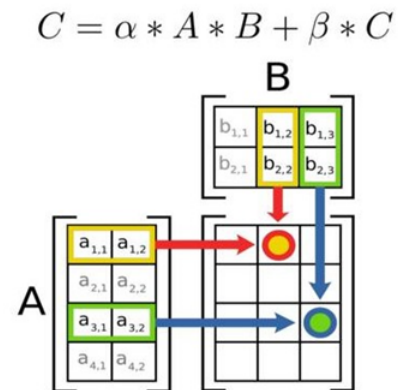


Домашнее задание №1

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Домашнее Задание 1. Параллельное умножение матриц (DGEMM)

1. Реализовать параллельную реализацию умножения матриц DGEMM (**D**ouble precision **G**eneral **M**atrix **M**ultiplication) из пакета BLAS с использованием OpenMP. (4 балла)
2. Привести анализ сильной/слабой масштабируемости параллельной реализации на суперкомпьютере Харизма. (2 балла)
3. Реализовать оптимизированную под узлы суперкомпьютера Харизма параллельную реализацию DGEMM, проанализировать характеристики ее сильной/слабой масштабируемости (2 балла).
4. Реализовать вычисление суммы ряда с использованием pthreads и поддержкой произвольного количества потоков.



$$C = \alpha * A * B + \beta * C$$

- alpha = 1 и beta = 0;
- элементы A, B и C имеют тип `double`;
- A, B и C хранятся в одномерных массивах в column-major порядке (https://en.wikipedia.org/wiki/Row_and_column-major_order);
- функция умножения матриц должна реализовывать следующий интерфейс:

```
void blas_dgemm(int M, int N, int K, double *A, double *B, double *C)
{
    /* My DGEMM implementation goes here */
}
```
- ДЗ1 должно быть реализовано на языке C;
- код должен быть оформлен в соответствии с Linux kernel coding style (<https://www.kernel.org/doc/html/v4.10/process/coding-style.html>) (за невыполнение этого критерия оценка за ДЗ1 будет снижена на 3 балла!);
- комментарии должны **объяснять** неочевидные моменты (если таковые имеются), **а не дублировать написанный код**;
- комментарии должны приводиться **на английском языке**;
- на сдачу ДЗ1 дается вторая попытка при неудовлетворительной первой попытке;
- дедлайн по ДЗ1 будет объявлен на Семинаре 3.

*Дополнительное задание:

Найти максимальный элемент на каждом потоке и максимальный элемент среди них

Задание 1

Реализовать параллельную реализацию умножения матриц DGEMM (**D**ouble precision **G**eneral **M**atrix **M**ultiplication) из пакета BLAS с использованием OpenMP.

Реализация

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

// Filling matrix with random double numbers from 0 to 9
void fill_matrix(double* H, int M, int N)
{
    int i;
    #pragma omp parallel for
    for (i = 0; i < M * N; ++i)
    {
        H[i] = (rand() % 9);
    }
}
```

```

// Printing the matrix
void print_matrix(double* H, int M, int N)
{
    int i, j;
    for (j = 0; j < M; ++j)
    {
        for (i = 0; i < N; ++i)
        {
            if (i != N - 1)
            {
                printf("%f\t", H[i * M + j]);
            }
            else
            {
                printf("%f\n", H[i * M + j]);
            }
        }
    }
    printf("\n");
}

```

```

// Sequential blas_dgemm
void blas_dgemm_pos(int M, int N, int K, double* A, double* B, double* copy, int alpha, int beta)
{
    int i, j;
    double* tmp;
    // The result of alpha * A * B is stored in tmp
    tmp = (double*) calloc (M * K, sizeof(double));

    // alpha * A * B
    for (j = 0; j < M * K; ++j)
    {
        tmp[j] = 0;
        for (i = 0; i < N; ++i)
        {
            tmp[j] += (alpha * A[i * M + j % M] * B[(j / M) * N + i]);
        }
    }
}

```

```

    // tmp + beta * C
    for (int j = 0; j < M * K; ++j)
    {
        copy[j] = tmp[j] + beta * copy[j];
    }
    //print_matrix(C, M, K);

    // Deallocating the memory
    free(tmp);
}

```

```

// Parallel blas_dgemm
void blas_dgemm(int M, int N, int K, double* A, double* B, double* C, int alpha, int beta)
{
    int i, j, num;
    double *tmp, *max, maximum;
    maximum = 0;
    // The result of alpha * A * B is stored in tmp
    tmp = (double*) calloc (M * K, sizeof(double));
    max = (double*) calloc (num, sizeof(double));
    // alpha * A * B
    #pragma omp parallel for shared (A, B) private(j, i)
    for ( j = 0; j < M * K; ++j)
    {
        num = omp_get_num_threads();
        tmp[j] = 0;
        for ( i = 0; i < N; ++i)
        {
            tmp[j] += (alpha * A[i * M + j % M] * B[(j / M) * N + i]);
        }
    }
}

```

```

// tmp + beta * C
#pragma omp parallel for shared (C) private(j)
for (j = 0; j < M * K; ++j)
{
    C[j] = tmp[j] + beta * C[j];
    // printf("Elements in thread %d: %f\n", omp_get_thread_num(), C[j]);
    // //Additional task to find max element in each thread and max element among all threads
    // if (max[omp_get_thread_num()] < C[j])
    // {
    //     max[omp_get_thread_num()] = C[j];
    // }
}
printf("\n");
//Printing array of maxes in each thread
// for (i = 0; i < num; ++i)
// {
//     printf("max for thread %d is: %f\n", i + 1, max[i]);
// }

```

```

    // maximum = max[0];
    // for (i = 1; i < num; ++i)
    // {
    //     if (max[i] > maximum)
    //     {
    //         maximum = max[i];
    //     }
    // }
    // printf("Resulting max = %f\n", maximum);
    // Deallocating the memory
    free(tmp);
    free(max);
}

```

```

// Creating the identity matrix
void identity_matrix(double* H, int M, int N)
{
    int i;
    #pragma omp parallel for
    for (int i = 0; i < M * N; ++i)
    {
        if (i % M != i / M)
        {
            H[i] = 0;
        }
        else
        {
            H[i] = 1;
        }
    }
}

```

```

// Comparing matrices
void compare_matrices(double* C, double* copy, int M, int K)
{
    int i, flag;
    double eps;
    flag = 0;
    eps = 0.001;
    for (i = 0; i < M * K; ++i)
    {
        if (abs(C[i] - copy[i]) >= eps)
        {
            flag = 1;
            break;
        }
    }
    if (flag == 0)
    {
        printf("Results of sequential and parallel multiplications are equal \n");
    }
}

```

```

    else
    {
        printf("Results of sequential and parallel multiplications are different \n");
    }
}

```

```

int main()
{
    int M, N, K, alpha, beta, i, threads;
    double start, end;
    double *A, *B, *C, *I, *copy;

    M = 5;
    N = 4;
    K = 3;
    alpha = 1;
    beta = 0;

    // Allocating memory for matrices, matrices are stored in column-major order
    A = (double*) calloc (M * N, sizeof(double));
    B = (double*) calloc (N * K, sizeof(double));
    C = (double*) calloc (M * K, sizeof(double));
    copy = (double*) calloc (M * K, sizeof(double));
    // Creating an identity matrix to compare with result
    I = (double*) calloc (M * K, sizeof(double));

```

```

// Filling matrices with random numbers

```

```

fill_matrix(A, M, N);
fill_matrix(B, N, K);
fill_matrix(C, M, K);

```

```

// Creating a copy of C matrix

```

```

for (i = 0; i < M * K; ++i)
{
    copy[i] = C[i];
}

```

```

// Creating identity matrices

```

```

//identity_matrix(A, M, N);
//identity_matrix(B, N, K);
//identity_matrix(C, M, K);
//identity_matrix(I, M, K);

```

```

// Printing matrices

```

```

//print_matrix(A, M, N);
//print_matrix(B, N, K);
// print_matrix(C, M, K);

```

```

// blas_dgemm_pos function

```

```

start = omp_get_wtime();
blas_dgemm_pos(M, N, K, A, B, copy, alpha, beta);
end = omp_get_wtime();
//print_matrix(copy, M, K);
printf("Time of sequential multiplication: %f \n", end - start);
//printf("Result: \n");
//print_matrix(copy, M, K);

```

```

// blas_dgemm function

```

```

start = omp_get_wtime();
blas_dgemm(M, N, K, A, B, C, alpha, beta);
end = omp_get_wtime();
//print_matrix(C, M, K);
printf("Time of parallel multiplication: %f \n", end - start);
//printf("Result: \n");
//print_matrix(C, M, K);

```

```

// Comparing results

```

```

compare_matrices(C, copy, M, K);

```

```

//printf("Expected identity matrix:\n");
//print_matrix(I, M, K);

// Deallocating the memory
free(A);
free(B);
free(C);
free(copy);
//free(I);

return 0;

```

Примеры работы

Результат последовательного и параллельного умножения

```

● [oskireeva@sms program]$ gcc -o res -fopenmp lab1.c
● [oskireeva@sms program]$ ./res
1.000000      5.000000      1.000000      5.000000
0.000000      7.000000      4.000000      7.000000
7.000000      0.000000      6.000000      5.000000
3.000000      4.000000      6.000000      7.000000
7.000000      1.000000      1.000000      5.000000

6.000000      8.000000      8.000000
0.000000      8.000000      8.000000
4.000000      6.000000      1.000000
8.000000      5.000000      1.000000

```

Time of sequantial multiplication: 0.000002

Result:

50.000000	79.000000	54.000000
72.000000	115.000000	67.000000
106.000000	117.000000	67.000000
98.000000	127.000000	69.000000
86.000000	95.000000	70.000000

Time of parallel multiplication: 0.051593

Result:

50.000000	79.000000	54.000000
72.000000	115.000000	67.000000
106.000000	117.000000	67.000000
98.000000	127.000000	69.000000
86.000000	95.000000	70.000000

Results of sequantial and parallel multiplications are equal

Результат произведения матриц с размерностями 5 x 4 и 4 x 3


```

• [oskireeva@sms program]$ gcc -o res -fopenmp lab1.c
• [oskireeva@sms program]$ ./res
1.000000      7.000000      7.000000      5.000000
7.000000      4.000000      1.000000      5.000000
6.000000      1.000000      5.000000      7.000000
3.000000      1.000000      0.000000      6.000000
5.000000      7.000000      4.000000      0.000000

1.000000      8.000000      4.000000
8.000000      0.000000      6.000000
1.000000      5.000000      8.000000
6.000000      8.000000      8.000000

Time of sequantial multiplication: 0.000017
Time of parallel multiplication: 0.048111
Result:
94.000000      83.000000      142.000000
70.000000      101.000000      100.000000
61.000000      129.000000      126.000000
47.000000      72.000000      66.000000
65.000000      60.000000      94.000000

Results are equal

```

$$\mathbf{C} = \mathbf{A} \cdot \mathbf{B} = \begin{pmatrix} 1 & 7 & 7 & 5 \\ 7 & 4 & 1 & 5 \\ 6 & 1 & 5 & 7 \\ 3 & 1 & 0 & 6 \\ 5 & 7 & 4 & 0 \end{pmatrix} \cdot \begin{pmatrix} 1 & 8 & 4 \\ 8 & 0 & 6 \\ 1 & 5 & 8 \\ 6 & 8 & 8 \end{pmatrix} = \begin{pmatrix} 94 & 83 & 142 \\ 70 & 101 & 100 \\ 61 & 129 & 126 \\ 47 & 72 & 66 \\ 65 & 60 & 94 \end{pmatrix}$$

С единичными матрицами с размерностями 5 x 4 и 4 x 3

```

• [oskireeva@sms program]$ gcc -o res -fopenmp lab1.c
• [oskireeva@sms program]$ ./res
1.000000      0.000000      0.000000      0.000000
0.000000      1.000000      0.000000      0.000000
0.000000      0.000000      1.000000      0.000000
0.000000      0.000000      0.000000      1.000000
0.000000      0.000000      0.000000      0.000000

1.000000      0.000000      0.000000
0.000000      1.000000      0.000000
0.000000      0.000000      1.000000
0.000000      0.000000      0.000000

Time of sequential multiplication: 0.000004
Time of parallel multiplication: 0.052723
Result:
1.000000      0.000000      0.000000
0.000000      1.000000      0.000000
0.000000      0.000000      1.000000
0.000000      0.000000      0.000000
0.000000      0.000000      0.000000

```

```

Results of sequential and parallel multiplications are equal
Expected identity matrix:
1.000000      0.000000      0.000000
0.000000      1.000000      0.000000
0.000000      0.000000      1.000000
0.000000      0.000000      0.000000
0.000000      0.000000      0.000000

```

Задание 2

Привести анализ сильной/слабой масштабируемости параллельной реализации на суперкомпьютере Харизма.

Анализ сильной масштабируемости

Для матриц с размерностями 1700 x 1600 и 1600 x 1500

```
[oskireeva@sms program]$ srun -c1 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851854 queued and waiting for resources
srun: job 851854 has been allocated resources
Time of sequential multiplication: 49.134849
Time of parallel multiplication: 50.468217
Results of sequential and parallel multiplications are equal
```

```
[oskireeva@sms program]$ srun -c2 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851860 queued and waiting for resources
srun: job 851860 has been allocated resources
Time of sequential multiplication: 38.588532
Time of parallel multiplication: 23.608273
Results of sequential and parallel multiplications are equal
```

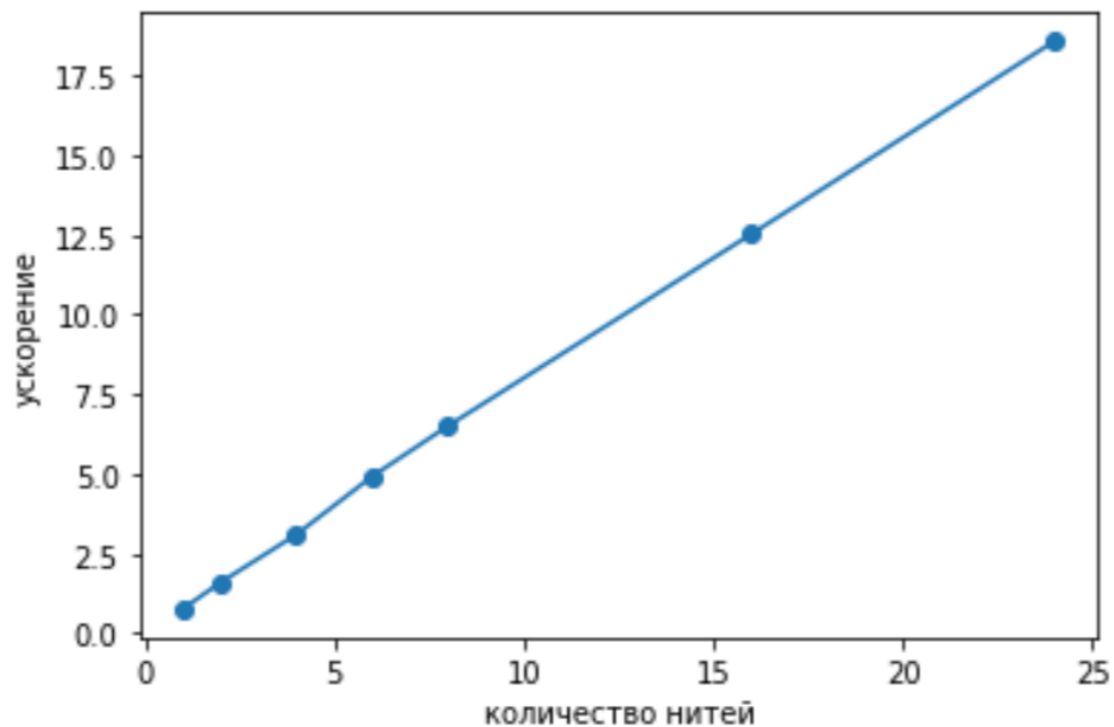
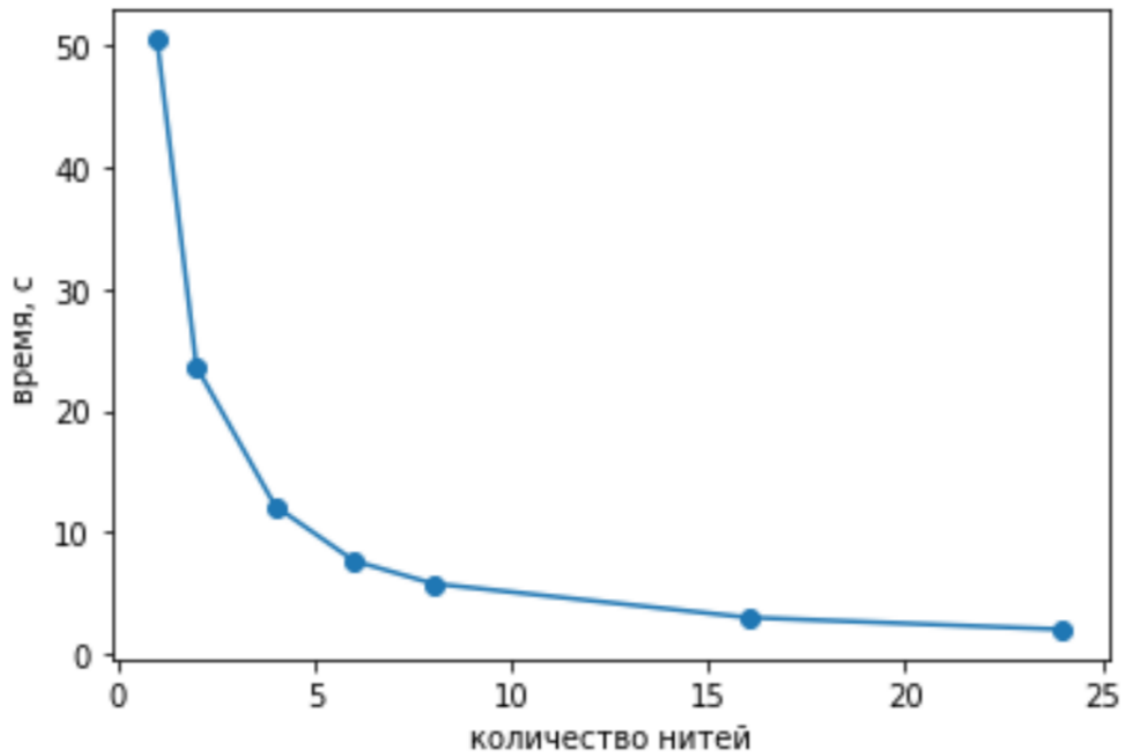
```
[oskireeva@sms program]$ srun -c4 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851865 queued and waiting for resources
srun: job 851865 has been allocated resources
Time of sequential multiplication: 36.875343
Time of parallel multiplication: 12.167895
Results of sequential and parallel multiplications are equal
```

```
[oskireeva@sms program]$ srun -c6 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851871 queued and waiting for resources
srun: job 851871 has been allocated resources
Time of sequential multiplication: 33.567290
Time of parallel multiplication: 7.662201
Results of sequential and parallel multiplications are equal
```

```
[oskireeva@sms program]$ srun -c8 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851875 queued and waiting for resources
srun: job 851875 has been allocated resources
Time of sequential multiplication: 34.911701
Time of parallel multiplication: 5.799089
Results of sequential and parallel multiplications are equal
```

```
[oskireeva@sms program]$ srun -c16 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851880 queued and waiting for resources
srun: job 851880 has been allocated resources
Time of sequential multiplication: 35.285499
Time of parallel multiplication: 3.013455
Results of sequential and parallel multiplications are equal
```

```
[oskireeva@sms program]$ srun -c24 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851885 queued and waiting for resources
srun: job 851885 has been allocated resources
Time of sequential multiplication: 34.563699
Time of parallel multiplication: 2.031707
Results of sequential and parallel multiplications are equal
```



Анализ слабой масштабируемости $W/p = \text{const}$

```
[oskireeva@sms program]$ srun -c1 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851904 queued and waiting for resources
srun: job 851904 has been allocated resources
Time of parallel multiplication: 35.033090
```

```
[oskireeva@sms program]$ srun -c2 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851909 queued and waiting for resources
srun: job 851909 has been allocated resources
Time of parallel multiplication: 49.456841
```

```
[oskireeva@sms program]$ srun -c4 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851910 queued and waiting for resources
srun: job 851910 has been allocated resources
Time of parallel multiplication: 53.487661
```

```
[oskireeva@sms program]$ srun -c6 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851914 queued and waiting for resources
srun: job 851914 has been allocated resources
Time of parallel multiplication: 47.353722
```

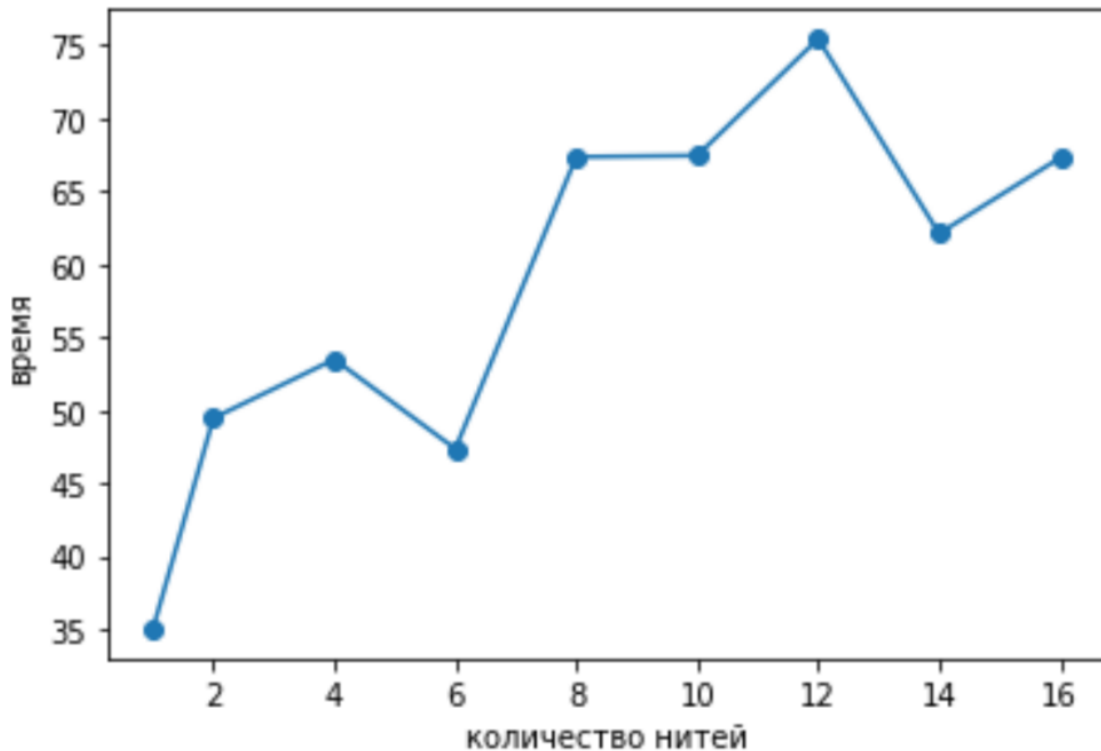
```
[oskireeva@sms program]$ srun -c8 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851915 queued and waiting for resources
srun: job 851915 has been allocated resources
Time of parallel multiplication: 67.354527
```

```
[oskireeva@sms program]$ srun -c10 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851916 queued and waiting for resources
srun: job 851916 has been allocated resources
Time of parallel multiplication: 67.446074
```

```
[oskireeva@sms program]$ srun -c12 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851918 queued and waiting for resources
srun: job 851918 has been allocated resources
Time of parallel multiplication: 75.440770
```

```
[oskireeva@sms program]$ srun -c14 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851920 queued and waiting for resources
srun: job 851920 has been allocated resources
Time of parallel multiplication: 62.103231
```

```
[oskireeva@sms program]$ srun -c16 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851924 queued and waiting for resources
srun: job 851924 has been allocated resources
Time of parallel multiplication: 67.289815
```



Задание 3

Реализовать оптимизированную под узлы суперкомпьютера Харизма параллельную реализацию DGEMM, проанализировать характеристики ее сильной/слабой масштабируемости

для оптимизации -O0

Анализ сильной масштабируемости

Для матриц с размерностями 1700 x 1600 и 1600 x 1500

```
[oskireeva@sms program]$ srun -c1 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851854 queued and waiting for resources
srun: job 851854 has been allocated resources
Time of sequential multiplication: 49.134849
Time of parallel multiplication: 50.468217
Results of sequential and parallel multiplications are equal
```

```
[oskireeva@sms program]$ srun -c2 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851860 queued and waiting for resources
srun: job 851860 has been allocated resources
Time of sequential multiplication: 38.588532
Time of parallel multiplication: 23.608273
Results of sequential and parallel multiplications are equal
```

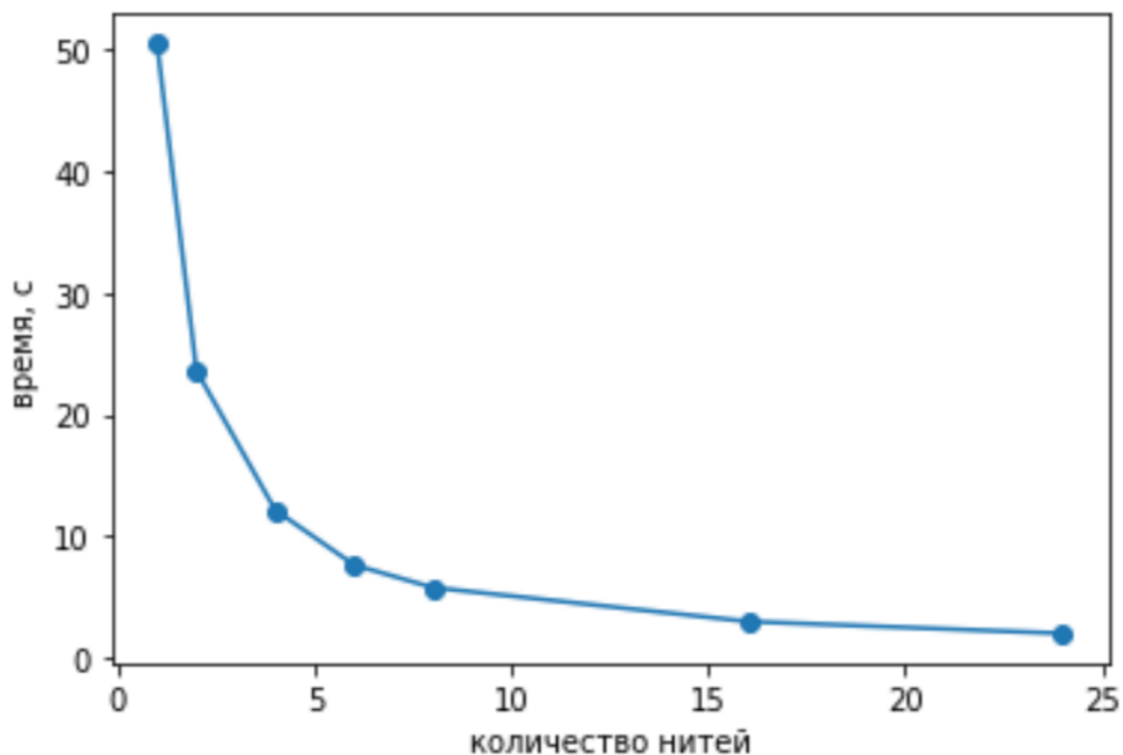
```
[oskireeva@sms program]$ srun -c4 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851865 queued and waiting for resources
srun: job 851865 has been allocated resources
Time of sequential multiplication: 36.875343
Time of parallel multiplication: 12.167895
Results of sequential and parallel multiplications are equal
```

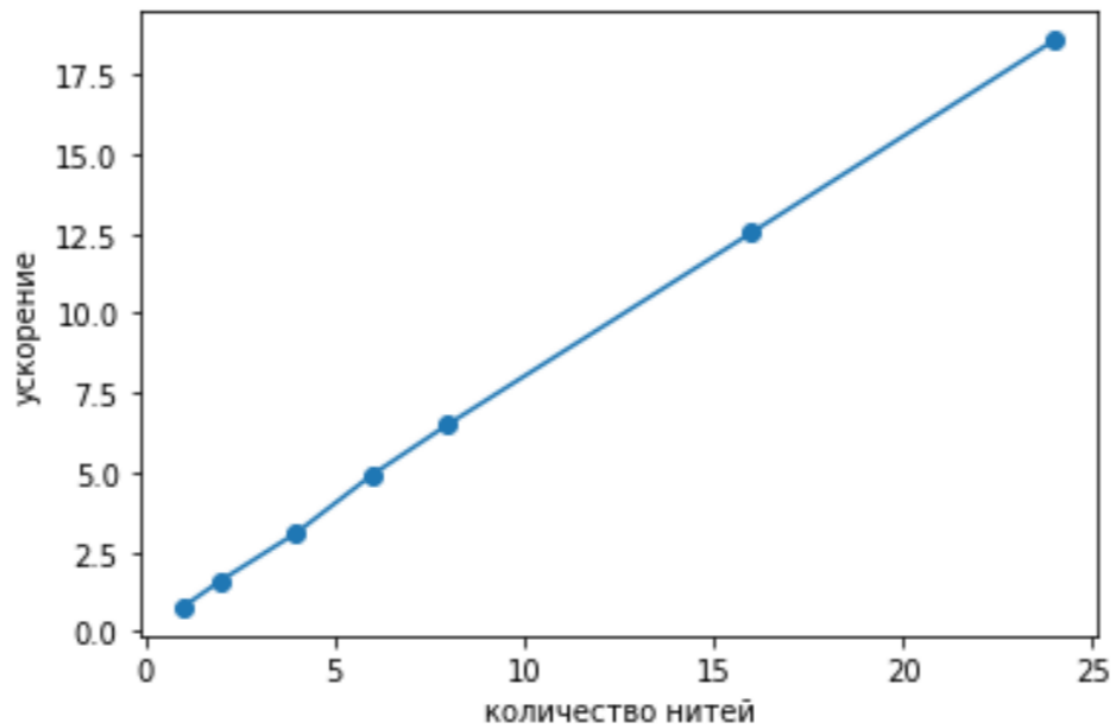
```
[oskireeva@sms program]$ srun -c6 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851871 queued and waiting for resources
srun: job 851871 has been allocated resources
Time of sequential multiplication: 33.567290
Time of parallel multiplication: 7.662201
Results of sequential and parallel multiplications are equal
```

```
[oskireeva@sms program]$ srun -c8 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851875 queued and waiting for resources
srun: job 851875 has been allocated resources
Time of sequential multiplication: 34.911701
Time of parallel multiplication: 5.799089
Results of sequential and parallel multiplications are equal
```

```
[oskireeva@sms program]$ srun -c16 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851880 queued and waiting for resources
srun: job 851880 has been allocated resources
Time of sequential multiplication: 35.285499
Time of parallel multiplication: 3.013455
Results of sequential and parallel multiplications are equal
```

```
[oskireeva@sms program]$ srun -c24 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851885 queued and waiting for resources
srun: job 851885 has been allocated resources
Time of sequential multiplication: 34.563699
Time of parallel multiplication: 2.031707
Results of sequential and parallel multiplications are equal
```





Анализ слабой масштабируемости $W/p = \text{const}$

```
[oskireeva@sms program]$ srun -c1 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851904 queued and waiting for resources
srun: job 851904 has been allocated resources
Time of parallel multiplication: 35.033090
```

```
[oskireeva@sms program]$ srun -c2 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851909 queued and waiting for resources
srun: job 851909 has been allocated resources
Time of parallel multiplication: 49.456841
```

```
[oskireeva@sms program]$ srun -c4 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851910 queued and waiting for resources
srun: job 851910 has been allocated resources
Time of parallel multiplication: 53.487661
```

```
[oskireeva@sms program]$ srun -c6 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851914 queued and waiting for resources
srun: job 851914 has been allocated resources
Time of parallel multiplication: 47.353722
```

```
[oskireeva@sms program]$ srun -c8 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851915 queued and waiting for resources
srun: job 851915 has been allocated resources
Time of parallel multiplication: 67.354527
```

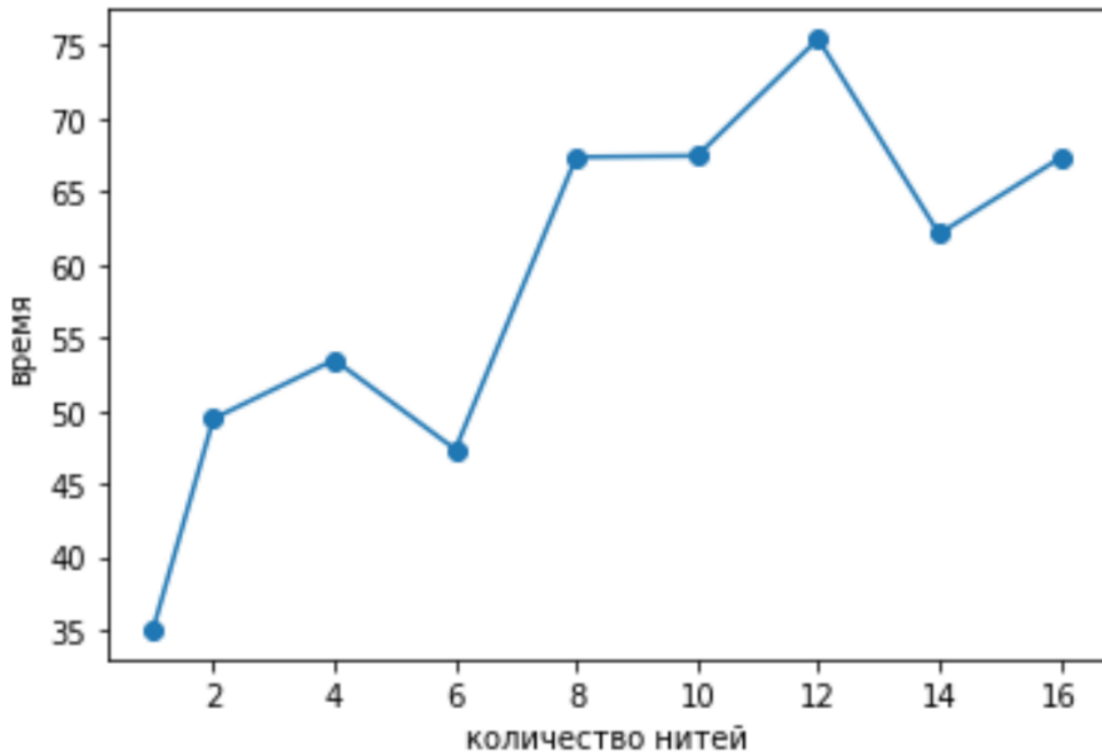
```
[oskireeva@sms program]$ srun -c10 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851916 queued and waiting for resources
srun: job 851916 has been allocated resources
Time of parallel multiplication: 67.446074
```

```
[oskireeva@sms program]$ srun -c12 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851918 queued and waiting for resources
srun: job 851918 has been allocated resources
Time of parallel multiplication: 75.440770
```



```
[oskireeva@sms program]$ srun -c14 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851920 queued and waiting for resources
srun: job 851920 has been allocated resources
Time of parallel multiplication: 62.103231
```

```
[oskireeva@sms program]$ srun -c16 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 851924 queued and waiting for resources
srun: job 851924 has been allocated resources
Time of parallel multiplication: 67.289815
```



для оптимизации -О3

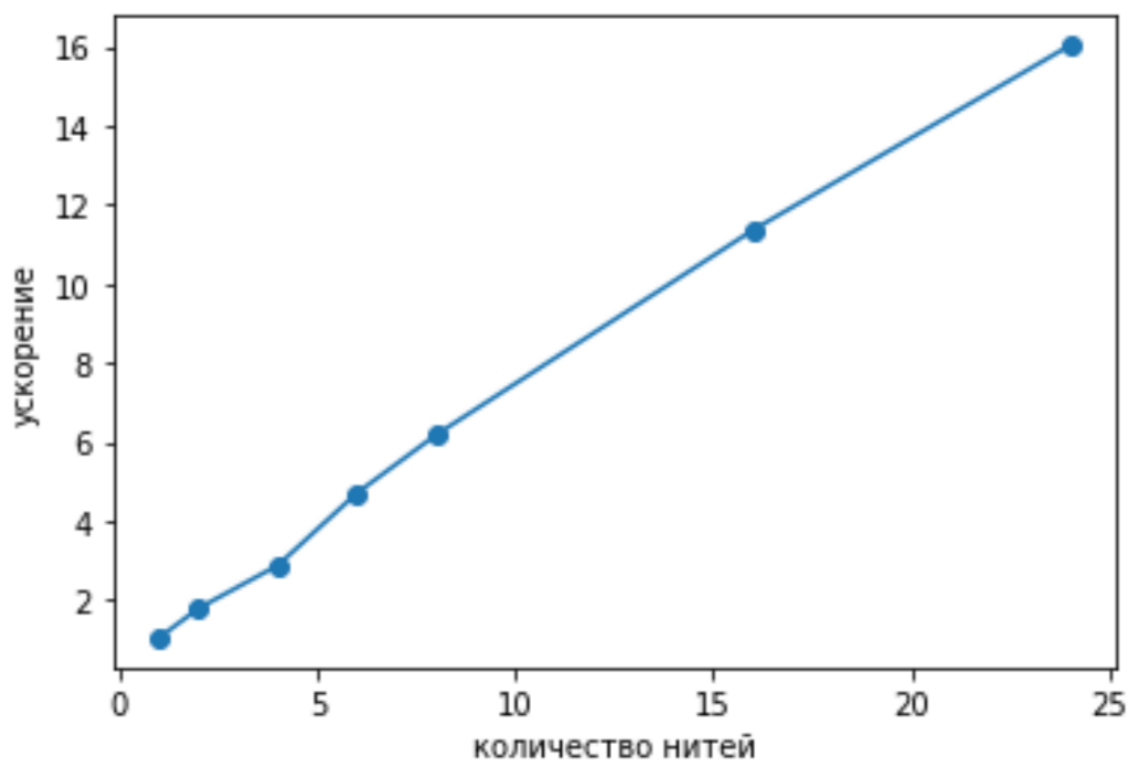
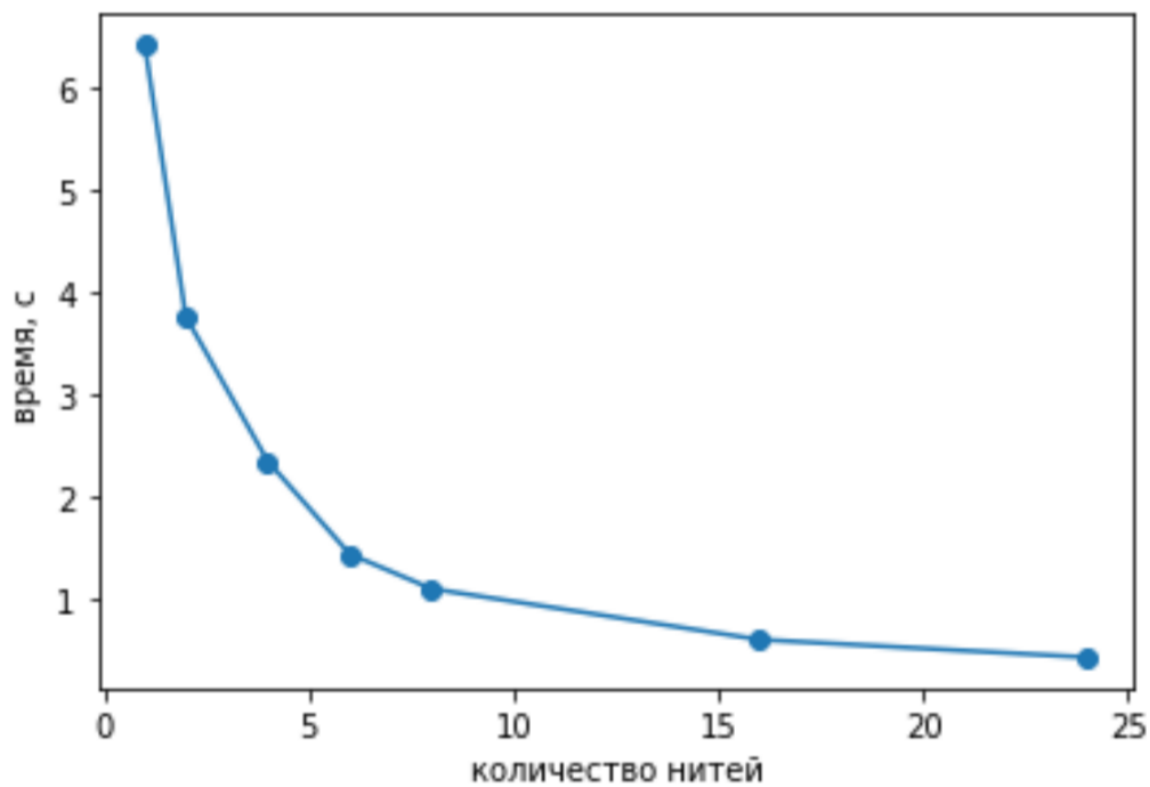
Анализ сильной масштабируемости

Для матриц с размерностями 1700 x 1600 и 1600 x 1500

```
[oskireeva@sms program]$ srun -c1 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852003 queued and waiting for resources
srun: job 852003 has been allocated resources
Time of sequential multiplication: 6.322150
Time of parallel multiplication: 6.418601
Results of sequential and parallel multiplications are equal
[oskireeva@sms program]$ srun -c2 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852006 queued and waiting for resources
srun: job 852006 has been allocated resources
Time of sequential multiplication: 6.780908
Time of parallel multiplication: 3.756711
Results of sequential and parallel multiplications are equal
[oskireeva@sms program]$ srun -c4 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852007 queued and waiting for resources
srun: job 852007 has been allocated resources
Time of sequential multiplication: 7.891773
Time of parallel multiplication: 2.342510
Results of sequential and parallel multiplications are equal
```

```
[oskireeva@sms program]$ srun -c6 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852008 queued and waiting for resources
srun: job 852008 has been allocated resources
Time of sequential multiplication: 6.589171
Time of parallel multiplication: 1.433381
Results of sequential and parallel multiplications are equal
[oskireeva@sms program]$ srun -c8 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852010 queued and waiting for resources
srun: job 852010 has been allocated resources
Time of sequential multiplication: 6.802186
Time of parallel multiplication: 1.092384
Results of sequential and parallel multiplications are equal
[oskireeva@sms program]$ srun -c16 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852011 queued and waiting for resources
srun: job 852011 has been allocated resources
Time of sequential multiplication: 6.554993
Time of parallel multiplication: 0.594624
Results of sequential and parallel multiplications are equal
```

```
[oskireeva@sms program]$ srun -c24 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852014 queued and waiting for resources
srun: job 852014 has been allocated resources
Time of sequential multiplication: 6.345289
Time of parallel multiplication: 0.421494
Results of sequential and parallel multiplications are equal
```



Анализ слабой масштабируемости $W/p = \text{const}$

```
[oskireeva@sms program]$ srun -c1 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852018 queued and waiting for resources
srun: job 852018 has been allocated resources
Time of parallel multiplication: 6.441725
```

```
[oskireeva@sms program]$ srun -c2 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852020 queued and waiting for resources
srun: job 852020 has been allocated resources
Time of parallel multiplication: 9.103492
```

```
[oskireeva@sms program]$ srun -c4 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852021 queued and waiting for resources
srun: job 852021 has been allocated resources
Time of parallel multiplication: 9.353064
```

```
[oskireeva@sms program]$ srun -c6 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852024 queued and waiting for resources
srun: job 852024 has been allocated resources
Time of parallel multiplication: 8.926870
```

```
[oskireeva@sms program]$ srun -c8 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852028 queued and waiting for resources
srun: job 852028 has been allocated resources
Time of parallel multiplication: 18.188316
```

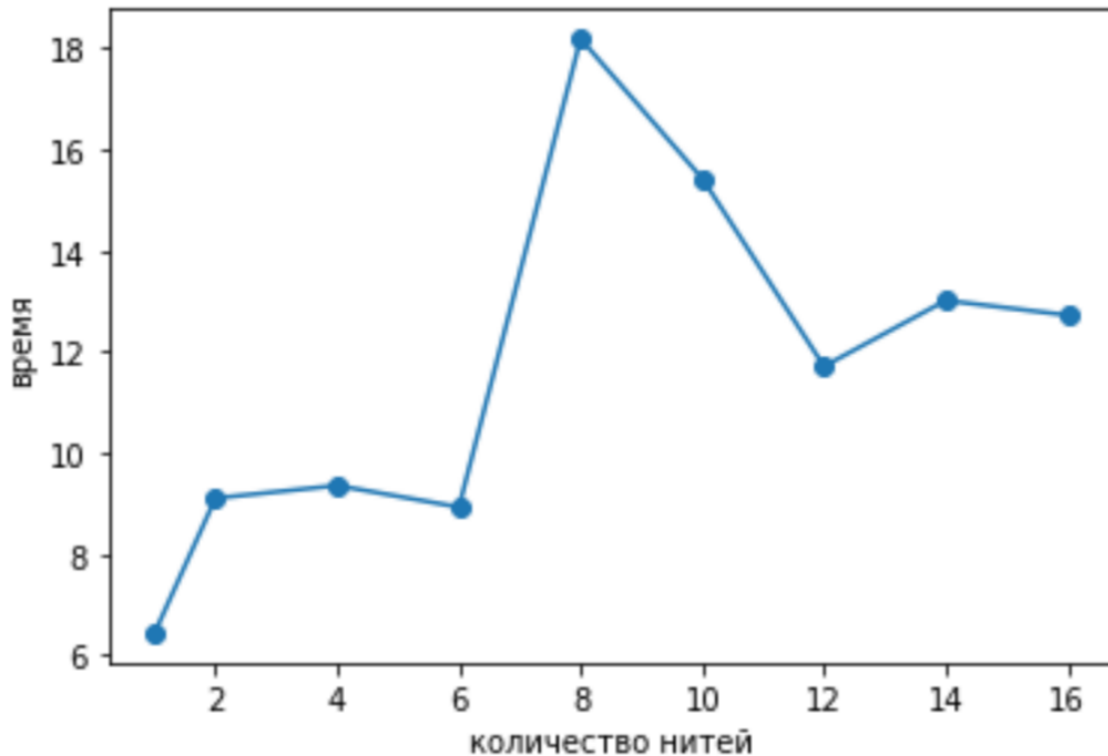
```
[oskireeva@sms program]$ srun -c10 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852039 queued and waiting for resources
srun: job 852039 has been allocated resources
Time of parallel multiplication: 15.425424
```

```
[oskireeva@sms program]$ srun -c12 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852043 queued and waiting for resources
srun: job 852043 has been allocated resources
Time of parallel multiplication: 11.710867
```

```
[oskireeva@sms program]$ srun -c14 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852048 queued and waiting for resources
srun: job 852048 has been allocated resources
Time of parallel multiplication: 13.013276
```

```
[oskireeva@sms program]$ srun -c16 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852053 queued and waiting for resources
srun: job 852053 has been allocated resources
Time of parallel multiplication: 12.723514
```

[Перейти к строке/столбцу](#)



***Дополнительное задание:**

Найти максимальный элемент на каждом потоке и
максимальный элемент среди них

Реализация:

```
#pragma omp parallel for shared (C) private(j)
for (j = 0; j < M * K; ++j)
{
    C[j] = tmp[j] + beta * C[j];
    printf("Elements in thread %d: %f\n", omp_get_thread_num(), C[j]);
    //Additional task to find max element in each thread and max element among all threads
    if (max[omp_get_thread_num()] < C[j])
    {
        max[omp_get_thread_num()] = C[j];
    }
}
printf("\n");
//Printing array of maxes in each thread
for (i = 0; i < num; ++i)
{
    printf("max for thread %d is: %f\n", i + 1, max[i]);
}
maximum = max[0];
```

```

maximum = max[0];
for (i = 1; i < num; ++i)
{
    if (max[i] > maximum)
    {
        maximum = max[i];
    }
}

printf("Resulting max = %f\n", maximum);

```

Пример для матриц с размерностями 5 x 4 и 4 x 3 и 4
ПОТОКОВ

```

[oskireeva@sms program]$ gcc -o res -fopenmp lab1.c
[oskireeva@sms program]$ srun -c4 ./res
srun: The job is starting as part of project: Учебный курс «Высокопроизводительные вычисления» 2022-2023 (proj_1343)
srun: job 852079 queued and waiting for resources
srun: job 852079 has been allocated resources
Elements in thread 3: 58.000000
Elements in thread 3: 127.000000
Elements in thread 1: 79.000000
Elements in thread 1: 77.000000
Elements in thread 1: 115.000000
Elements in thread 0: 106.000000
Elements in thread 3: 55.000000
Elements in thread 0: 88.000000
Elements in thread 0: 64.000000
Elements in thread 0: 153.000000
Elements in thread 2: 147.000000
Elements in thread 2: 73.000000
Elements in thread 1: 40.000000
Elements in thread 2: 99.000000
Elements in thread 2: 69.000000

```

```
max for thread 1 is: 153.000000
max for thread 2 is: 115.000000
max for thread 3 is: 147.000000
max for thread 4 is: 127.000000
Resulting max = 153.000000
Time of parallel multiplication: 0.000188
106.000000      77.000000      99.000000
88.000000       115.000000     69.000000
64.000000       40.000000     58.000000
153.000000      147.000000     127.000000
79.000000       73.000000     55.000000
```