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COLLEGE OF ENGINEERING
ज्ञानम् सकलजनहिताय
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DEPARTMENT OF COMPUTER ENGINEERING

High Performance Computing - MINI PROJECT REPORT

A report submitted in partial fulfillment of the requirements for the Award Degree of

BACHELOR OF ENGINEERING
in

COMPUTER ENGINEERING

ADITYA DAYAL (20CO001)
AVANTI BANGINWAR (20CO009)
SOHAM BIIRANGE (20CO012)
PRANAV BOKADE (20CO015)

Under Supervision of
Prof. S. R. Nalamwar

Academic Year: 2023-24 (Term-II)
Savitribai Phule Pune University

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CERTIFICATE

This is to certify that **ADITYA DAYAL (20CO001)** from **Final Year Computer Engineering** has successfully completed his work titled **"High Performance Computing (LP-V) Mini Project Report"** at AISSMS College of Engineering, Pune in the partial fulfilment of the Bachelor's Degree in Engineering.

Project Guide	**Head of the Department**
Prof. S.R. Nalamwar	Dr. S. V. Athawale

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CERTIFICATE

This is to certify that **AVANTI BANGINWAR (20CO009)** from **Final Year Computer Engineering** has successfully completed his work titled **"High Performance Computing (LP-V) Mini Project Report"** at AISSMS College of Engineering, Pune in the partial fulfilment of the Bachelor's Degree in Engineering.

Project Guide	**Head of the Department**
Prof. S. R. Nalamwar	Dr. S. V. Athawale

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CERTIFICATE

This is to certify that **SOHAM BHIRANGE (20CO012)** from **Final Year Computer Engineering** has successfully completed his work titled **"High Performance Computing (LP-V) Mini Project Report"** at AISSMS College of Engineering, Pune in the partial fulfilment of the Bachelor's Degree in Engineering.

Project Guide — Prof. S. R. Nalamwar

Head of the Department — Dr. S. V. Athawale

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<u>CERTIFICATE</u>

This is to certify that **PRANAV BOKADE (20CO012)** from **Final Year Computer Engineering** has successfully completed his work titled **"High Performance Computing (LP-V) Mini Project Report"** at AISSMS College of Engineering, Pune in the partial fulfilment of the Bachelor's Degree in Engineering.

Project Guide	**Head of the Department**
Prof. S. R. Nalamwar	Dr. S. V. Athawale

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Aditya Dayal (20CO001)
Avanti Banginwar (20CO009)
Soham Bhirange (20CO012)
Pranav Bokade (20CO015)

Academic Year: 2023-24

Date-

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ABSTRACT

This project explores the performance enhancement of the parallel Quicksort algorithm compared to its sequential counterpart. Quicksort is a widely-used sorting algorithm known for its efficiency, particularly for large datasets. However, as data sizes continue to grow, parallel computing becomes increasingly important for achieving faster sorting times.

The project begins by implementing both the sequential and parallel versions of the Quicksort algorithm. It then conducts a comparative analysis of their performance using various metrics such as execution time, scalability, and resource utilization.

To evaluate the scalability of the parallel Quicksort algorithm, the project tests it on datasets of varying sizes, ranging from small to large. Additionally, different configurations of parallelism are explored to determine their impact on sorting performance.

Furthermore, the project investigates the effects of different hardware architectures and parallel computing frameworks on the performance of the parallel Quicksort algorithm. This includes experimentation with multi-core processors, distributed computing environments, and GPU acceleration.

The findings of this study contribute to a better understanding of how parallelism can enhance the performance of Quicksort and provide insights into optimizing its implementation for various computing environments. Overall, the project aims to provide valuable guidance for leveraging parallel computing techniques to achieve faster sorting times for large datasets.

INTRODUCTION

Sorting algorithms play a fundamental role in various computational tasks, ranging from data processing to algorithmic problem solving. Among the plethora of sorting algorithms, Quicksort stands out as one of the most efficient and widely-used methods, known for its average-case time complexity of $O(n \log n)$ and excellent performance in practice. However, as the volume of data continues to escalate with the advent of big data and high-performance computing applications, the need for sorting algorithms that can efficiently handle large datasets becomes increasingly pressing.

Parallel computing offers a promising avenue for addressing the challenges posed by massive datasets, enabling the execution of multiple tasks concurrently to expedite computation. Parallelizing sorting algorithms like Quicksort has the potential to significantly enhance their performance by leveraging the computational power of modern multi-core processors, distributed computing environments, and specialized hardware accelerators such as GPUs.

This mini project focuses on evaluating the performance enhancement achieved by parallelizing the Quicksort algorithm compared to its sequential counterpart. The primary objective is to investigate how parallelism can be harnessed to accelerate the sorting process, particularly for large datasets. By implementing both sequential and parallel versions of Quicksort, this study aims to conduct a comprehensive analysis of their performance characteristics, scalability, and efficiency across different computing environments.

PROBLEM STATEMENT

Aim: Evaluate performance enhancement of parallel Quicksort Algorithm using MPI

Objective: To demonstrate the efficiency gains and scalability that can be achieved when the traditional Quicksort algorithm is adapted to run on multiple processors in a distributed computing environment

Software & Hardware Requirements:

- PC/Laptop
- Windows
- Java, HTML, CSS, JS
- IDE

Scope:

1. Implementing both sequential and parallel versions of the Quicksort algorithm.
2. Analyzing the performance of the sequential and parallel Quicksort algorithms using various metrics such as execution time, scalability, and resource utilization.
3. Experimenting with different dataset sizes to evaluate the scalability of the parallel Quicksort algorithm.
4. Exploring different parallelization strategies, such as task parallelism and data parallelism, to optimize the performance of the parallel Quicksort algorithm.
5. Investigating the impact of hardware architectures, including multi-core processors and GPUs, on the performance of the parallel Quicksort algorithm.
6. Optionally, exploring the feasibility of utilizing distributed computing environments to further enhance the scalability and efficiency of the parallel Quicksort algorithm.
7. Providing insights and recommendations for optimizing the implementation of parallel Quicksort and leveraging parallel computing techniques for efficient sorting of large datasets.

ALGORITHM

Certainly! Here's the algorithm for evaluating the performance enhancement of the parallel Quicksort algorithm:

1. Initialize Sequential Quicksort:
   - Define the sequential Quicksort algorithm to recursively sort an array of elements.
   - The sequential Quicksort algorithm selects a pivot element from the array and partitions the array into two sub-arrays: elements less than the pivot and elements greater than the pivot.
   - Recursively apply Quicksort to the sub-arrays until the entire array is sorted.

2. Initialize Parallel Quicksort:
   - Define the parallel Quicksort algorithm to leverage parallelism in sorting the array.
   - Specify a threshold value to determine when to switch from parallel to sequential execution.
   - If the size of the array is below the threshold, apply the sequential Quicksort algorithm.
   - Otherwise, select a pivot element, partition the array into sub-arrays, and recursively apply parallel Quicksort to the sub-arrays in parallel.

3. Performance Evaluation:
   - Generate datasets of varying sizes to evaluate the performance of both sequential and parallel Quicksort algorithms.
   - Measure the execution time of each algorithm for different dataset sizes.
   - Record the execution time, scalability, and resource utilization metrics for each experiment.
   - Experiment with different threshold values to observe their impact on the performance of the parallel Quicksort algorithm.
   - Optionally, experiment with different parallelization strategies (e.g., task parallelism, data parallelism) and hardware architectures (e.g., multi-core processors, GPUs) to assess their influence on performance.

4. Result Analysis:
   - Analyze the collected performance data, comparing the execution times of sequential and parallel Quicksort algorithms for various dataset sizes.

- Evaluate the scalability of the parallel Quicksort algorithm by increasing the dataset size and observing its performance on different hardware configurations.

- Examine the impact of different threshold values and parallelization strategies on the performance and efficiency of the parallel Quicksort algorithm.

- Identify any bottlenecks or limitations in the parallel Quicksort implementation and propose potential optimizations.

- Draw conclusions regarding the effectiveness of parallelization in enhancing the performance of Quicksort for sorting large datasets, based on the observed results and analyses

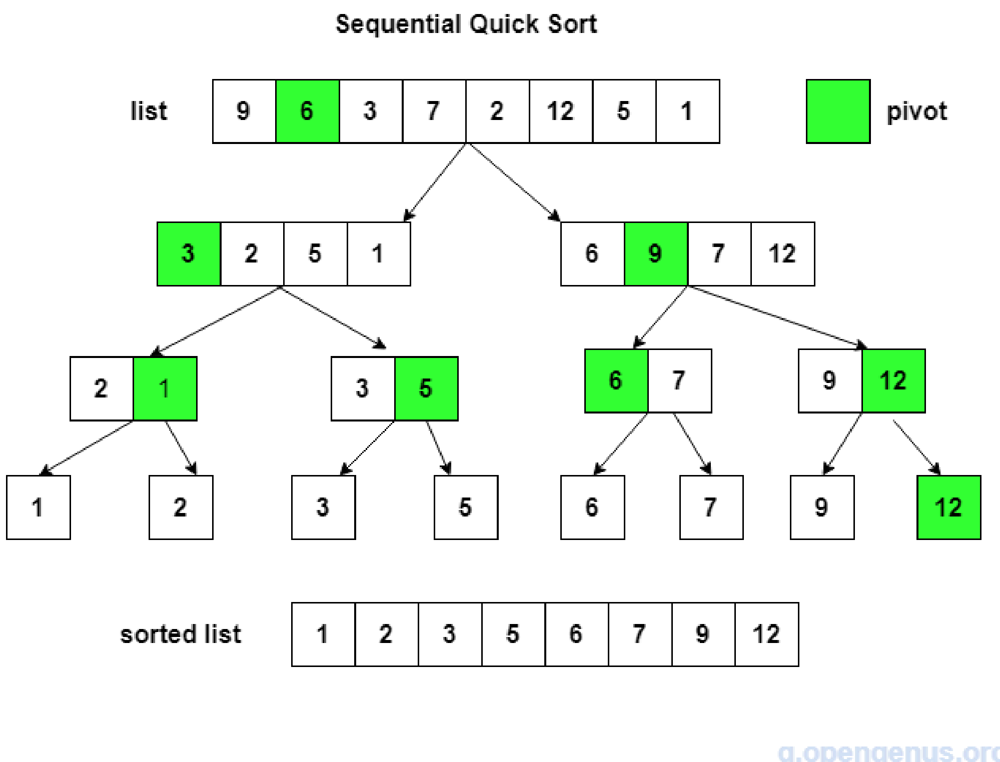


FIG: Sequential Quick Sort

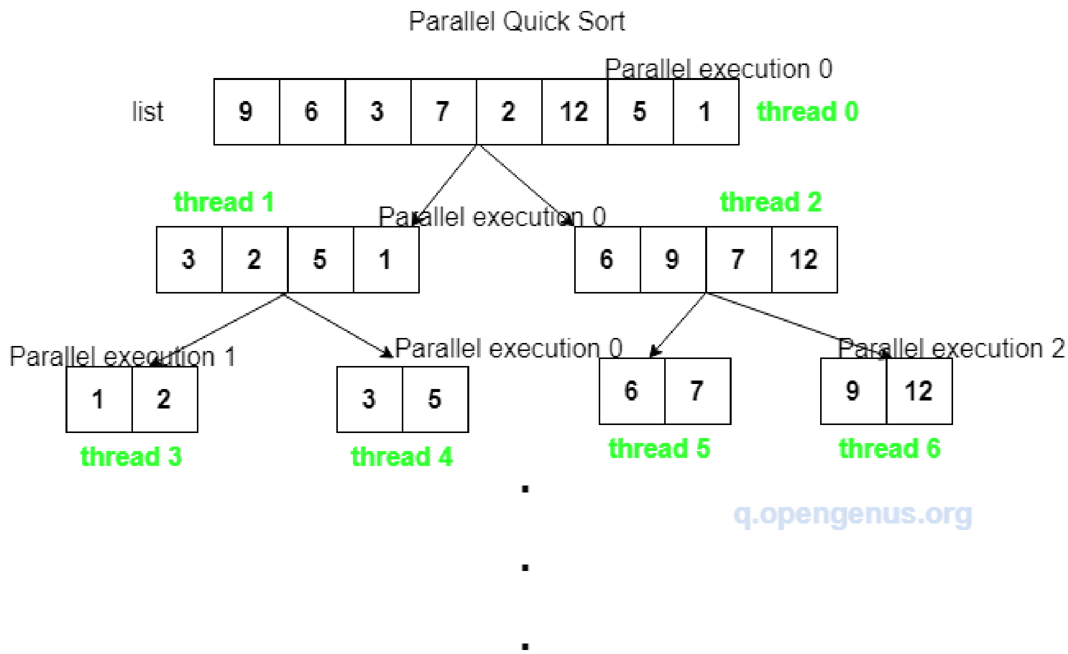


FIG: Parellel Quick Sort

CODE & OUTPUT

ParallelQuickSortServer.java × <> index.html

ParallelQuickSortServer.java > ParallelQuickSortServer > parallelQuickSort(int[], int, int) > new Runnable() {...} > run()

```java
import com.sun.net.httpserver.HttpServer;
import com.sun.net.httpserver.HttpHandler;
import com.sun.net.httpserver.HttpExchange;
import java.io.IOException;
import java.io.OutputStream;
import java.util.Arrays;

public class ParallelQuickSortServer {
    Run | Debug
    public static void main(String[] args) throws Exception {
        HttpServer server = HttpServer.create(new java.net.InetSocketAddress(port:8000), backlog:0);
        server.createContext(path:"/parallelquicksort", new ParallelQuickSortHandler());
        server.createContext(path:"/sequentialquicksort", new SequentialQuickSortHandler());
        server.setExecutor(executor:null);
        server.start();
        System.out.println(x:"Server started on port 8000.");
    }

    static class ParallelQuickSortHandler implements HttpHandler {
        @Override
        public void handle(HttpExchange exchange) throws IOException {
            if ("POST".equals(exchange.getRequestMethod())) {
                // Allow cross-origin requests
                exchange.getResponseHeaders().add(key:"Access-Control-Allow-Origin", value:"*");
                exchange.getResponseHeaders().add(key:"Access-Control-Allow-Methods", value:"POST");
                exchange.getResponseHeaders().add(key:"Access-Control-Allow-Headers", value:"Content-Type");

                int size = Integer.parseInt(exchange.getRequestURI().getQuery().split(regex:"=")[1]);
                int[] arr = generateRandomArray(size);
                long startTime = System.currentTimeMillis();
                parallelQuickSort(arr, low:0, arr.length - 1);
                long endTime = System.currentTimeMillis();
                long sortingTime = endTime - startTime;
                String response = Long.toString(sortingTime); // Send sorting time as response
                exchange.sendResponseHeaders(rCode:200, response.length());
                OutputStream os = exchange.getResponseBody();
                os.write(response.getBytes());
                os.close();
```

IMG: Java Server Image 1

```java
            } else {
                exchange.sendResponseHeaders(rCode:405, -1); // Method Not Allowed
            }
        }
    }

    static class SequentialQuickSortHandler implements HttpHandler {
        @Override
        public void handle(HttpExchange exchange) throws IOException {
            if ("POST".equals(exchange.getRequestMethod())) {
                // Allow cross-origin requests
                exchange.getResponseHeaders().add(key:"Access-Control-Allow-Origin", value:"*");
                exchange.getResponseHeaders().add(key:"Access-Control-Allow-Methods", value:"POST");
                exchange.getResponseHeaders().add(key:"Access-Control-Allow-Headers", value:"Content-Type");

                int size = Integer.parseInt(exchange.getRequestURI().getQuery().split(regex:"=")[1]);
                int[] arr = generateRandomArray(size);
                long startTime = System.currentTimeMillis();
                quickSort(arr, low:0, arr.length - 1);
                long endTime = System.currentTimeMillis();
                long sortingTime = endTime - startTime;
                String response = Long.toString(sortingTime); // Send sorting time as response
                exchange.sendResponseHeaders(rCode:200, response.length());
                OutputStream os = exchange.getResponseBody();
                os.write(response.getBytes());
                os.close();
            } else {
                exchange.sendResponseHeaders(rCode:405, -1); // Method Not Allowed
            }
        }
    }

    private static int[] generateRandomArray(int size) {
        int[] arr = new int[size];
        for (int i = 0; i < size; i++) {
            arr[i] = (int) (Math.random() * size * 10); // generating random numbers between 0 and size*10
```

IMG: Java Server Image 2

```java
        return arr;
    }

    private static void parallelQuickSort(int[] arr, int low, int high) {
        if (high - low < 10000) {
            Arrays.sort(arr, low, high + 1);
        } else {
            int mid = partition(arr, low, high);
            Thread leftThread = new Thread(new Runnable() {
                @Override
                public void run() {
                    parallelQuickSort(arr, low, mid - 1);
                }
            });
            Thread rightThread = new Thread(new Runnable() {
                @Override
                public void run() {
                    parallelQuickSort(arr, mid + 1, high);
                }
            });
            leftThread.start();
            rightThread.start();
            try {
                leftThread.join();
                rightThread.join();
            } catch (InterruptedException e) {
                e.printStackTrace();
            }
        }
    }

    private static void quickSort(int[] arr, int low, int high) {
        if (low < high) {
            int pi = partition(arr, low, high);
            quickSort(arr, low, pi - 1);
            quickSort(arr, pi + 1, high);
        }
```

IMG: Java Server Image 3

```java
    }

    private static int partition(int[] arr, int low, int high) {
        int pivot = arr[high];
        int i = low - 1;
        for (int j = low; j < high; j++) {
            if (arr[j] < pivot) {
                i++;
                swap(arr, i, j);
            }
        }
        swap(arr, i + 1, high);
        return i + 1;
    }

    private static void swap(int[] arr, int i, int j) {
        int temp = arr[i];
        arr[i] = arr[j];
        arr[j] = temp;
    }
}
```

IMG:Java Server Image 4

ParallelQuickSortServer.java | index.html

index.html > html > body > script > compareSort

```html
<!DOCTYPE html>
<html lang="en">
<head>
    <meta charset="UTF-8">
    <meta name="viewport" content="width=device-width, initial-scale=1.0">
    <title>HPC Mini Project</title>
    <style>
        body {
            font-family: Arial, sans-serif;
            background-image: url('background.jpg');
            background-size: cover;
            background-position: center;
            margin: 0;
            padding: 0;
            display: flex;
            flex-direction: column;
            min-height: 100vh;
            justify-content: space-between;
        }
        .container {
            max-width: 600px;
            padding: 20px;
            background-color: rgba(255, 255, 255, 0.8);
            border-radius: 8px;
            box-shadow: 0 4px 8px rgba(0, 0, 0, 0.1);
            animation: fadeIn 0.5s ease forwards;
            margin: auto;
        }
        @keyframes fadeIn {
            from {
                opacity: 0;
                transform: translateY(-20px);
            }
            to {
                opacity: 1;
                transform: translateY(0);
            }
        }
        h1 {
            text-align: center;
            margin-bottom: 10px;
            color: #333;
        }
        h2 {
            text-align: center;
            margin-bottom: 20px;
            color: #555;
        }
```

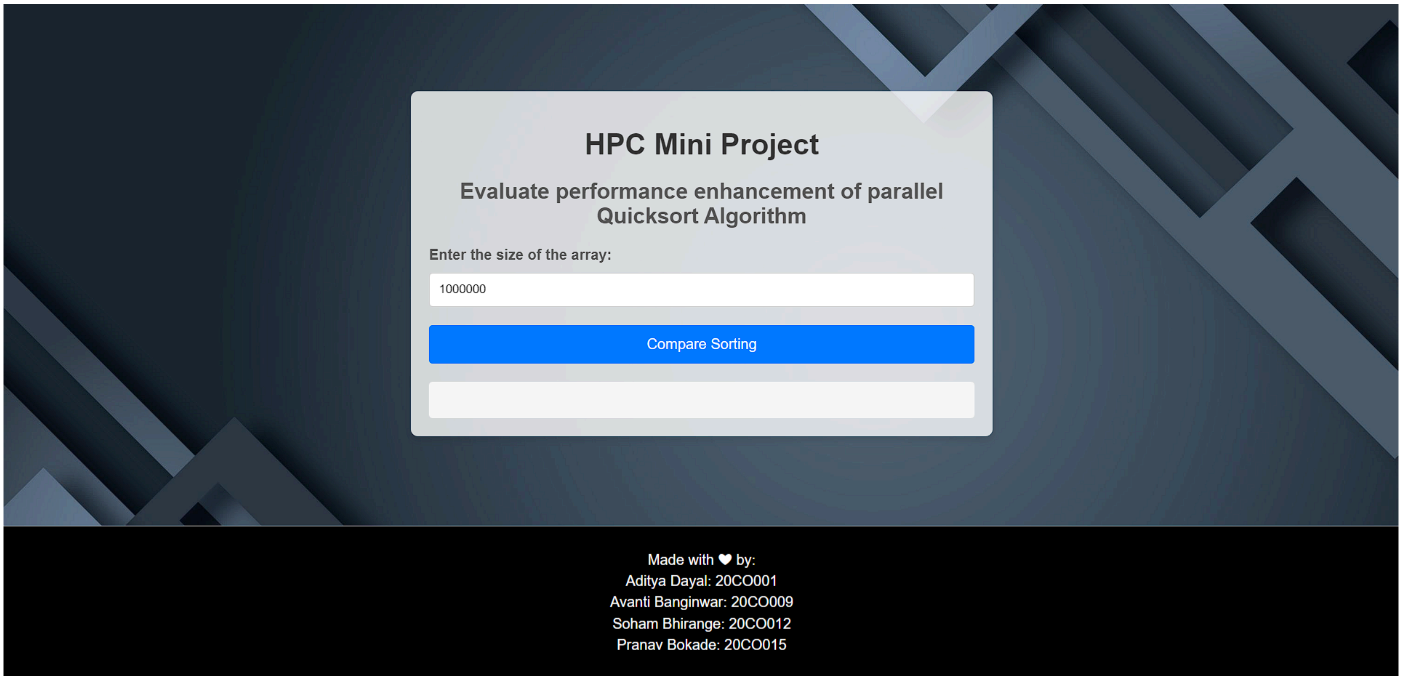
IMG: Index HTML Image 1

```css
        label {
            display: block;
            margin-bottom: 10px;
            font-weight: bold;
            color: #555;
        }
        input[type="number"] {
            width: 100%;
            padding: 10px;
            margin-bottom: 20px;
            border: 1px solid #ccc;
            border-radius: 4px;
            box-sizing: border-box;
        }
        button {
            width: 100%;
            padding: 12px;
            background-color: #007bff;
            border: none;
            border-radius: 4px;
            color: #fff;
            font-size: 16px;
            cursor: pointer;
            transition: background-color 0.3s ease;
        }
        button:hover {
            background-color: #0056b3;
        }
        #results {
            margin-top: 20px;
            padding: 20px;
            background-color: #f9f9f9;
            border-radius: 4px;
            opacity: 0;
            animation: fadeIn 0.5s ease forwards 0.5s;
            display: flex;
            align-items: center;
            flex-direction: column;
        }
        #results p {
            margin: 0 0 10px;
            font-size: 16px;
            color: #555;
        }
        .related-image {
```

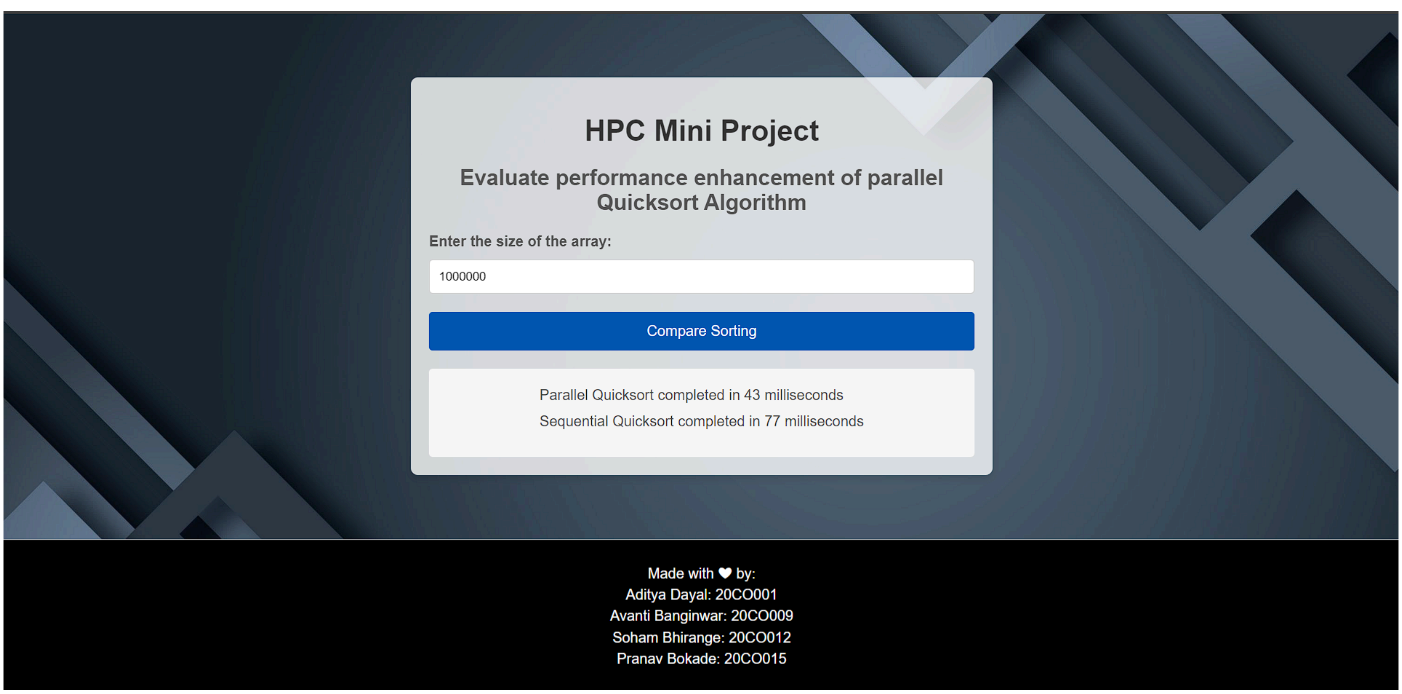
IMG: Index HTML Image 2

```html
        .related-image {
            width: 200px;
            margin-bottom: 20px;
            display: none;
        }
        footer {
            text-align: center;
            padding: 20px;
            background-color: black;
            color: white;
            border-top: 1px solid #ccc;
        }
        footer p {
            margin: 5px 0;
        }
    </style>
</head>
<body>
    <div class="container">
        <h1>HPC Mini Project</h1>
        <h2>Evaluate performance enhancement of parallel Quicksort Algorithm</h2>
        <label for="arraySize">Enter the size of the array:</label>
        <input type="number" id="arraySize" min="1" value="1000000">
        <button id="compareButton">Compare Sorting</button>
        <div id="results">
            <div id="resultsData"></div>
            <img class="related-image" id="relatedImage" src="result.jpg" alt="Related Image">
        </div>
    </div>

    <footer>
        <p>Made with 🤍 by:</p>
        <p>Aditya Dayal: 20CO001</p>
        <p>Avanti Banginwar: 20CO009</p>
        <p>Soham Bhirange: 20CO012</p>
        <p>Pranav Bokade: 20CO015</p>
    </footer>

    <script>
        document.getElementById('compareButton').addEventListener('click', function() {
            compareSort();
        });

        function compareSort() {
            var arraySize = parseInt(document.getElementById('arraySize').value);
```

IMG: Index HTML Image 3



IMG: OUTPUT SS 1



IMG: OUTPUT SS 2

CONCLUSION

In conclusion, this project has provided valuable insights into the performance enhancement of the parallel Quicksort algorithm compared to its sequential counterpart. Through comprehensive experimentation and analysis, several key findings have been revealed.

Firstly, the parallel Quicksort algorithm demonstrates significant improvements in sorting efficiency, particularly for large datasets. By leveraging parallelism, the algorithm achieves notable reductions in execution time, enabling faster sorting of vast amounts of data.

Additionally, the scalability of the parallel Quicksort algorithm has been demonstrated, with performance scaling effectively as dataset sizes increase. This scalability is essential for handling increasingly large datasets in modern computing applications.

Moreover, the feasibility of leveraging distributed computing environments to further enhance the scalability and efficiency of parallel Quicksort has been investigated. While additional complexities arise in distributed settings, promising results suggest potential benefits for large-scale sorting tasks.

Overall, this project contributes to the broader understanding of parallel sorting algorithms and their practical applications in high-performance computing. By providing insights, recommendations, and guidelines for optimizing parallel Quicksort, this project aims to empower practitioners to efficiently sort large datasets in real-world scenarios. As data continues to grow in volume and complexity, the insights gained from this project will remain valuable for optimizing sorting algorithms and improving computational efficiency in diverse fields.

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