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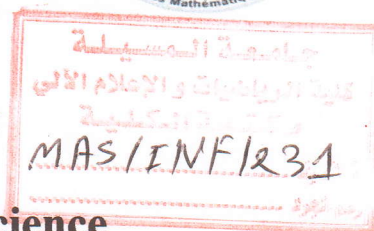


**UNIVERSITY MOHAMED BOUDIAF OF M'SILA**  
**FACULTY OF MATHEMATICS AND**  
**INFORMATICS**



**COMPUTER SCIENCE DEPARTMENT**

**A dissertation in fulfillment  
For the requirement of  
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Domain: Mathematics and Informatics  
Branch: Computer Science  
Option: Networks**



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**SUBJECT**

**Quantum-Inspired Genetic Algorithm for a  
Class of Combinatorial Optimization**

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## General Introduction:

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This study proposes a novel genetic algorithm inspired from quantum information and computation concepts (QIQA) which combines both quantum interference between the registers of quantum computation and genetic algorithm (GA) with population with all its dynamic characteristics, like: individual representation, the fitness function, but their definition is inspired by quantum notions, as: Hadamard gate (H), unitary transformation (crossover and mutation), measurement (Qbit to Cbit).

## General Introduction

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### General Introduction:

Quantum information and computation is a new exciting field of research, while quantum information investigates the informational power of quantum bit (Qbit) which is the quantum information unit, the quantum computation tries to exploit this quantum informational capability to build a strong quantum algorithms to solve a class of problems that seems to be unsolvable by the conventional computers. Unfortunately, the design of quantum computer faces the difficulty of coherence with environment.

Still we can exploit the concepts of quantum information to inspire classical techniques that could give classical algorithms better performance. A quantum computation is probabilistic by nature, and so it can be more exploitable when combined with random algorithms which are more powerful than exact ones.

Evolutionary algorithms like genetic ones try to deal with probability through nice models inspired of biological real ones in nature. It seems natural that these two different techniques should combine their computational powers in a hope to require better capability to solve hard problems.

Genetic algorithms are stochastic ones; they deal with probability upon the notion of population, rather than quantum information, in which the probability is intrinsic to the quantum bit (Qbit). So, the population will be an ensemble of Qbits.

The algebra of the Qbits is built upon matrices, which suggest, that the inspired quantum algorithms should choose the same algebra. Q\_algebra has three notions: Qbit is represented by a binary linear Hilbert space, so each Qbit is represented by a unitary binary column vector; geometrically it can better represented by Bloch sphere. The evolution of the Qbit is represented by a unitary matrix, and the measurement of the Qbit collapsed it in the classical bit (Cbit)  $\in \{0, 1\}$ .

The algebra of GAs evolves initial population of potential solutions taken randomly from the whole solution space. This evolution is done applying the principle of genetics like crossover and mutation. The fittest individuals make next generation. This process iterate in hope that each generation approaches better the solution seeking than the generation that generate them.

Q\_algebra and G\_algebra have to interfere constructively to create a better algorithm.

This study proposes a novel genetic algorithm inspired from quantum information and computation concepts (QIGA) which resulted from nice interference between the algebra of quantum computation and genetic algorithm. QIGA still based population with all its dynamic characteristics, like : individual representation, the evolution function, but their definition is inspired by quantum notions, as, linear superposition (Qbit), unitary transformation (crossover and mutation), measurement (Qbit to Cbit).

## General Introduction

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QIGA offers better diversity, because probability is taken deep to the representation of the individual itself. This manner augments the exploration and mutation because they manipulate probabilities through Qbits.

To validate the performance of QIGA, experiments are carried out on knapsack problem.

To appropriately do our study, we organized the dissertation as follows:

Chapter 1: presentation of quantum information and computation formalism.

Chapter 2 : quantum inspired evolutionary algorithm are introduced

Chapter 3 : the proposed algorithm QIGA is presented.

Chapter 4 : experiments are carried out and results are discussed.

## General Conclusion

In this work we have been interested to the combinatorial problems, where we have propose a novel evolutionary quantum inspired algorithm to attempt solve this challenging class of problems, at least with a good accuracy.

Our idea is inspired from the superposition principle of quantum mechanics, which contains all the secret and weirdness of this fundamental theory. Interference and phase shifting were the two implication of superposition principle that we have modeled to catch and benefit the proposed algorithm with the computational power of quantum computation. Genetic Algorithm was the natural evolutionary technique choice to this task, because its mechanism fit well. The interference phenomenon is well modeled by the recombination (crossover) operator applied on the phenotype rather than its genotype. Also, the phase shifting is perfectly modeled by the mutation operation.

We have investigate our propose algorithm named Genetic Inspired Quantum Algorithm to study its performance. We have chosen the Knapsack NP-Hard problem as a model to evaluate and valid our proposed algorithm. So, several experiments were done, with a statistics vision, were the algorithm was executed several time (40 executions) to have a consistent and credible results, knowing that our algorithm is a random one.

We have recorded a great accuracy of our solution compared to the expected solution of the problem. The algorithm reached the expected exact solution with a sensible percentage; so , we have pushed our investigation to more understand its behavior and find the adequate parameters to adjust them to increase the percentage of finding the exact solution. Our goal was successfully attained with high accuracy.

Our further researches will focus on extending our proposed algorithm genetic Quantum Inspired Algorithm **GIQA** to the General model of Knapsack problem and the other NP-Hard problem. We hope also adapt **GIQA** to the multi-objective NP-Hard problems.

## webGraphe:

[10] <http://www.geuthx.com/doc/06index/01.html#TopOfPage> consulted 20/05/2016

[9] <https://slidesplayer.com/slide/718510/> consulted 19/05/2016

[16] [https://en.wikipedia.org/wiki/Quantum\\_mechanics](https://en.wikipedia.org/wiki/Quantum_mechanics) consulted 26/05/2016

[17] [https://en.wikipedia.org/wiki/Genetic\\_algorithm](https://en.wikipedia.org/wiki/Genetic_algorithm) consulted 26/05/2016

[19] <http://www.geuthx.com/doc/06index/01.html#TopOfPage> consulted 26/05/2016

## Bibliographie :

[1] : Holland, J. H.: *Adaptation in natural and artificial systems*. Ann Arbor: The University of Michigan Press, 1975.

[2]: Rechenberg, I.: *Evolutionsstrategie - Optimierung technischer Systeme nach Prinzipien der biologischen Evolution*. Stuttgart: Frommann-Holzboog, 1973.

[3]: Schwefel, H.-P.: *Numerical optimization of computer models*. Chichester: Wiley & Sons, 1981.

[4]. Fogel, L. J., Owens, A. J. and Walsh, M. J.: *Artificial Intelligence through Simulated Evolution*. New York: John Wiley, 1966.

[5]:[6]:[8][11] *IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTATION, VOL. 6, NO. 6, DECEMBER 2002 580 Quantum-Inspired Evolutionary Algorithm for a Class of Combinatorial Optimization*.

[12]: *Memory Méthodes de résolution de problèmes difficiles académiques* .2013

[13] "FORTRAN". *American Heritage Dictionary of the English Language* (5 ed.). The Free Dictionary. 2011. Retrieved 2016-02-08.

[14] John Backus. "The history of FORTRAN I, II and III" (PDF). *Softwarepreservation.org*. Retrieved 19 November 2014.

[15] Eugene Loh (18 June 2010). "The Ideal HPC Programming Language". *Queue* (Association of Computing Machines)

[18] Singh, Madhusudan. "gnuplotfortran - the Fortran 95 interface to gnuplot". *gnuplotfortran.sourceforge.net*. Retrieved 10 May 2016.

## webGraphe:

[7][10] : <http://www.geatbx.com/docu/algindex-01.html#TopOfPage> consulted 20/05/2016

[9] : <http://slideplayer.com/slide/7285101> consulted 19/05/2016

[16] <https://en.wikipedia.org/wiki/Code::Blocks> consulted 26/05/2016

[17] <https://en.wikipedia.org/wiki/Gnuplot> consulted 26/05/2016

[19] [http://linuxgazette.net/168/misc/lg/2\\_cent\\_tip\\_piping\\_to\\_gnu\\_plot\\_from\\_c.html](http://linuxgazette.net/168/misc/lg/2_cent_tip_piping_to_gnu_plot_from_c.html) consulted 26/05/2016

### Abstract

The quantum-inspired evolutionary algorithm is new area of intelligent computation. In this work we propose a new quantum inspired genetic algorithm, to solve a class of combinatorial optimization problems. our QIGA is applied to the 0-1 Knapsack problem to evaluation and validation.

**Key words:** QIGA, Quantum Computing , Genetic Algorithms, Knapsack Problem

### Abstrait

Les algorithmes évolutionnaire inspiré du quantique est un nouveau domaine de la computation intelligente. Dans notre travail, nous avons proposé un nouvel algorithme génétique inspiré du quantique, pour la résolution d'une class de problèmes d'optimisation combinatoire. notre QIGA est appliqué sur le problème du 0-1 Knapsack pour l'évaluation et la validation.

**Mots clés:** QIGA, computation quantique , algorithmes évolutionnaire, problème de knapsack

### ملخص

الخوارزمية التطورية المستوحات من ميكانيك الكم هي حقل جديد للحاسوبية الذكية . في عملنا هذا , اقترحنا خوارزمية جينية مستوحات من ميكانيك الكم جديدة , لحل قسم من مشاكل التحسينات التوافقية . الخوارزمية المقترحة طبقت على مشكلة حقيبة الظهر 0-1 من أجل التقييم والتحقق .

**الكلمات المفتاحية :** الخوارزمية الجينية المستوحات من الكم , الحوسبة الكمية, الخوارزميات التطورية , مشكل حقيبة الظهر.