ΕΘΝΙΚΟ ΜΕΤΣΟΒΙΟ ΠΟΛΥΤΕΧΝΕΙΟ

ΣΧΟΛΗ ΗΜ&ΜΥ
Συστήματα Παράλληλης Επεξεργασίας 1η Άσκηση
Ακ. έτος 2012-2013

Ομάδα 8η

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12 Νοεμβρίου 2012

Πηγαίος κώδικας

Κοινή βιβλιοθήκη

```c
/* -.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.
 * File Name : common.h
 * Creation Date : 06-11-2012
 * Last Modified : Mon 12 Nov 2012 10:06:15 AM EET
 * Created By : Greg Liras <gregliras@gmail.com>
 * Created By : Alex Maurogiannis <nalfemp@gmail.com>
 _.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.*/

#ifndef DEBUG_FUNC
#define DEBUG_FUNC

#if main_DEBUG
#define debug(fmt,arg...)     fprintf(stdout, "%s: " fmt, __func__ , ##arg)
#else
#define debug(fmt,arg...)     do { } while(0)
#endif /* main_DEBUG */

#endif /* DEBUG_FUNC */

#ifndef COMMON_H
#define COMMON_H

#include <stdlib.h>
#include <stdio.h>
#include <mpi.h>

double *allocate_2d(int N, int M);
double *allocate_2d_with_padding(int N, int M, int max_rank);
double *parse_matrix_2d(FILE *fp, int N, int M, double *A);
void fprint_matrix_2d(FILE *fp, int N, int M, double *A);
void print_matrix_2d(int N, int M, double *A);
double timer(void);
void usage(int argc, char **argv);

#ifdef USE_MPI /* USE_MPI */
void propagate_with_send(void *buffer, int count , MPI_Datatype datatype, \
        int root, MPI_Comm comm);
void propagate_with_flooding(void *buffer, int count , MPI_Datatype datatype, \
        int root, MPI_Comm comm);
#endif /* USE_MPI */

#endif /* COMMON_H */
```

```c
/* -.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.
 * File Name : common.c
 * Creation Date : 06-11-2012
 * Last Modified : Mon 12 Nov 2012 10:06:02 AM EET
 * Created By : Greg Liras <gregliras@gmail.com>
 * Created By : Alex Maurogiannis <nalfemp@gmail.com>
 _.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.*/

#include "common.h"
#include <sys/time.h>

double *allocate_2d(int N, int M)
{
    double *A;
    A = malloc(N * M * sizeof(double));
    return A;
}

double *allocate_2d_with_padding(int N, int M, int max_rank)
{
    double *A;
    A = allocate_2d(N + max_rank, M);
    return A;
}

double *parse_matrix_2d(FILE *fp, int N, int M, double *A)
{
    int i,j;
```

```
    double *p;
    p = A;
    for (i = 0; i < N; i++) {
        for (j = 0; j < M; j++) {
            if(!fscanf(fp, "%lf", p++)) {
                return NULL;
            }
        }
    }
    return A;
}

void fprint_matrix_2d(FILE *fp, int N, int M, double *A)
{
    int i,j;
    double *p;
    p = A;
    for (j = 0; j < M; j++) {
        fprintf(fp, "=");
    }
    fprintf(fp, "\n");
    for (i = 0; i < N; i++) {
        for (j = 0; j < M; j++) {
            fprintf(fp, "%lf\t", *p++);
        }
        fprintf(fp, "\n");
    }
    for (j = 0; j < M; j++) {
        fprintf(fp, "=");
    }
    fprintf(fp, "\n");
}

void print_matrix_2d(int N, int M, double *A)
{
    fprint_matrix_2d(stdout, N, M, A);
}

double timer(void)
{
    static double seconds = 0;
    static int operation = 0;
    struct timeval tv;
    gettimeofday(&tv, NULL);
    if (operation == 0) {
        seconds = tv.tv_sec + (((double) tv.tv_usec)/1e6);
        operation = 1;
        return 0;
    }
    else {
        operation = 0;
        return tv.tv_sec + (((double) tv.tv_usec)/1e6) - seconds;
    }
}

void usage(int argc, char **argv)
{
    if(argc != 3) {
        printf("Usage: %s <matrix file> <output file>\n", argv[0]);
        exit(EXIT_FAILURE);
    }
}

#ifdef USE_MPI /* USE_MPI */
void propagate_with_send(void *buffer, int count, MPI_Datatype datatype, \
        int root, MPI_Comm comm)
{
    int rank;
    int i;
    int max_rank;

    MPI_Comm_rank(comm, &rank);
    MPI_Comm_size(comm, &max_rank);
    if(rank == root) {
        for(i = 0; i < max_rank; i++) {
```

```
            if(i == rank) {
                continue;
            }
            else {
                debug("%d\n", i);
                MPI_Send(buffer, count, datatype, i, root, comm);
            }
        }
    }
    else {
        MPI_Status status;
        MPI_Recv(buffer, count, datatype, root, root, comm, &status);
    }
}

void propagate_with_flooding(void *buffer, int count , MPI_Datatype datatype, \
        int root, MPI_Comm comm)
{
    int rank;
    int max_rank;
    int cur;

    MPI_Comm_rank(comm, &rank);
    MPI_Comm_size(comm, &max_rank);

    if(root != 0) {
        if(rank == root) {
            MPI_Send(buffer, count, datatype, 0, root, comm);
        }
        if(rank == 0) {
            MPI_Status status;
            MPI_Recv(buffer, count, datatype, root, root, comm, &status);
        }
    }

    if(rank != 0) {
        MPI_Status status;
        MPI_Recv(buffer, count, datatype, (rank-1)/2, root, comm, &status);
    }
    cur = 2*rank+1;
    if(cur < max_rank) {
        MPI_Send(buffer, count, datatype, cur, root, comm);
    }
    if(++cur < max_rank) {
        MPI_Send(buffer, count, datatype, cur, root, comm);
    }
}
#endif /* USE_MPI */
```

Ζητούμενο 1 Σειριακό Πρόγραμμα

```
/* -.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.
* File Name : main.c
* Creation Date : 30-10-2012
* Last Modified : Thu 08 Nov 2012 09:50:55 AM EET
* Created By : Greg Liras <gregliras@gmail.com>
* Created By : Alex Maurogiannis <nalfemp@gmail.com>
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#include <stdio.h>
#include <stdlib.h>

#include "common.h"

int main(int argc, char **argv)
{
    int i,j,k;
    int N;
    double *A;
    double l;
    double sec;

    FILE *fp = NULL;
    usage(argc, argv);
    /*
```
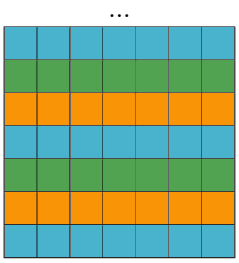
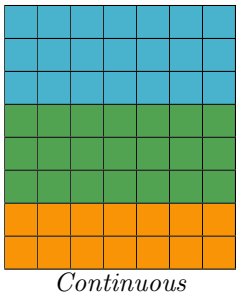

```
     * Allocate me!
     */
    fp = fopen(argv[1], "r");
    if(fp) {
        if(!fscanf(fp, "%d\n", &N)) {
            exit(EXIT_FAILURE);
        }
    }

    if((A = allocate_2d(N, N)) == NULL) {
        exit(EXIT_FAILURE);
    }
    if(parse_matrix_2d(fp, N, N, A) == NULL) {
        exit(EXIT_FAILURE);
    }


    sec = timer();
    for (k = 0; k < N - 1; k++)
    {
        for (i = k + 1; i < N; i++)
        {
            l = A[i * N + k] / A[k * N + k];
            for (j = k; j < N; j++)
            {
                A[i * N + j] = A[i * N + j] - l * A[k * N + j];
            }
        }
    }
    sec = timer();
    printf("Calc Time: %lf\n", sec);

    fp = fopen(argv[2], "w");
    fprint_matrix_2d(fp, N, N, A);
    fclose(fp);
    free(A);

    return 0;
}
```

Ζητούμενο 2 Παραλληλισμός Αλγορίθμου

Ο παραλληλισμός του αλγορίθμου εντοπίζεται στο γεγονός ότι υπάρχει ανεξαρτησία του υπολογισμού κατά γραμμές για δεδομένο k. Καθ όλη την εκτέλεση του προγράμματος κρατάμε σταθερό τον τρόπο διαμοιρασμού των γραμμών του πίνακα, μοιράζοντας σε κάθε επανάληψη την k^{th} γραμμή.



Circular



Continuous

Ζητούμενο 3 Μοντέλο κοινού χώρου διευθύνσεων (OpenMP)

Ζητούμενο 4 Μοντέλο ανταλλαγής μηνυμάτων (MPI)

Ζητούμενο 4.1 Point to Point

Η υλοποίηση **point-to-point** με χρήση flooding για λογαριθμικό propagation και κυκλική κατανομή των γραμμών (*Circular*).

```c
/* -.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.
 * File Name : main.c
 * Creation Date : 30-10-2012
 * Last Modified : Mon 12 Nov 2012 09:58:12 AM EET
 * Created By : Greg Liras <gregliras@gmail.com>
 * Created By : Alex Maurogiannis <nalfemp@gmail.com>
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#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>
#include <signal.h>
#include <signal.h>
#include <unistd.h>
#include <string.h>

#include "common.h"

#define BLOCK_ROWS 1


void process_rows(int k, int rank, int N, int max_rank, double *A)
{
    /*      performs the calculations for a given set of rows.
     *      In this hybrid version each thread is assigned blocks of
     *      continuous rows in a cyclic manner.
     */
    int i, j, w;
    double l;
    /* For every cyclic repetition of a block */
    for (i = (rank + ((BLOCK_ROWS * max_rank) * (k / (BLOCK_ROWS * max_rank)))); \
            i < N ; i+=(max_rank * BLOCK_ROWS)) {
        if (i > k) {
            /* Calculate each continuous row in the block*/
            for (w = i; w < (i + BLOCK_ROWS) && w < (N * N); w++){
                l = A[(w * N) + k] / A[(k * N) + k];
                for (j = k; j < N; j++) {
                    A[(w * N) + j] = A[(w * N) + j] - l * A[(k* N) + j];
                }
            }
        }
    }
}

int main(int argc, char **argv)
{
    int k;
    int N;
    int rank;
    int max_rank;
    int last_rank;
    double *A = NULL;
    double sec = 0;

    int ret = 0;
    FILE *fp = NULL;
    usage(argc, argv);

    MPI_Init(&argc, &argv);
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &max_rank);

    if (rank == 0) {
        debug("rank: %d opens file: %s\n", rank, argv[1]);
        fp = fopen(argv[1], "r");
        if(fp) {
            if(!fscanf(fp, "%d\n", &N)) {
                MPI_Abort(MPI_COMM_WORLD, 1);
            }
```

```
        }
        else {
            MPI_Abort(MPI_COMM_WORLD, 1);
        }
    }

    MPI_Barrier(MPI_COMM_WORLD);
    propagate_with_flooding(&N, 1, MPI_INT, 0, MPI_COMM_WORLD);

    /* Everyone allocates the whole table */
    debug("Max rank = %d\n", max_rank);
    if((A = allocate_2d_with_padding(N, N, max_rank)) == NULL) {
        MPI_Abort(MPI_COMM_WORLD, 1);
    }
    /* Root Parses file */
    if (rank == 0) {
        if(parse_matrix_2d(fp, N, N, A) == NULL) {
            MPI_Abort(MPI_COMM_WORLD, 1);
        }
        fclose(fp);
        fp = NULL;
    }
    /* And distributes the table */
    MPI_Barrier(MPI_COMM_WORLD);
    propagate_with_flooding(A, N*N, MPI_DOUBLE, 0, MPI_COMM_WORLD);

    last_rank = (N - 1) % max_rank;

    if(rank == 0) {
        sec = timer();
    }

    for (k = 0; k < N - 1; k++) {
        /* The owner of the row for this k broadcasts it*/
        MPI_Barrier(MPI_COMM_WORLD);
        propagate_with_flooding(&A[k * N], N, MPI_DOUBLE, \
                ((k % (max_rank * BLOCK_ROWS)) / BLOCK_ROWS), MPI_COMM_WORLD);
        process_rows(k, rank, N, max_rank, A);
    }

    MPI_Barrier(MPI_COMM_WORLD);
    if (rank == 0) {
        sec = timer();
        printf("Calc Time: %lf\n", sec);
    }
    ret = MPI_Finalize();

    if(ret == 0) {
        debug("%d FINALIZED!!! with code: %d\n", rank, ret);
    }
    else {
        debug("%d NOT FINALIZED!!! with code: %d\n", rank, ret);
    }

    /* Last process has table */
    if (rank == last_rank) {
        //print_matrix_2d(N, N, A);
        fp = fopen(argv[2], "w");
        fprint_matrix_2d(fp, N, N, A);
        fclose(fp);
    }
    free(A);

    return 0;
}
```

Η υλοποίηση **point-to-point** με χρήση flooding για λογαριθμικό propagation και συνεχή κατανομή των γραμμών (*Continuous*).

```
/* -.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.
 * File Name : main.c
 * Creation Date : 30-10-2012
 * Last Modified : Mon 12 Nov 2012 09:56:29 AM EET
 * Created By : Greg Liras <gregliras@gmail.com>
 * Created By : Alex Maurogiannis <nalfemp@gmail.com>
```

```c
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#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>
#include <signal.h>
#include <signal.h>
#include <unistd.h>
#include <string.h>

#include "common.h"


int get_bcaster(int *ccounts, int bcaster)
{
    if (ccounts[bcaster]-- > 0 ){
        return bcaster;
    } else {
        return bcaster+1;
    }
}

void get_displs(int *counts, int max_rank, int *displs)
{
    int j;
    displs[0] = 0;
    for (j = 1; j < max_rank ; j++) {
        displs[j] = displs[j - 1] + counts[j - 1];
    }
}

int max(int a, int b)
{
    return a > b ? a : b;
}

void process_rows(int k, int rank, int N, int max_rank, int block_rows, int *displs, double *A)
{
    /*      performs the calculations for a given set of rows.
     *      In this hybrid version each thread is assigned blocks of
     *      continuous rows in a cyclic manner.
     */
    int j, w;
    double l;
    int start = max(displs[rank], k+1);
    for (w = start; w < (start + block_rows) && w < N; w++){
        l = A[(w * N) + k] / A[(k * N) + k];
        for (j = k; j < N; j++) {
            A[(w * N) + j] = A[(w * N) + j] - l * A[(k * N) + j];
        }
    }
}

/*  distributes the rows in a continuous fashion */
void distribute_rows(int max_rank, int N, int *counts)
{
        int j, k;
        int rows = N;

        /* Initialize counts */
        for (j = 0; j < max_rank ; j++) {
            counts[j] = (rows / max_rank);
        }

        /* Distribute the indivisible leftover */
        if (rows / max_rank != 0) {
            j = rows % max_rank;
            for (k = 0; k < max_rank && j > 0; k++, j--) {
                    counts[k] += 1;
            }
        } else {
            for (k = 0; k < max_rank; k++){
                counts[k] = 1;
            }
        }
```

```
82
83  }
84
85
86  int main(int argc, char **argv)
87  {
88      int i, j, k;
89      int N;
90      int rank;
91      int max_rank;
92      int block_rows;
93      int *counts;
94      int *displs;
95      int *ccounts;
96      int ret = 0;
97      int bcaster = 0;
98      double l;
99      double sec;
100     double *A = NULL;
101     FILE *fp = NULL;
102
103
104     usage(argc, argv);
105
106     MPI_Init(&argc, &argv);
107     MPI_Comm_rank(MPI_COMM_WORLD, &rank);
108     MPI_Comm_size(MPI_COMM_WORLD, &max_rank);
109
110     if (rank == 0) {
111         debug("rank: %d opens file: %s\n", rank, argv[1]);
112         fp = fopen(argv[1], "r");
113         if(fp) {
114             if(!fscanf(fp, "%d\n", &N)) {
115                 MPI_Abort(MPI_COMM_WORLD, 1);
116             }
117         }
118         else {
119             MPI_Abort(MPI_COMM_WORLD, 1);
120         }
121
122     }
123
124     MPI_Barrier(MPI_COMM_WORLD);
125     propagate_with_flooding(&N, 1, MPI_INT, 0, MPI_COMM_WORLD);
126
127     counts = malloc(max_rank * sizeof(int));
128     displs = malloc(max_rank * sizeof(int));
129     ccounts = malloc(max_rank * sizeof(int));
130
131     distribute_rows(max_rank, N, counts);
132     get_displs(counts, max_rank, displs);
133     memcpy(ccounts, counts, max_rank * sizeof(int));
134 #if main_DEBUG
135         printf("CCounts is :\n");
136         for (j = 0; j < max_rank ; j++) {
137             printf("%d\n", ccounts[j]);
138         }
139 #endif
140
141     /* Everybody Allocates the whole table */
142     if((A = allocate_2d_with_padding(N, N, max_rank)) == NULL) {
143         MPI_Abort(MPI_COMM_WORLD, 1);
144     }
145     if (rank == 0) {
146         if(parse_matrix_2d(fp, N, N, A) == NULL) {
147             MPI_Abort(MPI_COMM_WORLD, 1);
148         }
149         fclose(fp);
150         fp = NULL;
151     }
152
153     MPI_Barrier(MPI_COMM_WORLD);
154     propagate_with_flooding(A, N*N, MPI_DOUBLE, 0, MPI_COMM_WORLD);
155
156     /* Start Timing */
```

```
    if(rank == 0) {
        sec = timer();
    }


    for (k = 0; k < N - 1; k++) {
        block_rows = counts[rank];
        bcaster = get_bcaster(ccounts, bcaster);

        debug(" broadcaster is %d\n", bcaster);
        MPI_Barrier(MPI_COMM_WORLD);
        propagate_with_flooding(&A[k * N], N, MPI_DOUBLE, bcaster, MPI_COMM_WORLD);

        process_rows(k, rank, N, max_rank, block_rows, displs, A);
    }

    MPI_Barrier(MPI_COMM_WORLD);
    if(rank == 0) {
        sec = timer();
        printf("Calc Time: %lf\n", sec);
    }
    ret = MPI_Finalize();

    if(ret == 0) {
        debug("%d FINALIZED!!! with code: %d\n", rank, ret);
    }
    else {
        debug("%d NOT FINALIZED!!! with code: %d\n", rank, ret);
    }

    if(rank == (max_rank - 1)) {
        fp = fopen(argv[2], "w");
        fprint_matrix_2d(fp, N, N, A);
        fclose(fp);
    }
    free(A);
    free(counts);
    free(ccounts);

    return 0;
}
```

Ζητούμενο 4.2 Collective

Η **collective** υλοποίηση για κυκλική κατανομή των γραμμών (*Circular*).

```
/* -.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.
 * File Name : main.c
 * Creation Date : 30-10-2012
 * Last Modified : Mon 12 Nov 2012 10:03:37 AM EET
 * Created By : Greg Liras <gregliras@gmail.com>
 * Created By : Alex Maurogiannis <nalfemp@gmail.com>
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#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>
#include <signal.h>
#include <signal.h>
#include <unistd.h>
#include <string.h>

#include "common.h"

#define BLOCK_ROWS 1


void process_rows(int k, int rank, int N, int max_rank, double *A)
{
    /*      performs the calculations for a given set of rows.
     *      In this hybrid version each thread is assigned blocks of
     *      continuous rows in a cyclic manner.
     */
    int i, j, w;
    double l;
```

```
    /* For every cyclic repetition of a block */
    for (i = (rank + ((BLOCK_ROWS * max_rank) * (k / (BLOCK_ROWS * max_rank)))); i < N ; i+=(max_rank * BLOCK_ROWS)) {
        if (i > k) {
            /* Calculate each continuous row in the block*/
            for (w = i; w < (i + BLOCK_ROWS) && w < (N * N); w++){
                l = A[(w * N) + k] / A[(k * N) + k];
                for (j = k; j < N; j++) {
                    A[(w * N) + j] = A[(w * N) + j] - l * A[(k* N) + j];
                }
            }
        }
    }
}

int main(int argc, char **argv)
{
    int k;
    int N;
    int rank;
    int max_rank;
    int last_rank;
    double *A = NULL;
    double sec = 0;

    int ret = 0;
    FILE *fp = NULL;
    usage(argc, argv);

    MPI_Init(&argc, &argv);
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &max_rank);

    if (rank == 0) {
        debug("rank: %d opens file: %s\n", rank, argv[1]);
        fp = fopen(argv[1], "r");
        if(fp) {
            if(!fscanf(fp, "%d\n", &N)) {
                MPI_Abort(MPI_COMM_WORLD, 1);
            }
        }
        else {
            MPI_Abort(MPI_COMM_WORLD, 1);
        }

    }

    MPI_Barrier(MPI_COMM_WORLD);
    MPI_Bcast(&N, 1, MPI_INT, 0, MPI_COMM_WORLD);

    /* Everyone allocates the whole table */
    debug("Max rank = %d\n", max_rank);
    if((A = allocate_2d_with_padding(N, N, max_rank)) == NULL) {
        MPI_Abort(MPI_COMM_WORLD, 1);
    }
    /* Root Parses file */
    if (rank == 0) {
        if(parse_matrix_2d(fp, N, N, A) == NULL) {
            MPI_Abort(MPI_COMM_WORLD, 1);
        }
        fclose(fp);
        fp = NULL;
    }
    /* And distributes the table */
    MPI_Barrier(MPI_COMM_WORLD);
    MPI_Bcast(A, N*N, MPI_DOUBLE, 0, MPI_COMM_WORLD);

    last_rank = (N - 1) % max_rank;

    if(rank == 0) {
        sec = timer();
    }

    for (k = 0; k < N - 1; k++) {
        /* The owner of the row for this k broadcasts it*/
        MPI_Barrier(MPI_COMM_WORLD);
```

```
        MPI_Bcast(&A[k * N], N, MPI_DOUBLE, ((k % (max_rank * BLOCK_ROWS)) / BLOCK_ROWS), MPI_COMM_WORLD);

        process_rows(k, rank, N, max_rank, A);
    }

    MPI_Barrier(MPI_COMM_WORLD);
    if (rank == 0) {
        sec = timer();
        printf("Calc Time: %lf\n", sec);
    }
    ret = MPI_Finalize();

    if(ret == 0) {
        debug("%d FINALIZED!!! with code: %d\n", rank, ret);
    }
    else {
        debug("%d NOT FINALIZED!!! with code: %d\n", rank, ret);
    }

    /* Last process has table */
    if (rank == last_rank) {
        //print_matrix_2d(N, N, A);
        fp = fopen(argv[2], "w");
        fprint_matrix_2d(fp, N, N, A);
        fclose(fp);
    }
    free(A);

    return 0;
}
```

Η **collective** υλοποίηση για συνεχή κατανομή των γραμμών (*Continuous*).

```
/* -.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.-.
 * File Name : main.c
 * Creation Date : 30-10-2012
 * Last Modified : Mon 12 Nov 2012 10:03:03 AM EET
 * Created By : Greg Liras <gregliras@gmail.com>
 * Created By : Alex Maurogiannis <nalfemp@gmail.com>
 _.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-._.-.*/

#include <mpi.h>
#include <stdio.h>
#include <stdlib.h>
#include <signal.h>
#include <signal.h>
#include <unistd.h>
#include <string.h>

#include "common.h"


int get_bcaster(int *ccounts, int bcaster)
{
    if (ccounts[bcaster]-- > 0 ){
        return bcaster;
    }
    else {
        return bcaster+1;
    }
}

void get_displs(int *counts, int max_rank, int *displs)
{
    int j;
    displs[0] = 0;
    for (j = 1; j < max_rank ; j++) {
        displs[j] = displs[j - 1] + counts[j - 1];
    }
}

int max(int a, int b)
{
    return a > b ? a : b;
}

```

```
44  void process_rows(int k, int rank, int N, int max_rank, int block_rows, int *displs, double *A)
45  {
46      /*      performs the calculations for a given set of rows.
47       *      In this hybrid version each thread is assigned blocks of
48       *      continuous rows in a cyclic manner.
49       */
50      int j, w;
51      double l;
52      int start = max(displs[rank], k+1);
53      for (w = start; w < (start + block_rows) && w < N; w++){
54          l = A[(w * N) + k] / A[(k * N) + k];
55          for (j = k; j < N; j++) {
56              A[(w * N) + j] = A[(w * N) + j] - l * A[(k * N) + j];
57          }
58      }
59  }
60
61  /*  distributes the rows in a continuous fashion */
62  void distribute_rows(int max_rank, int N, int *counts)
63  {
64      int j, k;
65      int rows = N;
66
67      /* Initialize counts */
68      for (j = 0; j < max_rank ; j++) {
69          counts[j] = (rows / max_rank);
70      }
71
72      /* Distribute the indivisible leftover */
73      if (rows / max_rank != 0) {
74          j = rows % max_rank;
75          for (k = 0; k < max_rank && j > 0; k++, j--) {
76              counts[k] += 1;
77          }
78      }
79      else {
80          for (k = 0; k < max_rank; k++) {
81              counts[k] = 1;
82          }
83      }
84
85  }
86
87
88  int main(int argc, char **argv)
89  {
90      int i, j, k;
91      int N;
92      int rank;
93      int max_rank;
94      int block_rows;
95      int *counts;
96      int *displs;
97      int *ccounts;
98      int ret = 0;
99      int bcaster = 0;
100     double l;
101     double sec;
102     double *A = NULL;
103     FILE *fp = NULL;
104
105
106     usage(argc, argv);
107
108     MPI_Init(&argc, &argv);
109     MPI_Comm_rank(MPI_COMM_WORLD, &rank);
110     MPI_Comm_size(MPI_COMM_WORLD, &max_rank);
111
112     if (rank == 0) {
113         debug("rank: %d opens file: %s\n", rank, argv[1]);
114         fp = fopen(argv[1], "r");
115         if(fp) {
116             if(!fscanf(fp, "%d\n", &N)) {
117                 MPI_Abort(MPI_COMM_WORLD, 1);
118             }
```

```
        }
        else {
            MPI_Abort(MPI_COMM_WORLD, 1);
        }

    }

    MPI_Barrier(MPI_COMM_WORLD);
    MPI_Bcast(&N, 1, MPI_INT, 0, MPI_COMM_WORLD);

    counts = malloc(max_rank * sizeof(int));
    displs = malloc(max_rank * sizeof(int));
    ccounts = malloc(max_rank * sizeof(int));

    distribute_rows(max_rank, N, counts);
    get_displs(counts, max_rank, displs);
    memcpy(ccounts, counts, max_rank * sizeof(int));

#if main_DEBUG
    printf("CCounts is :\n");
    for (j = 0; j < max_rank ; j++) {
        printf("%d\n", ccounts[j]);
    }
#endif

    /* Everybody Allocates the whole table */
    if((A = allocate_2d_with_padding(N, N, max_rank)) == NULL) {
        MPI_Abort(MPI_COMM_WORLD, 1);
    }
    if (rank == 0) {
        if(parse_matrix_2d(fp, N, N, A) == NULL) {
            MPI_Abort(MPI_COMM_WORLD, 1);
        }
        fclose(fp);
        fp = NULL;
    }

    MPI_Barrier(MPI_COMM_WORLD);
    MPI_Bcast(A, N*N, MPI_DOUBLE, 0, MPI_COMM_WORLD);

    /* Start Timing */
    if(rank == 0) {
        sec = timer();
    }


    for (k = 0; k < N - 1; k++) {
        block_rows = counts[rank];
        bcaster = get_bcaster(ccounts, bcaster);

        MPI_Barrier(MPI_COMM_WORLD);
        debug(" broadcaster is %d\n", bcaster);
        MPI_Barrier(MPI_COMM_WORLD);
        MPI_Bcast(&A[k * N], N, MPI_DOUBLE, bcaster, MPI_COMM_WORLD);

        process_rows(k, rank, N, max_rank, block_rows, displs, A);
    }

    MPI_Barrier(MPI_COMM_WORLD);
    if(rank == 0) {
        sec = timer();
        printf("Calc Time: %lf\n", sec);
    }
    ret = MPI_Finalize();

    if(ret == 0) {
        debug("%d FINALIZED!!! with code: %d\n", rank, ret);
    }
    else {
        debug("%d NOT FINALIZED!!! with code: %d\n", rank, ret);
    }

    if(rank == (max_rank - 1)) {
        fp = fopen(argv[2], "w");
        fprint_matrix_2d(fp, N, N, A);
```

```
        fclose(fp);
    }
    free(A);
    free(counts);
    free(ccounts);

    return 0;
}
```