20BCE1550
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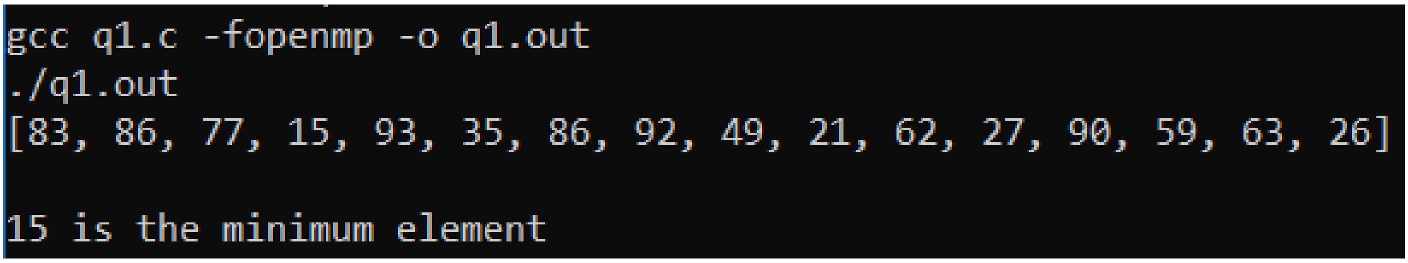
CSE4001 Lab 4
Sections

Q1.
Code:

```c
#include <stdio.h>
#include <stdlib.h>
#include <omp.h>

void function1() {
    // int n = 100000;
    int n = 16;
    int *nums = (int *)calloc(n, sizeof(int));

    for (int i = 0; i < n; i++) {
        nums[i] = rand() % 100;
    }

    int i = 0;
    int local_min_1, local_min_2, local_min_3, local_min_4;
    int min = 100;

    #pragma omp parallel shared(nums, n, min) private(i, local_min_1, local_min_2, local_min_3, local_min_4) num_threads(4)
    {
        #pragma omp sections
        {
            min = 100;
            #pragma omp section
            {
                local_min_1 = 100;
                for (i = 0; i < n/4; i++) {
                    if (nums[i] < local_min_1) local_min_1 = nums[i];
                }
                #pragma omp critical
                {
                    if (local_min_1 < min) min = local_min_1;
                }
            }
            #pragma omp section
            {
                local_min_2 = 100;
                for (i = n/4; i < 2 * n/4; i++) {
                    if (nums[i] < local_min_2) local_min_2 = nums[i];
                }
                #pragma omp critical
                {
                    if (local_min_2 < min) min = local_min_2;
                }
            }
            #pragma omp section
            {
                local_min_3 = 100;
                for (i = 2 * n/4; i < 3 * n/4; i++) {
                    if (nums[i] < local_min_3) local_min_3 = nums[i];
                }
                #pragma omp critical
                {
                    if (local_min_3 < min) min = local_min_3;
                }
            }
            #pragma omp section
            {
                local_min_4 = 100;
                for (i = 3 * n/4; i < n; i++) {
                    if (nums[i] < local_min_4) local_min_4 = nums[i];
                }
                #pragma omp critical
                {
                    if (local_min_4 < min) min = local_min_4;
                }
            }
        }
    }

        for (i = 0; i < n; i++) {
            printf(
                "%s%d%s",
                i == 0 ? "[" : " ",
                nums[i],
                i == n - 1 ? "]\n" : ","
            );
        }
        printf("\n%d is the minimum element", min);
        free(nums);
}

int main() {
    function1();

    printf("\n");
    return 0;
}
```

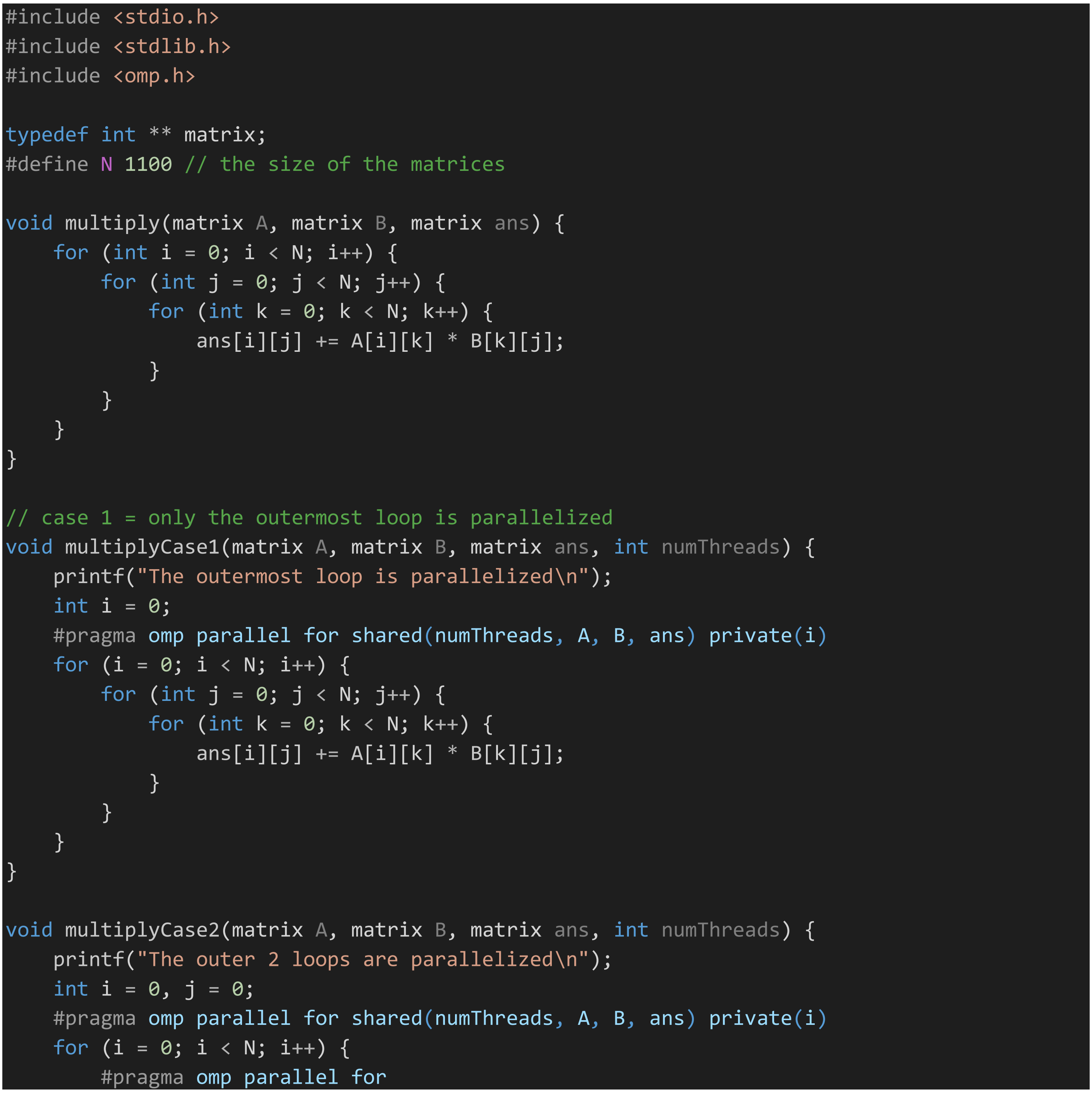
Output:



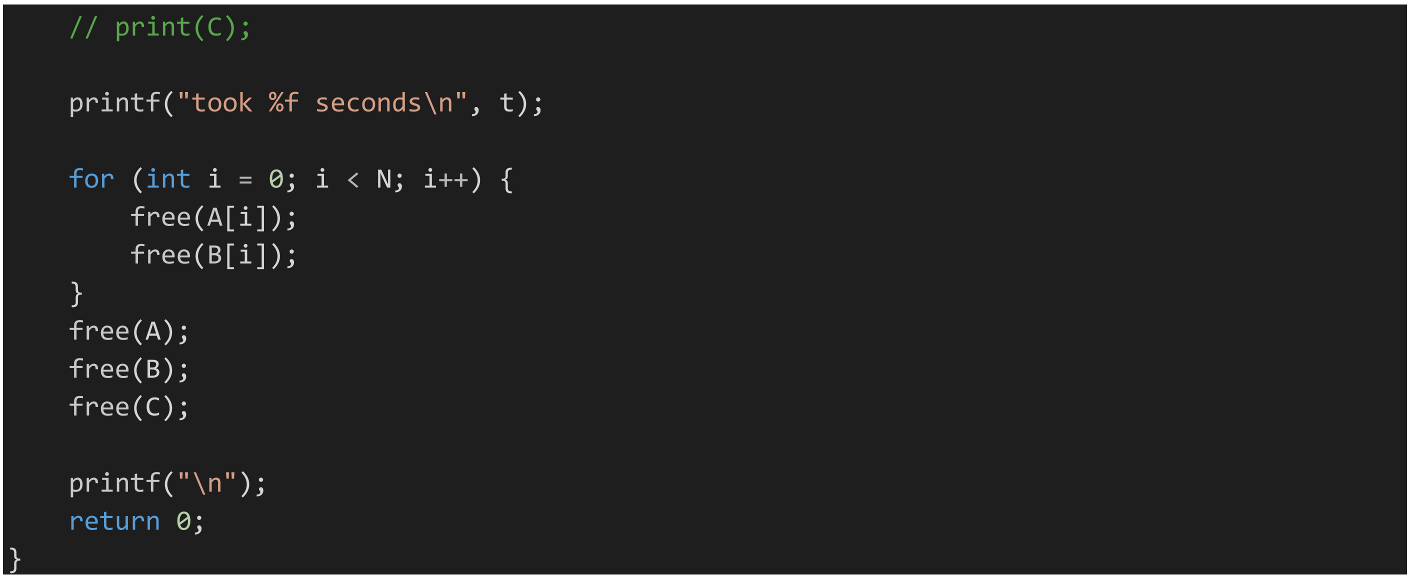
```
gcc q1.c -fopenmp -o q1.out
./q1.out
[83, 86, 77, 15, 93, 35, 86, 92, 49, 21, 62, 27, 90, 59, 63, 26]

15 is the minimum element
```

Q2.

Code:

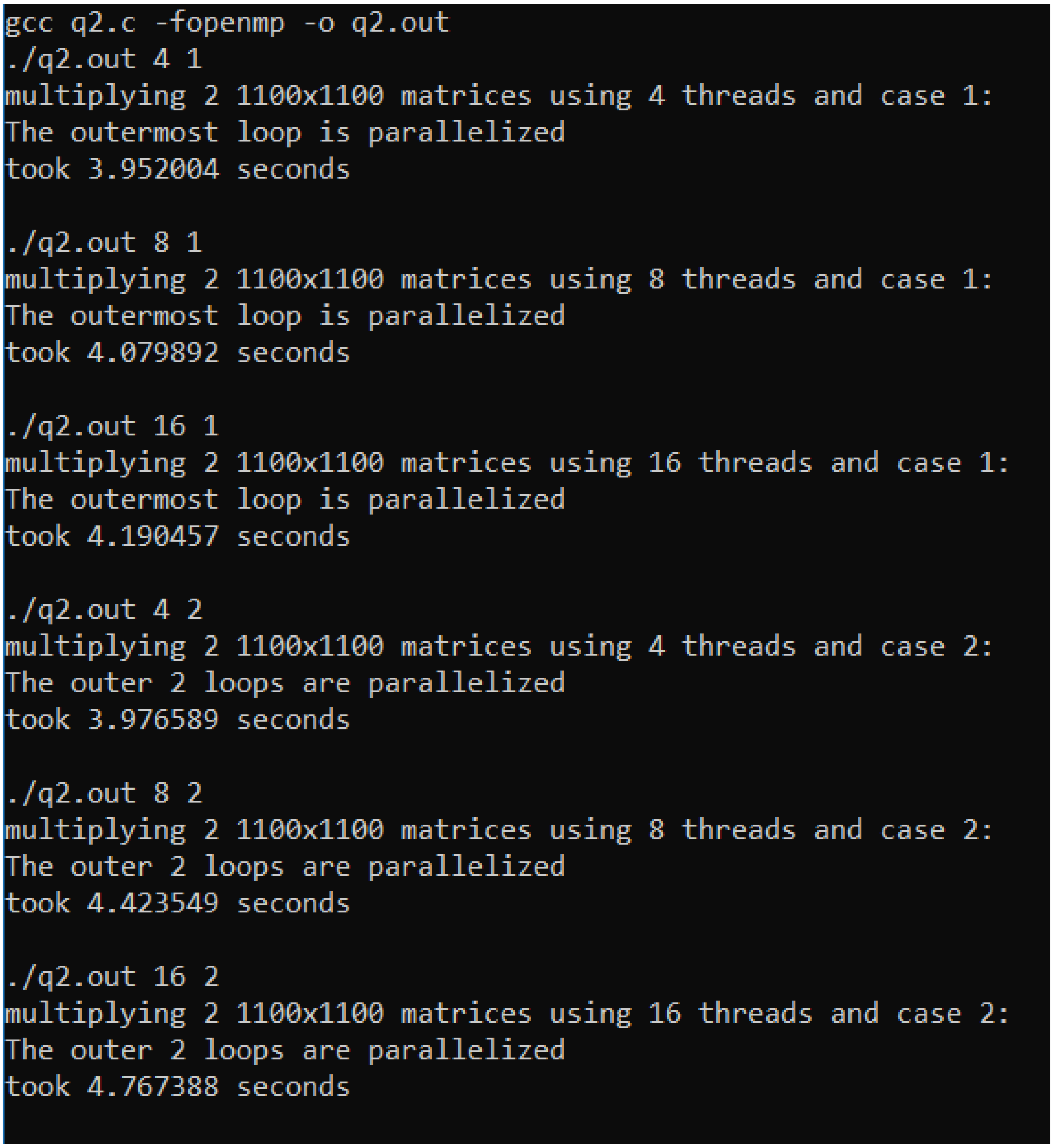


```c
#include <stdio.h>
#include <stdlib.h>
#include <omp.h>

typedef int ** matrix;
#define N 1100 // the size of the matrices

void multiply(matrix A, matrix B, matrix ans) {
    for (int i = 0; i < N; i++) {
        for (int j = 0; j < N; j++) {
            for (int k = 0; k < N; k++) {
                ans[i][j] += A[i][k] * B[k][j];
            }
        }
    }
}

// case 1 = only the outermost loop is parallelized
void multiplyCase1(matrix A, matrix B, matrix ans, int numThreads) {
    printf("The outermost loop is parallelized\n");
    int i = 0;
    #pragma omp parallel for shared(numThreads, A, B, ans) private(i)
    for (i = 0; i < N; i++) {
        for (int j = 0; j < N; j++) {
            for (int k = 0; k < N; k++) {
                ans[i][j] += A[i][k] * B[k][j];
            }
        }
    }
}

void multiplyCase2(matrix A, matrix B, matrix ans, int numThreads) {
    printf("The outer 2 loops are parallelized\n");
    int i = 0, j = 0;
    #pragma omp parallel for shared(numThreads, A, B, ans) private(i)
    for (i = 0; i < N; i++) {
        #pragma omp parallel for
        for (j = 0; j < N; j++) {
            for (int k = 0; k < N; k++) {
                ans[i][j] += A[i][k] * B[k][j];
            }
        }
    }
}

void multiplyCase3(matrix A, matrix B, matrix ans, int numThreads) {
    printf("All loops are parallelized\n");
    int i = 0, j = 0, k = 0;
    #pragma omp parallel for shared(numThreads, A, B, ans) private(i)
    for (i = 0; i < N; i++) {
        #pragma omp parallel for
        for (j = 0; j < N; j++) {
            #pragma omp parallel for
            for (k = 0; k < N; k++) {
                ans[i][j] += A[i][k] * B[k][j];
            }
        }
    }
}

void multiplyCase4(matrix A, matrix B, matrix ans, int numThreads) {
    printf("All loops are parallelized\n");
    int i = 0, j = 0, k = 0;
    #pragma omp parallel for shared(numThreads, A, B, ans) private(i) collapse(3)
    for (i = 0; i < N; i++) {
        for (j = 0; j < N; j++) {
            for (k = 0; k < N; k++) {
                ans[i][j] += A[i][k] * B[k][j];
            }
        }
    }
}

void print(matrix A) {
    for (int i = 0; i < N; i++) {
        printf("%s", i == 0 ? "[\n " : " ");
        for (int j = 0; j < N; j++) {
            printf(
                "%s%d%s",
                j == 0 ? "[" : " ",
                A[i][j],
                j == N - 1 ? "]" : ","
            );
        }
        printf("%s", i == N - 1 ? "\n]\n" : ",\n");
    }
}

int main(int argc, char *argv[]) {
    int numThreads = atoi(argv[1]);
    int type = atoi(argv[2]);
    printf("multiplying 2 %dx%d matrices using %d threads and case %d:\n", N, N,
numThreads, type);

    matrix A, B, C;

    A = (int **)calloc(N, sizeof(int*));
    B = (int **)calloc(N, sizeof(int*));
    C = (int **)calloc(N, sizeof(int*));

    for (int i = 0; i < N; i++) {
        A[i] = (int *) calloc(N, sizeof(int));
        B[i] = (int *) calloc(N, sizeof(int));
        C[i] = (int *) calloc(N, sizeof(int));

        for (int j = 0; j < N; j++) {
            A[i][j] = rand() % 10;
            B[i][j] = rand() % 10;
            C[i][j] = 0;
        }
    }

    // print(A);
    // print(B);

    double t = omp_get_wtime();

    switch (type)
    {
    case 0:
        multiply(A, B, C);
        break;

    case 1:
        multiplyCase1(A, B, C, numThreads);
        break;

    case 2:
        multiplyCase2(A, B, C, numThreads);
        break;

    case 3:
        multiplyCase3(A, B, C, numThreads);
        break;

    case 4:
        multiplyCase4(A, B, C, numThreads);
        break;

    default:
    }

    t = omp_get_wtime() - t;
```

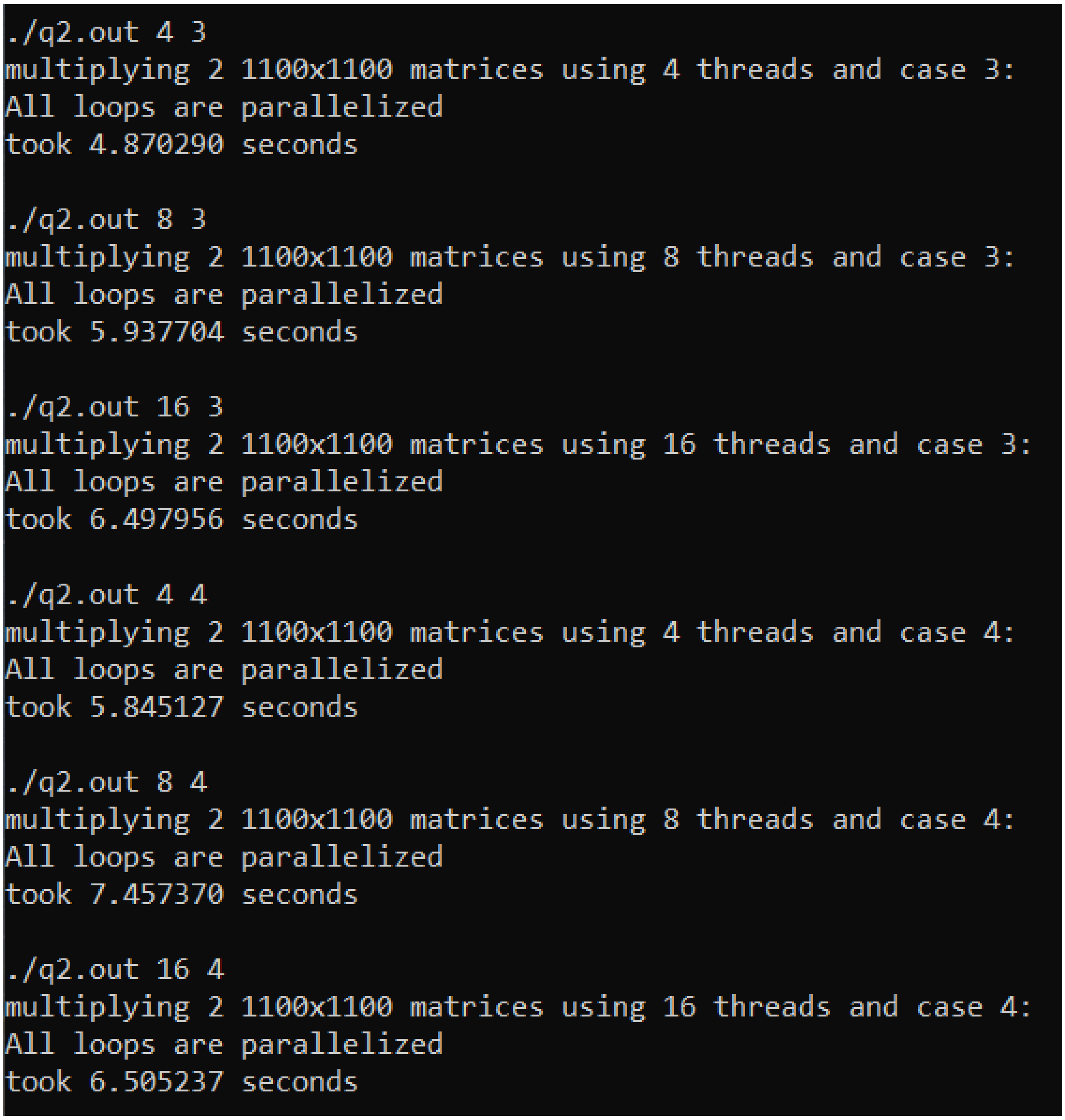


```
    // print(C);

    printf("took %f seconds\n", t);

    for (int i = 0; i < N; i++) {
        free(A[i]);
        free(B[i]);
    }
    free(A);
    free(B);
    free(C);

    printf("\n");
    return 0;
}
```

Output:



```
gcc q2.c -fopenmp -o q2.out
./q2.out 4 1
multiplying 2 1100x1100 matrices using 4 threads and case 1:
The outermost loop is parallelized
took 3.952004 seconds

./q2.out 8 1
multiplying 2 1100x1100 matrices using 8 threads and case 1:
The outermost loop is parallelized
took 4.079892 seconds

./q2.out 16 1
multiplying 2 1100x1100 matrices using 16 threads and case 1:
The outermost loop is parallelized
took 4.190457 seconds

./q2.out 4 2
multiplying 2 1100x1100 matrices using 4 threads and case 2:
The outer 2 loops are parallelized
took 3.976589 seconds

./q2.out 8 2
multiplying 2 1100x1100 matrices using 8 threads and case 2:
The outer 2 loops are parallelized
took 4.423549 seconds

./q2.out 16 2
multiplying 2 1100x1100 matrices using 16 threads and case 2:
The outer 2 loops are parallelized
took 4.767388 seconds
```



```
./q2.out 4 3
multiplying 2 1100x1100 matrices using 4 threads and case 3:
All loops are parallelized
took 4.870290 seconds

./q2.out 8 3
multiplying 2 1100x1100 matrices using 8 threads and case 3:
All loops are parallelized
took 5.937704 seconds

./q2.out 16 3
multiplying 2 1100x1100 matrices using 16 threads and case 3:
All loops are parallelized
took 6.497956 seconds

./q2.out 4 4
multiplying 2 1100x1100 matrices using 4 threads and case 4:
All loops are parallelized
took 5.845127 seconds

./q2.out 8 4
multiplying 2 1100x1100 matrices using 8 threads and case 4:
All loops are parallelized
took 7.457370 seconds

./q2.out 16 4
multiplying 2 1100x1100 matrices using 16 threads and case 4:
All loops are parallelized
took 6.505237 seconds
```