CS 461

Lab Assignment 9

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**Q1. Parallel Quicksort Implementation using OpenMP**

#include <stdio.h>  
#include <omp.h>  
  
void swap(int \*a, int \*b)  
{  
    int temp = \*a;  
    \*a = \*b;  
    \*b = temp;  
}  
  
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], &arr[j]);  
        }  
    }  
    swap(&arr[i + 1], &arr[high]);  
    return (i + 1);  
}  
  
void parallel\_quicksort(int arr[], int low, int high)  
{  
    if (low < high)  
    {  
        int pi = partition(arr, low, high);  
  
// Parallel regions using OpenMP  
#pragma omp parallel sections  
        {  
#pragma omp section  
            parallel\_quicksort(arr, low, pi - 1);  
  
#pragma omp section  
            parallel\_quicksort(arr, pi + 1, high);  
        }  
    }  
}  
  
int main()  
{  
    int arr[] = {10, 80, 30, 90, 40, 50, 70};  
    int n = sizeof(arr) / sizeof(arr[0]);  
  
// Parallel region with single thread to kick off quicksort  
#pragma omp parallel  
    {  
#pragma omp single  
        parallel\_quicksort(arr, 0, n - 1);  
    }  
  
    printf("Sorted array: ");  
    for (int i = 0; i < n; i++)  
    {  
        printf("%d ", arr[i]);  
    }  
    printf("\n");  
    return 0;  
}

**Code Explanation:**

**1. Swap Function**: Swaps two elements in the array.

**2.** **Partition Function**: Selects a pivot and rearranges the array so that all elements less than the pivot are on the left and those greater are on the right. It returns the pivot index.

**3. Parallel Quicksort Function**:

* Recursively sorts the array.
* Uses OpenMP to run the recursive quicksort on the left and right subarrays **in parallel**.
* OpenMP directives (#pragma omp parallel sections and #pragma omp section) parallelize the recursion.

4. **Main Function**:

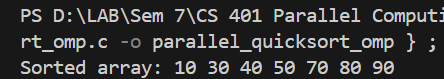
* Initializes the array, calls parallel quicksort, and prints the sorted array.

**Key Features:**

* Parallelizes the recursive sorting of the subarrays.
* Improves performance by using multiple threads for different parts of the array.

**Testing Phase:**

**Input: arr[] = {10, 80, 30, 90, 40, 50, 70};**

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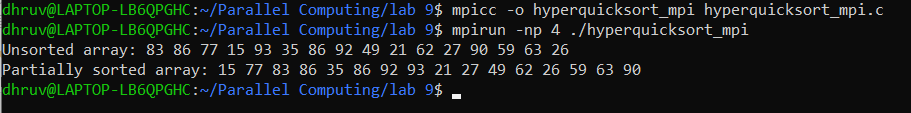
**Q2. Hyperquicksort Implementation using MPI**

#include <mpi.h>  
#include <stdio.h>  
#include <stdlib.h>  
  
void quicksort(int \*arr, int low, int high);  
int partition(int \*arr, int low, int high);  
  
int main(int argc, char \*argv[])  
{  
    int rank, size, n = 16, local\_n;  
    int \*arr = NULL, \*local\_arr = NULL;  
    int pivot;  
  
    MPI\_Init(&argc, &argv);  
    MPI\_Comm\_rank(MPI\_COMM\_WORLD, &rank);  
    MPI\_Comm\_size(MPI\_COMM\_WORLD, &size);  
  
    if (rank == 0)  
    {  
        // Master process initializes the array  
        arr = (int \*)malloc(n \* sizeof(int));  
        for (int i = 0; i < n; i++)  
        {  
            arr[i] = rand() % 100;  
        }  
        printf("Unsorted array: ");  
        for (int i = 0; i < n; i++)  
        {  
            printf("%d ", arr[i]);  
        }  
        printf("\n");  
    }  
    // Scatter data to all processes  
    local\_n = n / size;  
    local\_arr = (int \*)malloc(local\_n \* sizeof(int));  
    MPI\_Scatter(arr, local\_n, MPI\_INT, local\_arr, local\_n, MPI\_INT, 0, MPI\_COMM\_WORLD);  
  
    // Local quicksort  
    quicksort(local\_arr, 0, local\_n - 1);  
  
    // Gather sorted subarrays back to master  
    MPI\_Gather(local\_arr, local\_n, MPI\_INT, arr, local\_n, MPI\_INT, 0, MPI\_COMM\_WORLD);  
  
    if (rank == 0)  
    {  
        printf("Partially sorted array: ");  
        for (int i = 0; i < n; i++)  
        {  
            printf("%d ", arr[i]);  
        }  
        printf("\n");  
        free(arr);  
    }  
  
    free(local\_arr);  
    MPI\_Finalize();  
    return 0;  
}  
  
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++;  
            int temp = arr[i];  
            arr[i] = arr[j];  
            arr[j] = temp;  
        }  
    }  
    int temp = arr[i + 1];  
    arr[i + 1] = arr[high];  
    arr[high] = temp;  
    return i + 1;  
}  
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);  
    }  
}

**Code Explanation:**

1. **MPI Initialization**: Initialize MPI and get the rank (ID) and size (total processes).
2. **Data Distribution**: The master process (rank 0) generates an array and distributes portions to all processes using MPI\_Scatter.
3. **Local Sorting**: Each process sorts its local subarray using the quicksort() function.
4. **Data Gathering**: After local sorting, the sorted subarrays are gathered back into the master process using MPI\_Gather.
5. **Final Output**: The master process prints the partially sorted array.

**Testing Phase:**

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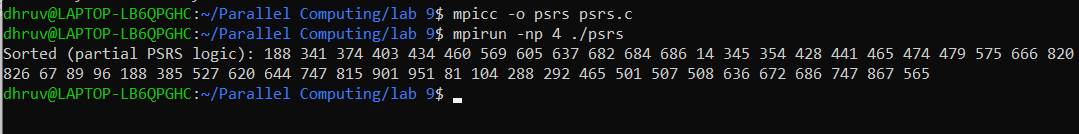
**Q3. Parallel Sorting by Regular Sampling (PSRS)**

#include <mpi.h>  
#include <stdio.h>  
#include <stdlib.h>  
#include <omp.h>  
#include <time.h>  
  
void quicksort(int \*arr, int low, int high);  
int partition(int \*arr, int low, int high);  
  
int main(int argc, char \*argv[]) {  
    int rank, size, n = 50;  
    int \*arr = NULL, \*local\_arr = NULL;  
  
    MPI\_Init(&argc, &argv);  
    MPI\_Comm\_rank(MPI\_COMM\_WORLD, &rank);  
    MPI\_Comm\_size(MPI\_COMM\_WORLD, &size);  
  
    if (rank == 0) {  
        arr = (int \*)malloc(n \* sizeof(int));  
        srand(time(NULL));  
        for (int i = 0; i < n; i++) {  
            arr[i] = rand() % 1000;  
        }  
    }  
  
    // Distribute data among processes  
    int local\_n = n / size;  
    local\_arr = (int \*)malloc(local\_n \* sizeof(int));  
    MPI\_Scatter(arr, local\_n, MPI\_INT, local\_arr, local\_n, MPI\_INT, 0, MPI\_COMM\_WORLD);  
  
    // Sort locally using OpenMP  
    #pragma omp parallel  
    {  
        #pragma omp single  
        quicksort(local\_arr, 0, local\_n - 1);  
    }  
  
    // Gather results and continue sampling and redistribution (full PSRS logic omitted)  
    MPI\_Gather(local\_arr, local\_n, MPI\_INT, arr, local\_n, MPI\_INT, 0, MPI\_COMM\_WORLD);  
  
    if (rank == 0) {  
        printf("Sorted (partial PSRS logic): ");  
        for (int i = 0; i < n; i++) {  
            printf("%d ", arr[i]);  
        }  
        printf("\n");  
        free(arr);  
    }  
  
    free(local\_arr);  
    MPI\_Finalize();  
    return 0;  
}  
  
void quicksort(int \*arr, int low, int high) {  
    if (low < high) {  
        int pivot = partition(arr, low, high);  
        #pragma omp task shared(arr)  
        quicksort(arr, low, pivot - 1);  
        #pragma omp task shared(arr)  
        quicksort(arr, pivot + 1, high);  
        #pragma omp taskwait  
    }  
}  
  
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++;  
            int temp = arr[i];  
            arr[i] = arr[j];  
            arr[j] = temp;  
        }  
    }  
    int temp = arr[i + 1];  
    arr[i + 1] = arr[high];  
    arr[high] = temp;  
    return i + 1;  
}

**Code Explanation:**

1. **MPI Initialization**: Initializes MPI and gets the rank and size of the processes.
2. **Array Distribution**: The master process generates an array of random numbers and distributes parts of the array to each process using MPI\_Scatter.
3. **Local Sorting**: Each process sorts its local subarray using the quicksort() function, which is parallelized using OpenMP. OpenMP tasks allow parallel execution of subarray sorting.
4. **Gathering Results**: After local sorting, the sorted subarrays are gathered back into the master process using MPI\_Gather.
5. **Partial PSRS Logic**: While the code demonstrates partial PSRS logic (local sorting and gathering), the full PSRS process would also involve sampling and redistributing data to ensure global ordering.

**Testing Phase:**

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**Q4. Calculate the Sum of Large Array**

#include <mpi.h>  
#include <omp.h>  
#include <stdio.h>  
#include <stdlib.h>  
  
#define ARRAY\_SIZE 1000000  
  
int main(int argc, char \*argv[]) {  
    int rank, size, i;  
    long long local\_sum = 0, global\_sum = 0;  
    int \*array = NULL;  
    int local\_n;  
  
    // Initialize MPI  
    MPI\_Init(&argc, &argv);  
    MPI\_Comm\_rank(MPI\_COMM\_WORLD, &rank);  
    MPI\_Comm\_size(MPI\_COMM\_WORLD, &size);  
  
    // Allocate array and distribute data among processes  
    if (rank == 0) {  
        array = (int \*)malloc(ARRAY\_SIZE \* sizeof(int));  
        for (i = 0; i < ARRAY\_SIZE; i++) {  
            array[i] = i + 1;  // Fill array with values 1 to ARRAY\_SIZE  
        }  
    }  
  
    // Divide the array among processes  
    local\_n = ARRAY\_SIZE / size;  
    int \*local\_array = (int \*)malloc(local\_n \* sizeof(int));  
  
    // Scatter the array to all processes  
    MPI\_Scatter(array, local\_n, MPI\_INT, local\_array, local\_n, MPI\_INT, 0, MPI\_COMM\_WORLD);  
  
    // Each process computes its partial sum using OpenMP  
    #pragma omp parallel for reduction(+:local\_sum)  
    for (i = 0; i < local\_n; i++) {  
        local\_sum += local\_array[i];  
    }  
  
    // Reduce all local sums to a global sum  
    MPI\_Reduce(&local\_sum, &global\_sum, 1, MPI\_LONG\_LONG, MPI\_SUM, 0, MPI\_COMM\_WORLD);  
  
    // Display result  
    if (rank == 0) {  
        printf("Total sum = %lld\n", global\_sum);  
        free(array);  
    }  
  
    // Clean up  
    free(local\_array);  
    MPI\_Finalize();  
  
    return 0;  
}

**Code Explanation:**

1. **MPI Initialization**:

* Initializes MPI with MPI\_Init, gets the rank and size of the processes using MPI\_Comm\_rank and MPI\_Comm\_size.

2. **Array Initialization and Distribution**:

* The master process (rank == 0) creates an array of size ARRAY\_SIZE and fills it with values from 1 to ARRAY\_SIZE.
* The array is divided among all processes. Each process gets a part of the array, and this is done using MPI\_Scatter.

3. **Local Sum Computation**:

* Each process computes the sum of its local portion of the array using a parallelized for loop with **OpenMP**. The reduction(+:local\_sum) clause ensures that each thread’s local sum is added to the local\_sum variable safely.

4. **Global Sum Calculation**:

* After computing the local sum, the process uses MPI\_Reduce to gather all local sums from the processes and compute the global sum on the master process (rank == 0).

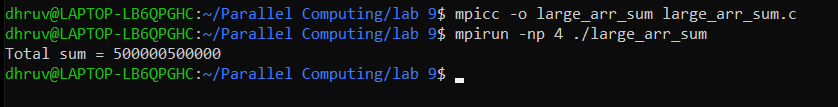
5. **Final Output**:

* The master process prints the total sum of the array.

6. **Cleanup**:

* Memory allocated for the arrays is freed, and MPI\_Finalize is called to end the MPI session.

**Testing Phase:**

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**Conclusion: The above four codes cover real-life implementation on OpenMP and MPI libraries.**