

# **UNIVERSIDAD NACIONAL DE INGENIERIA**

## **FACULTAD DE CIENCIAS**

**PROYECTO:**  
**Paralelismo y Concurrencia en N dimensiones cuánticas**



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**Codigo Curso:** CC462

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## **Introducción**

Quantum Programming es un conjunto de lenguajes de programación que permiten la expresión de algoritmos cuánticos usando construcciones de alto nivel. El punto de los lenguajes cuánticos no es tanto proporcionar una herramienta para los programadores, sino de proporcionar herramientas para los investigadores para comprender mejor cómo funciona cuántica de cálculo y cómo razonar formalmente sobre los algoritmos cuánticos.

Se puede destacar dos grupos principales de los lenguajes de programación cuántica: lenguajes de programación imperativo cuántica y lenguajes de programación funcionales cuántica.

Los representantes más destacados del primer grupo son QCL y LanQ.

### **- Lista de lenguajes para computación cuántica:**

C/C++

- CHP
  - description: a high-performance simulator of stabilizer circuits
  - webpage: <http://www.scottaaronson.com/chp/>
  - status: finished
- Eqcs
  - description: library for quantum computer simulation
  - webpage: <http://home.snafu.de/pbelkner/eqcs/>
  - status: active
- LanQ
  - description: quantum programming language supporting multiple processes runs
  - webpage: <http://lanq.sourceforge.net/>
  - status: alive
- libquantum (C)
  - description: C library to perform quantum computation
  - webpage: <http://www.enyo.de/libquantum/>
  - status: under development
- libquantum (C++)
  - description: C++ library to perform quantum computation
  - webpage: <http://w3-phystheo.ups-tlse.fr/~bettelli/> gone
  - status: development stopped in 2003
- Open Qubit
  - description: C++ simulation library
  - webpage: <http://www.ennui.net/~quantum/> gone
  - status: development stopped in 2000
- Q++
  - description: C++ template library for simulating quantum computation, developed at [Cybernet](#)
  - webpage: <http://sourceforge.net/projects/qplusplus/>
  - status: finished

- Quantum++
  - description: Quantum++ is a C++11 general purpose quantum computing library, composed solely of template header files. Quantum++ is written in standard C++11 and has very low external dependencies, using only the [Eigen 3](#) linear algebra header-only template library and, if available, the [OpenMP](#) multi-processing library.
  - author: Vlad Gheorghiu, vgheorgh AT gmail DOT com
  - webpage: <http://vsoftco.github.io/qpp/>
  - status: active, version 0.8.6 released on 1 November 2015 under the GNU Public License
  - Copyright (c) 2013 - 2016 Vlad Gheorghiu
- QCLib
  - description: transparent simulation of quantum algorithms
  - webpage: <http://www.quantware.ups-tlse.fr/QWLIB/>
  - status: finished
- QCSim
  - description: simulator written in C++
  - webpage: <http://hissa.nist.gov/~black/Quantum/qcsim.html>
  - status: unknown
- QDD
  - description: C++ simulation library
  - webpage: <http://thegreves.com/david/QDD/qdd.html>
  - status: unknown
- QGAME
  - description: Quantum Gate And Measurement Emulator
  - webpage: <http://hampshire.edu/lspector/qgame.html>
  - status: unknown
- qsims
  - description: a general-purpose quantum simulation software package, capable of simulating the dynamics of systems with a wide range of Hamiltonians
  - webpage: <http://qsims.sourceforge.net/>
  - status: active, under development
- QTM simulator
  - description: Quantum Turing Machine Simulator
  - webpage: <http://web.archive.org/web/20050923134721/http://www.lri.fr/~durr/Attic/qtm/>
  - status: unknown Finished?
- Quantum Computer Language
  - description: language similar to C or Pascal integrated with a simulator of quantum computation
  - webpage: <http://tph.tuwien.ac.at/~oemer/qcl.html>
  - status: under development
- Quantum Computer Simulator
  - description: simulator of quantum computers
  - webpage: <http://www-imai.is.s.u-tokyo.ac.jp/~tokunaga/QCS/simulator.html>
  - status: unknown
- Quantum Construct (qC++)
  - description: rapid development of quantum mechanical simulations
  - webpage: <http://sourceforge.net/projects/qcplusplus/>
  - status: active

- Quantum Information Matrix Toolkit
  - description: The toolkit is intended to facilitate coding C++ numerics related to Quantum Information. in it.
  - webpage: <http://www.physics.uq.edu.au/people/dawson/matrix/doc/>
  - status: finished
- Quantum Network Computing
  - description: environment for developing quantum computer simulations
  - webpage: <http://sourceforge.net/projects/qnc/>
  - status: No longer under active development
- QuBit
  - description: QM-like superpositions
  - webpage: <http://www.bluedust.com/qubit/>
  - status: unknown
- Qubiter
  - description: quantum compiler based on CS decomposition
  - webpage: <http://www.ar-tiste.com/qubiter.html>
  - status: alive
- QuCoSi
  - description: C++ library for simulating a quantum computer
  - webpage: <http://qucosi.sourceforge.net/>
  - status: active
- QuIDDDPro
  - description: Uses the Quantum Information Decision Diagram (QuIDD) datastructure to simulate a number of important circuits using asymptotically less runtime and memory resources than simulation techniques based on explicit matrices and vectors.
  - webpage: <http://vlsicad.eecs.umich.edu/Quantum/qp/>
  - status: finished
- QWalk
  - description: simulator of quantum walks for one- and two-dimensional lattices
  - webpage: <http://www.cos.ufrj.br/~franklin/qwalk/>
  - status: alive
- Shor's Algorithm Simulation
  - description: simulator of quantum Shor's algorithm
  - webpage: <http://alumni.imsa.edu/~matth/quant/> gone
  - status: finished
- SpinDec
  - description: library for spin decoherence implementing the cluster correlation expansion.
  - webpage: <http://bitbucket.org/sbalian/spindec>
  - status: active
- sqct - Single qubit circuit toolkit
  - description: software for exact and approximate synthesis of single qubit circuits using Clifford and T gate library.
  - webpage: <http://code.google.com/p/sqct/> and <http://arxiv.org/abs/1206.5236>
  - status: active

## CaML

- Q-gol
  - description: system for simulation of quantum computations

- webpage: <http://www.ifost.org.au/~gregb/q-gol/>
- status: finished

## F#

- LIQUiD
  - description: Microsoft Research's F# based simulation platform
  - webpage: <http://research.microsoft.com/en-us/projects/liquid/>
  - repository: <https://github.com/msr-quarc/Liquid>
  - status: active

## GUI based

- Bloch Sphere Simulator of Quantum-Mechanical gates and Spintronics
  - description: 3d visualization of qubits on the Bloch sphere
  - webpage: <http://www.ece.uc.edu/~mcahay/blochsphere/>
  - status: finished
- DEKOMPMAT
  - description: decomposition of unitary matrices into quantum logic circuits
  - webpage: <http://www.quniverse.sk/people/sedlak/>
  - status: finished
- Linear AI
  - description: quantum development environment; research, design and teaching tool for quantum computing and quantum information
  - webpage: <http://linearal.sourceforge.net/>
  - status: active
- Optical Simulator
  - description: visualisation of linear optics quantum computing
  - webpage: <http://strc.herts.ac.uk/tp/info/qucomp/>
  - status: finished
- QC Simulator
  - description: universal quantum computation simulator
  - webpage: <http://www.senko-corp.co.jp/qcs/>
  - status: unknown
- QCAD
  - description: Windows-based environment for quantum computing simulation (Open Source)
  - webpage: <http://qcad.sourceforge.jp/>
  - status: active
- QSim
  - description: simulation of NMR experiments
  - webpage: <http://www.bpc.lu.se/QSim/>
  - status: unknown
- Qdns
  - description: GUI program - Quantum Designer and Network Simulator
  - webpage: <http://www.hit.bme.hu/people/imre/pages/QDNS/>
  - status: under development
- Quantum Computer Emulator
  - description: QC simulator solving Schrodinger equation
  - webpage: <http://rugth30.phys.rug.nl/QCE/Default.aspx>
  - status: active
- Quantum Fog

- description: quantum simulator (and graphic programming language) that uses quantum generalization of Bayesian Networks; works only on MacOS X (10.2 or later)
- webpage: <http://www.ar-tiste.com/qfog.html>
- status: alive
- Quantum Qudit Simulator
  - description: Windows-based qudit circuits simulator, part of Master's thesis
  - webpage: <http://www.compsoc.nuigalway.ie/~damo642/QuantumSimulator/QuantumSimulator/QuantumQuditSimulator.htm>>
  - status: finished
- SimQubit
  - description: quantum circuit simulator on the basis of Q++
  - webpage: <http://sourceforge.net/projects/simqubit/>
  - status: active

#### Java

- Bloch Sphere Simulator of Quantum-Mechanical gates and Spintronics
  - description: 3d visualization of qubits on the Bloch sphere
  - webpage: <http://www.ece.uc.edu/~mcahay/blochsphere/>
  - status: finished
- jaQuzzi
  - description: interactive quantum computer simulator
  - webpage: <http://www.eng.buffalo.edu/~phygons/jaQuzzi/>
  - status: unknown
- jQuantum - Quantum Computer Simulator
  - description: simulator of quantum circuits with a visual editor
  - webpage: <http://jqquantum.sourceforge.net/>
  - status: unknown
- qsim
  - description: quantum computation simulator concentrating and based on quantum circuits
  - webpage: <http://www.dennisweyland.de/qsim/>
  - status: unknown
- jSQ- Java Quantique Simulator
  - description: simulator of quantum dial able to generate binary keys
  - webpage: <http://sourceforge.net/projects/simu-quantique/>
  - status: active
- QuanSuite
  - description: Suite of 7 Java applications, all based on a common class library called QWalk. Each application compiles a different kind of evolution operator.
  - webpage: <http://www.ar-tiste.com/QuanSuite.html>
  - status: alive
- Quantomatic
  - description: high level graphical calculus for quantum information
  - webpage: <http://quantomatic.github.io/>
  - status: active
- Quantum Algorithm Designer
  - description: graphical algorithm construction tool and simulator
  - webpage: <http://www-users.cs.york.ac.uk/~sok/QAD/>

- status: unknown, probably dead
- Quantum Search Applet
  - description: interactive quantum search applet
  - webpage: <http://www.cit.gu.edu.au/~s55086/qucomp/qucompApplet.html>
  - status: finished
- QuaSi 1 / 2
  - description: graphical algorithm construction tool and simulator
  - webpage: <http://iaks-www.ira.uka.de/QIV/QuaSi/aboutquasi.html>
  - status: probably finished
- qMIPS101
  - description: two quantum computing Java applications: Qubit101 an usable and efficient quantum circuit simulator and qMIPS a simulator of a processor with an integrated quantum functional unit.
  - webpage: <http://institucional.us.es/qmipsmaster/>
  - status: active
- QuSAnn (and Multiplexor Expander)
  - description: 2 Java applications. QuSAnn outputs quantum circuit for doing simulated annealing on a quantum computer. MultiplexorExpander is a utility tool that expands quantum multiplexor gate into sequence of more elementary gates.
  - webpage: <http://www.ar-tiste.com/qusann.html>
  - status: alive
- Squankum
  - description: interactive quantum computation applet
  - webpage: <http://www.pha.jhu.edu/~jeffwass/squankum/> **Moved to** <http://jeffwass.github.com/Squankum/>
  - status: active
- Virtual quantum mechanics
  - description: applet visualising basic quantum operations
  - webpage: <http://www.pha.jhu.edu/~javalab/qubit/qubit.html>
  - status: unknown
- Zeno
  - description: universal quantum circuit simulator which allows edition and simulation of quantum circuits with pure and mixed states
  - webpage: [http://dsc.ufcg.edu.br/~iquanta/zeno/index\\_en.html](http://dsc.ufcg.edu.br/~iquanta/zeno/index_en.html)
  - status: finished

#### Javascript

- jsqis - Javascript Quantum Information Simulator
  - description: a quantum simulator for use in the browser, emphasizing a complete, precise, visual representation of quantum bits and registers
  - webpage: <https://github.com/garrison/jsqis>
  - status: active

#### Maple

- FEYNMAN
  - description: simulation of n-qubit quantum systems
  - webpage: <http://cpc.cs.qub.ac.uk/summaries/ADWE>
  - status: active
- OpenQUACS
  - description: general-purpose universal Quantum Computer Simulator

- webpage:  
<http://web.archive.org/web/20060116174553/http://userpages.umbc.edu/~cmccub1/quacs/quacs.html>
- status: unknown
- Quantavo
  - description: a Maple toolbox for linear optics and quantum information in Fock space
  - webpage: <http://www3.imperial.ac.uk/quantuminformation/research/downloads>
  - status: active

## Mathematica

- QDENSITY
  - description: Mathematica package operating on density matrices
  - webpage: <http://www.pitt.edu/~tabakin/QDENSITY/>
  - status: active
- qmatrix
  - description: Mathematica package for Quantum Information Theory
  - webpage: <http://library.wolfram.com/infocenter/MathSource/1893/>
  - status: unknown
- Quantum
  - description: Mathematica add-on for simulating quantum algorithms
  - webpage: <http://homepage.cem.itesm.mx/lgomez/quantum/index.htm>
  - status: active
- Quantum Information Programs in Mathematica
  - description: functions and other objects useful for simulating small quantum circuits
  - webpage: <http://quantum.phys.cmu.edu/QPM/>
  - status: active
- Quantum Turing Machine Simulator
  - description: toolkit to construct, run, and research quantum Turing machines
  - webpage: <http://library.wolfram.com/infocenter/Articles/3893/>
  - status: finished
- QuCalc
  - description: Mathematica package for doing quantum computation
  - webpage: <http://crypto.cs.mcgill.ca/QuCalc/>
  - status: active
- QI
  - description: package for analysing quantum states and quantum channels with Mathematica
  - webpage: <http://zksi.iitis.pl/wiki/projects:mathematica-qi>
  - status: active
- TRQS
  - description: package for Mathematica computing system allowing to generate true random quantum states. It can be used with Quantis random number generator or QRNG service as a source of randomness.
  - webpage: <http://www.iitis.pl/~miszczak/trqs>
  - status: active

## Maxima

- description: Qinf quantum information and entanglement package
- webpage: <http://www.johnlapeyre.com/qinf/index.html>
- status: Unknown



## MATLAB/Octave

- CS 596 Quantum Computing
  - description: routines for quantum algorithms
  - webpage: <http://www.sci.sdsu.edu/Faculty/Don.Short/QuantumC/cs662.htm>
  - status: finished
- drqubit
  - description: various routines for quantum information research
  - webpage: <http://www.dr-qubit.org/matlab.php>
  - status: active
- M-fun for QC Progs
  - description: tool box of Octave/MATLAB m-files for QC programming
  - webpage: <http://www.ar-tiste.com/m-fun/m-fun-index.html>
  - status: alive
- QC simulator
  - description: simulator of a quantum computer
  - webpage: <http://www-m3.ma.tum.de/twiki/bin/view/Software/QCWebHome>
  - status: active
- QCTOOLS
  - description: toolbox to simulate ion trap quantum computers
  - webpage: <http://physics.berkeley.edu/research/haeffner/teaching/exp-quant-info/exp-quant-info>
  - status: active
- QETLAB
  - description: toolbox for quantum information theory and entanglement
  - webpage: <http://www.getlab.com>
  - status: active
- QLib
  - description: a MATLAB library for Quantum Information calculations
  - webpage: <http://www.tau.ac.il/~quantum/qlib/qlib.html>
  - status: active
- qotoolbox
  - description: Quantum Optics and Computation Toolbox for MATLAB
  - webpage: <http://www.qo.phy.auckland.ac.nz/qotoolbox.html>
  - status: finished
- Quack!
  - description: MATLAB based quantum computer simulator
  - webpage: [http://www.physics.uq.edu.au/people/rohde/blog/?page\\_id=20](http://www.physics.uq.edu.au/people/rohde/blog/?page_id=20)
  - status: complete and under continual development
- Quantum Computing Functions for Matlab (QFC)
  - description: a library of MATLAB functions for simulating quantum computing algorithms
  - webpage: <http://www.robots.ox.ac.uk/~charles/>
  - status: active
- Quantum Octave
  - description: Gnu Octave package performing QC on mixed states
  - webpage: <http://quantum-octave.sf.net/>
  - status: Not maintained any more
- Qubit4matlab

- description: MATLAB routines for quantum information
- webpage: <http://bird.szfki.kfki.hu/~toth/qubit4matlab.html>
- status: active

#### Maxima

- Qinf
  - description: quantum information and entanglement package
  - webpage: <http://www.johnlapeyre.com/qinf/index.html>
  - status: Unknown

#### .NET

- Cove
  - description: A practical quantum computer programming framework
  - webpage: <https://cove.purkeypile.com/trac/>
  - status: active
- Quantum Information Suite
  - description: framework for Quantum Computation
  - webpage: <http://dotqcf.sourceforge.net/>
  - status: active

#### Online Services

- Factor 15 Circuit
  - description: online simulation of Shor's algorithm
  - webpage: [http://web.archive.org/web/20060203095655/http://www.isi.edu/acal/quantum/quantum\\_intro.html](http://web.archive.org/web/20060203095655/http://www.isi.edu/acal/quantum/quantum_intro.html)
  - status: unknown
- Fraunhofer Quantum Computing Simulator
  - description: simulates quantum circuits and Hamiltonians up to 31 qubits
  - webpage: <http://www.qc.fraunhofer.de/>
  - status: discontinued
- GQC
  - description: an online quantum compiler
  - webpage: <http://www.physics.uq.edu.au/gqc/>
  - status: active
- QRBGS
  - description: online quantum random number generator
  - webpage: <http://random.irb.hr/>
  - status: active
- Quantum eXpress
  - description: Java-based quantum computer simulator
  - webpage: <https://www.research.ge.com/quantum/>
  - status: unknown
- Quantum Walks
  - description: Online calculator for simulating quantum walks on cycles hosted at The National University of Ireland, Galway.
  - webpage: <http://walk.to/quantum>
  - status: unknown
- Quantum Computer Simulator
  - Description: development of a library for quantum calculation and the implementation of a graphic interface that uses the library. Hosted at University of Patras

- Webpage: <http://www.wcl.ece.upatras.gr/ai/resources/demo-quantum-simulation>
- Status: Complete

#### Perl/PHP

- Quantum::Entanglement
  - description: entanglement of variables in Perl
  - webpage: <http://search.cpan.org/~ajgough/Quantum-Entanglement-0.32/>
  - status: finished
- Quantum::Entanglement
  - description: online entanglement calculator in PHP
  - webpage: <http://grobner.it.nuigalway.ie/ent/start.php>
  - status: finished
- Quantum::Superpositions
  - description: QM-like superpositions in Perl
  - webpage: <http://search.cpan.org/~lembark/Quantum-Superpositions-2.02/>
  - status: finished

#### Python

- PyQu
  - description: High-level quantum programming in Python (C extension module using libquantum).
  - webpage: <http://code.google.com/p/pyqu>
  - status: under developement
- qitensor
  - matrix-level quantum operations, with labeled component Hilbert spaces. Symbolics supported in Sage.
  - webpage: <http://www.stahlke.org/dan/qitensor>
  - status: active
- Qubiter
  - Python tools for reading, writing, compiling, simulating quantum computer circuits
  - webpage: <https://github.com/artiste-qb-net/qubiter>
  - status: active
- Quantum Fog
  - Python tools for analyzing both classical and quantum Bayesian Networks
  - webpage: <https://github.com/artiste-qb-net/quantum-fog>
  - status: active
- QuTiP
  - Framework for solving open quantum systems using master equation and monte-carlo methods.
  - webpage: <http://code.google.com/p/qutip/>
  - status: active

#### Scheme/Haskell/LISP/ML

- CS 20c Project
  - description: Quantum Turing Machine simulation
  - webpage: <http://web.archive.org/web/20011207175140/www.cs.caltech.edu/~thoth/code.html>
  - status: finished
- Haskell Simulator of Quantum Computer
  - description: Haskell module for quantum computer simulations
  - webpage: <http://web.archive.org/web/20010803034527/http://www.numeric-quest.com/haskell/QuantumComputer.html>

- status: unknown
- qlambda
  - description: functional language based on Scheme for expressing and simulating quantum algorithms
  - webpage: <http://www.het.brown.edu/people/andre/qlambda/>
  - status: unknown
- QML
  - description: functional quantum programming language
  - webpage: <http://sneezy.cs.nott.ac.uk/qml/>
  - status: active
- Quipper
  - description: an embedded, scalable functional programming language for quantum computing
  - webpage: <http://www.mathstat.dal.ca/~selinger/quipper/>
  - status: active
- Simulating Quantum Circuits on a parallel machine
  - description: Windows-based quantum computer parallel simulator
  - webpage: <http://www.themilkyway.com/quantum/>
  - status: unknown

## **- Quantum computing language:**

QCL es uno de los primeros lenguajes que implementa un lenguaje de programación cuántico. Su sintaxis es similar a la del lenguaje C e incluso tiene sus data types similares a las primitivas de C. con QCL se puede combinar el código clásico y cuántico en el mismo programa.

Una manera básica de definir un tipo de dato en QCL es qureg (quantum register). Que se puede interpretar como un array de qubits.

Ejemplos:

```
qureg x1[2];    // 2-qubit quantum register x1
qureg x2[2];    // 2-qubit quantum register x2
H(x1);         // Hadamard operation on x1
H(x2[1]);      // Hadamard operation on the first qubit of the register x2
```

Para interpretar el código se usa la librería qlib que muestra datos de ejecución en uso de memoria mientras se ejecuta el programa cuántico.

```
qcl> dump
: STATE: 4 / 32 qubits allocated, 28 / 32 qubits free
0.35355 |0> + 0.35355 |1> + 0.35355 |2> + 0.35355 |3>
+ 0.35355 |8> + 0.35355 |9> + 0.35355 |10> + 0.35355 |11>
```

La librería standard QCL provee operadores cuánticos usados en algoritmos como: Hadamard o parse.

La característica más resaltante de QCL es que soporta la definición de operaciones y funciones nuevas. Es decir, puede definir tus propias operaciones y la manera en como quieras usarlas (similar a objetos).

Ejemplo:

```
operator diffuse (qreg q) {  
    H(q);           // Hadamard Transform  
    Not(q);         // Invert q  
    CPhase(pi, q);  // Rotate if q=1111..  
    !Not(q);        // undo inversion  
    !H(q);          // undo Hadamard Transform  
}
```

## **- Q Language**

[1] Qlang es la segunda implementación imperativa para la programación cuántica. Es una extensión de C++, tiene clases para operadores cuánticos como Qhadamard, Qfourier, Qnot y Qswap. Las cuales derivan de la clase Qop. Se puede definir nuevos operadores.

Ejemplo:

```
Qreg x1; // 1-qubit quantum register with initial value 0  
Qreg x2(2,0); // 2-qubit quantum register with initial value 0
```

## **- Quantum computing Playground**

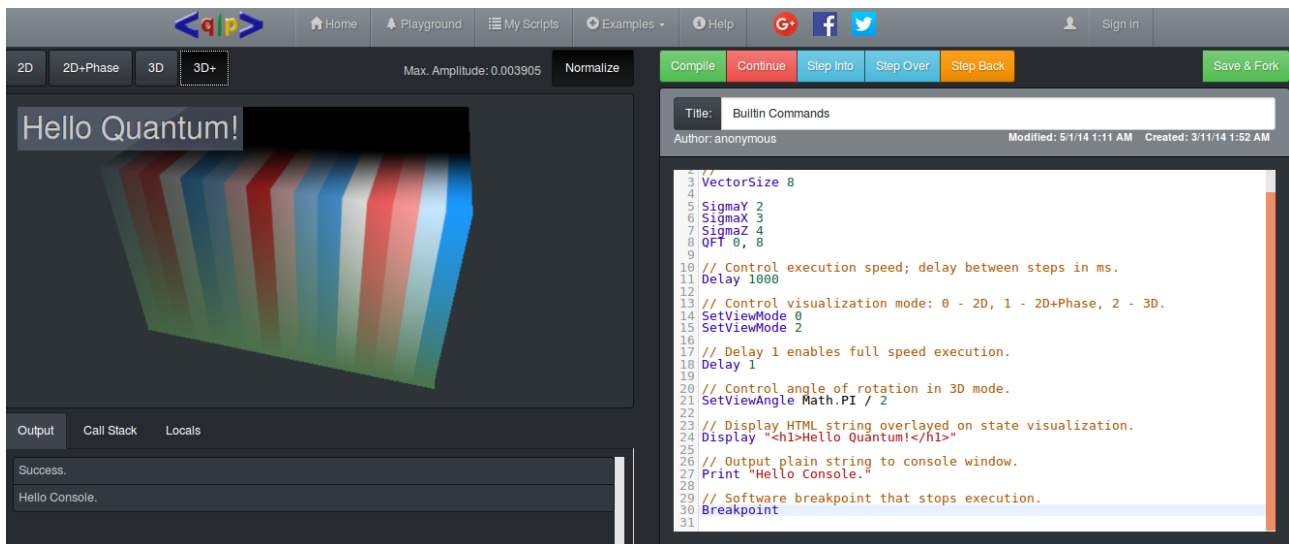
Actualmente se tiene el simulador de google para computación cuántica. le permite escribir el tipo de software que se correría en una computadora cuántica.

El simulador basado en la nube funciona en Google Chrome preferiblemente e imita un computador cuántico acelerado por GPU.

Utiliza su propio lenguaje de scripting Qscript y características especiales de visualización de estado cuántico en 3D.

Puede simular eficientemente registros cuánticos hasta 22 qubits, ejecutar los algoritmos de Grover y de Shor, y tiene una variedad de puertas cuánticas integradas en el propio lenguaje de scripting.

<http://www.quantumplayground.net/#/playground/5165166324875264>



## Bibliografia

[1] Quantum Programming Language LangQ, Hynek Mlnarík, Masaryk University, Faculty of Informatics, PhD Tesis, 2007.