

## SIMULATION OF QUANTUM COMPUTATIONS ON CLASSICAL COMPUTERS

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In the last years the importance of quantum computing has significantly increased due to both continuously shrinking of the size of silicon-based integrated circuits and the results in quantum algorithms development. Quantum computing devices are not available outside of research labs so quantum computing simulators represent important instruments in the development and testing of those algorithms. We present several quantum algorithms and their simulations using a quantum programming language, Quantum Computation Language (QCL)

### INTRODUCTION

Quantum computing is the new field of science which uses quantum phenomena to perform operations on data. The goal of quantum computing is to find algorithms that are considerably faster than classical algorithms solving the same problem.

The fundamental unit of quantum information is *quantum bit* or *qubit*. The general state of a qubit is a linear combination - or a superposition- of the basis states  $|0\rangle$  and  $|1\rangle$ :

$$|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

where  $\alpha$  and  $\beta$  are complex numbers which satisfy the relation:

$$|\alpha|^2 + |\beta|^2 = 1$$

A qubit can exist as a zero, a one, or simultaneously as 0 and 1. A system consisting of  $n$  qubits has  $2^n$  basis states, written  $|00\dots 0\rangle, \dots, |1\dots 1\rangle$ . The general state of an  $n$ -qubit system is a superposition of all  $2^n$  basis states:

$$|\psi\rangle = \sum_{k=0}^{2^n-1} c_k |k\rangle$$

where:  $|k\rangle = |k_{n-1}\rangle \dots |k_1\rangle |k_0\rangle$  and  $\sum_{k=0}^{2^n-1} c_k |k\rangle =$

Like the single-qubit system, a  $n$ -qubit register can store simultaneously all basic states.

Measurement collapses a quantum state into one of the possible basis states, so measurement is a destructive operation. If a qubit is in the state  $|\Psi\rangle = \alpha|0\rangle + \beta|1\rangle$  and a measure is performed, it obtains 0 with probability  $\alpha^2$  (the state of qubit become  $|0\rangle$ ) and 1 with probability  $\beta^2$  (the state of qubit become  $|1\rangle$ ).

A unitary transformation that acts on a small number of qubits is called a *quantum gate*. A quantum gate has the same number of inputs and outputs.

Hadamard gate:

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

Not (X) gate:

$$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

Controlled-NOT (CNOT) gate:

$$CNOT = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

SWAP gate:

$$SWAP = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

### SIMULATORS OF QUANTUM COMPUTERS

➤ computer programs which can be run on a classical machine to simulate the actions of a quantum computer

#### CLASSIFICATION

- programming languages for quantum computers (Quantum Computation Language – QCL, Quantum Superpositions, Quantum Entanglement, Quantum Fog, QDD)
- quantum compilers (Qubiter, GQC)
- quantum circuit simulators, or gate-level simulators (QCAD, QuaSi, JaQuzzi)
- quantum computer emulators (QCE, QSS)
- pedagogical software (Quantum Turing machine simulator, QTM simulator, Quantum Search Simulator)

#### QUANTUM PROGRAMMING LANGUAGES - key characteristics:

- *completeness* - every current and future quantum algorithm can be written in the language
- *separability* - easy separation of classical computations from quantum computations
- *based on familiar concepts and constructs*
- *high-level of abstraction*
- *hardware independent*

#### Quantum Computation Language – QCL

- ❖ high level language for quantum programming
- ❖ open-source
- ❖ runs under Linux operating system
- ❖ C or Pascal like syntax
- ❖ a classical control language with functions, flow-control, interactive I/O and various classical data types (int, real, complex, boolean, string)
- ❖ 2 quantum operator types: general unitarian (operator) and reversible pseudo-classic gates (qfunct)
- ❖ inverse execution, allowing for on-the-fly determination of the inverse operator through caching of operator calls
- ❖ various quantum data types (qubit registers) for compile time information on access modes (qureg, quconst, quvoid, quscratch)
- ❖ convenient functions to manipulate quantum registers (q[n] - qubit, q[n:m] - substring, q&p - combined register)
- ❖ quantum memory management (quheap) allowing for local quantum variables

## QUANTUM ALGORITHMS

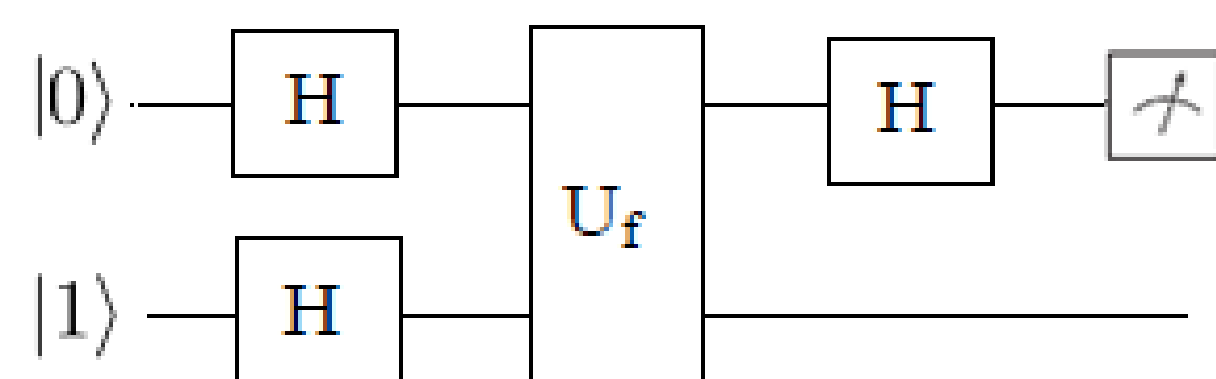


Fig.1. The quantum circuit for Deutsch-Jozsa algorithm

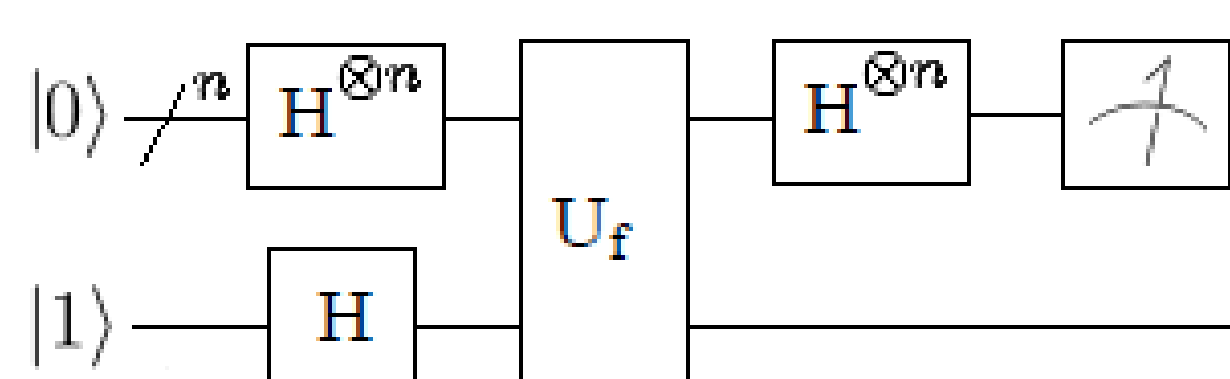


Fig.2. The quantum circuit for Simon algorithm

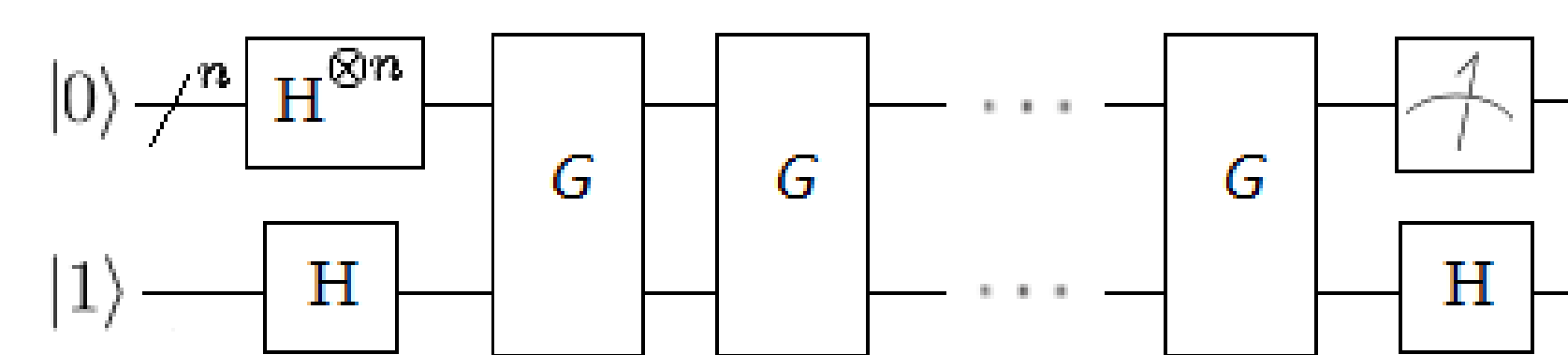


Fig.3. The quantum circuit for Grover algorithm

```
//Uf operator simulated by CNOT and
//NOT(X) gates
qfunct Uf(quvoid x, quvoid y, int n) {
  if (n==2) or (n==3) {
    CNot(y, x);
  }
  if (n==3) or (n==4) {
    X(y);
  }
}
```

The implementation of Uf transformation for Deutsch algorithm in QCL

```
procedure simon2() {
  qureg x[2]; qureg y[2]; int m;
  {
    reset;
    //Hadamard gate
    H(x);
    //Uf transformation
    CNot(y[0], x[0]);
    //Hadamard gate
    H(x);
    //the x register is measured
    measure x,m;
    print "The measured value is: ", m;
  } until (m!=0);
}
```

QCL implementation of Simon algorithm in the case n=2

```
procedure grover(int n) {
  // number of qubits
  int l=floor(log(n,2))+1;
  //number of iterations
  int nr=ceil(pi/8*sqrt(2^l));
  int m; int i; qureg q[l]; qureg f[l];
  {
    reset;
    H(q); // Hadamard gate
    for i= 1 to nr { // Grover iterations
      query(q,f,n); // oracol operator
      CPhase(pi, f);
      !query(q,f,n);
      diffuse(q); // diffusion operator
    }
    measure q,m; // measure
    print "The result of mesurement: ",m;
  } until m==n;
  reset;
}
```

The implementation of Grover algorithm in QCL



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RESEARCH AND INNOVATION EXHIBITION

First edition



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On behalf of the Organizing Committee, we are pleased to inform you that your poster has been accepted for presentation at The 1st Edition of Research and Innovation Exhibition, UGAL INVENT 2014, which will take place during 8-10 October 2014 in Galati. The exhibition will be held in the Great Hall of Dunarea de Jos University of Galati, Romania, 47 Domneasca Street.

Please prepare your poster in accordance with the instructions posted on the website <http://invent.ugal.ro>.

The posters must be displayed on special poster boards no later than 8th of October 9.00 AM, and are requested to be posted throughout the exhibition period (October 8 to 10, 2014).

If you are not attending the exhibition, and if you want your poster to be displayed, you should submit your poster by regular mail no later than 7th of October, 16.00 PM to the following address: 111 Domneasca Str., D Building, Room D11d, 800 201, Galati, Romania (Tel. 0732 585 298, Contact person: Laurentiu Sandu).

For any question regarding the exhibition and poster submission please contact the secretariat by the following e-mail address: [florin.susac@ugal.ro](mailto:florin.susac@ugal.ro)

The list of participants in the UGAL INVENT 2014 is now available on the website: <http://www.invent.ugal.ro/catalogue.html>

We're looking forward to seeing you in Galati.

Sincerely,

Organizing Committee

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Department of Manufacturing Engineering  
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