Quantum Computing From 500,000 Feet

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Agenda

Uses for Quantum Computing

Limits of Classical Technology (Video)

Quantum Principles

How Does a Quantum Computer Work? (Video)

Quantum States

Mathematics of Quantum Computing (Video)

IBM Q Experience

Visual Studio 2017

Visual Studio Code

Uses: Decryption

Prime factorization is non-trivial once you begin working with the semi-prime product of two very large prime numbers.

RSA encryption has been a reliably unbreakable seal.

A sufficiently powerful quantum computer could break open RSA encryption with relative ease using Shor's Algorithm. The technique exists; the quantum hardware does not … yet.

Uses: Security

Quantum Cryptography: can perfectly secure communications from eavesdropping or interception.

The very act of intercepting the data (measuring it) corrupts it.

The interceptor cannot get usable information from the data.

The recipient can be alerted to the eavesdropping attempt.

Uses: New Medicines

New medicines require testing hundreds of possible variables in a chemical formula in order to find the desired characteristics needed to treat a variety of illnesses.

Therefore development time often exceeds 10 years before a new drug is brought to market.

The cost is billions of dollars.

Quantum Computers can combine and recombine elements “quickly” to test the results.

Uses: Fertilizer

Fertilizer: Making it is extremely energy intensive—the reaction gas required is taken from natural gas, which is in turn required in very large amounts.

A tiny anaerobic bacteria in the roots of plants performs this same process every day at very low energy cost using a specific molecule—nitrogenase.

This molecule is beyond the abilities of our largest supercomputers to analyze.

Within the reach of a moderate scale quantum computer.

Limits of Classical Technology

Back to Basics ⇒ classical vs quantum; superposition & entanglement; the future

Quantum Computing efficiency over Classical Computing: sqrt (O Classical)

O(1000) vs O(1,000,000)

Caveat: Since the measured output may not be the best choice, the calculations are run multiple times.

Quantum programming is in the early stages. Involves gates and qubits.

The final result must be measurable in N numbers.

Quantum States

Classical Bit: the bit is in one state or the other

Quantum Bit (Quantum Binary Digit): can be in both states or neither state or some combination of both states simultaneously. Only when measured does the qubit ‘collapse’ to one of the two possible states.

Quantum Principles: Superposition, Entanglement and Reversability

Superposition

<0| (ket 0 from bra-ket) symbol simply indicates that we are talking about the ZERO state of a qubit.

A qubit can be 0 or 1 or some combination of both:

a<0| + b<1| where a,b are coefficients in the real, imaginary or complex domain until measured when it collapses into a definite state

Four Classical bits: hold one of 2^4 (that is 16) states of which we can use 1 state.

Four qubits can be in all 16 states at the same time.

Twenty qubits can store a million values in parallel.

Entanglement

A connection that between qubits that makes one qubit change state due to a change in state in the other qubit.

Measuring one qubit means we can deduce the properties of its partners without having to look.

Reversibility

Qubits that are entangled on their way into the quantum gate remain entangled on the way out, keeping their information safely sealed throughout the transition.

Many of the classical gates found in conventional computers, on the other hand, do lose information, and therefore can’t retrace their steps.

E.g. 8 gates chain into four gates that output 1010. What was the state of the eight gates?

How Does a Quantum Computer Work

To describe the state of a 3 qubit system takes 8 numbers (data points) ->

So N qubits gives you 2^N pieces of classical information.

Non-trivial usage

How do you program a quantum computer?

Pretty much everything that you know about traditional programming becomes obsolete when you step up to the Quantum Computing.

Think in terms of probabilities, distributions of probabilities, and so forth.

Ket-state Coefficient ^ 2 = probability of ket state, e.g.

    0.8 <0| -> 0.8^2 = .64 = 64% probability qubit is in 0 state

Programming: Qubit Manipulation

Classical Computing: gates get one set of inputs and produce one definite output

Quantum Computing: quantum gate manipulates a set of superpositions, evaluates all probabilities and produces one superposition as its measured output.

The entire lot of calculations are all done with one setup at the same time.

Gates, Circuits and Algorithms

A logic gate, whether classical or quantum: any physical structure/system that takes a set of binary inputs (0s/1s, spin-up/spin-down electrons, etc) and outputs a single binary output: a 1, a spin-up electron, etc.

Output governed by a Boolean function: rule to respond to Yes/No questions.

The gates are combined into circuits, and the circuits into CPUs or other computational components.

This is true whether we're talking about Babbage's Difference Engine (mid 1800's), ENIAC (1944), retired chess champion Deep Blue (1997), or the latest room-filling, bone-chilling, headline-making quantum computer.(2010s).

Major Concern

There’s a long way to go: a quantum simulation needs about 150 logical qubits, each of which consists of anywhere from ten to thousands of “physical” qubits, which are required for error correction and stability.

Today’s quantum processors use noisy physical qubits with limited capability and a penchant for errors.

The Mathematics Of Quantum Computers?

Focus on the runtime; not the numbers.

Our first quantum calculation with two qubits.

Shor’s Algorithm to de-factor a really large prime. Invalidates all current forms of data encryption.

Quantum Decoherence: the environment is constantly trying to measure and therefore collapse the delicate quantum state before the equation is solved.

The math is solid, altho’ the technical challenges remain.

How Superposition Differs

To describe the state of a one bit classical system requires one number.

To describe the state of a one bit quantum system requires two numbers.

a<0| + b<1| = 1.0   .8 <0| + .6 <1| = 1.0 /* just one of many possible states */

a<0| + b<1| = 1.0   .5 <0| + .87 <1| = 1.0 /* just one of many possible states */

One qubit contains two pieces of information.

To describe the state of a two bit classical system requires two numbers.

To describe the state of a two bit quantum system requires four numbers.

a<00| + b<01| + c<10| + d<11| = 1.0 /* two qubits - four pieces of information */

The Advantage of Superposition

N qubits contain 2^N pieces of classical information.

300 fully entangled qubits contains 2 ^ 300 pieces of classical information.

2 ^ 300 pieces of classical information is more than the number of atoms in the universe.

Must design the computation so that the final result of a quantum computation must be in a unique state. This is non-trivial.

The number of operations required to arrive at a result is exponentially small.

Problems We Can Solve

Coin(s) Flip

Roll a Die/Dice

IBM

IBM Quantum Computing Site

Partnership Program

Try Quantum

Qiskit Toolkit

IBM Q Experience

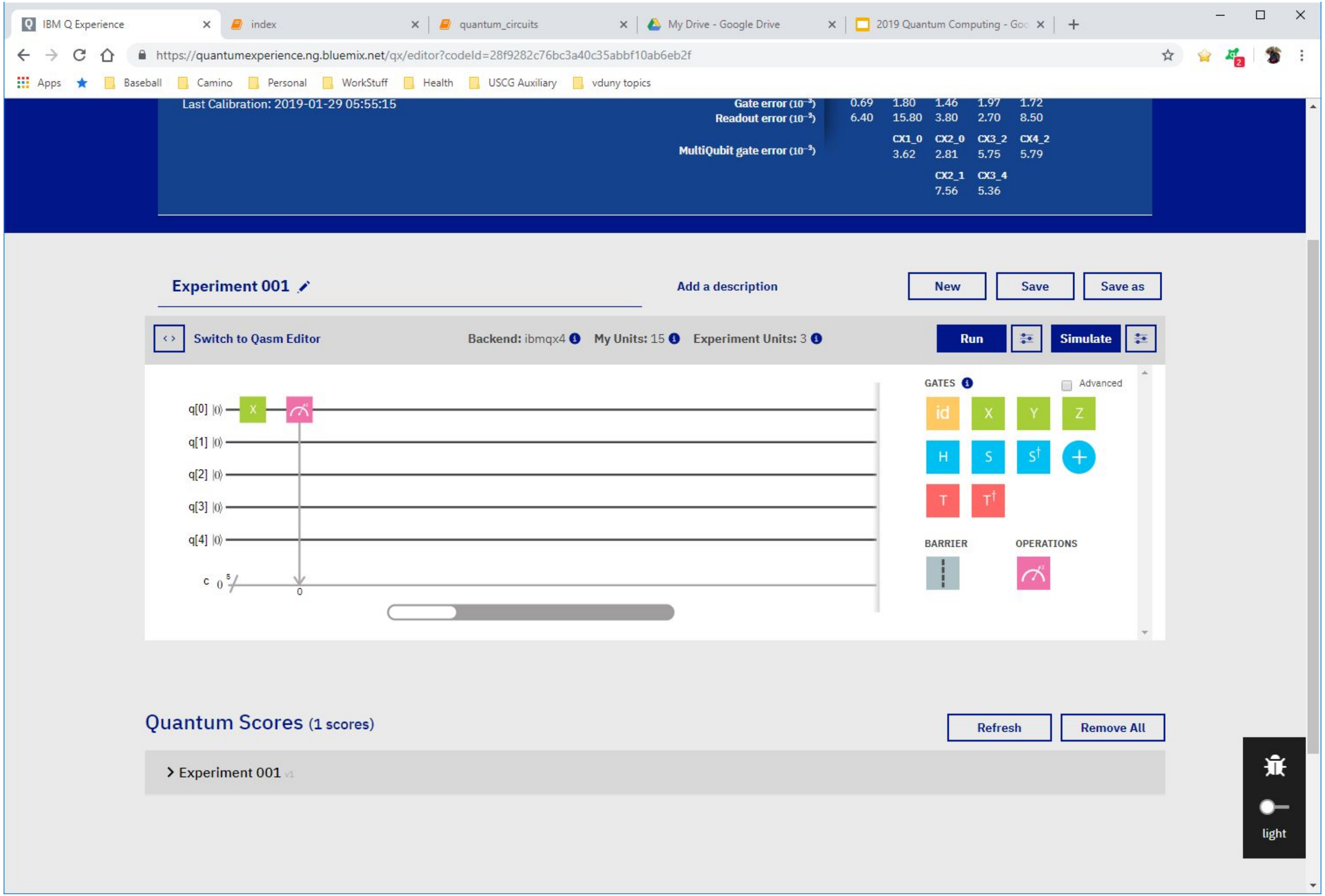
Graphical Development Tool / Editor

Run in simulator or on hardware (if have account)

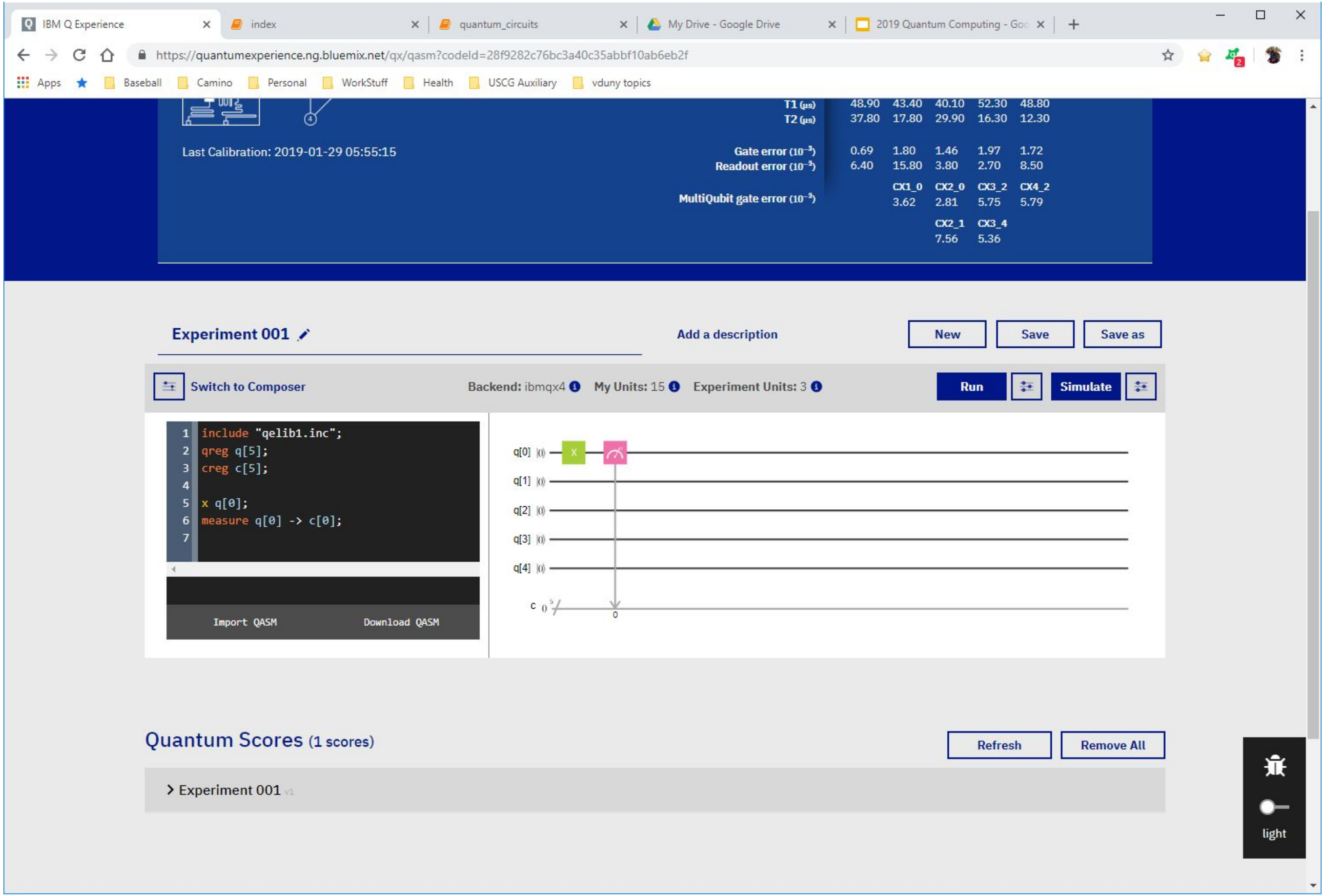
Save experiments

Composer

Only for very small problems

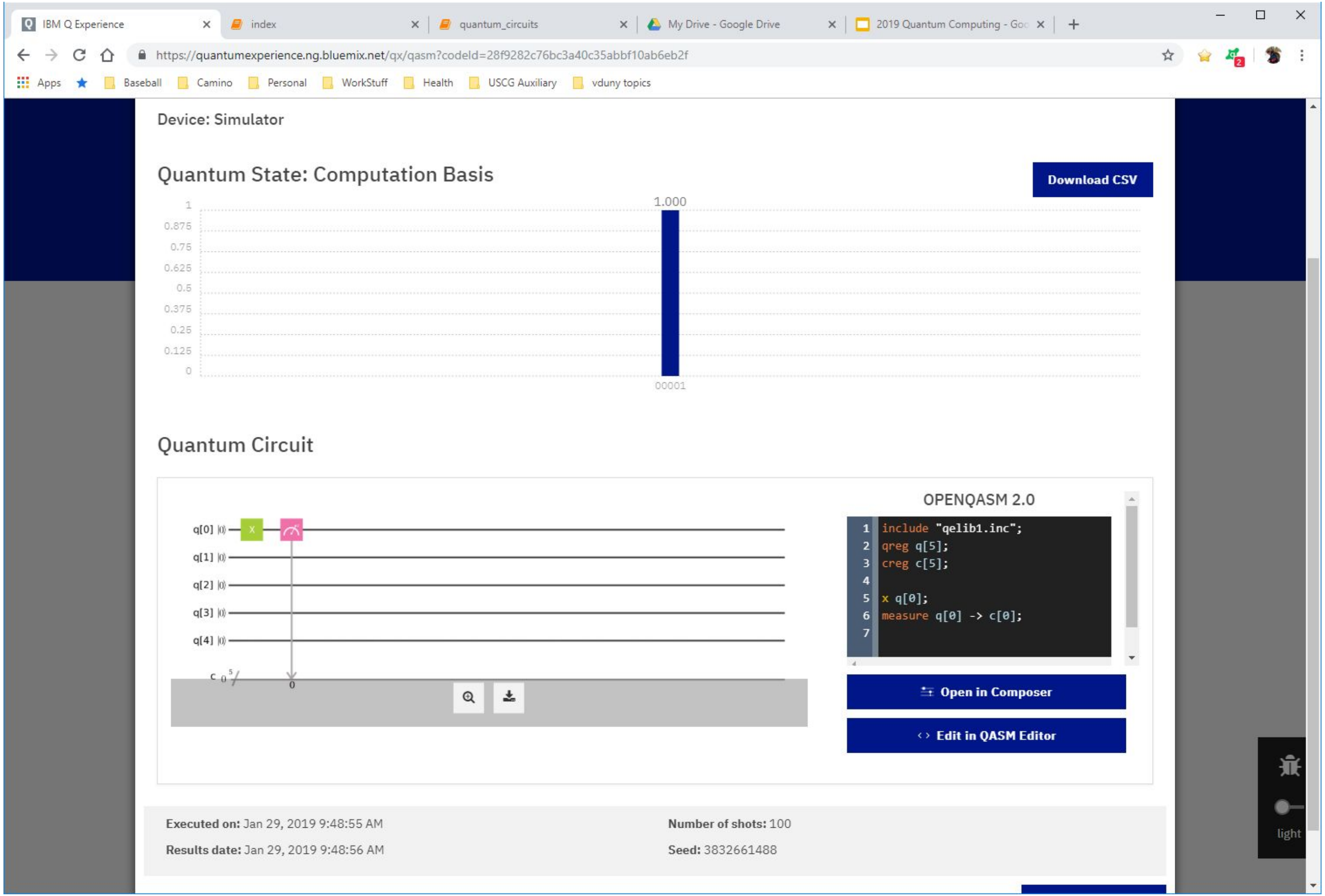


QASM Editor



IBM Q Experience
index
quantum_circuits
My Drive - Google Drive
2019 Quantum Computing - Goo
https://quantumexperience.ng.bluemix.net/qx/qasm?codeId=28f9282c76bc3a40c35abbf10ab6eb2f
Apps
Baseball
Camino
Personal
WorkStuff
Health
USCG Auxiliary
vduny topics
T1 (µs) 48.90 43.40 40.10 52.30 48.80
T2 (µs) 37.80 17.80 29.90 16.30 12.30
Last Calibration: 2019-01-29 05:55:15
Gate error (10⁻³) 0.69 1.80 1.46 1.97 1.72
Readout error (10⁻²) 6.40 15.80 3.80 2.70 8.50
MultiQubit gate error (10⁻²)
CX1_0 3.62 CX2_0 2.81 CX3_2 5.75 CX4_2 5.79
CX2_1 7.56 CX3_4 5.36
Experiment 001
Add a description
New
Save
Save as
Switch to Composer
Backend: ibmqx4
My Units: 15
Experiment Units: 3
Run
Simulate
include "qelib1.inc";
qreg q[5];
creg c[5];
x q[0];
measure q[0] -> c[0];
Import QASM
Download QASM
q[0]
q[1]
q[2]
q[3]
q[4]
c
Quantum Scores (1 scores)
Refresh
Remove All
Experiment 001
light

Results


IBM Q Experience
index
quantum_circuits
My Drive - Google Drive
2019 Quantum Computing - Goo
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Baseball
Camino
Personal
WorkStuff
Health
USCG Auxiliary
vduny topics
Device: Simulator
Quantum State: Computation Basis
Download CSV
1
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0.5
0.375
0.25
0.125
0
1.000
00001
Quantum Circuit
q[0] |0⟩
q[1] |0⟩
q[2] |0⟩
q[3] |0⟩
q[4] |0⟩
c 0 5
X
0
OPENQASM 2.0
1 include "qelib1.inc";
2 qreg q[5];
3 creg c[5];
4
5 x q[0];
6 measure q[0] -> c[0];
7
Open in Composer
Edit in QASM Editor
Executed on: Jan 29, 2019 9:48:55 AM
Results date: Jan 29, 2019 9:48:56 AM
Number of shots: 100
Seed: 3832661488
light

Gates

M - Measurement (not a quantum gate; not reversible)

X - inverter

Y - inverter

Z - no change

Hademard - superposition

Why Develop Q#? (Microsoft)

Algorithms must be expressed in terms of abstract qubits, rather than physical qubits. The compiler and runtime should manage the mapping from platform qubits to logical (error-corrected) qubits, and then to physical qubits.

Algorithms need to allow integrated quantum and classical computation.

Higher-order protocols: “meta-algorithms” which operate on other operations rather than on qubits.

For design principles, follow link above.

Visual Studio Q#

Importing Q# Into Visual Studio 2017

1. VS 2017 v 15.8 or later or VS 2017 Community Edition
2. .Net Framework 4.6.1
3. Download Microsoft.Quantum.Development.Kit-0.4.1901.3104 .vsix file
4. MS Quantum Development Kit Installation
5. Validate the kit. Just follow instructions.

Visual Studio Code

.Net SDK 2.0

Visual Studio Code 1.32.3 (64-bit)

Open VS Code.

Ctrl - P : ext install c# (ver 1.17)

Ctrl - P : ext install quantum.quantum-devkit-vscode

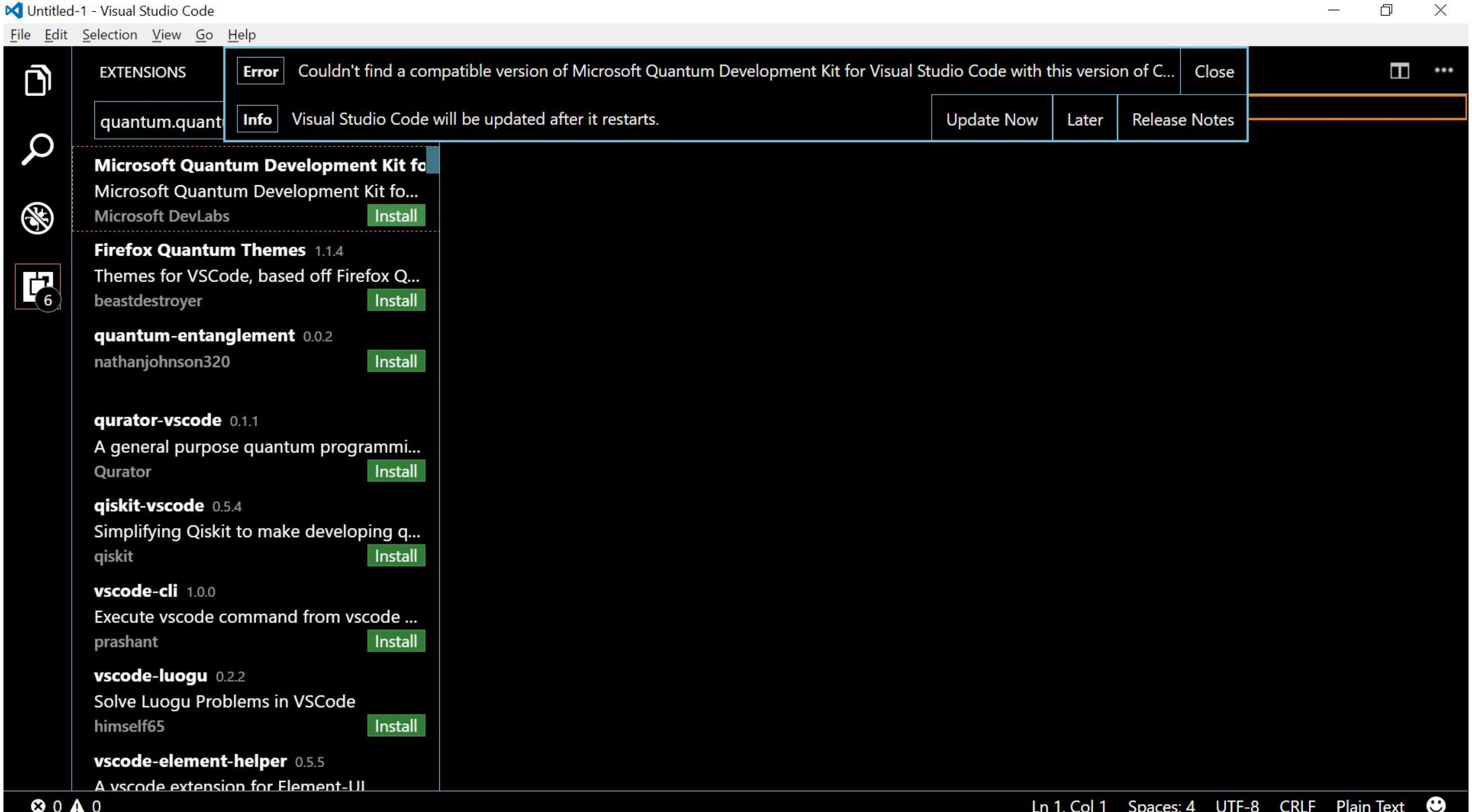
View - Open Terminal : git clone https://github.com/Microsoft/Quantum.git

cd c:\users\loheron\Quantum\Samples\src\Teleportation

\\ cd c:\users\lohe\Quantum\Samples\src\Teleportation

dotnet run

Visual Studio Code （Menu - View - Ext）



Visual Studio Code

Create folder.   // installed 64-bit version. As prompted, added extensions.

Open cmd session. Change to new folder.

> code

Ctrl - `   // Opens terminal session

dotnet new console   // create c# project; new syntax; should execute restore

dotnet restore

dotnet run

Build Msil Architecture Not Match x64 Quantum SDK

Added to vscode .csproj file via VS 2017 Prj Build Properties

```
<PropertyGroup Condition="'$(Configuration)|$(Platform)'=='Debug|AnyCPU'">
   <PlatformTarget>x64</PlatformTarget>
 </PropertyGroup>
```

Next Run After Changing Build to x64

Installing C# dependencies… Platform: win32, x86_64

Validating download… Integrity Check succeeded.

Installing package 'OmniSharp for Windows (.NET 4.6 / x64)'

Validating download… Integrity Check succeeded.

Installing package '.NET Core Debugger (Windows / x64)'

Installing package 'Razor Language Server (Windows / x64)'

Finished

Price Quotes for Quantum Computing

	IBM	Google	Amazon	Microsoft
Name	Q System One		QC2	
Processor	20 qubit (sim: 49)	72 qubit		
				Azure integration
Environment				Windows Mac Linux

The Future? Or The Past?

Physicists Reverse Time Using Quantum Computer

No, Physicists Didn't Reverse Time With a Quantum Computer

References

IBM Quantum Computing Site

Q Experience

Using QISkit: SDK for Quantum Computing

How Does A Quantum Computer Work

The Mathematics of Quantum Computing

References

John Preskill, “Quantum Computing in the NISQ era and beyond,” January 27, 2018.

IBM Q Experience: loheron@msn.com/<StarTrekCharacter>