# Chapter 12
# Quantum Computing Significance on Multidimensional Data:
## R-Tree Search Based on Grover's Search Algorithm

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## ABSTRACT

*Quantum computing is an emerging field of study and gains importance due to the fact that with the introduction of quantum computers, many challenges and changes are presented for the existing algorithms. The main reason for this is the exponential speed of such computers. This study analyzes some of the benefits and implications of quantum computing on geometrical problems such as the multidimensional search for window queries with R-Trees. A review of the window query on R-Trees in classical computing is done to consider its adaptability to quantum computers by applying the Grover's quantum search algorithm from a theoretical point of view. Thereby, the query time complexity in worst-case scenarios could be improved to quadratic search time.*

## INTRODUCTION

Quantum computing (Nielsen, 2000; Hirvensalo, 2003) has been derived from quantum mechanics, which explains and predicts the behavior of atoms and molecules in a way that redefines our understanding of nature. Quantum computer performance is best when the data size is large and it is also used in problems

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that involve selection from a large number of possible combinations such as quantum cryptography, machine learning (Akshita, T. et al., 2022), and search problems. Recently quantum computing has been applied to decision diagrams (Hillmich, S. et al., 2022).

The very first quantum search algorithm was proposed by Lov K.Grover(Grover, 1997) who found that Quantum mechanical computers can be in a superposition of states due to which search operations can be done in parallel thus saving a lot of time.

Given an unsorted list of N elements, Grover's algorithm finds a target element with $O(\sqrt{N})$ operations, whereas a classical algorithm requires O(N) operations thus resulting in a quadratic time. Moreover, the Grover's algorithm also suggests that the quantum model can be advantageous to data processing in the RAM (Random Access Machine) model as against the pointer machine model of computation. Thus, the theoretical comparisons of the RAM model with the quantum model are gaining importance in determining the efficiency of algorithms. The efficiency of Grover's algorithm was experimentally evaluated by Chuang et al. Later (Mandviwalla, A. et al., 2018) implemented Grover's algorithm on IBM quantum computers using 4 qubits. Brassard et al., 2000 studied amplitude amplification.

Computational geometry (Preparata, 2012) is a field of study that uses a wide variety of shapes such as points, lines, and rectangles, to represent a problem domain. For instance, a set of cities on a map are considered as points, and a region in the map enclosing the points is represented as a rectangle. These points could be multidimensional depending on the application wherein each dimension represents a characteristic. Data structures storing such multidimensional data are based on the RAM model of computations with running time for search operations increasing with an increase in data size. The reason for this increase in running time is attributed to more branching of the tree depending on the volume of data. Interestingly, with the advent of quantum computing, due to the concept of simultaneous search operation using states, it is probable that they will be able to achieve an enormous reduction in search time.

## RELATED WORK

Data structures play a key role in data storage and retrieval. In the field of computer graphics, multimedia databases, information retrieval, etc., it is required to store multidimensional data objects in which case multidimensional data structures play a key role. One such data structure based on B-Tree is the R-Tree (A.Guttman, 1984). The R-tree algorithm is a bulk loading algorithm and nodes correspond to disk pages. The worst-case search time of R-trees and its variants when many nodes are visited at a given level increases as the data size increases for classical computers. Quantum computing has been gaining importance in various fields, especially in cryptography where Shor's algorithm (Shor, P. W., 1994) could break the well-known RSA algorithm that is considered secure when run on a classical computer but quantum computers break the cryptographic codes by factoring. Hence a lot of research is ongoing to overcome the challenges to many such existing algorithms due to the emergence of quantum computing. The key reason is the speedup of quantum computers. The role of quantum computing in Computational geometry (Sadakane, K., et al.,2002) on geometric algorithms for convex hulls, minimum enclosing balls, linear programming, and intersection problem based on Grover's algorithm substantiates the evolving research on quantum computing in various domains.

Quantum search algorithms have been extensively studied by (Ambainis, A.,2004), (Chuang et al., 1998). Yet another related work by (Ambainis, A., et al.,2004) describes a discrete-time quantum walks with an algorithm for spatial search $O(\sqrt{N} \log N)$ time for d=2, where d is the dimensions. Further-

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