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Insights on Quantum Computing Operators for EM Optimization

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Abstract

The introduction of quantum computing is right now dramatically impacting the research activities in many engineering fields, in particular where a lot of data have to be considered, stored, analyzed to find the best possible strategy to tackle a complex problem, such as dealing with electromagnetic (EM) optimization. In fact, EM problems are critical from a computational point of view, because they often require thousands of different numerical solutions that can be obtained by extremely time and resource consuming numerical solvers both in the frequency or in the time domain.

In this framework, the combined application of quantum computing and evolutionary optimization algorithms can have a great effectiveness to manage the electromagnetic optimization of complex structures.

1 Introduction

Optimization is a key aspect in electromagnetic system design and management since many years; however, recently the increased computational capability makes feasible the numerical optimization of complex and highly nonlinear electromagnetic problems [5]. Due to their characteristics, these problems are often managed with iterative population-based algorithms, namely Evolutionary Algorithms . In fact, they are able to well-approximate the global minimum even in high-dimension, highly non-linear problems [7].

Quantum mechanics has been studied since the 1920s, but only in the last decades the main quantum ideas has been started to be studied to define a new paradigm for numerical computation. As well as what it happened when the first digital computers spread out among the scientific community, when the digital scientific revolution started, and new approaches had to be suitably introduced to exploit the new instruments available for scientific investigation, now, the availability of new intrinsically parallel, extremely high speed, no more strictly digital quantum computers, will allow a new leap forward in numerical investigation.

The most important key point is that the quantum numerical analysis overcomes the usual digital approach, since the unit of information is no more the "bit", a 2 possible status variable, but the "qubit", a variable that can be exactly as the bit either 0 or 1, but can also show the superposition property, i.e. a combination of the two "basis states". Another very interesting quantum computing property that can be extremely effective dealing with the construction of effective optimization algorithms, is the so called entanglement, a typical behavior of quantum mechanics that is beyond classic mechanics. In fact, in quantum mechanics, particles may show quantic entanglement when the state of a single particle of a set of particles, the entangled particles. is strictly dependent from the state of other particles of the same set, even when the particles are completely separated, i.e. very far one from the others. This property can be effectively adopted in evolutionary optimization algorithms, where the influence of different agents has to be considered dealing with complex solution spaces, where often counterintuitive solutions stand [11]. Furthermore, the hybridization of quantum properties and evolutionary inspired approaches looks very promising to overcome most of the state of the art limits in electromagnetic optimization [6].

The aim of this paper is to analyze the main features of Evolutionary Algorithm application to electromagnetic optimization that make them feasible for an effective codification via quantum computing operators.

The following of the paper is structured as follows: in Section 2 the basic characteristics of Evolutionary Algorithms are described, and in Section 3 the advantages of the combination of EAs and quantum computing in the electromagnetic field are analyzed. Finally in Section 4 some conclusions are drawn.

2 Evolutionary Optimization Algorithms

By means of Evolutionary Algorithms (EAs) is intended a class of population-based, biologically-inspired optimization algorithms. All these algorithms are characterized by a population of candidate solutions that are iteratively evolved in order to reach the global minimum or maximum of the objective function.

The generic strucutre of an EA is depicted in Figure 1: the population of candidate solutions are evaluated by the objective function, associating at each individual a cost or fitness value. Then the population is evolved by means of the specific algorithm operators: their type differentiate the algorithms. Then the new population is again evaluated and the iterative process continues.

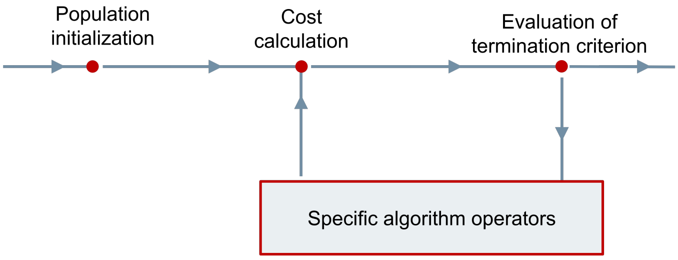

Figure 1. Basic flowchart of the common iteration in Evolutionary Algorithms.

The proper definition of the termination criterion is a key factor for obtaining good solutions; there are several possibilities, such as considering the best objective value obtained or the optimization improvement derivative. These criteria are not often used in EM design because they can lead to a very long optimization processes or can block the optimization in a local minima. Usually, the termination criteria implemented are associated to the available optimization time. Due to this reason, the computational capability is a key factor in these applications. In particular, the number of objective function calls is often used because this is the main driver of the optimization time in most of the engineering applications [2].

Several algorithm operators have been implemented in literature. The most famous are the ones associated to the Genetic Algorithms, *i.e.* the selection, the crossover, and the mutation. Figure 2 shows the basic flow chart of Genetic Algorithms The Particle Swarm Optimization implements a force-like attraction operator, and all the other evolutionary algorithms are based on different type or a different combination of similar operators [8].

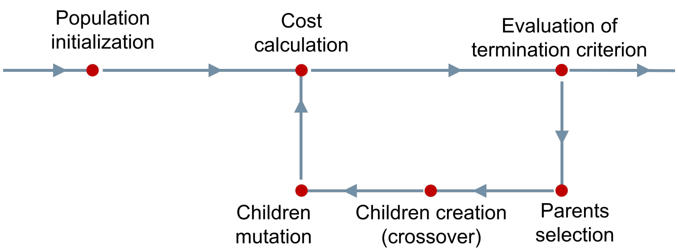

Figure 2. Basic flowchart Genetic Algorithms.

The use of a population of candidate solution that interacts at each iteration makes Evolutionary Algorithm very suitable for parallel computing: it can be effectively applied for the parallelization of the objective function computation. Due to this reason, quantum computing can be effectively applied to this class of problems [1].

3 Quantum-based Electromagnetic Optimization

Quantum operators are well-applicable in Evolutionary Algorithms, fully exploiting the parallelization capabilities of these algorithms. In particular, this can be applied to the complex and multi-objective functions of electromagnetic design and operation.

The main features of the qbits, mainly the entanglement, allows the simultaneous analysis of different states and, thus, a drastic reduction in the optimization time required for the optimization [3].

In addition, the non-binary nature of qbits makes them closer to the physical problems to which they are associated, increasing even more the effectiveness of the optimization algorithms. Their modification to be adapted to quantum computing in a critical aspect, but the use of a population of candidate solutions makes them easier to be effectively implemented than other traditional optimization algorithms [4].

A key point that should be considered is the implementation in a quantum computer of electromagnetic solvers, such as full-wave analysis [10, 9]. The most interesting point is the possibility to develop quantum-specific algorithm on quantum circuits, perfectly exploiting all the computational capabilities.

4 Conclusions

In this paper, the main features of Evolutionary Algorithms have been analyzed, considering their implementation in quantum computing. Ehis can be a very important step ahead in electromagnetic optimization because it can deeply exploit the parallelization of the objective function evaluation, that is very often a time consuming operation that nowadays many times limits the quality of the obtained solutions.

A numerical analysis of the results will be deeply investigated in the fiture.

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