HOCHSCHULE
HAMM-LIPPSTADT

Parallel Computing

Präsentiert von Jean Sokolov

Inhaltsverzeichnis

- Problemstellung
- Implementation in OpenMP
- Implementation in MPI

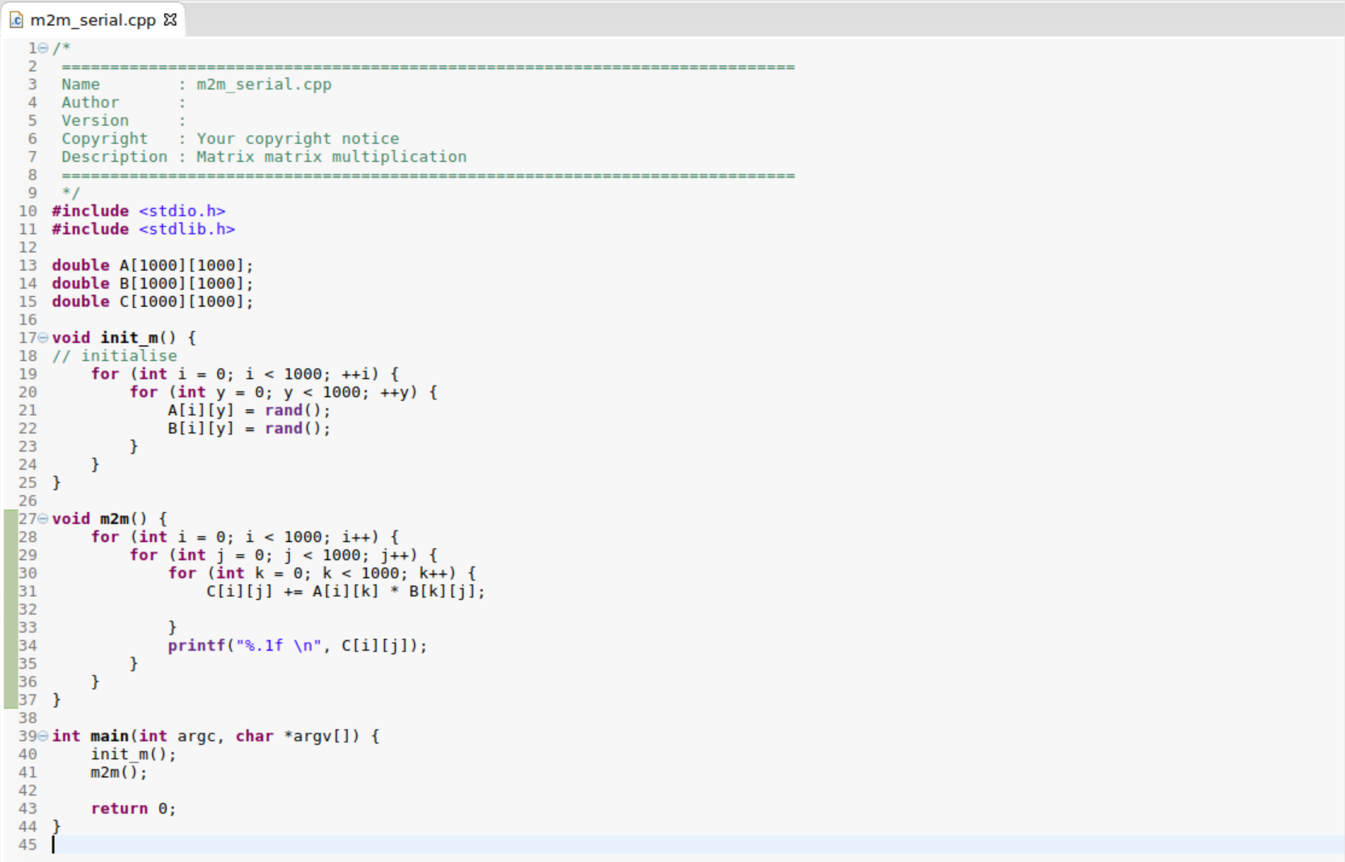
PROBLEMSTELLUNG

Matrix-Multiplikation

- Parallelisieren der Kalkulation
- In C++ mit OpenMP und MPI

IMPLEMENTATION IN C++

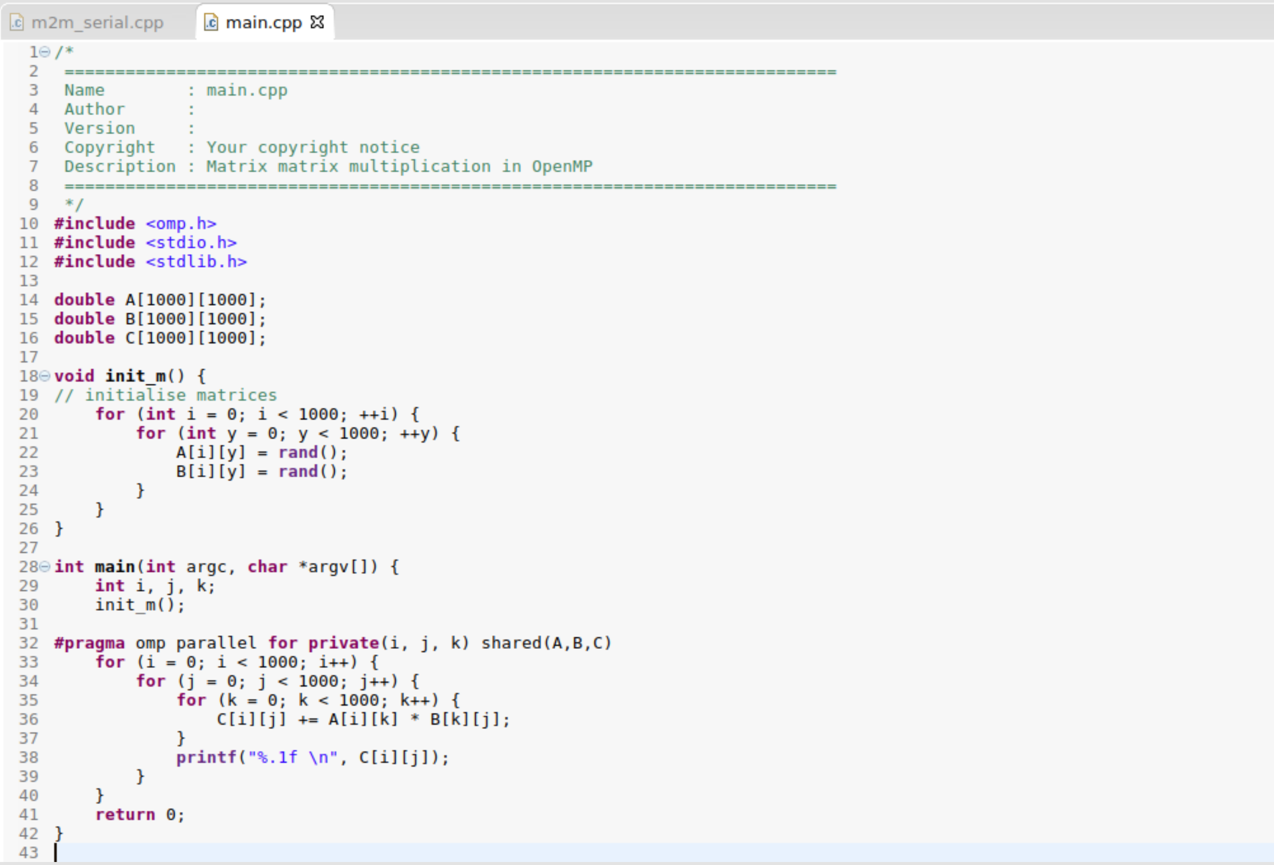
Single-thread



```
/*
 ============================================================================
 Name        : m2m_serial.cpp
 Author      :
 Version     :
 Copyright   : Your copyright notice
 Description : Matrix matrix multiplication
 ============================================================================
 */
#include <stdio.h>
#include <stdlib.h>

double A[1000][1000];
double B[1000][1000];
double C[1000][1000];

void init_m() {
// initialise
    for (int i = 0; i < 1000; ++i) {
        for (int y = 0; y < 1000; ++y) {
            A[i][y] = rand();
            B[i][y] = rand();
        }
    }
}

void m2m() {
    for (int i = 0; i < 1000; i++) {
        for (int j = 0; j < 1000; j++) {
            for (int k = 0; k < 1000; k++) {
                C[i][j] += A[i][k] * B[k][j];

            }
            printf("%.1f \n", C[i][j]);
        }
    }
}

int main(int argc, char *argv[]) {
    init_m();
    m2m();

    return 0;
}
```

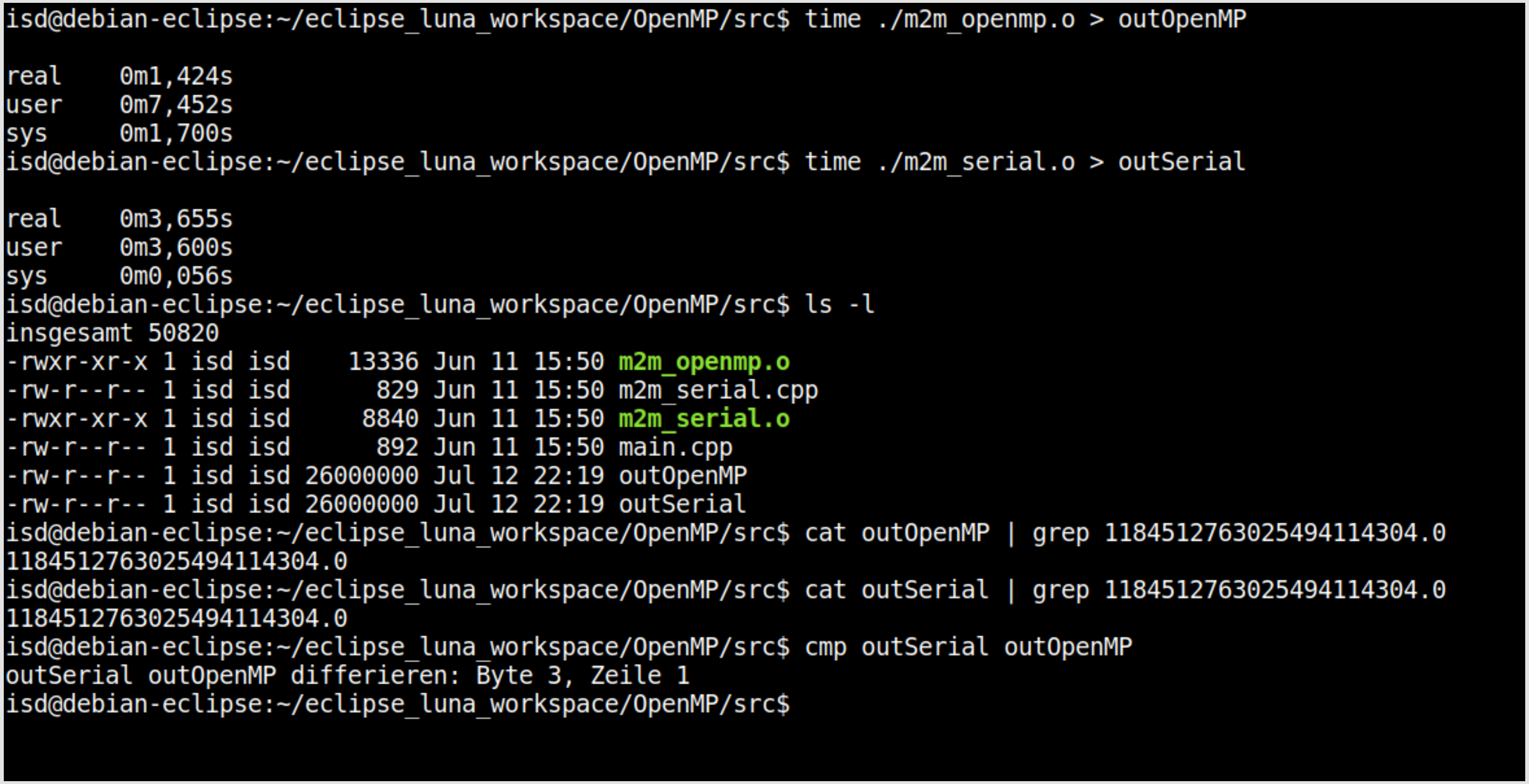
IMPLEMENTATION IN OPENMP

Multi-thread



```
/*
 ============================================================================
 Name        : main.cpp
 Author      :
 Version     :
 Copyright   : Your copyright notice
 Description : Matrix matrix multiplication in OpenMP
 ============================================================================
 */
#include <omp.h>
#include <stdio.h>
#include <stdlib.h>

double A[1000][1000];
double B[1000][1000];
double C[1000][1000];

void init_m() {
// initialise matrices
    for (int i = 0; i < 1000; ++i) {
        for (int y = 0; y < 1000; ++y) {
            A[i][y] = rand();
            B[i][y] = rand();
        }
    }
}

int main(int argc, char *argv[]) {
    int i, j, k;
    init_m();

#pragma omp parallel for private(i, j, k) shared(A,B,C)
    for (i = 0; i < 1000; i++) {
        for (j = 0; j < 1000; j++) {
            for (k = 0; k < 1000; k++) {
                C[i][j] += A[i][k] * B[k][j];
            }
            printf("%.1f \n", C[i][j]);
        }
    }
    return 0;
}

```

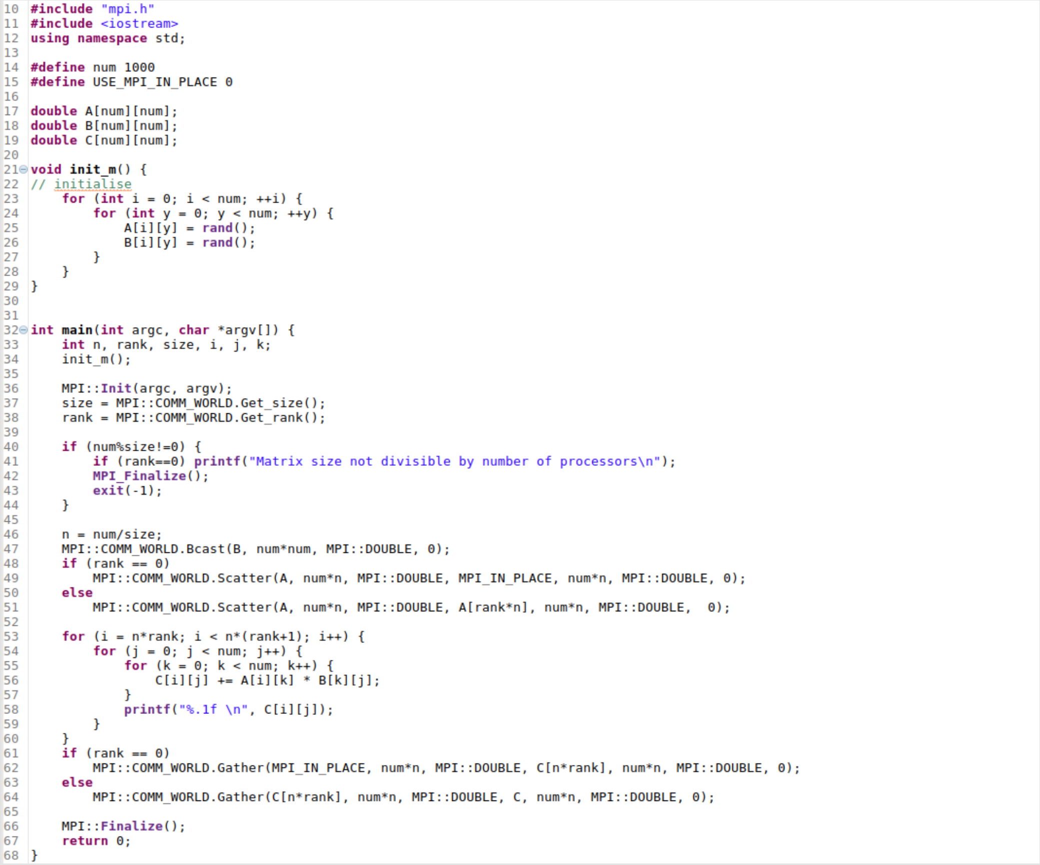
Laufzeit und Validierung



```
isd@debian-eclipse:~/eclipse_luna_workspace/OpenMP/src$ time ./m2m_openmp.o > outOpenMP

real    0m1,424s
user    0m7,452s
sys     0m1,700s
isd@debian-eclipse:~/eclipse_luna_workspace/OpenMP/src$ time ./m2m_serial.o > outSerial

real    0m3,655s
user    0m3,600s
sys     0m0,056s
isd@debian-eclipse:~/eclipse_luna_workspace/OpenMP/src$ ls -l
insgesamt 50820
-rwxr-xr-x 1 isd isd    13336 Jun 11 15:50 m2m_openmp.o
-rw-r--r-- 1 isd isd      829 Jun 11 15:50 m2m_serial.cpp
-rwxr-xr-x 1 isd isd     8840 Jun 11 15:50 m2m_serial.o
-rw-r--r-- 1 isd isd      892 Jun 11 15:50 main.cpp
-rw-r--r-- 1 isd isd 26000000 Jul 12 22:19 outOpenMP
-rw-r--r-- 1 isd isd 26000000 Jul 12 22:19 outSerial
isd@debian-eclipse:~/eclipse_luna_workspace/OpenMP/src$ cat outOpenMP | grep 1184512763025494114304.0
1184512763025494114304.0
isd@debian-eclipse:~/eclipse_luna_workspace/OpenMP/src$ cat outSerial | grep 1184512763025494114304.0
1184512763025494114304.0
isd@debian-eclipse:~/eclipse_luna_workspace/OpenMP/src$ cmp outSerial outOpenMP
outSerial outOpenMP differieren: Byte 3, Zeile 1
isd@debian-eclipse:~/eclipse_luna_workspace/OpenMP/src$
```

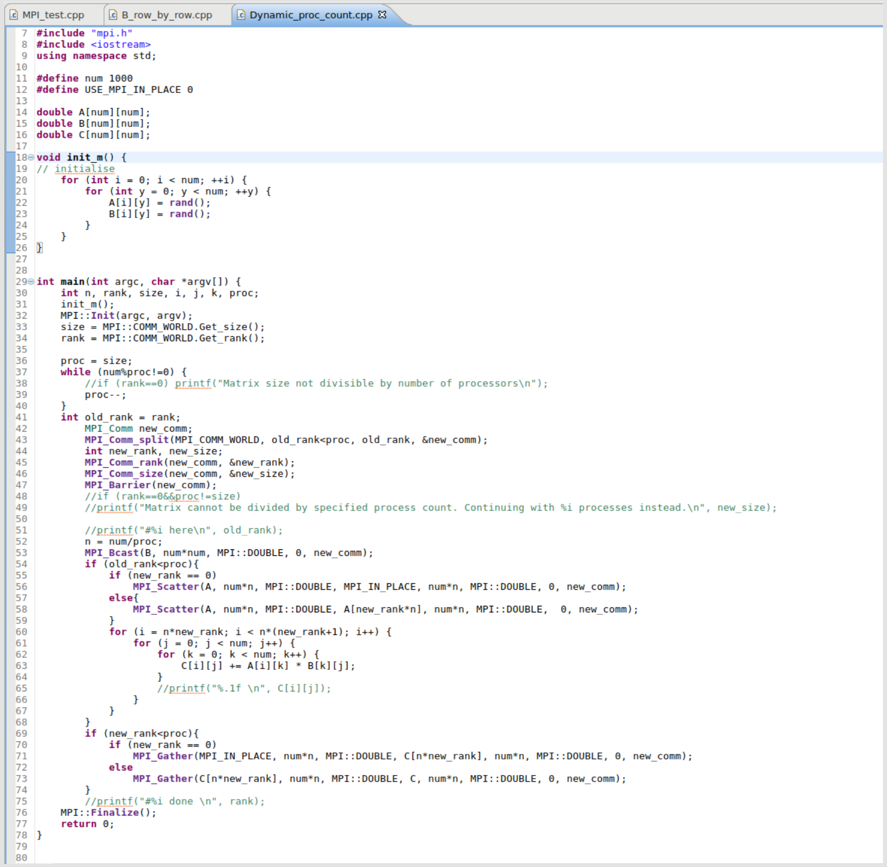
IMPLEMENTATION IN MPI

Statische Prozesszahl



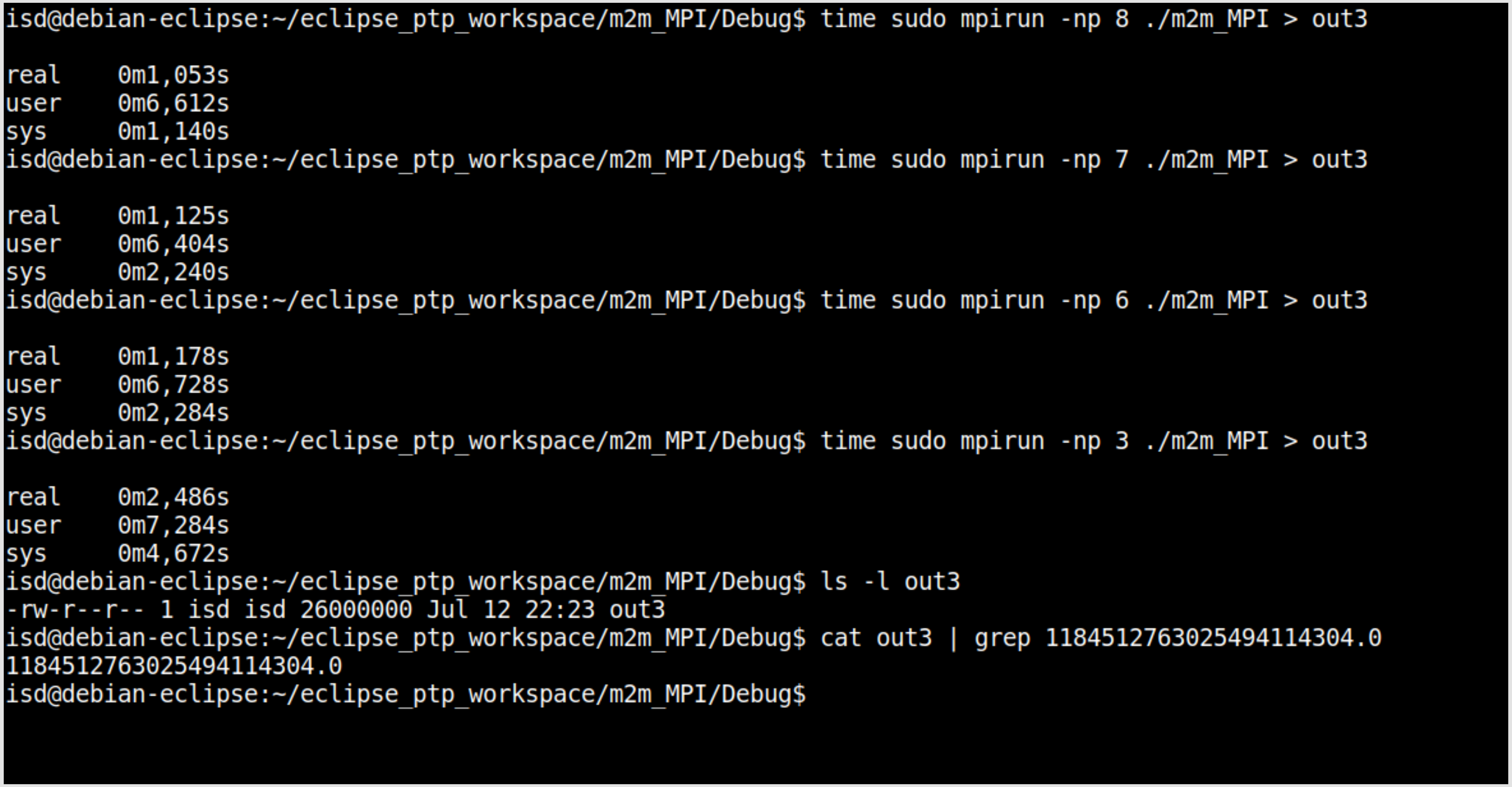
```cpp
#include "mpi.h"
#include <iostream>
using namespace std;

#define num 1000
#define USE_MPI_IN_PLACE 0

double A[num][num];
double B[num][num];
double C[num][num];

void init_m() {
// initialise
    for (int i = 0; i < num; ++i) {
        for (int y = 0; y < num; ++y) {
            A[i][y] = rand();
            B[i][y] = rand();
        }
    }
}


int main(int argc, char *argv[]) {
    int n, rank, size, i, j, k;
    init_m();

    MPI::Init(argc, argv);
    size = MPI::COMM_WORLD.Get_size();
    rank = MPI::COMM_WORLD.Get_rank();

    if (num%size!=0) {
        if (rank==0) printf("Matrix size not divisible by number of processors\n");
        MPI_Finalize();
        exit(-1);
    }

    n = num/size;
    MPI::COMM_WORLD.Bcast(B, num*num, MPI::DOUBLE, 0);
    if (rank == 0)
        MPI::COMM_WORLD.Scatter(A, num*n, MPI::DOUBLE, MPI_IN_PLACE, num*n, MPI::DOUBLE, 0);
    else
        MPI::COMM_WORLD.Scatter(A, num*n, MPI::DOUBLE, A[rank*n], num*n, MPI::DOUBLE,  0);

    for (i = n*rank; i < n*(rank+1); i++) {
        for (j = 0; j < num; j++) {
            for (k = 0; k < num; k++) {
                C[i][j] += A[i][k] * B[k][j];
            }
            printf("%.1f \n", C[i][j]);
        }
    }
    if (rank == 0)
        MPI::COMM_WORLD.Gather(MPI_IN_PLACE, num*n, MPI::DOUBLE, C[n*rank], num*n, MPI::DOUBLE, 0);
    else
        MPI::COMM_WORLD.Gather(C[n*rank], num*n, MPI::DOUBLE, C, num*n, MPI::DOUBLE, 0);

    MPI::Finalize();
    return 0;
}
```

Dynamische Prozesszahl



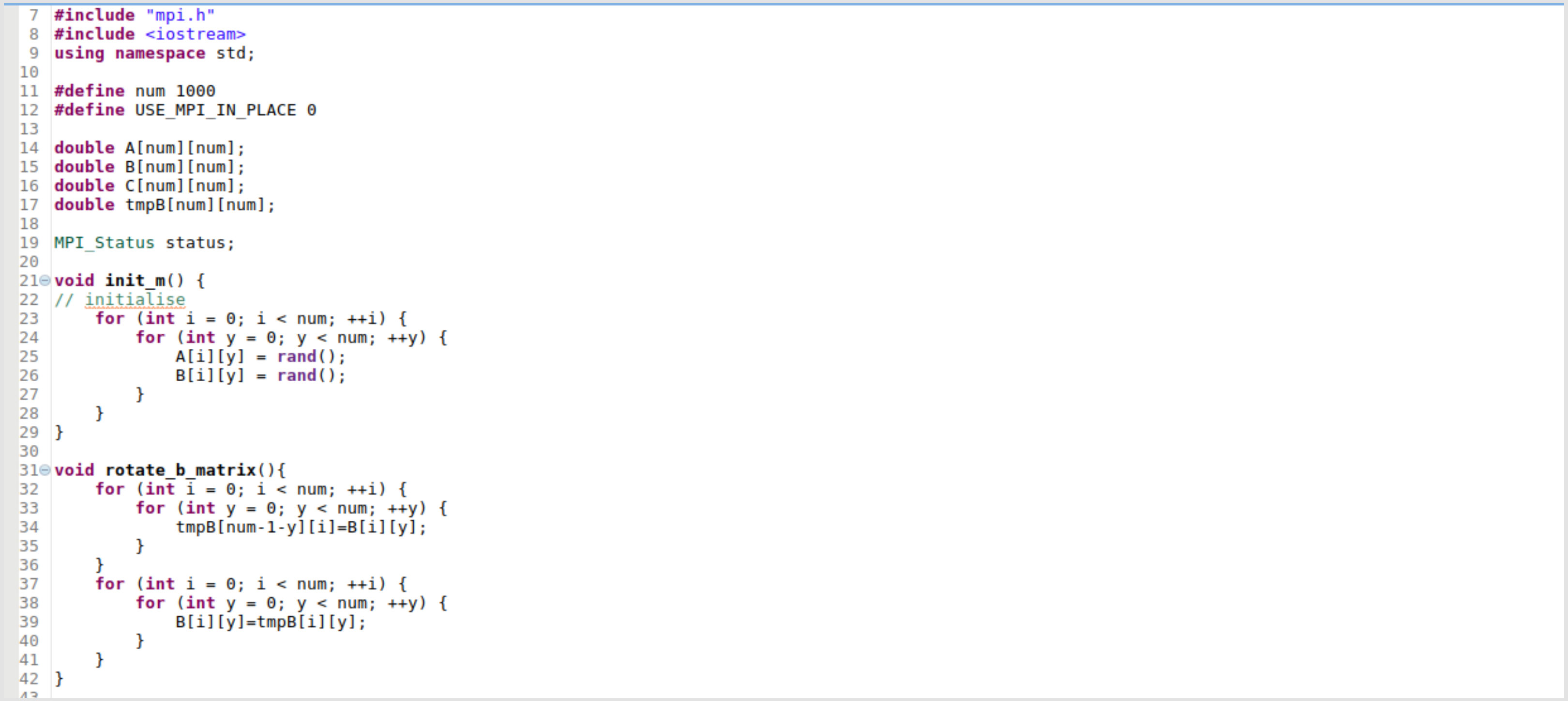
```cpp
#include "mpi.h"
#include <iostream>
using namespace std;

#define num 1000
#define USE_MPI_IN_PLACE 0

double A[num][num];
double B[num][num];
double C[num][num];

void init_m() {
// initialise
    for (int i = 0; i < num; ++i) {
        for (int y = 0; y < num; ++y) {
            A[i][y] = rand();
            B[i][y] = rand();
        }
    }
}


int main(int argc, char *argv[]) {
    int n, rank, size, i, j, k, proc;
    init_m();
    MPI::Init(argc, argv);
    size = MPI::COMM_WORLD.Get_size();
    rank = MPI::COMM_WORLD.Get_rank();

    proc = size;
    while (num%proc!=0) {
        //if (rank==0) printf("Matrix size not divisible by number of processors\n");
        proc--;
    }
    int old_rank = rank;
        MPI_Comm new_comm;
        MPI_Comm_split(MPI_COMM_WORLD, old_rank<proc, old_rank, &new_comm);
        int new_rank, new_size;
        MPI_Comm_rank(new_comm, &new_rank);
        MPI_Comm_size(new_comm, &new_size);
        MPI_Barrier(new_comm);
        //if (rank==0&&proc!=size)
        //printf("Matrix cannot be divided by specified process count. Continuing with %i processes instead.\n", new_size);

        //printf("#%i here\n", old_rank);
        n = num/proc;
        MPI_Bcast(B, num*num, MPI::DOUBLE, 0, new_comm);
        if (old_rank<proc){
            if (new_rank == 0)
                MPI_Scatter(A, num*n, MPI::DOUBLE, MPI_IN_PLACE, num*n, MPI::DOUBLE, 0, new_comm);
            else{
                MPI_Scatter(A, num*n, MPI::DOUBLE, A[new_rank*n], num*n, MPI::DOUBLE,  0, new_comm);
            }
            for (i = n*new_rank; i < n*(new_rank+1); i++) {
                for (j = 0; j < num; j++) {
                    for (k = 0; k < num; k++) {
                        C[i][j] += A[i][k] * B[k][j];
                    }
                    //printf("%.1f \n", C[i][j]);
                }
            }
        }
        if (new_rank<proc){
            if (new_rank == 0)
                MPI_Gather(MPI_IN_PLACE, num*n, MPI::DOUBLE, C[n*new_rank], num*n, MPI::DOUBLE, 0, new_comm);
            else
                MPI_Gather(C[n*new_rank], num*n, MPI::DOUBLE, C, num*n, MPI::DOUBLE, 0, new_comm);
        }
        //printf("#%i done \n", rank);
    MPI::Finalize();
    return 0;
}
```

Laufzeit und Validierung



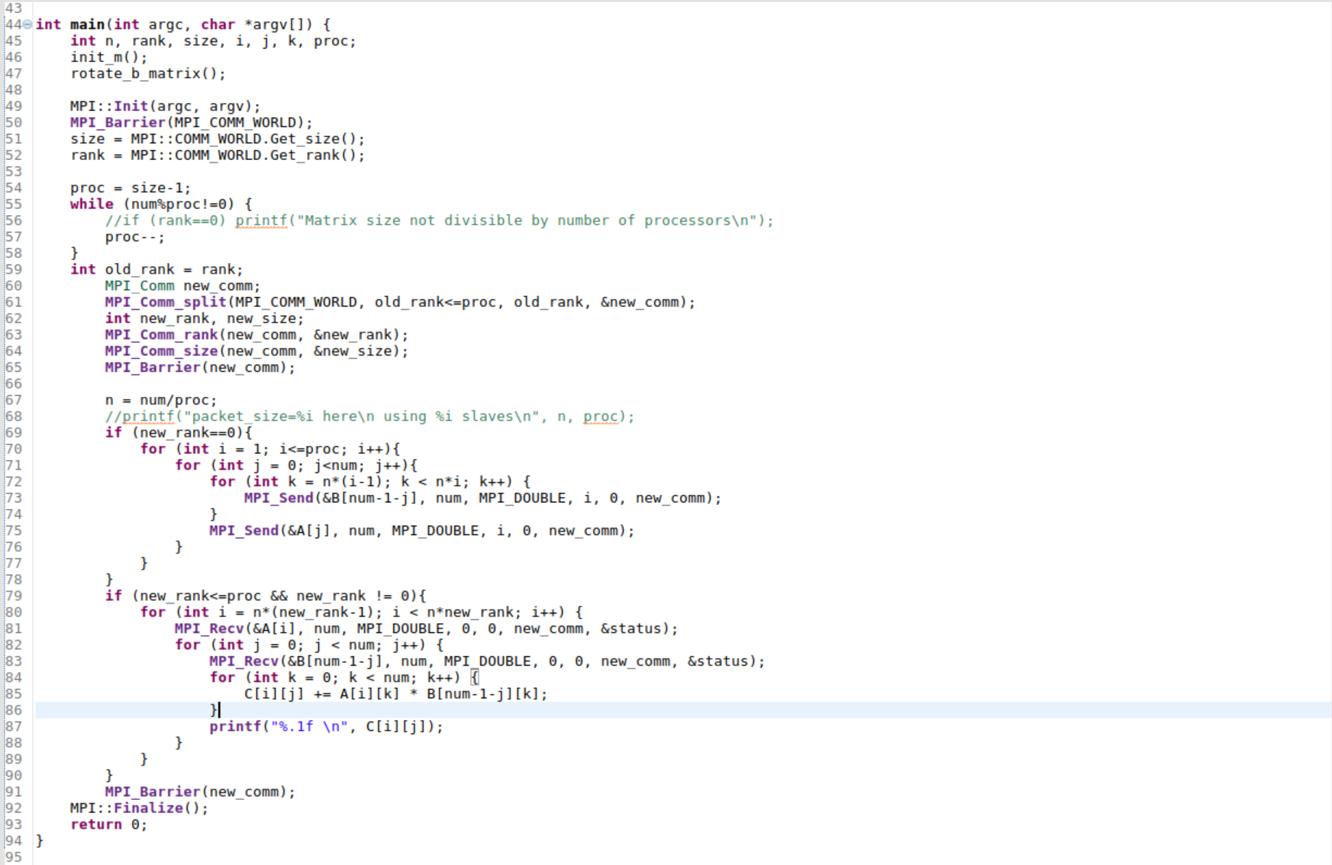
```
isd@debian-eclipse:~/eclipse_ptp_workspace/m2m_MPI/Debug$ time sudo mpirun -np 8 ./m2m_MPI > out3

real	0m1,053s
user	0m6,612s
sys	0m1,140s
isd@debian-eclipse:~/eclipse_ptp_workspace/m2m_MPI/Debug$ time sudo mpirun -np 7 ./m2m_MPI > out3

real	0m1,125s
user	0m6,404s
sys	0m2,240s
isd@debian-eclipse:~/eclipse_ptp_workspace/m2m_MPI/Debug$ time sudo mpirun -np 6 ./m2m_MPI > out3

real	0m1,178s
user	0m6,728s
sys	0m2,284s
isd@debian-eclipse:~/eclipse_ptp_workspace/m2m_MPI/Debug$ time sudo mpirun -np 3 ./m2m_MPI > out3

real	0m2,486s
user	0m7,284s
sys	0m4,672s
isd@debian-eclipse:~/eclipse_ptp_workspace/m2m_MPI/Debug$ ls -l out3
-rw-r--r-- 1 isd isd 26000000 Jul 12 22:23 out3
isd@debian-eclipse:~/eclipse_ptp_workspace/m2m_MPI/Debug$ cat out3 | grep 1184512763025494114304.0
1184512763025494114304.0
isd@debian-eclipse:~/eclipse_ptp_workspace/m2m_MPI/Debug$
```

Speichereffiziente Variation



```
#include "mpi.h"
#include <iostream>
using namespace std;

#define num 1000
#define USE_MPI_IN_PLACE 0

double A[num][num];
double B[num][num];
double C[num][num];
double tmpB[num][num];

MPI_Status status;

void init_m() {
// initialise
    for (int i = 0; i < num; ++i) {
        for (int y = 0; y < num; ++y) {
            A[i][y] = rand();
            B[i][y] = rand();
        }
    }
}

void rotate_b_matrix(){
    for (int i = 0; i < num; ++i) {
        for (int y = 0; y < num; ++y) {
            tmpB[num-1-y][i]=B[i][y];
        }
    }
    for (int i = 0; i < num; ++i) {
        for (int y = 0; y < num; ++y) {
            B[i][y]=tmpB[i][y];
        }
    }
}
```

Speichereffiziente Variation



```
int main(int argc, char *argv[]) {
    int n, rank, size, i, j, k, proc;
    init_m();
    rotate_b_matrix();

    MPI::Init(argc, argv);
    MPI_Barrier(MPI_COMM_WORLD);
    size = MPI::COMM_WORLD.Get_size();
    rank = MPI::COMM_WORLD.Get_rank();

    proc = size-1;
    while (num%proc!=0) {
        //if (rank==0) printf("Matrix size not divisible by number of processors\n");
        proc--;
    }
    int old_rank = rank;
        MPI_Comm new_comm;
        MPI_Comm_split(MPI_COMM_WORLD, old_rank<=proc, old_rank, &new_comm);
        int new_rank, new_size;
        MPI_Comm_rank(new_comm, &new_rank);
        MPI_Comm_size(new_comm, &new_size);
        MPI_Barrier(new_comm);

        n = num/proc;
        //printf("packet_size=%i here\n using %i slaves\n", n, proc);
        if (new_rank==0){
            for (int i = 1; i<=proc; i++){
                for (int j = 0; j<num; j++){
                    for (int k = n*(i-1); k < n*i; k++) {
                        MPI_Send(&B[num-1-j], num, MPI_DOUBLE, i, 0, new_comm);
                    }
                    MPI_Send(&A[j], num, MPI_DOUBLE, i, 0, new_comm);
                }
            }
        }
        if (new_rank<=proc && new_rank != 0){
            for (int i = n*(new_rank-1); i < n*new_rank; i++) {
                MPI_Recv(&A[i], num, MPI_DOUBLE, 0, 0, new_comm, &status);
                for (int j = 0; j < num; j++) {
                    MPI_Recv(&B[num-1-j], num, MPI_DOUBLE, 0, 0, new_comm, &status);
                    for (int k = 0; k < num; k++) {
                        C[i][j] += A[i][k] * B[num-1-j][k];
                    }
                    printf("%.1f \n", C[i][j]);
                }
            }
        }
        MPI_Barrier(new_comm);
    MPI::Finalize();
    return 0;
}
```

Quellcode

- https://github.com/JeanSokolov/ParallelComputing

Vielen Dank für Ihre Aufmerksamkeit