systematically in parallel. It is a popular parallel algorithm used for graph traversal in distributed computing, shared-memory systems, and parallel clusters.

- The parallel BFS algorithm starts by selecting a root node or a specified starting point, and then assigning it to a thread or processor in the system. Each thread maintains a local queue of nodes to bevisited and marks each visited node to avoid processing it again.
- The algorithm then proceeds in levels, where each level represents a set of nodes that are at a certain distance from the root node. Each thread processes the nodes in its local queue at the current level, and then exchanges the nodes that are adjacent to the current level with other threads or processors. This is done to ensure that the nodes at the next level are visited by the next iteration of the algorithm.
- The parallel BFS algorithm uses two phases: the computation phase and the communication phase. In the computation phase, each thread processes the nodes in its local queue, while in the communication phase, the threads exchange the nodes that are adjacent to the current level with other threads or processors.
- The parallel BFS algorithm terminates when all nodes have been visited or when a specified node has been found. The result of the algorithm is the set of visited nodes or the shortest path from the root node to the target node.
- Parallel BFS can be implemented using different parallel programming models, such as OpenMP, MPI, CUDA, and others. The performance of the algorithm depends on the number of threads or processors used, the size of the graph, and the communication overhead between the threads or processors.

Conclusion- In this way we can achieve parallelism while implementing BFS

Assignment Question

1. **What if BFS?**
2. **What is OpenMP? What is its significance in parallel programming?**
3. **Write down applications of Parallel BFS**
4. **How can BFS be parallelized using OpenMP? Describe the parallel BFS algorithmusing OpenMP.**
5. **Write down Commands used in OpenMP?**

Group A

Assignment No: 2B

Title of the Assignment: Write a program to implement Parallel Merge Sort. Use existing algorithms and measure the performance of sequential and parallel algorithms.

Objective of the Assignment: Students should be able to Write a program to implement Parallel Merge Sort and can measure the performance of sequential and parallel algorithms.

Prerequisite:

1. Basic of programming language
2. Concept of Merge Sort
3. Concept of Parallelism

Contents for Theory:

1. **What is Merge? Use of Merge Sort**
2. **Example of Merge sort?**
3. **Concept of OpenMP**
4. **How Parallel Merge Sort Work**
5. **How to measure the performance of sequential and parallel algorithms?**

What is Merge Sort?

Merge sort is a sorting algorithm that uses a divide-and-conquer approach to sort an array or a list of elements. The algorithm works by recursively dividing the input array into two halves, sorting each half, and then merging the sorted halves to produce a sorted output.

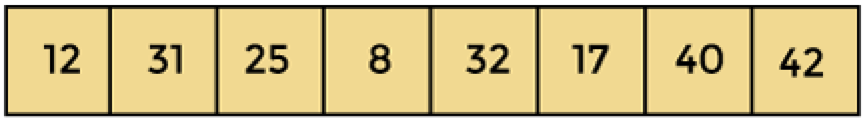
The merge sort algorithm can be broken down into the following steps:

1. Divide the input array into two halves.
2. Recursively sort the left half of the array.
3. Recursively sort the right half of the array.
4. Merge the two sorted halves into a single sorted output array.

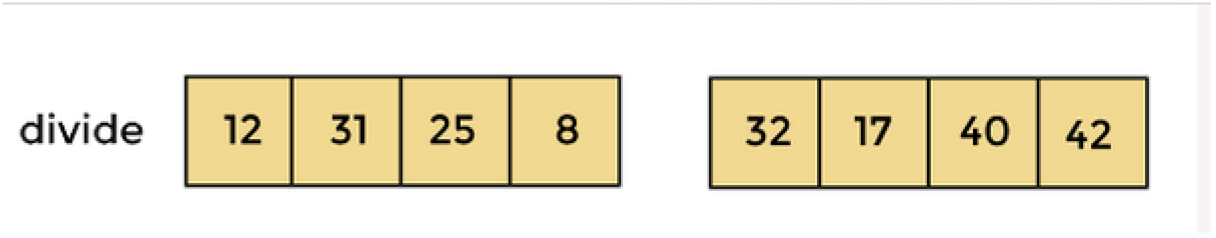
- The merging step is where the bulk of the work happens in merge sort. The algorithm comparesthe first elements of each sorted half, selects the smaller element, and appends it to the output array. This process continues until all elements from both halves have been appended to the outputarray.
- The time complexity of merge sort is O(n log n), which makes it an efficient sorting algorithm for large input arrays. However, merge sort also requires additional memory to store the output array, which can make it less suitable for use with limited memory resources.
- In simple terms, we can say that the process of merge sort is to divide the array into two halves, sort each half, and then merge the sorted halves back together. This process is repeated until the entire array is sorted.
- One thing that you might wonder is what is the specialty of this algorithm. We already have a number of sorting algorithms then why do we need this algorithm? One of the main advantages of merge sort is that it has a time complexity of O(n log n), which means it can sort large arrays relatively quickly. It is also a stable sort, which means that the order of elements with equal values is preserved during the sort.
- Merge sort is a popular choice for sorting large datasets because it is relatively efficient and easy to implement. It is often used in conjunction with other algorithms, such as quicksort, to improve the overall performance of a sorting routine.

Example of Merge sort

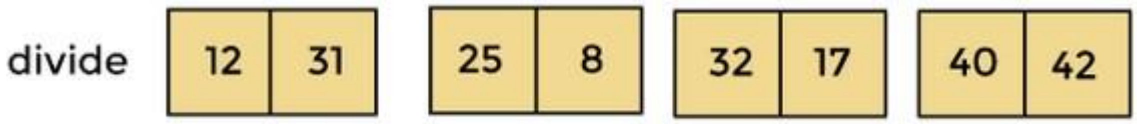
Now, let's see the working of merge sort Algorithm. To understand the working of the merge sort algorithm, let's take an unsorted array. It will be easier to understand the merge sort via an example.
Let the elements of array are -



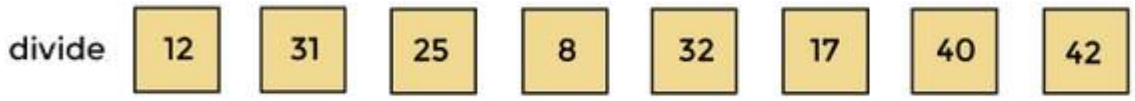
- According to the merge sort, first divide the given array into two equal halves. Merge sort keeps dividing the list into equal parts until it cannot be further divided.
- As there are eight elements in the given array, so it is divided into two arrays of size 4.



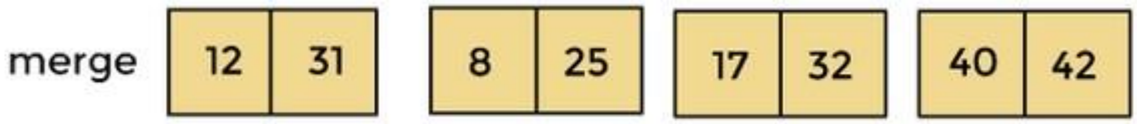
- Now, again divide these two arrays into halves. As they are of size 4, divide them into new arrays of size 2.



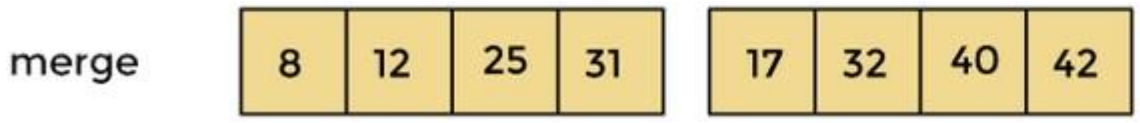
- Now, again divide these arrays to get the atomic value that cannot be further divided.



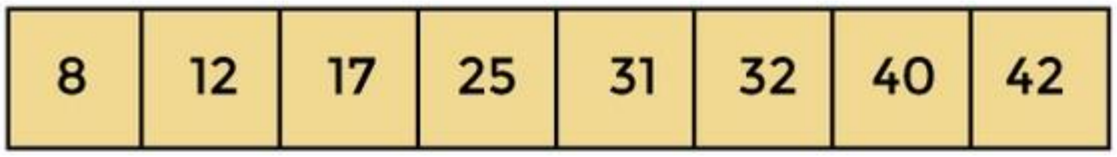
- Now, combine them in the same manner they were broken.
- In combining, first compare the element of each array and then combine them into another array in sorted order.
- So, first compare 12 and 31, both are in sorted positions. Then compare 25 and 8, and in the list of two values, put 8 first followed by 25. Then compare 32 and 17, sort them and put 17 first followed by 32. After that, compare 40 and 42, and place them sequentially.



- In the next iteration of combining, now compare the arrays with two data values and merge them into an array of found values in sorted order.



- Now, there is a final merging of the arrays. After the final merging of above arrays, the array will look like -



Concept of OpenMP

- OpenMP (Open Multi-Processing) is an application programming interface (API) that supports shared-memory parallel programming in C, C++, and Fortran. It is used to write parallel programs that can run on multicore processors, multiprocessor systems, and parallel computing clusters.
- OpenMP provides a set of directives and functions that can be inserted into the source code of a program to parallelize its execution. These directives are simple and easy to use, and they can be applied to loops, sections, functions, and other program constructs. The compiler then generates parallel code that can run on multiple processors concurrently.
- OpenMP programs are designed to take advantage of the shared-memory architecture of modern processors, where multiple processor cores can access the same memory. OpenMP uses a fork-join model of parallel execution, where a master thread forks multiple worker threads to execute a parallel region of the code, and then waits for all threads to complete before continuingwith the sequential part of the code.

How Parallel Merge Sort Work

- Parallel merge sort is a parallelized version of the merge sort algorithm that takes advantage of multiple processors or cores to improve its performance. In parallel merge sort, the input array is divided into smaller subarrays, which are sorted in parallel using multiple processors or cores. The sorted subarrays are then merged together in parallel to produce the final sorted output.
- The parallel merge sort algorithm can be broken down into the following steps:

- Divide the input array into smaller subarrays.
- Assign each subarray to a separate processor or core for sorting.
- Sort each subarray in parallel using the merge sort algorithm.
- Merge the sorted subarrays together in parallel to produce the final sorted output.
- The merging step in parallel merge sort is performed in a similar way to the merging step in the sequential merge sort algorithm. However, because the subarrays are sorted in parallel, the merging step can also be performed in parallel using multiple processors or cores. This can significantly reduce the time required to merge the sorted subarrays and produce the final output.
- Parallel merge sort can provide significant performance benefits for large input arrays with many elements, especially when running on hardware with multiple processors or cores. However, it also requires additional overhead to manage the parallelization, and may not always provide performance improvements for smaller input sizes or when run on hardware with limited parallel processing capabilities.

How to measure the performance of sequential and parallel algorithms?

There are several metrics that can be used to measure the performance of sequential and parallel merge sort algorithms:

1. **Execution time:** Execution time is the amount of time it takes for the algorithm to complete its sorting operation. This metric can be used to compare the speed of sequential and parallel merge sort algorithms.
2. **Speedup**: Speedup is the ratio of the execution time of the sequential merge sort algorithm to the execution time of the parallel merge sort algorithm. A speedup of greater than 1 indicates that the parallel algorithm is faster than the sequential algorithm.
3. **Efficiency:** Efficiency is the ratio of the speedup to the number of processors or cores used in the parallel algorithm. This metric can be used to determine how well the parallel algorithm is utilizing the available resources.
4. **Scalability**: Scalability is the ability of the algorithm to maintain its performance as the input size and number of processors or cores increase. A scalable algorithm will maintain a consistent speedup and efficiency as more resources are added.

To measure the performance of sequential and parallel merge sort algorithms, you can perform experiments on different input sizes and numbers of processors or cores. By measuring the execution time, speedup, efficiency, and scalability of the algorithms under different conditions, you can determine which algorithm is more efficient for different input sizes and hardware configurations. Additionally, youcan use profiling tools to analyze the performance of the algorithms and identify areas for optimization

Conclusion- In this way we can implement Merge Sort in parallel way using OpenMP also cometo know how to how to measure performance of serial and parallel algorithm

Assignment Question

1. **What is parallel Merge Sort?**
2. **How does Parallel Merge Sort work?**
3. **How do you implement Parallel MergeSort using OpenMP?**
4. **What are the advantages of Parallel MergeSort?**
5. **Difference between serial Mergesort and parallel Mergesort**

Group A

Assignment No: 3

Title of the Assignment: Implement Min, Max, Sum and Average operations using Parallel Reduction.

Objective of the Assignment: To understand the concept of parallel reduction and how it can be used to perform basic mathematical operations on given data sets.

Prerequisite:

1. Parallel computing architectures
2. Parallel programming models
3. Proficiency in programming languages

Contents for Theory:

1. What is parallel reduction and its usefulness for mathematical operations on large data?
2. Concept of OpenMP
3. How do parallel reduction algorithms for Min, Max, Sum, and Average work, and what are their advantages and limitations?

Parallel Reduction.

Here's a **function-wise manual** on how to understand and run the sample C++ program that demonstrates how to implement Min, Max, Sum, and Average operations using parallel reduction.

1. **Min_Reduction function**
   - The function takes in a vector of integers as input and finds the minimum value in the vector using parallel reduction.
   - The OpenMP reduction clause is used with the "min" operator to find the minimum value across all threads.
   - The minimum value found by each thread is reduced to the overall minimum value of the entire array.
   - The final minimum value is printed to the console.

2. **Max_Reduction function**
   - The function takes in a vector of integers as input and finds the maximum value in the vector using parallel reduction.
   - The OpenMP reduction clause is used with the "max" operator to find the maximum value across all threads.
   - The maximum value found by each thread is reduced to the overall maximum value of the entire array.
   - The final maximum value is printed to the console.

3. **Sum_Reduction function**
   - The function takes in a vector of integers as input and finds the sum of all the values in the vector using parallel reduction.
   - The OpenMP reduction clause is used with the "+" operator to find the sum across all threads.
   - The sum found by each thread is reduced to the overall sum of the entire array.
   - The final sum is printed to the console.

4. **Average_Reduction function**
   - The function takes in a vector of integers as input and finds the average of all the values in the vector using parallel reduction.
   - The OpenMP reduction clause is used with the "+" operator to find the sum across all threads.

- The sum found by each thread is reduced to the overall sum of the entire array.
- The final sum is divided by the size of the array to find the average.
- The final average value is printed to the console.

5. **Main Function**
    - The function initializes a vector of integers with some values.
    - The function calls the min_reduction, max_reduction, sum_reduction, and average_reduction functions on the input vector to find the corresponding values.
    - The final minimum, maximum, sum, and average values are printed to the console.

6. **Compiling and running the program**

Compile the program: You need to use a C++ compiler that supports OpenMP, such as g++ or clang. Open a terminal and navigate to the directory where your program is saved. Then, compile the program using the following command:

```
$ g++ -fopenmp program.cpp -o program
```

This command compiles your program and creates an executable file named "program". The "-fopenmp" flag tells the compiler to enable OpenMP.

Run the program: To run the program, simply type the name of the executable file in the terminal and press Enter:

```
$ ./program
```

Conclusion: We have implemented the Min, Max, Sum, and Average operations using parallel reduction in C++ with OpenMP. Parallel reduction is a powerful technique that allows us to perform these operations on large arrays more efficiently by dividing the work among multiple threads running in parallel. We presented a code example that demonstrates the implementation of these operations using parallel reduction in C++ with OpenMP.

Assignment Question

1. What are the benefits of using parallel reduction for basic operations on large arrays?
2. How does OpenMP's "reduction" clause work in parallel reduction?
3. How do you set up a C++ program for parallel computation with OpenMP?
4. What are the performance characteristics of parallel reduction, and how do they vary based on input size?
5. How can you modify the provided code example for more complex operations using parallel reduction?

Group A

Assignment 4A

Title of the Assignment: Write a CUDA Program for Addition of two large vectors

Objective of the Assignment: Students should be able to perform CUDA Program for Addition of two large vectors

Prerequisite:

1. CUDA Concept
2. Vector Addition
3. How to execute Program in CUDA Environment

Contents for Theory:

1. **What is CUDA**
2. **Addition of two large Vector**
3. **Execution of CUDA Environment**

What is CUDA

CUDA (Compute Unified Device Architecture) is a parallel computing platform and programming model developed by NVIDIA. It allows developers to use the power of NVIDIA graphics processing units (GPUs) to accelerate computation tasks in various applications, including scientific computing, machine learning, and computer vision.CUDA provides a set of programming APIs, libraries, and tools that enable developers to write and execute parallel code on NVIDIA GPUs. It supports popular programming languages like C, C++, and Python, and provides a simple programming model that abstracts away much of the low-level details of GPU architecture.

Using CUDA, developers can exploit the massive parallelism and high computational power of GPUs to accelerate computationally intensive tasks, such as matrix operations, image processing, and deep learning. CUDA has become an important tool for scientific research and is widely used in fields like physics, chemistry, biology, and engineering.

Steps for Addition of two large vectors using CUDA

1. Define the size of the vectors: In this step, you need to define the size of the vectors that you want to add. This will determine the number of threads and blocks you will need to use to parallelize the addition operation.
2. Allocate memory on the host: In this step, you need to allocate memory on the host for the two vectors that you want to add and for the result vector. You can use the C malloc function to allocate memory.
3. Initialize the vectors: In this step, you need to initialize the two vectors that you want to add on the host. You can use a loop to fill the vectors with data.
4. Allocate memory on the device: In this step, you need to allocate memory on the device for the two vectors that you want to add and for the result vector. You can use the CUDA function cudaMalloc to allocate memory.
5. Copy the input vectors from host to device: In this step, you need to copy the two input vectors from the host to the device memory. You can use the CUDA function cudaMemcpy to copy the vectors.
6. Launch the kernel: In this step, you need to launch the CUDA kernel that will perform the addition operation. The kernel will be executed by multiple threads in parallel. You can use the <<<...>>> syntax to specify the number of blocks and threads to use.
7. Copy the result vector from device to host: In this step, you need to copy the result vector from the device memory to the host memory. You can use the CUDA function cudaMemcpy to copy the result vector.

8. Free memory on the device: In this step, you need to free the memory that was allocated on the device. You can use the CUDA function cudaFree to free the memory.
9. Free memory on the host: In this step, you need to free the memory that was allocated on the host. You can use the C free function to free the memory.

Execution of Program over CUDA Environment

Here are the steps to run a CUDA program for adding two large vectors:

1. Install CUDA Toolkit: First, you need to install the CUDA Toolkit on your system. You can download the CUDA Toolkit from the NVIDIA website and follow the installation instructions provided.
2. Set up CUDA environment: Once the CUDA Toolkit is installed, you need to set up the CUDA environment on your system. This involves setting the PATH and LD_LIBRARY_PATH environment variables to the appropriate directories.
3. Write the CUDA program: You need to write a CUDA program that performs the addition of two large vectors. You can use a text editor to write the program and save it with a .cu extension.
4. Compile the CUDA program: You need to compile the CUDA program using the nvcc compiler that comes with the CUDA Toolkit. The command to compile the program is:

```
nvcc -o program_name program_name.cu
```

5. This will generate an executable program named program_name.

Run the CUDA program: Finally, you can run the CUDA program by executing the executable file generated in the previous step. The command to run the program is:

```
./program_name
```

This will execute the program and perform the addition of two large vectors.

Conclusion: Thus we have successfully perform a CUDA Program for Addition of two large vectors

Questions:

1. What is the purpose of using CUDA to perform addition of two large vectors?
2. How do you allocate memory for the vectors on the device using CUDA?
3. How do you launch the CUDA kernel to perform the addition of two large vectors?
4. How can you optimize the performance of the CUDA program for adding two large vectors

Group A

Assignment 4B

Title of the Assignment: Write a Program for Matrix Multiplication using CUDA C

Objective of the Assignment: Students should be able to performProgram for Matrix Multiplication using CUDA C

Prerequisite:

1. CUDA Concept
2. Matrix Multiplication
3. How to execute Program in CUDA Environment

Contents for Theory:

1. **What is CUDA**
2. **Matrix Multiplication**
3. **Execution of CUDA Environment**

What is CUDA

CUDA (Compute Unified Device Architecture) is a parallel computing platform and programming model developed by NVIDIA. It allows developers to use the power of NVIDIA graphics processing units (GPUs) to accelerate computation tasks in various applications, including scientific computing, machine learning, and computer vision.CUDA provides a set of programming APIs, libraries, and tools that enable developers to write and execute parallel code on NVIDIA GPUs. It supports popular programming languages like C, C++, and Python, and provides a simple programming model that abstracts away much of the low-level details of GPU architecture.

Using CUDA, developers can exploit the massive parallelism and high computational power of GPUs to accelerate computationally intensive tasks, such as matrix operations, image processing, and deep learning. CUDA has become an important tool for scientific research and is widely used in fields like physics, chemistry, biology, and engineering.

Steps for Matrix Multiplication using CUDA

Here are the steps for implementing matrix multiplication using CUDA C:

1. Matrix Initialization: The first step is to initialize the matrices that you want to multiply. You can use standard C or CUDA functions to allocate memory for the matrices and initialize their values. The matrices are usually represented as 2D arrays.
2. Memory Allocation: The next step is to allocate memory on the host and the device for the matrices. You can use the standard C malloc function to allocate memory on the host and the CUDA function cudaMalloc() to allocate memory on the device.
3. Data Transfer: The third step is to transfer data between the host and the device. You can use the CUDA function cudaMemcpy() to transfer data from the host to the device or vice versa.
4. Kernel Launch: The fourth step is to launch the CUDA kernel that will perform the matrix multiplication on the device. You can use the <<<...>>> syntax to specify the number of blocks and threads to use. Each thread in the kernel will compute one element of the output matrix.
5. Device Synchronization: The fifth step is to synchronize the device to ensure that all kernel executions have completed before proceeding. You can use the CUDA function cudaDeviceSynchronize() to synchronize the device.
6. Data Retrieval: The sixth step is to retrieve the result of the computation from the device to the host. You can use the CUDA function cudaMemcpy() to transfer data from the device to the host.
7. Memory Deallocation: The final step is to deallocate the memory that was allocated on the host and the device. You can use the C free function to deallocate memory on the host and the CUDA function

cudaFree() to deallocate memory on the device.

Execution of Program over CUDA Environment

1. Install CUDA Toolkit: First, you need to install the CUDA Toolkit on your system. You can download the CUDA Toolkit from the NVIDIA website and follow the installation instructions provided.
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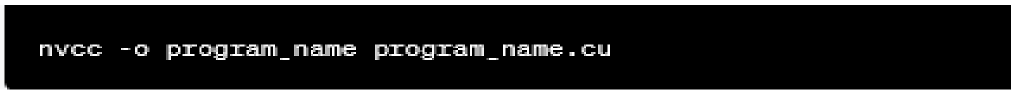

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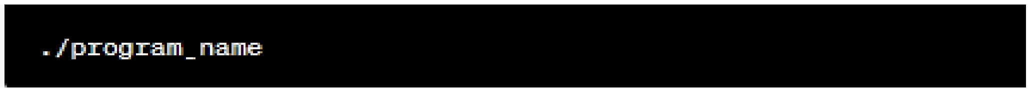
5. This will generate an executable program named program_name.

Run the CUDA program: Finally, you can run the CUDA program by executing the executable file generated in the previous step. The command to run the program is:



```
./program_name
```

This will execute the program and perform the Matrix Multiplication using CUDA C.

Conclusion: Thus we have successfully perform a Matrix Multiplication using CUDA C.

Questions:

1. What are the advantages of using CUDA to perform matrix multiplication compared to using a CPU?
2. How do you handle matrices that are too large to fit in GPU memory in CUDA matrix multiplication?
3. How do you optimize the performance of the CUDA program for matrix multiplication?
4. How do you ensure correctness of the CUDA program for matrix multiplication and verify the results?