ASSIGNMENT 2

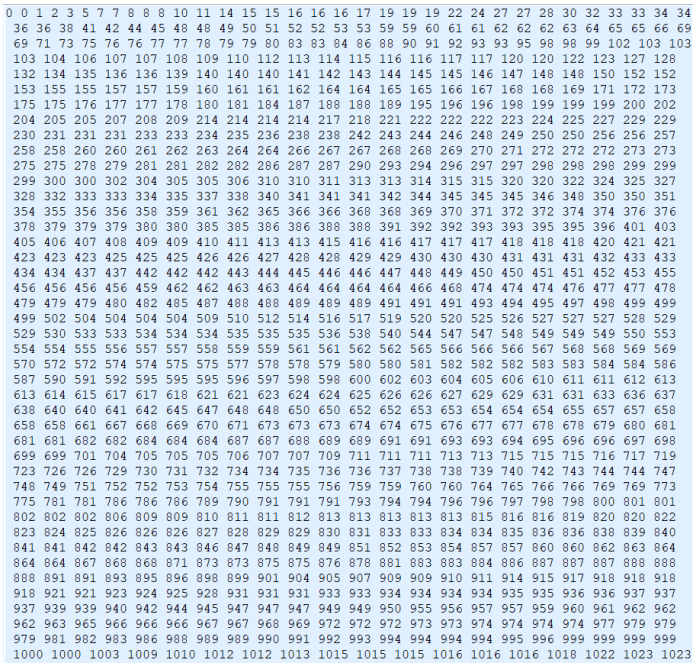
Group #3

Contents

Solution

Our solution is divided into two sections - generating the array files and merging the numbers.

We use ‘random.c’ to generate large arrays of numbers and store them into files - ’sa1.txt’ and ‘sa2.txt’. Both of the files contain a maximum of 32768 numbers which is 2 ^ 15.



A screen shot of ‘sa1.txt’

If you want to change the number, please change the following area in both two .c files:

```
#define MAX 32768
```

Our merging algorithm contains five steps.

First, partition array A into n groups, and each will have a_part_size[i] elements starting at index a_indices[i].

Second, find the b_part_size and b_indices.

```
void init_p4s(int total_size, int* A, int* B, int num_procs,
  int* a_part_size, int* a_indices, int* b_part_size, int* b_indices)
{
  printf("Starting to initialize...\n");

  int remainder = total_size % num_procs;
  int local_n = total_size / num_procs;

  for (int i = 0; i < num_procs; i++)
  {
    if (i < remainder)
      a_part_size[i] = local_n + 1;
    else
      a_part_size[i] = local_n;
  }

  for (int i = 0; i < num_procs; i++)
    a_indices[i] = i * local_n + MIN(i, remainder);

  int start = 0;
  int largest_a_index, largest_a;
  int largest_b_index;
  int size;

  for (int i = 0; i < num_procs; i++) {
    largest_a_index = a_part_size[i] + a_indices[i] - 1;
    largest_a = A[largest_a_index];

    largest_b_index = binary_search(B, largest_a, total_size);

    if (largest_b_index > 0) {

      size = largest_b_index + 1 - start;
      b_indices[i] = start;
      b_part_size[i] = size;
      start = largest_b_index + 1;
    }
    else {
      b_indices[i] = start;
      b_part_size[i] = 0;
    }

    largest_b_index += a_part_size[i + 1];
  }
  printf("Initializing finished...\n");
}
```

The initializing step

The first two steps are very important since we are using MPI_Scatterv() not MPI_Scatter(). The former can scatter the arrays to different processor with ununiform size while the latter function can't do this. But we need to calculate all the sizes and indices.

Third, processor 0 broadcasts the initialized array partition information to all processors and scatters each divided array to the corresponding processor.

```
MPI_Bcast(a_indies, num_procs, MPI_INT, 0, MPI_COMM_WORLD);
MPI_Bcast(a_part_length, num_procs, MPI_INT, 0, MPI_COMM_WORLD);
MPI_Bcast(b_indies, num_procs, MPI_INT, 0, MPI_COMM_WORLD);
MPI_Bcast(b_part_length, num_procs, MPI_INT, 0, MPI_COMM_WORLD);
```

```
MPI_Scatterv(A, a_part_length, a_indies, MPI_INT, a, a_size, MPI_INT, 0, MPI_COMM_WORLD);
MPI_Scatterv(B, b_part_length, b_indies, MPI_INT, b, b_size, MPI_INT, 0, MPI_COMM_WORLD);
```

Data distribution step

Forth, each processor merges assigned array a and array b.

```
void merge(int* a, int* b, int* merged, int size_a, int size_b) {
  int merged_index = 0, i = 0, j = 0;

  while (i < size_a && j < size_b)
  {
    if (a[i] < b[j])
    {
      merged[merged_index] = a[i];
      i++;
    }
    else
    {
      merged[merged_index] = b[j];
      j++;
    }
    merged_index++;
  }

  if (i == size_a)
  {
    while (j < size_b)
    {
      merged[merged_index] = b[j];
      merged_index++;
      j++;
    }
  }

  if (j == size_b)
  {
    while (i < size_a)
    {
      merged[merged_index] = a[i];
      merged_index++;
      i++;
    }
  }

}
```

The merging step of each processor

Last, processor 0 gathers all merged array.

```
if (rank == 0)
{
  result = malloc(sizeof(int) * (MAX * 2));
  result_indies = malloc(sizeof(int) * num_procs);
  result_part_size = malloc(sizeof(int) * num_procs);

  for (int i = 0; i < num_procs; i++)
  {
    result_part_size[i] = a_part_length[i] + b_part_length[i];
    result_indies[i] = a_indies[i] + b_indies[i];
  }
}

MPI_Gatherv(merged, merged_size, MPI_INT, result, result_part_size, result_indies, MPI_INT, 0, MPI_COMM_WORLD);
```

Result collection step

Source Code

Dear professor, please be careful when copying the code to run on your own computer. It may have some syntax errors because of the copying operation. But it will usually work I think.

random.c

```
#include <stdio.h>
#include <stdlib.h>
#include <time.h>

#define MAX 32768

void merge(int array[], int left, int m, int right) {
    int aux[MAX] = { 0 };
    int i;
    int j;
    int k;

    for (i = left, j = m + 1, k = 0; k <= right - left; k++)
    {
        if (i == m + 1)
        {
            aux[k] = array[j++];
            continue;
        }

        if (j == right + 1)
        {
            aux[k] = array[i++];
            continue;
        }
        if (array[i] < array[j])
        {
            aux[k] = array[i++];
        }

        else
        {
            aux[k] = array[j++];
        }
    }
```

```
        for (i = left, j = 0; i <= right; i++, j++)
        {
                array[i] = aux[j];
        }
}

void mergesort(int a[], int low, int high) {
        int mid;
        if (low < high) {
                mid = (high + low) / 2;
                mergesort(a, low, mid);
                mergesort(a, mid + 1, high);
                merge(a, low, mid, high);
        }
}

int main(int argc, char** argv) {
        int n = MAX;
        int original_array1[MAX];
        int original_array2[MAX];

        int c;
        srand(time(NULL));
        for (c = 0; c < n; c++) {

                original_array1[c] = rand() % n;
                original_array2[c] = rand() % n;
        }

        mergesort(original_array1, 0, n - 1);
        mergesort(original_array2, 0, n - 1);

        FILE* out1 = fopen("sa1.txt", "w");
        FILE* out2 = fopen("sa2.txt", "w");

        int i = 0;
        for (i = 0; i < n; i++) {
                fprintf(out1, "%d ", original_array1[i]);
                fprintf(out2, "%d ", original_array2[i]);
        }

        fclose(out1);
        fclose(out2);
```

```
    printf("Generation Done!\n");
}
```

merging_sorted_arrays.c

```
#include "mpi.h"
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <time.h>
#include <math.h>

#define MAX 32768
#define MIN(a,b) (a < b ? a : b)

// function used to read arrays from files
void file_to_array(int* init_array, int file)
{
    FILE* input;
    if (file == 0)
        input = fopen("sa1.txt", "r");
    else
        input = fopen("sa2.txt", "r");

    printf("Starting to read file...\n");

    int num;
    int count = 0;
    while (fscanf(input, "%d", &num) != EOF)
    {
        init_array[count] = num;
        count++;
    }
    fclose(input);

    printf("File reading finished...\n");
}

// function used to write the arrays to files
void array_to_file(int* array)
{
    FILE* out = fopen("result.txt", "w");
```

```
	int i = 0;
	for (i = 0; i < 2 * MAX; i++) {
		fprintf(out, "%d ", array[i]);
	}

	fclose(out);
}

// binary search method to find a target in one array
int binary_search(int* array, int target, int size)
{
	int left = 0;
	int right = size - 1;
	int mid = floor((left + right) / 2);

	int found_index = -1;

	while (left <= right)
	{
		if (array[mid] < target)
		{
			left = mid + 1;
		}
		else if (array[mid] == target)
		{
			left = mid + 1;
			found_index = mid;
		}
		else
		{
			right = mid - 1;
		}

		mid = floor((left + right) / 2);
	}

	return mid;
}

// function to init all the parameters for MPI_scatterv()
void init_p4s(int total_size, int* A, int* B, int num_procs,
	int* a_part_size, int* a_indices, int* b_part_size, int* b_indices)
{
	printf("Starting to initialize...\n");
```

```
    int remainder = total_size % num_procs;
    int local_n = total_size / num_procs;

    for (int i = 0; i < num_procs; i++)
    {
        if (i < remainder)
            a_part_size[i] = local_n + 1;
        else
            a_part_size[i] = local_n;
    }

    for (int i = 0; i < num_procs; i++)
        a_indices[i] = i * local_n + MIN(i, remainder);

    int start = 0;
    int largest_a_index, largest_a;
    int largest_b_index;
    int size;

    for (int i = 0; i < num_procs; i++) {
        largest_a_index = a_part_size[i] + a_indices[i] - 1;
        largest_a = A[largest_a_index];

        largest_b_index = binary_search(B, largest_a, total_size);

        if (largest_b_index > 0) {

            size = largest_b_index + 1 - start;
            b_indices[i] = start;
            b_part_size[i] = size;
            start = largest_b_index + 1;
        }
        else {
            b_indices[i] = start;
            b_part_size[i] = 0;
        }

        largest_b_index += a_part_size[i + 1];
    }
    printf("Initializing finished...\n");
}

// function used to merge two sorted arrays
```

```
void merge(int* a, int* b, int* merged, int size_a, int size_b) {
    int merged_index = 0, i = 0, j = 0;

    while (i < size_a && j < size_b)
    {
        if (a[i] < b[j])
        {
            merged[merged_index] = a[i];
            i++;
        }
        else
        {
            merged[merged_index] = b[j];
            j++;
        }
        merged_index++;
    }

    if (i == size_a)
    {
        while (j < size_b)
        {
            merged[merged_index] = b[j];
            merged_index++;
            j++;
        }
    }

    if (j == size_b)
    {
        while (i < size_a)
        {
            merged[merged_index] = a[i];
            merged_index++;
            i++;
        }
    }

}

int main(int argc, char** argv) {
    int num_procs;
    int rank;
```

```
// MPI init
MPI_Init(&argc, &argv);
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
MPI_Comm_size(MPI_COMM_WORLD, &num_procs);

int* A;
int* B;

// Define the arrays for using MPI_Scatterv().
// We are not using MPI_Scatter(), so this may be more complex.
int* a_indies = malloc(sizeof(int) * num_procs);
int* a_part_length = malloc(sizeof(int) * num_procs);
int* b_indies = malloc(sizeof(int) * num_procs);
int* b_part_length = malloc(sizeof(int) * num_procs);

// processor 0: read the arrays and init the parameters
if (rank == 0)
{
    A = malloc(sizeof(int) * MAX);
    B = malloc(sizeof(int) * MAX);
    file_to_array(A, 0);
    file_to_array(B, 1);

    init_p4s(MAX, A, B, num_procs, a_part_length, a_indies, b_part_length, b_indies);
}
// broadcast all the parameters
MPI_Bcast(a_indies, num_procs, MPI_INT, 0, MPI_COMM_WORLD);
MPI_Bcast(a_part_length, num_procs, MPI_INT, 0, MPI_COMM_WORLD);
MPI_Bcast(b_indies, num_procs, MPI_INT, 0, MPI_COMM_WORLD);
MPI_Bcast(b_part_length, num_procs, MPI_INT, 0, MPI_COMM_WORLD);


int a_size = a_part_length[rank];
int b_size = b_part_length[rank];
int merged_size = a_size + b_size;

int* a = malloc(sizeof(int) * a_size);
int* b = malloc(sizeof(int) * b_size);
int* merged = malloc(sizeof(int) * merged_size);

// scatter the divided sub-arrays to processors
MPI_Scatterv(A, a_part_length, a_indies, MPI_INT, a, a_size, MPI_INT, 0,
MPI_COMM_WORLD);
MPI_Scatterv(B, b_part_length, b_indies, MPI_INT, b, b_size, MPI_INT, 0,
```

```
MPI_COMM_WORLD);
    // merge the sub-arrays
    merge(a, b, merged, a_size, b_size);

    int* result;
    int* result_indies;
    int* result_part_size;
    // processor 0 gather all the merged sub-arrays
    if (rank == 0)
    {
        result = malloc(sizeof(int) * (MAX * 2));
        result_indies = malloc(sizeof(int) * num_procs);
        result_part_size = malloc(sizeof(int) * num_procs);

        for (int i = 0; i < num_procs; i++)
        {
            result_part_size[i] = a_part_length[i] + b_part_length[i];
            result_indies[i] = a_indies[i] + b_indies[i];
        }
    }

    MPI_Gatherv(merged, merged_size, MPI_INT, result, result_part_size, result_indies,
MPI_INT, 0, MPI_COMM_WORLD);

    // processor 0: write the final array to file "result.txt"
    if (rank == 0)
    {
        /*
            for (int i = 32760; i < 32768; ++i)
                printf("%d, ", A[i]);
            printf("\n");
            for (int i = 32760; i < 32768; ++i)
                printf("%d, ", B[i]);
            printf("\n");
            for (int i = 65522; i < 65536; ++i)
                printf("%d, ", result[i]);
            printf("\n");
        */
        array_to_file(result);

        // free all the memories for processor 0
        free(A); free(B); free(result);
        free(result_indies); free(result_part_size);
    }
```

```
    // free all the memories
    free(a_indies);
    free(a_part_length);
    free(b_indies);
    free(b_part_length);
    free(a);
    free(b);
    free(merged);

    printf("Processor %d done!\n", rank);

    MPI_Finalize();

    return 0;
}
```

Results

EX.

The first set

```
0  0  1  2  3  5  7  7  8  8  8  10  11  14  1
 73  75  76  76  77  77  78  79  79  80  8
 136  136  139  140  140  140  141  142
 178  180  181  184  187  188  188  189
 235  236  238  238  242  243  244  246
 287  287  290  293  294  296  297  297
 341  342  344  345  345  345  346  348
 392  392  393  393  395  395  396  401
 430  431  431  431  432  433  433  434
 474  476  477  477  478  479  479  479
```

The second set

```
0  0  1  1  2  2  3  4  5  10  10  11  12
 68  73  74  77  77  81  82  83  85  8
 126  127  128  128  129  129  130  1
 169  171  172  173  173  173  174  1
 219  219  220  221  221  223  225  2
 256  256  256  258  260  262  264  2
 302  302  303  303  304  304  304  3
 333  333  333  334  335  337  337  3
 381  382  383  384  387  387  387  3
```

The result:

```
0 0 0 0 1 1 1 2 2 2 3 3 4 5 5 7 7 8 8 8 10 10 10 11 11 12
 38 38 38 38 41 41 42 42 44 44 44 44 44 44 45 45 46 46 47
 71 73 73 74 75 76 76 77 77 77 77 78 79 79 80 81 82 83 83
 106 107 107 107 108 109 110 110 110 110 111 111 112 112
 128 129 129 130 131 132 132 133 133 134 135 135 135 136
 152 153 153 153 154 154 155 155 156 157 157 159 160 160
 173 174 174 174 175 175 175 175 176 177 177 177 178 179
 201 201 202 202 204 205 205 207 207 208 208 209 210 211
 229 229 229 229 230 230 230 231 231 231 231 231 232 233
 250 250 250 250 252 252 252 253 253 254 255 255 256 256
 271 272 272 272 272 273 273 273 274 274 275 275 275 275
 294 296 297 297 298 298 298 299 299 299 299 300 300 300
 312 312 313 313 313 314 314 314 315 315 316 316 317 320
 337 337 337 338 339 339 340 341 341 341 341 342 344 344
 365 365 366 366 366 367 368 368 369 369 370 370 371 371
```

We can determine the correctness of the program based on the first (or last) few numbers or using a simple check function.

Compilation and running

1. Compile and run the “random.c” (using gcc) and then we will get two array files named “sa1.txt” and “sat2.txt”.
2. Compile and run the “merging_sorted_arrays.c” (using mpicc and mpirun) and then we will get the file named “result.txt” which stores the merged array from the 2 sorted ones.