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Junior Background Research

With the increasing complexity of mathematical problems, quantum computing has become a popular solution to avoid long periods of computation. A quantum computer uses fundamental principles of quantum mechanics, including superposition and entanglement, in order to maximize computing power. In a traditional computer, data is usually encoded in bits, 0 and 1, which represent the on and off positions of a transistor; however, a quantum computer uses quantum bits, or qubits, to represent any of the infinite states between on and off. Although it is nearly impossible to determine the exact state of a qubit, scientists use probability amplitude to get an approximate value. By using the idea of probability and taking advantage of a qubit’s unique properties, a quantum computer will arrive at an accurate answer quickly. With algorithms such as the Fourier Transform, Shor’s Algorithm, and Grover’s Walk Algorithm, quantum computers have solved problems that have stumped classical computers for many years (Montanaro, 2016). Although a quantum computer can increase the rate of computation, a caveat with this system is that quantum computers heavily rely on probability which means that an answer has the possibility of being incorrect (Montanaro, 2016). For example, the black-box function used in Shor’s algorithm provides an output with an error range, thereby allowing a scenario to exist where the returned value is incorrect.

As researchers and programmers master different aspects of quantum computing, problems solved have started to increase in difficulty, and the algorithms have started to increase in complexity. One problem that has become prominent in the field of optimization is the knapsack problem. The knapsack problem is a combinatorial optimization problem with the goal of finding, in a set of items of given values and weights, the subset of items with the highest total value, subject to a total weight restraint (Bossaerts & Murawski, 2016). In this problem, which can appear in different aspects of life, a value has to be optimized while constrained under a certain factor. A common interpretation of the knapsack problem is to maximize the fuel available to use in a rocket while remaining within a certain budget. Throughout history, scientists and engineers have tried to find solutions to the knapsack problem and miserably failed. However, with quantum computers providing a drastic increase in computational ability, new approaches to the knapsack problem have been designed to take advantage of the computer’s speed and general reliability.

An efficient and quick approach to this problem has been the use of quantum-inspired genetic algorithms (QIGA). A standard genetic algorithm is a population-based search method which consists of 6 crucial components, including initialization, evaluation, population, parent selection mechanism, variation operators and survivor selection (Garg & Goyal, 2017). Using the concepts of evolution, proposed by Darwin, as inspiration, genetic algorithms will continue to modify a population based upon the fitness of each individual until a terminating condition is reached. When applied to quantum mechanics, a quantum genetic algorithm is proposed based on the concept of quantum bits and quantum superposition state. Using qubit encoding, where each qubit uses a ket vector to represent binary code, a quantum algorithm can use multiple qubit strings in a search space as an initial population (Fu, Liu, Wang, & Zhi, 2013). Once the initialization of the population has been completed, the majority of the genetic algorithm remains the same but a QIGA manipulates qubit strings instead of a classical value, and uses probability amplitude to create a survivor set based on an initial population and search space. Eventually, the manipulation of the probability amplitudes will result in a single converging value, the survivor. After the survivors have been determined, the algorithm will be called again and the probability amplitude will be plotted on a graph. The curve that results from the continuous plotting of probability amplitudes, representing the value of the best individual, will exhibit an asymptotic behavior. When the probability amplitude reaches the asymptote of the curve, the evolutionary algorithm is not called another time since the terminating condition has been reached (Kucharski & Nowotniak, 2014). However, a significant number iterations are usually required to reach this condition. Thus, the condition is usually decreased in order to reduce the number of evolutions. Either way, once the probability amplitude reaches the terminating condition, the asymptotic value is returned as the optimization for the problem trying to be solved.

In recent years, the standard QIGA has been used as a foundation for newer algorithms that improve optimization and efficiency. A major research project in this field decreases the time of convergence in later stages of the evolutionary algorithm, and improves local search performance by implementing a self-adaptive rotating angle strategy and a disaster algorithm (Fu et al., 2013). The rotating strategy used in the algorithm exploited different concepts of linear algebra to decrease the search space with each call of the algorithm. The disaster condition, however, imposed a self-made disaster once a certain condition has been reached. Although these researchers, from the College of Field Engineering in Nanjing, China, did not test their algorithm using the knapsack problem, their method involved similar computational abilities. After testing, researchers concluded that the addition of the rotating technique and the disaster condition improved the times of convergence of the quantum-inspired genetic algorithm, and returned a higher optimization value (Fu et al., 2013). However, the research that was performed by this team used isolated qubits to encode qubit strings, as common with QIGA 1 algorithms, and the simplicity of the design could have caused a lower optimization value than initially expected. In addition to that, the evolutionary algorithm was called a maximum of 200 times and that is too little to reach an optimum condition.

With the countless flaws in the current algorithms, including the use of single qubits and the minimal calls of the function, other teams have tried different modifications of the QIGA Researchers from Poland have developed a higher-order quantum-inspired genetic algorithm, which uses quantum registers to handle the encoding instead of isolated qubits (Kucharski & Nowotniak, 2014). The benefit of using quantum registers instead of single qubits is that error in the algorithm is drastically minimized. QIGA algorithms with Order-*r* can give a more accurate representation of a solution to the knapsack problem since the ability to model relations between separate genes allows the algorithm to work better for handling certain exceptions that may arise (Kucharski & Nowotniak, 2014). Apart from the use of a quantum register, a higher order QIGA is very similar to a tuned QIGA-1, which was proposed by the researchers from Nanjing. After testing the new algorithm different mathematical problems, including the knapsack problem, the Beijing problem, and Iran problem, this team concluded that the stabilization, or optimization, value for their algorithm was significantly higher than previous genetic algorithms proposed to solve similar problems (Kucharski & Nowotniak, 2014). However, this algorithm still has countless flaws. The current setup of the code does not account for the initial stabilization that occurs when an environment reaches a local optimum, or a meta-stable condition. A local minimum is when the genetic algorithm prematurely converges onto a single value for a certain period of time giving the illusion that the global minima, or extremity point, has been determined (Neves & Miguel, 1999).

The new research performed addresses the flaws in the previous research and allows for greater theoretical optimization of the knapsack problem. In the new algorithm, a disaster condition and quantum mutation will be added to the higher-order QIGA in order to prevent premature convergence. In fact, socials disasters technique, which applies a catastrophic operator once a local minimum is reached is one of the best methods to obtain the global extremity point instead of the local extrema (Neves & Miguel, 1999). In the algorithm that will be created, the quantum mutation will occur when the probability amplitudes of different qubits in the register fluctuate, and the disaster condition will implement a simple quantum catastrophe operator. Therefore, by tuning the higher-ordered QIGA using a disaster algorithm and a quantum mutation, the probability of reaching a global maximum will increase drastically, and the optimization value for the knapsack problem will be much higher than previous algorithms that have been designed. Researching this topic will allow the scientific and engineering community to accomplish countless tasks that have a limitation factor and an optimization value.

**References**

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