

Qubit-efficient quantum local search for combinatorial optimization

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An essential component of many sophisticated metaheuristics for solving combinatorial optimization problems is some variation of a local search routine that iteratively searches for a better solution within a chosen set of immediate neighbors. The size l of this set is limited due to the computational costs required to run the method on classical processing units. We present a qubit-efficient variational quantum algorithm that implements a quantum version of local search with only $\lceil \log_2 l \rceil$ qubits and, therefore, can potentially work with classically intractable neighborhood sizes when realized on near-term quantum computers. Increasing the amount of quantum resources employed in the algorithm allows for a larger neighborhood size, improving the quality of obtained solutions. This trade-off is crucial for present and near-term quantum devices characterized by a limited number of logical qubits. Numerically simulating our algorithm, we successfully solved the largest graph coloring instance that was tackled by a quantum method. This achievement highlights the algorithm's potential for solving large-scale combinatorial optimization problems on near-term quantum devices.

1 Introduction

Local search is one of the most fundamental heuristic algorithms successfully applied to many challenging combinatorial optimization problems. The so-called r -local search (or r -flip) algorithm [1] starts from a candidate solution and iteratively explores a chosen neighborhood, of size l , of solutions that differ by at most r bits (or Hamming distance r). The process stops when all the neighbors are not better than the current solution. Many metaheuristics, such as simulated annealing [2], tabu search [3], and memetic algorithms [4], are based on local search [5]. Increasing the size of the neighborhood by increasing r can yield better solutions at the cost of an exponentially growing runtime that follows the binomial coefficient $l \sim C_n^r \sim O(n^r)$ where n is the total number of variables. Therefore, the parameter r typically must be chosen as small.

In this work, we address the aforementioned problem by introducing a Variational Quantum Algorithm (VQA) that uses a parametrized quantum-circuit ansatz of sufficient depth to implement the r -local search heuristic. The distinct feature of our approach is that the number, N_q , of employed qubits adapts to the chosen parameter r , ranging from $N_q = \lceil \log_2 n \rceil$ when $r = 1$ to $N_q = n$ when $r = n$. In contrast to the previously proposed

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Table of Contents Local Search In Combinatorial Optimization

1. Understanding the eBook Local Search In Combinatorial Optimization
 - The Rise of Digital Reading Local Search In Combinatorial Optimization
 - Advantages of eBooks Over Traditional Books
2. Identifying Local Search In Combinatorial Optimization
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Local Search In Combinatorial Optimization
 - User-Friendly Interface
4. Exploring eBook Recommendations from Local Search In Combinatorial Optimization
 - Personalized Recommendations
 - Local Search In Combinatorial Optimization User Reviews and Ratings
 - Local Search In Combinatorial Optimization and Bestseller Lists
5. Accessing Local Search In Combinatorial Optimization Free and Paid eBooks

- Local Search In Combinatorial Optimization Public Domain eBooks
- Local Search In Combinatorial Optimization eBook Subscription Services
- Local Search In Combinatorial Optimization Budget-Friendly Options
- 6. Navigating Local Search In Combinatorial Optimization eBook Formats
 - ePub, PDF, MOBI, and More
 - Local Search In Combinatorial Optimization Compatibility with Devices
 - Local Search In Combinatorial Optimization Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Local Search In Combinatorial Optimization
 - Highlighting and Note-Taking Local Search In Combinatorial Optimization
 - Interactive Elements Local Search In Combinatorial Optimization
- 8. Staying Engaged with Local Search In Combinatorial Optimization
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Local Search In Combinatorial Optimization
- 9. Balancing eBooks and Physical Books Local Search In Combinatorial Optimization
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Local Search In Combinatorial Optimization
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Local Search In Combinatorial Optimization
 - Setting Reading Goals Local Search In Combinatorial Optimization
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Local Search In Combinatorial Optimization
 - Fact-Checking eBook Content of Local Search In Combinatorial Optimization
 - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development

- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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