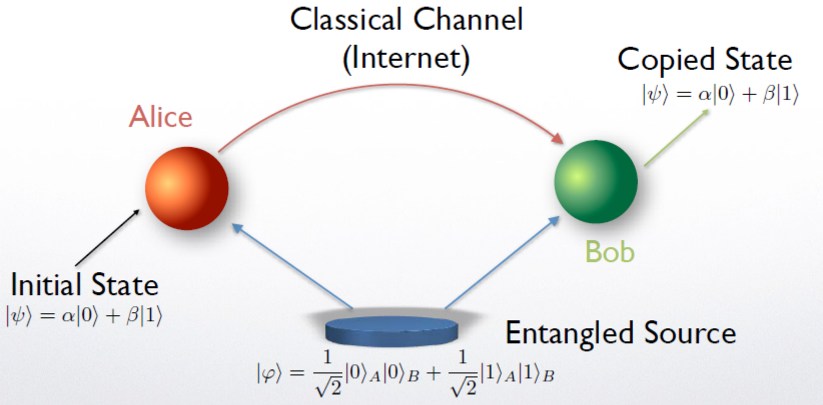
$$\equiv \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} = a|00\rangle + c|01\rangle + b|10\rangle + d|11\rangle$$

Quantum mechanics vs Neural Networks

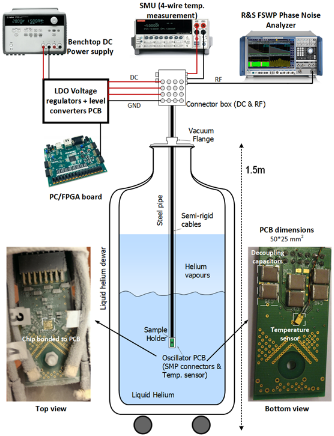
Quantum mechanics	Neural Networks
wave function	neuron
Superposition (coherence)	interconnections (weights)
Measurement (decoherence)	evolution to attractor
Entanglement	learning rule
unitary transformations	gain function (transformation)

Quantum neural networks by A.Ezhov and Dan Ventura

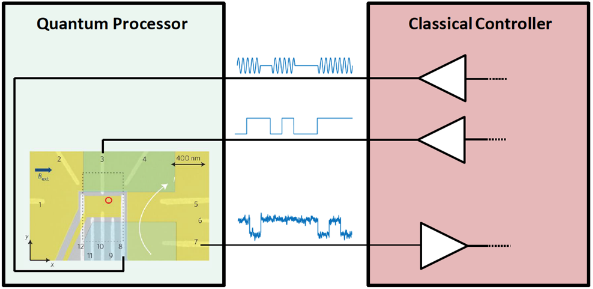
Communication Scheme

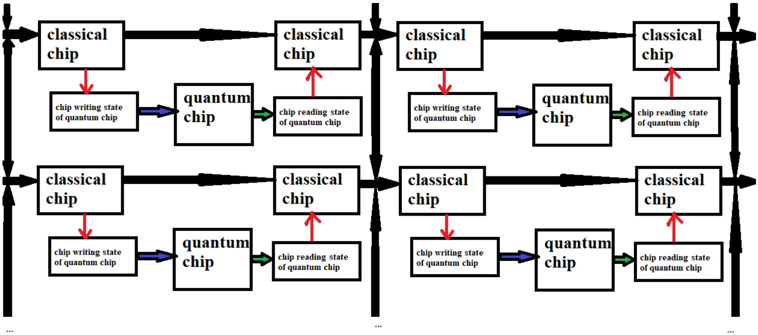


Measurement Setup



Current Quantum Computers




classical chip
classical chip
classical chip
classical chip
chip writing state of quantum chip
quantum chip
chip reading state of quantum chip
chip writing state of quantum chip
quantum chip
chip reading state of quantum chip
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classical chip
classical chip
classical chip
chip writing state of quantum chip
quantum chip
chip reading state of quantum chip
chip writing state of quantum chip
quantum chip
chip reading state of quantum chip
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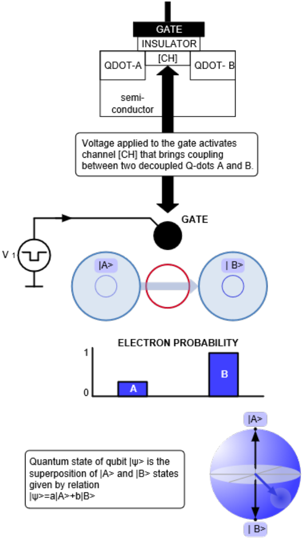
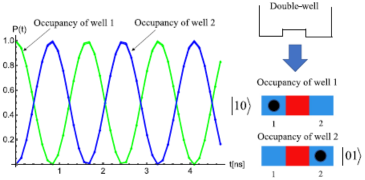
Overview

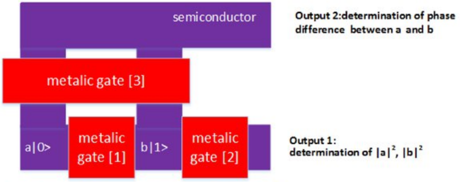
Main desired features of quantum programmable electronics

- Smooth interface between classical and quantum circuits
- High integration and high logical density
- Desired operational temperature above 1K
- Electrical writting up the qubits states
- Electrical reading up of qubits states
- Electrical way of entangling two particles
- Smooth transition from classical to quantum regime





Top view of readout circuit of position dependent qubit

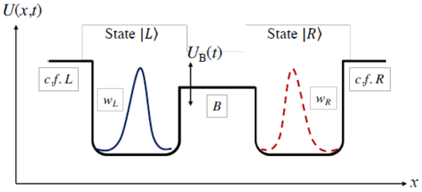


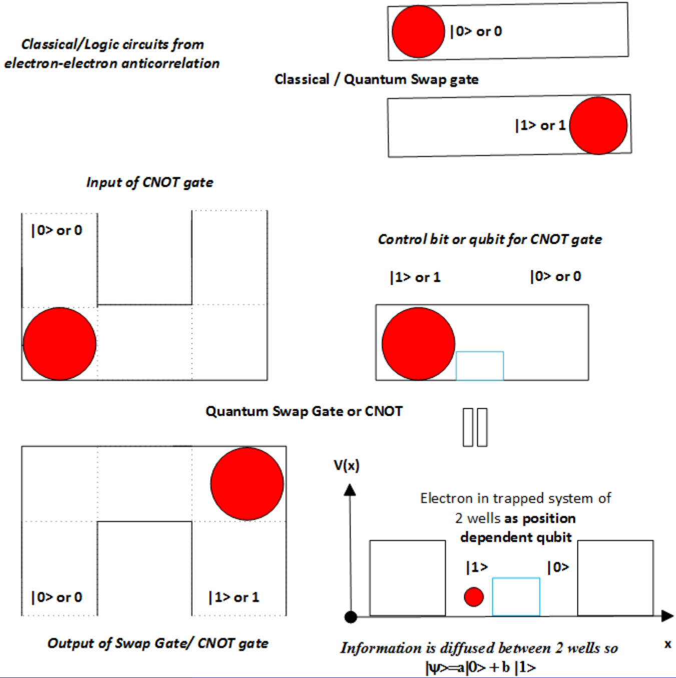
Electrostatic qubit by Panagiotis et al [IEEE Open Access, 2019], Pomorski et al. [Spie 2019], Fujisawa [2004]

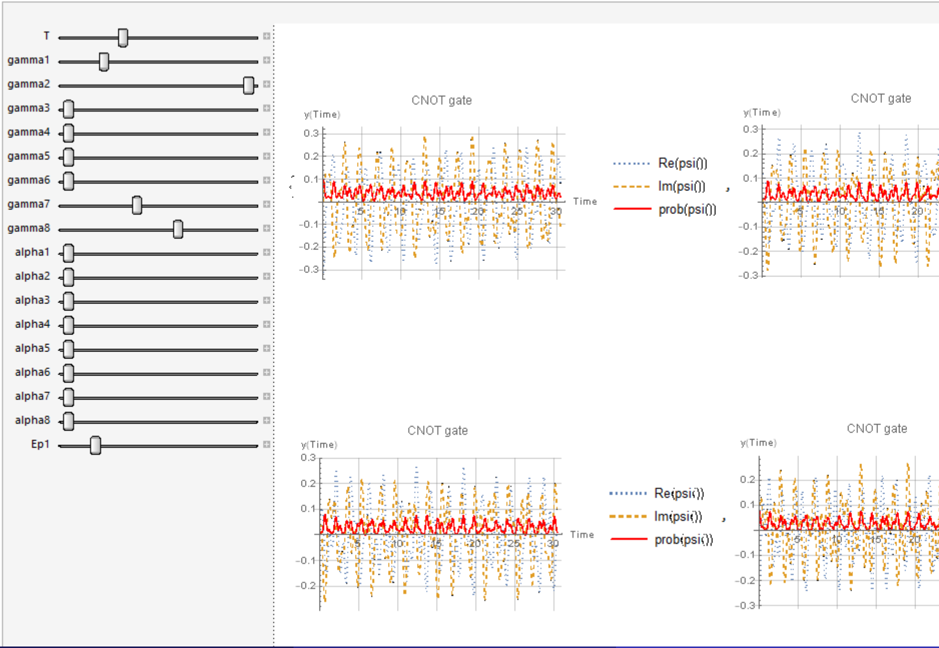
Position based qubit in tight binding model

The Hamiltonian of this system is given as

$$\hat{H}(t) = \begin{pmatrix} E_{p1}(t) & t_{s12}(t) \\ t_{s12}^{\dagger}(t) & E_{p2}(t) \end{pmatrix}_{[x=(x_1,x_2)]} =$$
$$= (E_1(t)\,|E_1\rangle_t\,\langle E_1|_t + E_2(t)\,|E_2\rangle\,\langle E_2|)_{[E=(E_1,E_2)]}. \quad (1)$$




Classical/Logic circuits from
electron-electron anticorrelation
|0> or 0
Classical / Quantum Swap gate
|1> or 1
Input of CNOT gate
|0> or 0
Control bit or qubit for CNOT gate
|1> or 1
|0> or 0
Quantum Swap Gate or CNOT
V(x)
Electron in trapped system of
2 wells as position
dependent qubit
|1>
|0>
|0> or 0
|1> or 1
Output of Swap Gate/ CNOT gate
x
Information is diffused between 2 wells so
|ψ>=a|0>+b |1>


T
gamma1
gamma2
gamma3
gamma4
gamma5
gamma6
gamma7
gamma8
alpha1
alpha2
alpha3
alpha4
alpha5
alpha6
alpha7
alpha8
Ep1
CNOT gate
y(Time)
Time
Re(psi())
Im(psi())
prob(psi())
CNOT gate
CNOT gate
CNOT gate

Occupancy ocillations in position based qubit at nodes 1 and 2

$$P_1(t) = |\alpha(t)|^2 = \frac{1}{2}((|\alpha(0)|^2 + |\beta(0)|^2) + \frac{1}{2}(|\alpha(0)|^2$$
$$-|\beta(0)|^2)\cos((\frac{E_2 - E_1)t}{\hbar})) = \cos(\Theta(t))^2,$$
$$P_2(t) = |\alpha(t)|^2 = \frac{1}{2}((|\alpha(0)|^2 + |\beta(0)|^2) - \frac{1}{2}(|\alpha(0)|^2$$
$$-|\beta(0)|^2)\cos((\frac{E_2 - E_1)t}{\hbar})) = \sin(\Theta(t))^2, \tag{2}$$

and it oscillates periodically with frequency proportional to distance between energetic levels E_2 and E_1 and is given as $\omega_0 = \frac{E_2 - E_1}{\hbar}$.

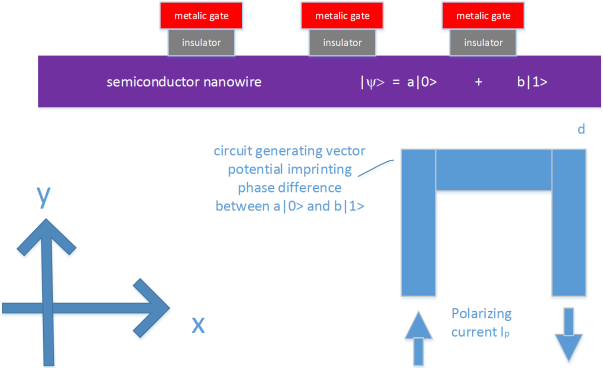
Bloch sphere dynamics for position based qubit

$$-\sin(\phi(t)) = \left[\frac{\sin(\frac{E_1 t}{\hbar})(|\alpha(0)|^2 - |\beta(0)|^2) + \sin(\frac{E_2 t}{\hbar})(|\alpha(0)|^2 + |\beta(0)|^2)}{\cos(\frac{E_1 t}{\hbar})(|\alpha(0)|^2 - |\beta(0)|^2) + \cos(\frac{E_2 t}{\hbar})(|\alpha(0)|^2 + |\beta(0)|^2)}\right] =$$

$$\frac{(1 - e^{-i\frac{2E_1 t}{\hbar}})(|\alpha(0)|^2 - |\beta(0)|^2) + \left(\frac{\cos(\Theta(t))^2 - \frac{1}{2}}{\frac{1}{2}(|\alpha(0)|^2 - |\beta(0)|^2)} + i|\sqrt{1 - (\frac{\cos(\Theta(t))^2 - \frac{1}{2}}{\frac{1}{2}(|\alpha(0)|^2 - |\beta(0)|^2)})^2}| - e^{-i\frac{(E_2 + E_1)t}{\hbar}}\right)}{i(1 + e^{-i\frac{2E_1 t}{\hbar}}))(|\alpha(0)|^2 - |\beta(0)|^2) + i\left(\frac{\cos(\Theta(t))^2 - \frac{1}{2}}{\frac{1}{2}(|\alpha(0)|^2 - |\beta(0)|^2)} + i|\sqrt{1 - (\frac{\cos(\Theta(t))^2 - \frac{1}{2}}{\frac{1}{2}(|\alpha(0)|^2 - |\beta(0)|^2)})^2}| + e^{-i\frac{(E_1 + E_2)t}{\hbar}}\right)}$$

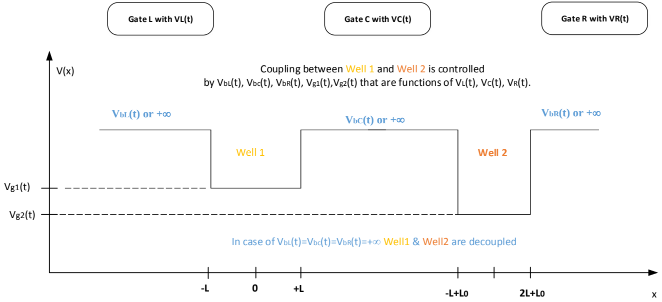
Coevolution of both Θ and ϕ on Bloch sphere.

Phase rotating gate

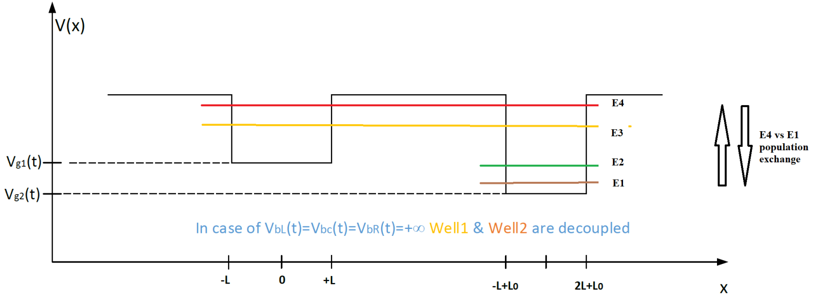


Effective potential in piece-wise approximation and electric Aharonov-Bohm effect (phase rotation gate)

Wavefunction phase difference across 2 deep wells controlled electrostatically is $\propto \frac{-1}{\hbar}\int_{t_0}^{t}(V_{g_1}(t') - V_{g_2}(t'))dt'$.



Localized vs delocalized state in system of coupled q-dots



AC field allows for the transition of the delocalized state into localized state and reversely !!!

Two types of position based qubits

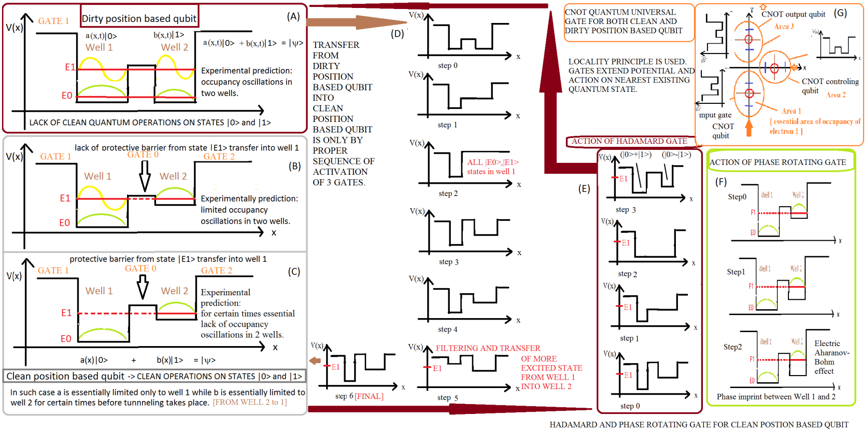
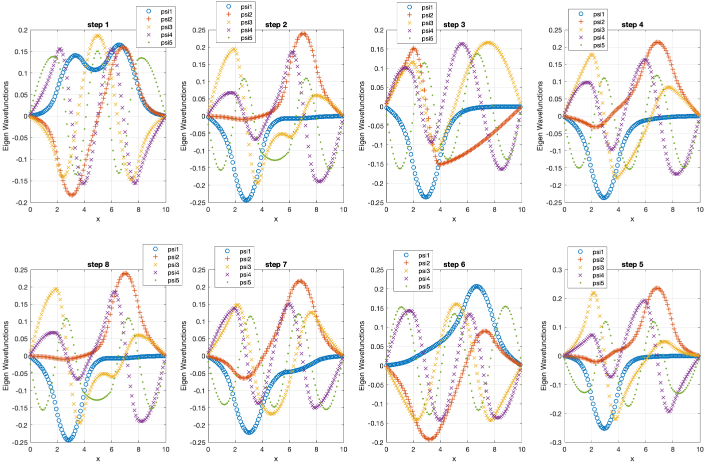


Figure: [Pomorski et al, Spie 2019]

Transition between two types of position based qubits



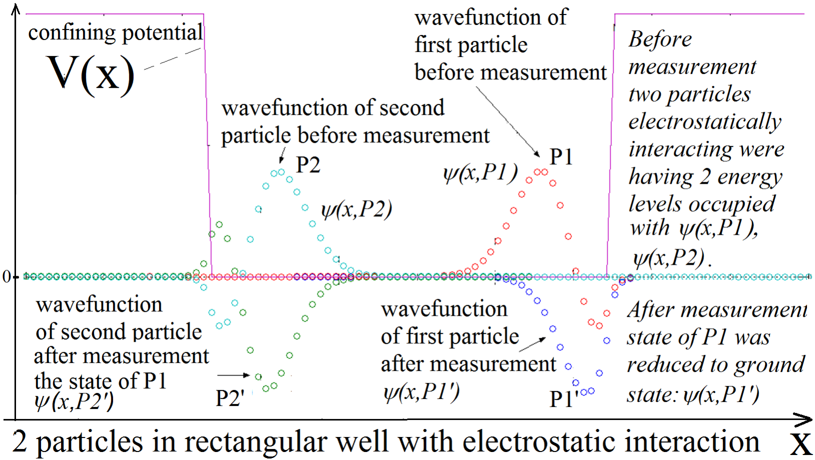
Problem of 2 electrostatically interacting particles in perturbative limit

In the case of 2 weakly interacting particles we have $\psi(x_A, x_B, t) = \psi(x_A, t)\psi(x_B, t)$ what gives

$$[-\frac{\hbar^2}{2m}\frac{d^2}{dx_A^2} + \lambda\frac{\int_{-\infty}^{+\infty} e^2\psi_B(x,t)\psi_B^\dagger(x,t)dx}{4\pi\epsilon_0|x_A - x|} + V_A(x_A)]\psi_A(x_A,t) = \\ = E_A\psi_A(x_A,t) \quad (3)$$

$$[-\frac{\hbar^2}{2m}\frac{d^2}{dx_B^2} + \lambda\frac{\int_{-\infty}^{+\infty} e^2\psi_A(x,t)\psi_A^\dagger(x,t)dx}{4\pi\epsilon_0|x_B - x|} + V_B(x_B)]\psi_B(x_B,t) = \\ = E_B(t)\psi_B(x_B,t). \quad (4)$$

Case of 2 electrons in single quantum well



J. Phys.: Condens. Matter 10 (1998) L105–L111. Printed in the UK PII: S0953-8984(98)89248-5

LETTER TO THE EDITOR

Spontaneous magnetic flux and quantum noise in an annular mesoscopic SND junction

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Received 4 November 1997

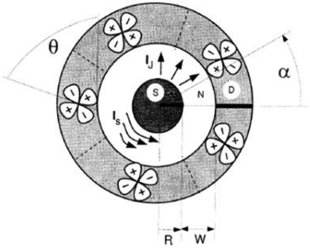


Figure 1. Annular SND junction. The *c*-axis of the *d*-wave superconductor is chosen to be parallel to the SD boundary; θ is the angle between the SD boundary and the nodal plane of the *d*-wave order parameter ($0 \leqslant \theta \leqslant \pi/2$).

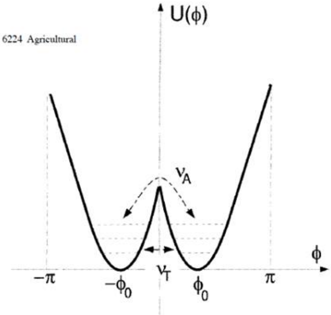
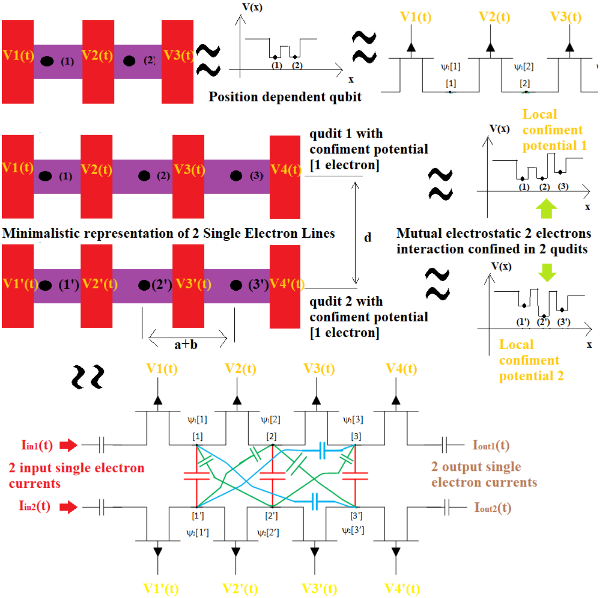


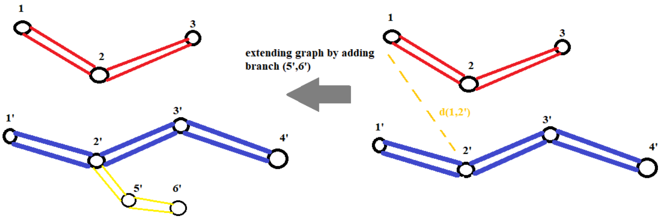
Figure 2. Effective potential and transition rates for the phase v junction.

Most features present in superconducting nanostructures are presented in single electron CMOS technology!!!

Case of 2 electrostatically coupled Single Electron Lines

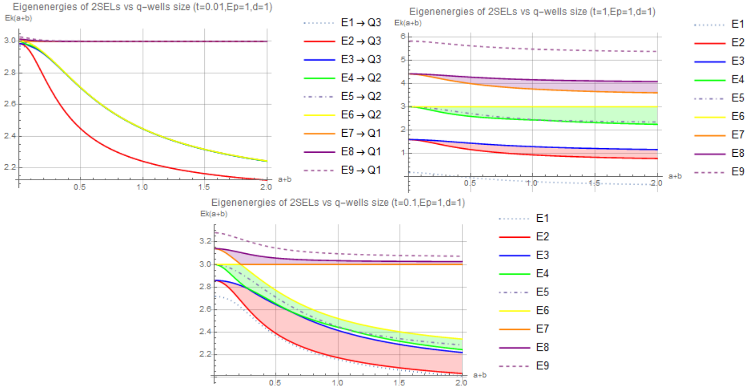


Electrostatically controlled topology of graphs of coupled q-dots in chain of semiconductor q-dots



In semiconductor one observes the anticorrelation of electrons positions due to electrostatic repulsion and minimization of electrostatic field energy. In superconductor one observes the anticorrelation of electric non-dissipative currents due to magnetic field shielding. There is charge-phase duality in anticorrelation!!!

Programmable band structure in chain of coupled q-dots



Analytical tight-binding approach for coupled q-dots

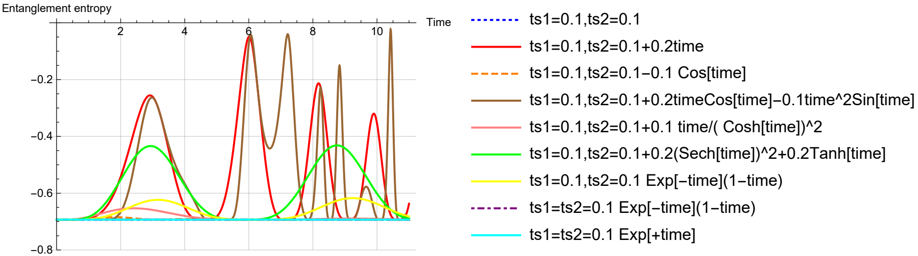
$$\hat{H}(t) = \begin{pmatrix} 2E_p(t) + \frac{q^2}{d_1} & t_{sr2}(t) & t_{sr1}(t) & 0 \\ t_{sr2}(t) & 2E_p(t) + \frac{q^2}{\sqrt{(d_1)^2+(b+a)^2}} & 0 & t_{sr1}(t) \\ t_{sr1}(t) & 0 & 2E_p(t) + \frac{q^2}{\sqrt{(d_1)^2+(b+a)^2}} & t_{sr2}(t) \\ 0 & t_{sr1}(t) & t_{sr2}(t) & 2E_p(t) + \frac{q^2}{d1} \end{pmatrix} =$$
$$= \hat{\sigma}_0 \times \hat{\sigma}_0 q_{11} + \hat{\sigma}_3 \times \hat{\sigma}_3 q_{22} + t_{sr2}(t)\hat{\sigma}_0 \times \hat{\sigma}_3 + t_{sr1}(t)\hat{\sigma}_3 \times \hat{\sigma}_0$$

that has only real value components $H_{k,l}$ with
$q_{11} = E_p(t) + \frac{E_{c1}+E_{c2}}{2} = E_p(t) + \frac{1}{2}(\frac{q^2}{d_1} + \frac{q^2}{\sqrt{(d_1)^2+(b+a)^2}})$,
$q_{22} = \frac{E_{c1}-E_{c2}}{2} = \frac{1}{2}(\frac{q^2}{d_1} - \frac{q^2}{\sqrt{(d_1)^2+(b+a)^2}})$ and $Q_{11}(t) = \int_{t_0}^{t} dt' q_{11}(t')$,
$Q_{22}(t) = \int_{t_0}^{t} dt' q_{22}(t')$, $TR1(t) = \int_{t_0}^{t} dt' t_{sr1}(t')$, $TR2(t) = \int_{t_0}^{t} dt' t_{sr2}(t')$.

$$S_B(t) = Tr[\rho_B(t) Log[\rho_B(t)]] \tag{5}$$

$$|\psi(t)\rangle = U(t,t_0)\,|\psi(t_0)\rangle = e^{\frac{1}{\hbar}\int_{t_0}^{t} \hat{H} dt}\,|\psi(t_0)\rangle.$$

Entanglement entropy of coupled qubits with time



Electrostatic control of entanglement is demonstrated by tight-binding model in symmetric Q-Swap gates when two hopping constants are the same at initial state and when the state is initially in the ground state.

Correlation function

$$C(E_{c1} - E_{c2} = \frac{q^2}{d} - \frac{q^2}{\sqrt{d^2 + (a+b)^2}}, t_{s1}, t_{s2}, p_{E1}, p_{E2}, p_{E3}, p_{E4}, \phi_{E10}, \phi_{E20}, \phi_{E30}, \phi_{E40}, t) =$$

$$= \frac{N_{+,+} + N_{-,-} - N_{-,+} - N_{+,-}}{N_{+,+} + N_{-,-} + N_{-,+} + N_{+,-}} =$$

$$4[\frac{\sqrt{p_{E1}}\sqrt{p_{E2}}(t_{s1} - t_{s2})\cos[-t\sqrt{(E_{c1} - E_{c2})^2 + 4(t_{s1} - t_{s2})^2} + \phi_{E10} - \phi_{E20}]}{\sqrt{(E_{c1} - E_{c2})^2 + 4(t_{s1} - t_{s2})^2}}$$

$$+ \frac{\sqrt{p_{E3}}\sqrt{p_{E4}}(t_{s1} + t_{s2})\cos[-t\sqrt{(E_{c1} - E_{c2})^2 + 4(t_{s1} + t_{s2})^2} + \phi_{E30} - \phi_{E40}]}{\sqrt{(E_{c1} - E_{c2})^2 + 4(t_{s1} + t_{s2})^2}}]$$

$$-(E_{c1} - E_{c2})[\frac{p_{E1} - p_{E2}}{\sqrt{(E_{c1} - E_{c2})^2 + 4(t_{s1} - t_{s2})^2}} + \frac{p_{E3} - p_{E4}}{\sqrt{(E_{c1} - E_{c2})^2 + 4(t_{s1} + t_{s2})^2}}] \tag{6}$$

We are going to use Jaynes-Cumming Hamiltonian [?] that describes the interactiton atom with cavity by means of electromagnetic field. In the simplest approach the cavity Hamiltonian describing waveguide without dissipation is represented as

$$H_{cavity} = \hbar\omega_c(\frac{1}{2} + \hat{a}^\dagger \hat{a}), \tag{7}$$

where $\hat{a}^\dagger$ ($\hat{a}$) is the photon creation (annihilation) operator and number of photons in cavity is given as $n = \hat{a}^\dagger \hat{a}$. At the same we can represent the two level qubit system

$$H_{qubit} = E_g \left|g\right\rangle \left\langle g\right| + E_e \left|e\right\rangle \left\langle e\right|. \tag{8}$$

The interaction Hamilonian is of the following form

$$H_{qubit-cavity} = g(\hat{a}^\dagger \sigma_- + \hat{a}\sigma_+), \tag{9}$$

where $\sigma_- = \sigma_1 - i\sigma_2$, $\sigma_+ = \sigma_1 + i\sigma_2$. The qubity-cavity interaction has the electric-dipole nature so quasiclassicaly we can write

$$H_{qubit-cavity} = \hat{d} \cdot \hat{E} = g(\sigma_- + \sigma_+)(\hat{a} + \hat{a}^\dagger) \approx g(\hat{a}^\dagger \sigma_- + \hat{a}\sigma_+). \tag{10}$$

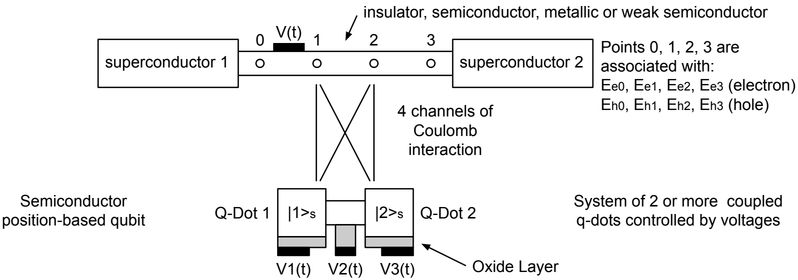
Here we have neglected the terms $g(\sigma_- \hat{a} + \sigma_+ \hat{a}^\dagger)$ and our approach is known as rotating phase

During photon emission from qubit the energy level is lowered and reversely during photon absorption the energy level of qubit is raised what is seen in the term $\hat{a}\sigma_+$. The system Hamiltonian is given as $H = H_{cavity} + H_{qubit} + H_{qubit-cavity}$. It is not hard to construct the Hilbert space for Jaynes-Cumming Hamiltonian. Essentially we are considering the tensor product of qubit space and cavity space.

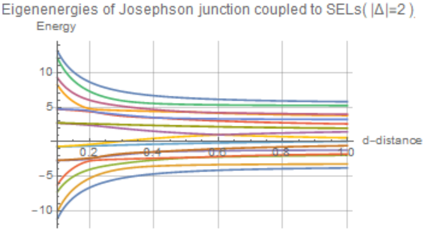
$$|\psi\rangle = \gamma_1 |\phi_1\rangle |0\rangle + \gamma_2 |\phi_1\rangle |1\rangle + \gamma_3 |\phi_2\rangle |0\rangle + \gamma_4 |\phi_2\rangle |1\rangle = \begin{pmatrix}\gamma_1\\ \gamma_2\\ \gamma_3\\ \gamma_4\end{pmatrix}, 1 = \langle\psi|\psi\rangle = |\gamma_1|^2 + .. + |\gamma_4|^2. \tag{11}$$

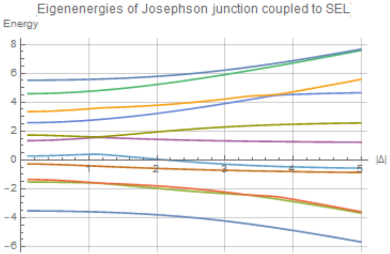
Electrostatic interface between semiconductor and superconducting qubit

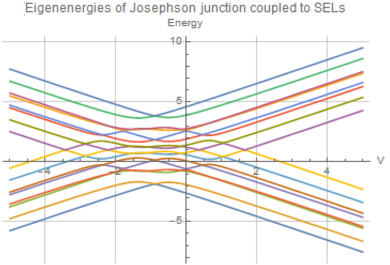
Josephson Junction interacting with two coupled Q-Dots semiconductor qubits



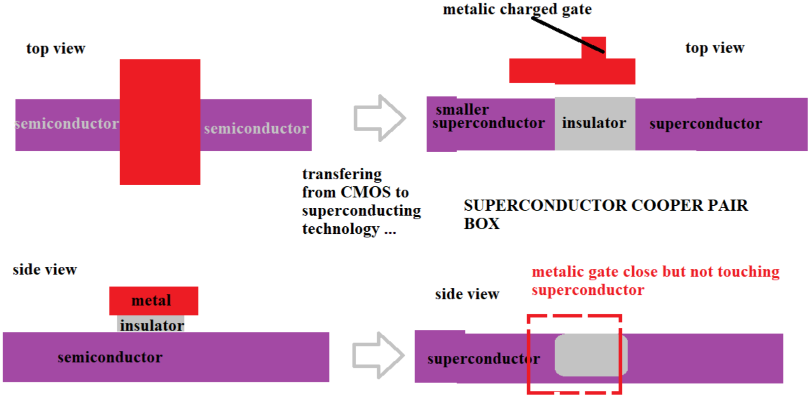
Tight-binding model in description of JJs coupled to semiconductor qubit and modification of ABS in JJ



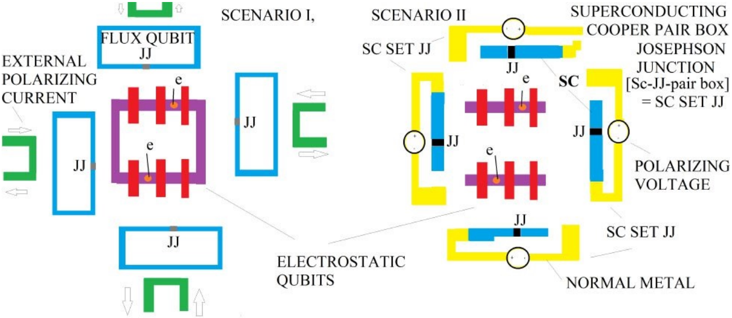




Electrostatically controlled superconducting and semiconducting qubits



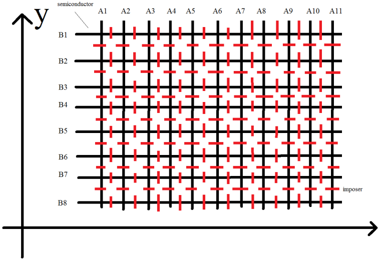
Electromagnetic interface between semiconductor and superconducting circuits

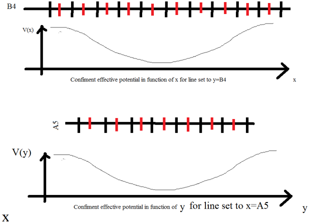


INTERFACE BETWEEN SUPERCONDUCTOR AND SEMICONDUCTOR QUBITS

[K.Pomorski, P.Giounanlis, E.Blokhina, D.Leipold, P.Peczkowski, Robert Bogdan Staszewski, From two types of electrostatic position-dependent semiconductor qubits to quantum universal gates and hybrid semiconductor-superconducting quantum computer, Proc. SPIE 11054, 2019]

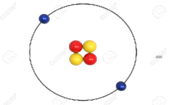
Quantum chemistry in semiconductor lattices





Concept of programmable Quantum Matter:

Having 2 electrons in cofiment potential created by imposers we can replicate dynamics of He atom and many body systems .



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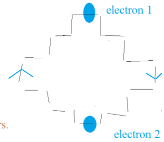
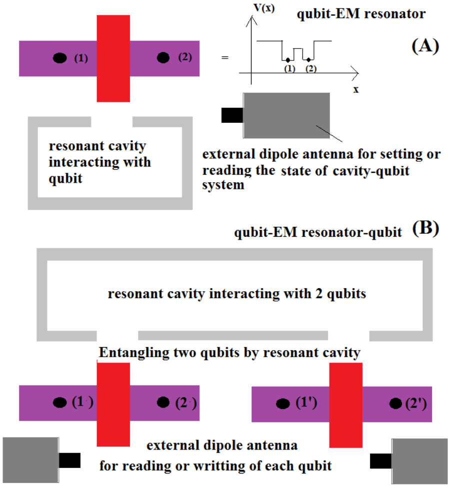
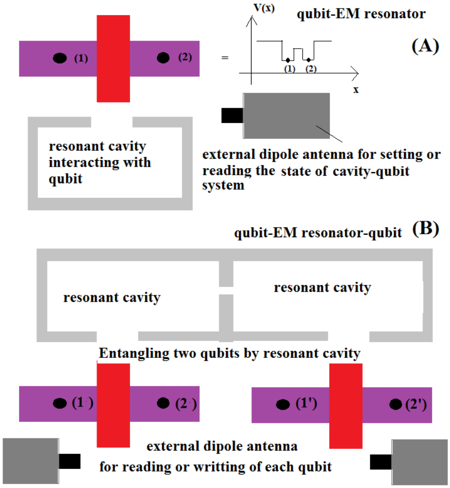


2 Electrons can move on 2 dimensional lattice simulating Helium atom etc , ...

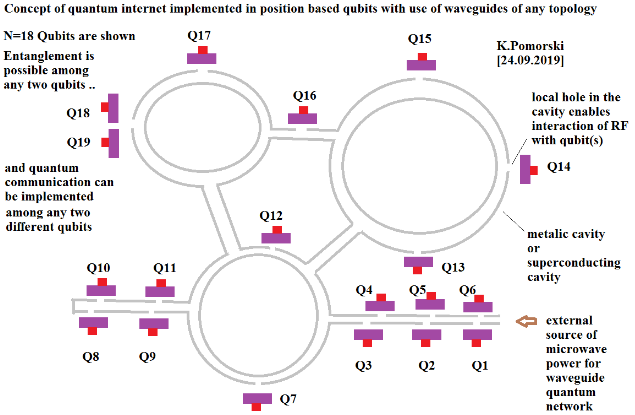
We can replicate N-body dynamics having N electrons in effective potential created by imposers.
In particular we can simulate vortices of magnetic field and many other phenomena


V(x)
qubit-EM resonator
(A)
(1)
(2)
=
(1) (2)
x
resonant cavity interacting with qubit
external dipole antenna for setting or reading the state of cavity-qubit system
qubit-EM resonator-qubit (B)
resonant cavity interacting with 2 qubits
Entangling two qubits by resonant cavity
(1')
(2')
(1')
(2')
external dipole antenna for reading or writting of each qubit

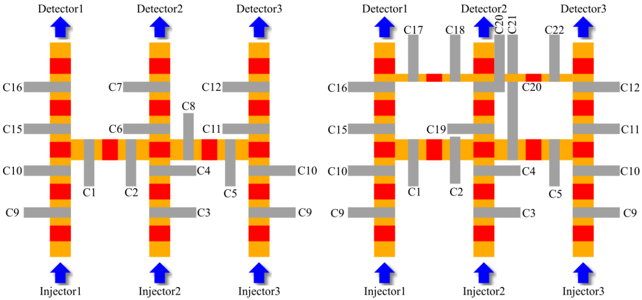
Quantum Communication over Long Line



Quantum Internet



Quantum Neural Network

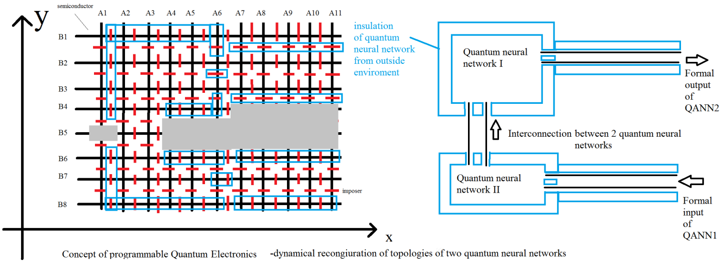


Concept of quantum and classical single electron neural network in CMOS. It can mimic all quantum universal gates. It can be controlled with voltages applied to C1,..,C12, .., C22 gates. Additionally one can use external magnetic field to control its performance.

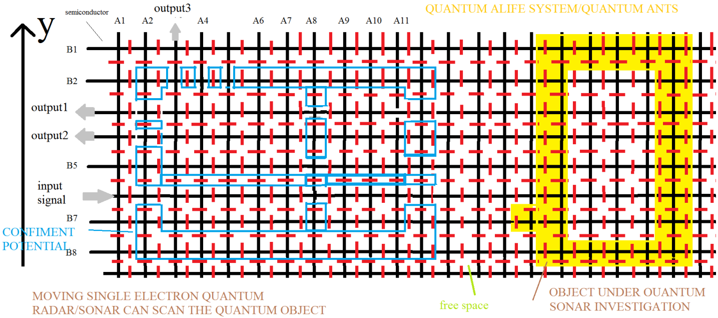
by Krzysztof Pomorski, 16 Nov 2018

Q-Neural Network can mimic any physical system of N bodies.

Reconfigurable Quantum Neural Networks



Quantum chemistry in semiconductor lattices



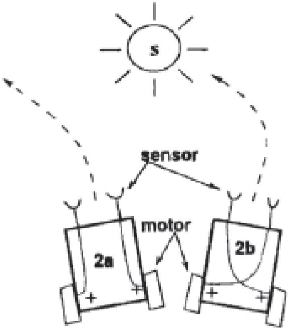
SINGLE ELECTRON RADAR CAN BE RECOGNIZED AS QUANTUM AGENT OR QUANTUM ANT HAVING SENSOR AND QUANTUM SONAR

IT CAN BE BASED ON NON-UNIFORM ELECTRIC OR MAGNETIC FIELD AS WELL AS CONGLOMERATION OF OTHER CHARGED PARTICLES CAPTURED BY CONFIMENT POTENTIAL (YELLOW)

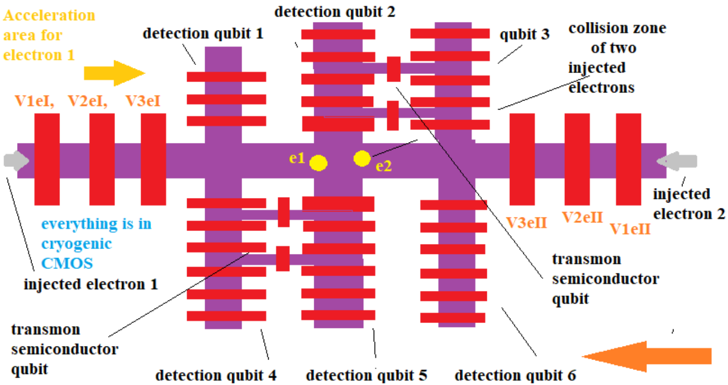
ALL CONFIMENT POTENTIALS CAN BE CONTROLLED EXTERNALLY BY FINITE STATE MACHINE [BLUE+YELLOW]

PROPER OPERATION OF QUANTUM AGENTS REQUIRES CONSTANT FLOW OF ELECTRONS AS INPUT SIGNAL AND CONSTANT ANALYSIS OF OUTPUT SIGNALS.

Braitenberg vehices



Quantum accelerator



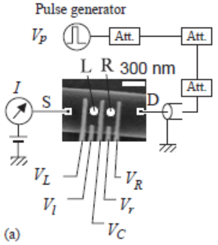
State of 6 qubits is affected and measured after collision of 2 high energetic electrons.

Acceleration area for electron 2

General view on the mikro-accelerator implemented in cryogenic CMOS
[Krzysztof Pomorski]

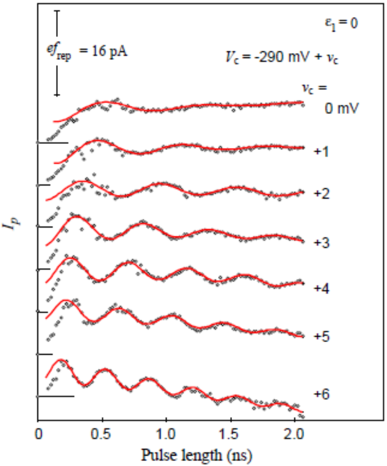
Various experiements can be conducted for various energies of colliding electrons.
Measurement of electron entangled state after collision can be attempted.

Previous experiments



T. Fujisawa et al. / Physica E 21 (2004) 1046–1052

The DQDs used in this work are defined by metal gates on top of a GaAs/AlGaAs heterostructure with a two-dimensional electron gas (2DEG). Each dot contains about 25 electrons with on-site charging energy $E_c \sim 1.3$ meV. The interdot charging energy is $U = 200$ μeV. The qubit parameters, ε and Δ, and tunneling rates, Γ_L and Γ_R, respectively, for left and right



Acknowledgments

All requirements for implementation of large scale Quantum Computer are to be fulfilled.

The project is supported by Science Foundation Ireland under Grant 14/RP/I2921. I would like to thank to professor Andrew Mitchell from UCD -School of Computer Science for helpful comments and to professor Robert Bogdan Staszewski for invitation of me for project on quantum computer in silicon. The initial ideas were developed by Dirk Leipold from Equal 1 company. However the whole tight-binding approach was developed by me and now is continued by dr Elena Blokhina and dr Panagiotis Giounanlis from UCD.

New company: Quantum Hardware Systems (QHS)

http : //www.quantumhardwaresystems.com/
Mission: Linking existing quantum and classical old and new technologies in realistic fashion ...

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The End