Министерство образования и науки Российской Федерации

Новосибирский национальный исследовательский государственный университет

Основы параллельного программирования

Отчет по лабораторной работе № 2

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1. **Цель работы**

Разработать и исследовать параллельные программы решения СЛАУ методом сопряженных градиентов с применением одной из библиотек, реализующих стандарты OpenMP.

1. **Краткое описание подходов к организации решения прикладной задачи параллельными взаимодействующими процессами**

Реализованы 2 подхода к организации параллельной программы при умножении матрицы на вектор:

1. Порождение потоков исполнения при локальной необходимости (распараллеливание непосредственно вычисляющего кода).
2. Однократное порождение потоков исполнения перед общим блоком вычислений.

В прикладной программе использованы возможности бибилотек blas и gsl.

1. **Исследование производительности программ**

Результаты измерений времени вычислений, ускорения и загруженности для обоих вариантов реализации параллельного кода с использованием средств OpenMP представлены на графиках ниже.

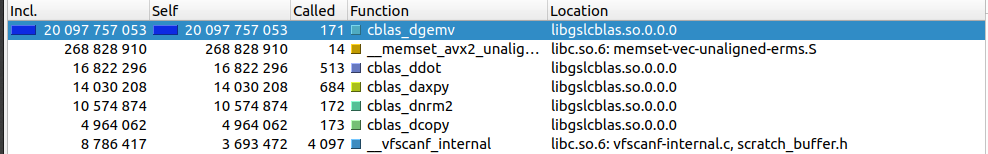
Результаты измерений времени вычислений, ускорения и загруженности для обоих вариантов реализации параллельного кода с использованием средств OpenMP представлены на графиках ниже.

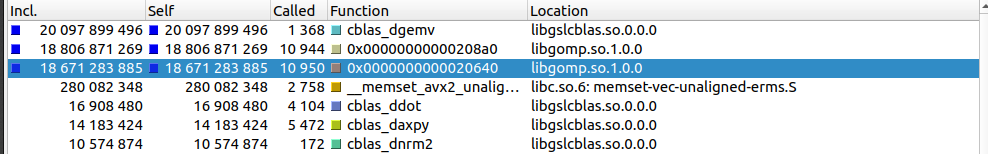
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Parallel1** | **Число потоков** | | | | | | | | | | | | | | | |
| **Размер задачи** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 64,00 | 3 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| 72,00 | 5 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 2 | 1 | 2 | 2 | 2 | 2 |
| 80,00 | 8 | 4 | 3 | 3 | 3 | 4 | 6 | 4 | 4 | 3 | 4 | 3 | 4 | 5 | 4 | 3 |
| 88,00 | 13 | 7 | 6 | 4 | 5 | 4 | 6 | 5 | 5 | 5 | 4 | 7 | 5 | 5 | 5 | 6 |
| 96,00 | 20 | 11 | 8 | 9 | 8 | 6 | 7 | 10 | 8 | 7 | 7 | 10 | 7 | 8 | 9 | 11 |
| 104,00 | 31 | 22 | 15 | 10 | 16 | 10 | 14 | 15 | 17 | 14 | 13 | 19 | 14 | 17 | 15 | 20 |
| 112,00 | 44 | 24 | 21 | 18 | 25 | 23 | 17 | 25 | 25 | 17 | 17 | 24 | 19 | 19 | 22 | 15 |
| 120,00 | 61 | 33 | 32 | 35 | 30 | 33 | 24 | 30 | 25 | 34 | 24 | 29 | 33 | 38 | 36 | 28 |
| 128,00 | 85 | 49 | 46 | 36 | 33 | 35 | 33 | 33 | 34 | 37 | 36 | 47 | 46 | 38 | 44 | 42 |

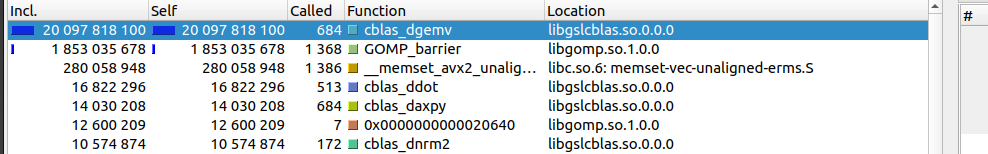
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Parallel 2** | **Число потоков** | | | | | | | | | | | | | | | |
| **Размер задачи** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 64,00 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 72,00 | 5 | 3 | 2 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 1 | 1 |
| 80,00 | 9 | 4 | 3 | 2 | 3 | 3 | 2 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 2 |
| 88,00 | 13 | 7 | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 | 4 | 5 | 4 | 4 | 5 |
| 96,00 | 20 | 11 | 8 | 7 | 6 | 6 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| 104,00 | 30 | 18 | 14 | 10 | 9 | 9 | 10 | 11 | 11 | 10 | 11 | 10 | 10 | 10 | 10 | 11 |
| 112,00 | 44 | 24 | 21 | 15 | 13 | 14 | 14 | 15 | 16 | 15 | 15 | 15 | 15 | 14 | 15 | 15 |
| 120,00 | 62 | 36 | 31 | 21 | 20 | 19 | 20 | 25 | 24 | 24 | 23 | 23 | 23 | 23 | 22 | 21 |
| 128,00 | 85 | 45 | 41 | 31 | 32 | 27 | 30 | 34 | 33 | 33 | 32 | 32 | 31 | 31 | 31 | 30 |

1. **Профилирование**

Данные о профилях вызовов функций в каждом варианте реализации представлены ниже.

Рисунок 1: Профиль вызовов для последовательной версии программы

Рисунок 2: Профиль вызовов для первой версии параллельной программы

Рисунок 3: Профиль вызовов для второй версии параллельной программы

По данным о вызовах функции в различных версиях программы видно, что основное время работы программы занимают вычисления операций вида матрица-вектор. Кроме того, в первой версии программы соразмерной нагрузкой выступают функции библиотеки libgomp (предположительно методы для конструирования и деконструирования программной репрезентации потоков), а во второй версии программы большую часть времени работы программы занимает синхронизация посредством барьеров.

1. **Заключение**

Реализованная на языке Си программа позволяет за обозримое время моделировать распределение тепла в пластине, разрешая СЛАУ с некоторой наперед заданной точностью.

Оба варианта реализации параллельного алгоритма дают соизмеримые результаты ускорения и загруженности исполнителей, аномалии в замерах времени для первого варианта реализации программы объясняются относительной малостью времени вычислений относительно времени на обслуживание параллелизма за счёт использования библиотек gsl и blas.

1. **Приложения**

**seq.c**

**// Copyright 2023 Olimpiev Y. Y.**

**#include <assert.h>**

**#include <stdio.h>**

**#include <stdlib.h>**

**#include <time.h>**

**#include <gsl/gsl\_blas.h>**

**#include <gsl/gsl\_matrix.h>**

**#include <gsl/gsl\_vector.h>**

**void pretty\_gsl\_matrix\_fprintf(FILE\* out, gsl\_matrix\* matrix, const char\* format) {**

**assert(out);**

**assert(matrix);**

**for (size\_t row = 0; row < matrix->size1; row++) {**

**for (size\_t col = 0; col < matrix->size2; col++) {**

**fprintf(out, format, gsl\_matrix\_get(matrix, row, col));**

**}**

**fprintf(out, "\n");**

**}**

**}**

**gsl\_matrix\* ReadGridMatrix(FILE\* in, size\_t rowsAmount, size\_t colsAmount) {**

**assert(in);**

**gsl\_matrix\* gridMatrix = gsl\_matrix\_calloc(rowsAmount, colsAmount);**

**assert(gridMatrix);**

**if (gsl\_matrix\_fscanf(in, gridMatrix) != 0) {**

**perror("Problem with grid matrix reading.\n");**

**return NULL;**

**}**

**#ifdef DEBUG**

**FILE\* out = fopen("gridmatrix.dat", "w");**

**assert(out);**

**pretty\_gsl\_matrix\_fprintf(out, gridMatrix, "%lf ");**

**fclose(out);**

**#endif**

**return gridMatrix;**

**}**

**double ConjugateGradientsMethodIteration(**

**gsl\_matrix\* A,**

**gsl\_vector\* x,**

**gsl\_vector\* r,**

**gsl\_vector\* z,**

**gsl\_vector\* tmpVec,**

**double bNorm) {**

**double err = 0.0;**

**double alpha = 0.0;**

**double betta = 0.0;**

**double tmp = 0.0;**

**gsl\_blas\_dgemv(CblasNoTrans, 1.0, A, z, 0.0, tmpVec);**

**// Calc (r\_n, r\_n). double tmp <- (r\_n, r\_n)**

**gsl\_blas\_ddot(r, r, &tmp);**

**// Calc (A \* z\_n, z\_n).**

**gsl\_blas\_ddot(tmpVec, z, &alpha);**

**// Calc (r\_n, r\_n) / (A \* z\_n, z\_n).**

**alpha = tmp / alpha;**

**// Calc x\_(n + 1) = x\_n + aplha \* z\_n.**

**gsl\_blas\_daxpy(alpha, z, x);**

**// Calc r\_(n + 1) = r\_n - aplha \* (A \* z\_n).**

**gsl\_blas\_daxpy(-alpha, tmpVec, r);**

**// Calc (r\_(n + 1), r\_(n + 1)).**

**gsl\_blas\_ddot(r, r, &betta);**

**// Calc betta\_(n + 1) = (r\_(n + 1), r\_(n + 1)) / (r\_n, r\_n).**

**betta /= tmp;**

**gsl\_vector\_set\_zero(tmpVec);**

**gsl\_blas\_daxpy(betta, z, tmpVec);**

**gsl\_blas\_daxpy(1.0, r, tmpVec);**

**gsl\_vector\_memcpy(z, tmpVec);**

**err = gsl\_blas\_dnrm2(r) / bNorm;**

**return err;**

**}**

**gsl\_vector\* ConjugateGradientsMethod(gsl\_matrix\* A, gsl\_vector\* B, gsl\_vector\* X) {**

**assert(A);**

**assert(B);**

**assert(X);**

**double eps = 0.00001;**

**gsl\_vector\* tmpVec = gsl\_vector\_calloc(B->size);**

**assert(tmpVec);**

**gsl\_vector\* r = gsl\_vector\_calloc(B->size);**

**assert(r);**

**// Calc r = b - Ax. But x = (0), so r = b.**

**gsl\_vector\_memcpy(r, B);**

**gsl\_vector\* z = gsl\_vector\_calloc(B->size);**

**assert(z);**

**gsl\_vector\_memcpy(z, r);**

**double err = 0.0;**

**double normB = gsl\_blas\_dnrm2(B);**

**time\_t start = time(0);**

**do {**

**err = ConjugateGradientsMethodIteration(A, X, r, z, tmpVec, normB);**

**} while (eps < err);**

**time\_t finish = time(0);**

**printf("%ld\n", finish - start);**

**gsl\_vector\_free(r);**

**gsl\_vector\_free(z);**

**gsl\_vector\_free(tmpVec);**

**return X;**

**}**

**gsl\_matrix\* BuildKernelMatrix(size\_t rowsAmount, size\_t colsAmount) {**

**size\_t kernelMatrixSize = colsAmount \* rowsAmount;**

**gsl\_matrix\* kernelMatrix = gsl\_matrix\_calloc(kernelMatrixSize, kernelMatrixSize);**

**assert(kernelMatrix);**

**for (size\_t row = 0; row < kernelMatrixSize - colsAmount; row++) {**

**// Set three diagonals.**

**gsl\_matrix\_set(kernelMatrix, row, row, -4.0);**

**gsl\_matrix\_set(kernelMatrix, row, row + 1, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row + 1, row, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row + colsAmount, row, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row, row + colsAmount, 1.0);**

**}**

**for (size\_t row = kernelMatrixSize - colsAmount; row < kernelMatrixSize; row++) {**

**// Set three diagonals.**

**gsl\_matrix\_set(kernelMatrix, row, row, -4.0);**

**gsl\_matrix\_set(kernelMatrix, row, row - 1, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row - 1, row, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row - colsAmount, row, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row, row - colsAmount, 1.0);**

**}**

**#ifdef DEBUG**

**FILE\* out = fopen("kernelmatrix.dat", "w");**

**assert(out);**

**pretty\_gsl\_matrix\_fprintf(out, kernelMatrix, "%lf ");**

**fclose(out);**

**#endif**

**return kernelMatrix;**

**}**

**gsl\_vector\* BuildAnswerVector(size\_t rowsAmount, size\_t colsAmount) {**

**gsl\_vector\* answerVector = gsl\_vector\_calloc(rowsAmount \* colsAmount);**

**assert(answerVector);**

**#ifdef DEBUG**

**FILE\* out = fopen("answervector.dat", "w");**

**assert(out);**

**gsl\_vector\_fprintf(out, answerVector, "%lf ");**

**fclose(out);**

**#endif**

**return answerVector;**

**}**

**gsl\_vector\* BuildCoeffsVector(gsl\_matrix\* gridMatrix) {**

**size\_t vectorSize = gridMatrix->size1 \* gridMatrix->size2;**

**gsl\_vector\* coeffsVector = gsl\_vector\_calloc(vectorSize);**

**assert(coeffsVector);**

**for (size\_t i = 0; i < vectorSize; i++) {**

**gsl\_vector\_set(coeffsVector, i, gsl\_matrix\_get(gridMatrix, i / gridMatrix->size2, i % gridMatrix->size2));**

**}**

**#ifdef DEBUG**

**FILE\* out = fopen("coeffsvector.dat", "w");**

**assert(out);**

**gsl\_vector\_fprintf(out, coeffsVector, "%lf ");**

**fclose(out);**

**#endif**

**return coeffsVector;**

**}**

**gsl\_vector\* CalcGridHeatDistribution(gsl\_matrix\* gridMatrix) {**

**assert(gridMatrix);**

**gsl\_matrix\* kernelMatrix = BuildKernelMatrix(gridMatrix->size1, gridMatrix->size2);**

**assert(kernelMatrix);**

**gsl\_vector\* X = BuildAnswerVector(gridMatrix->size1, gridMatrix->size2);**

**assert(X);**

**gsl\_vector\* B = BuildCoeffsVector(gridMatrix);**

**assert(B);**

**gsl\_vector\* ret = ConjugateGradientsMethod(kernelMatrix, B, X);**

**gsl\_matrix\_free(kernelMatrix);**

**gsl\_vector\_free(B);**

**return ret;**

**}**

**int main(int argc, char\* argv[]) {**

**size\_t colsAmount = 0;**

**size\_t rowsAmount = 0;**

**gsl\_matrix\* gridMatrix = NULL;**

**FILE\* in = (argc == 1) ? stdin : fopen(argv[1], "r");**

**assert(in);**

**if (fscanf(in, "%zu %zu", &rowsAmount, &colsAmount) != 2) {**

**perror("Invalid matrix size input.\n");**

**return EXIT\_FAILURE;**

**}**

**gridMatrix = ReadGridMatrix(in, rowsAmount, colsAmount);**

**if (argc != 1) fclose(in);**

**gsl\_vector\* result = CalcGridHeatDistribution(gridMatrix);**

**if (result) {**

**//gsl\_vector\_fprintf(stdout, result, "%4lf ");**

**gsl\_vector\_free(result);**

**}**

**gsl\_matrix\_free(gridMatrix);**

**return EXIT\_SUCCESS;**

**}**

**prll\_1.c**

**// Copyright 2023 Olimpiev Y. Y.**

**#include <assert.h>**

**#include <omp.h>**

**#include <stdio.h>**

**#include <stdlib.h>**

**#include <string.h>**

**#include <time.h>**

**#include <gsl/gsl\_blas.h>**

**#include <gsl/gsl\_matrix.h>**

**#include <gsl/gsl\_vector.h>**

**#include "builders.h"**

**void pretty\_gsl\_matrix\_fprintf(FILE\* out, gsl\_matrix\* matrix, const char\* format) {**

**assert(out);**

**assert(matrix);**

**for (size\_t row = 0; row < matrix->size1; row++) {**

**for (size\_t col = 0; col < matrix->size2; col++) {**

**fprintf(out, format, gsl\_matrix\_get(matrix, row, col));**

**}**

**fprintf(out, "\n");**

**}**

**}**

**gsl\_matrix\* ReadGridMatrix(FILE\* in, size\_t rowsAmount, size\_t colsAmount) {**

**assert(in);**

**gsl\_matrix\* gridMatrix = gsl\_matrix\_calloc(rowsAmount, colsAmount);**

**assert(gridMatrix);**

**if (gsl\_matrix\_fscanf(in, gridMatrix) != 0) {**

**perror("Problem with grid matrix reading.\n");**

**return NULL;**

**}**

**return gridMatrix;**

**}**

**gsl\_vector\* ConjugateGradientsMethod(gsl\_matrix\* A, gsl\_vector\* B, gsl\_vector\* X) {**

**assert(A);**

**assert(B);**

**assert(X);**

**double eps = 0.00001;**

**gsl\_vector\* tmpVec = gsl\_vector\_calloc(B->size);**

**assert(tmpVec);**

**gsl\_vector\* r = gsl\_vector\_calloc(B->size);**

**assert(r);**

**// Calc r = b - Ax. But x = (0), so r = b.**

**gsl\_vector\_memcpy(r, B);**

**gsl\_vector\* z = gsl\_vector\_calloc(B->size);**

**assert(z);**

**gsl\_vector\_memcpy(z, r);**

**// Произвольное относительно большое для значения ошибки число.**

**double err = 100.0;**

**double normB = gsl\_blas\_dnrm2(B);**

**size\_t numThreads = omp\_get\_max\_threads();**

**size\_t\* jobSizes = (size\_t\*)calloc(numThreads, sizeof(size\_t));**

**assert(jobSizes);**

**size\_t\* displs = (size\_t\*)calloc(numThreads, sizeof(size\_t));**

**assert(displs);**

**size\_t rowsPerThread = A->size1 / numThreads;**

**for (size\_t i = 0; i < numThreads; i++) {**

**jobSizes[i] = rowsPerThread;**

**}**

**size\_t unallocatedJobSize = A->size1 % numThreads;**

**// Распределяем неподеленную работу между исполнителями.**

**for (size\_t i = 0; unallocatedJobSize; i++, unallocatedJobSize--) {**

**jobSizes[i]++;**

**}**

**displs[0] = 0;**

**for (size\_t i = 1; i < numThreads; i++) {**

**displs[i] = displs[i - 1] + jobSizes[i - 1];**

**}**

**time\_t start = time(0);**

**#pragma omp parallel**

**while (err > eps) {**

**double alpha = 0.0;**

**double betta = 0.0;**

**double tmp = 0.0;**

**int rank = omp\_get\_thread\_num();**

**gsl\_vector\* resPart = gsl\_vector\_calloc(jobSizes[rank]);**

**assert(resPart);**

**gsl\_matrix\_view subMatrixA = gsl\_matrix\_submatrix(A, displs[rank], 0, jobSizes[rank], A->size2);**

**gsl\_blas\_dgemv(CblasNoTrans, 1.0, &subMatrixA.matrix, z, 0.0, resPart);**

**memcpy(tmpVec->data + displs[rank], resPart->data, sizeof(double) \* jobSizes[rank]);**

**gsl\_vector\_free(resPart);**

**#pragma omp barrier**

**if (rank == 0) {**

**// Calc (r\_n, r\_n). double tmp <- (r\_n, r\_n)**

**gsl\_blas\_ddot(r, r, &tmp);**

**// Calc (A \* z\_n, z\_n).**

**gsl\_blas\_ddot(tmpVec, z, &alpha);**

**// Calc (r\_n, r\_n) / (A \* z\_n, z\_n).**

**alpha = tmp / alpha;**

**// Calc x\_(n + 1) = x\_n + aplha \* z\_n.**

**gsl\_blas\_daxpy(alpha, z, X);**

**// Calc r\_(n + 1) = r\_n - aplha \* (A \* z\_n).**

**gsl\_blas\_daxpy(-alpha, tmpVec, r);**

**// Calc (r\_(n + 1), r\_(n + 1)).**

**gsl\_blas\_ddot(r, r, &betta);**

**// Calc betta\_(n + 1) = (r\_(n + 1), r\_(n + 1)) / (r\_n, r\_n).**

**betta /= tmp;**

**gsl\_vector\_set\_zero(tmpVec);**

**gsl\_blas\_daxpy(betta, z, tmpVec);**

**gsl\_blas\_daxpy(1.0, r, tmpVec);**

**gsl\_vector\_memcpy(z, tmpVec);**

**err = gsl\_blas\_dnrm2(r) / normB;**

**}**

**#pragma omp barrier**

**}**

**time\_t finish = time(0);**

**printf("%ld\n", finish - start);**

**gsl\_vector\_free(r);**

**gsl\_vector\_free(z);**

**gsl\_vector\_free(tmpVec);**

**return X;**

**}**

**gsl\_vector\* CalcGridHeatDistribution(gsl\_matrix\* gridMatrix) {**

**assert(gridMatrix);**

**gsl\_matrix\* kernelMatrix = BuildKernelMatrix(gridMatrix->size1, gridMatrix->size2);**

**assert(kernelMatrix);**

**gsl\_vector\* X = BuildAnswerVector(gridMatrix->size1, gridMatrix->size2);**

**assert(X);**

**gsl\_vector\* B = BuildCoeffsVector(gridMatrix);**

**assert(B);**

**gsl\_vector\* ret = ConjugateGradientsMethod(kernelMatrix, B, X);**

**gsl\_matrix\_free(kernelMatrix);**

**gsl\_vector\_free(B);**

**return ret;**

**}**

**int main(int argc, char\* argv[]) {**

**size\_t colsAmount = 0;**

**size\_t rowsAmount = 0;**

**gsl\_matrix\* gridMatrix = NULL;**

**FILE\* in = (argc == 1) ? stdin : fopen(argv[1], "r");**

**assert(in);**

**if (fscanf(in, "%zu %zu", &rowsAmount, &colsAmount) != 2) {**

**perror("Invalid matrix size input.\n");**

**return EXIT\_FAILURE;**

**}**

**gridMatrix = ReadGridMatrix(in, rowsAmount, colsAmount);**

**if (argc != 1) fclose(in);**

**gsl\_vector\* result = CalcGridHeatDistribution(gridMatrix);**

**if (result) {**

**//gsl\_vector\_fprintf(stdout, result, "%4lf ");**

**gsl\_vector\_free(result);**

**}**

**gsl\_matrix\_free(gridMatrix);**

**return EXIT\_SUCCESS;**

**}**

**prll\_2.c**

**// Copyright 2023 Olimpiev Y. Y.**

**#include <assert.h>**

**#include <omp.h>**

**#include <stdio.h>**

**#include <stdlib.h>**

**#include <string.h>**

**#include <time.h>**

**#include <gsl/gsl\_blas.h>**

**#include <gsl/gsl\_matrix.h>**

**#include <gsl/gsl\_vector.h>**

**#include "builders.h"**

**void pretty\_gsl\_matrix\_fprintf(FILE\* out, gsl\_matrix\* matrix, const char\* format) {**

**assert(out);**

**assert(matrix);**

**for (size\_t row = 0; row < matrix->size1; row++) {**

**for (size\_t col = 0; col < matrix->size2; col++) {**

**fprintf(out, format, gsl\_matrix\_get(matrix, row, col));**

**}**

**fprintf(out, "\n");**

**}**

**}**

**gsl\_matrix\* ReadGridMatrix(FILE\* in, size\_t rowsAmount, size\_t colsAmount) {**

**assert(in);**

**gsl\_matrix\* gridMatrix = gsl\_matrix\_calloc(rowsAmount, colsAmount);**

**assert(gridMatrix);**

**if (gsl\_matrix\_fscanf(in, gridMatrix) != 0) {**

**perror("Problem with grid matrix reading.\n");**

**return NULL;**

**}**

**return gridMatrix;**

**}**

**gsl\_vector\* ConjugateGradientsMethod(gsl\_matrix\* A, gsl\_vector\* B, gsl\_vector\* X) {**

**assert(A);**

**assert(B);**

**assert(X);**

**double eps = 0.00001;**

**gsl\_vector\* tmpVec = gsl\_vector\_calloc(B->size);**

**assert(tmpVec);**

**gsl\_vector\* r = gsl\_vector\_calloc(B->size);**

**assert(r);**

**// Calc r = b - Ax. But x = (0), so r = b.**

**gsl\_vector\_memcpy(r, B);**

**gsl\_vector\* z = gsl\_vector\_calloc(B->size);**

**assert(z);**

**gsl\_vector\_memcpy(z, r);**

**// Произвольное относительно большое для значения ошибки число.**

**double err = 100.0;**

**double normB = gsl\_blas\_dnrm2(B);**

**size\_t numThreads = omp\_get\_max\_threads();**

**size\_t\* jobSizes = (size\_t\*)calloc(numThreads, sizeof(size\_t));**

**assert(jobSizes);**

**size\_t\* displs = (size\_t\*)calloc(numThreads, sizeof(size\_t));**

**assert(displs);**

**size\_t rowsPerThread = A->size1 / numThreads;**

**for (size\_t i = 0; i < numThreads; i++) {**

**jobSizes[i] = rowsPerThread;**

**}**

**size\_t unallocatedJobSize = A->size1 % numThreads;**

**// Распределяем неподеленную работу между исполнителями.**

**for (size\_t i = 0; unallocatedJobSize; i++, unallocatedJobSize--) {**

**jobSizes[i]++;**

**}**

**displs[0] = 0;**

**for (size\_t i = 1; i < numThreads; i++) {**

**displs[i] = displs[i - 1] + jobSizes[i - 1];**

**}**

**time\_t start = time(0);**

**#pragma omp parallel**

**while (err > eps) {**

**double alpha = 0.0;**

**double betta = 0.0;**

**double tmp = 0.0;**

**int rank = omp\_get\_thread\_num();**

**gsl\_vector\* resPart = gsl\_vector\_calloc(jobSizes[rank]);**

**assert(resPart);**

**gsl\_matrix\_view subMatrixA = gsl\_matrix\_submatrix(A, displs[rank], 0, jobSizes[rank], A->size2);**

**gsl\_blas\_dgemv(CblasNoTrans, 1.0, &subMatrixA.matrix, z, 0.0, resPart);**

**memcpy(tmpVec->data + displs[rank], resPart->data, sizeof(double) \* jobSizes[rank]);**

**gsl\_vector\_free(resPart);**

**#pragma omp barrier**

**if (rank == 0) {**

**// Calc (r\_n, r\_n). double tmp <- (r\_n, r\_n)**

**gsl\_blas\_ddot(r, r, &tmp);**

**// Calc (A \* z\_n, z\_n).**

**gsl\_blas\_ddot(tmpVec, z, &alpha);**

**// Calc (r\_n, r\_n) / (A \* z\_n, z\_n).**

**alpha = tmp / alpha;**

**// Calc x\_(n + 1) = x\_n + aplha \* z\_n.**

**gsl\_blas\_daxpy(alpha, z, X);**

**// Calc r\_(n + 1) = r\_n - aplha \* (A \* z\_n).**

**gsl\_blas\_daxpy(-alpha, tmpVec, r);**

**// Calc (r\_(n + 1), r\_(n + 1)).**

**gsl\_blas\_ddot(r, r, &betta);**

**// Calc betta\_(n + 1) = (r\_(n + 1), r\_(n + 1)) / (r\_n, r\_n).**

**betta /= tmp;**

**gsl\_vector\_set\_zero(tmpVec);**

**gsl\_blas\_daxpy(betta, z, tmpVec);**

**gsl\_blas\_daxpy(1.0, r, tmpVec);**

**gsl\_vector\_memcpy(z, tmpVec);**

**err = gsl\_blas\_dnrm2(r) / normB;**

**}**

**#pragma omp barrier**

**}**

**time\_t finish = time(0);**

**printf("%ld\n", finish - start);**

**gsl\_vector\_free(r);**

**gsl\_vector\_free(z);**

**gsl\_vector\_free(tmpVec);**

**return X;**

**}**

**gsl\_vector\* CalcGridHeatDistribution(gsl\_matrix\* gridMatrix) {**

**assert(gridMatrix);**

**gsl\_matrix\* kernelMatrix = BuildKernelMatrix(gridMatrix->size1, gridMatrix->size2);**

**assert(kernelMatrix);**

**gsl\_vector\* X = BuildAnswerVector(gridMatrix->size1, gridMatrix->size2);**

**assert(X);**

**gsl\_vector\* B = BuildCoeffsVector(gridMatrix);**

**assert(B);**

**gsl\_vector\* ret = ConjugateGradientsMethod(kernelMatrix, B, X);**

**gsl\_matrix\_free(kernelMatrix);**

**gsl\_vector\_free(B);**

**return ret;**

**}**

**int main(int argc, char\* argv[]) {**

**size\_t colsAmount = 0;**

**size\_t rowsAmount = 0;**

**gsl\_matrix\* gridMatrix = NULL;**

**FILE\* in = (argc == 1) ? stdin : fopen(argv[1], "r");**

**assert(in);**

**if (fscanf(in, "%zu %zu", &rowsAmount, &colsAmount) != 2) {**

**perror("Invalid matrix size input.\n");**

**return EXIT\_FAILURE;**

**}**

**gridMatrix = ReadGridMatrix(in, rowsAmount, colsAmount);**

**if (argc != 1) fclose(in);**

**gsl\_vector\* result = CalcGridHeatDistribution(gridMatrix);**

**if (result) {**

**//gsl\_vector\_fprintf(stdout, result, "%4lf ");**

**gsl\_vector\_free(result);**

**}**

**gsl\_matrix\_free(gridMatrix);**

**return EXIT\_SUCCESS;**

**}**

**builders.c**

**//Copyright 2023 Olimpiev Y. Y.**

**#include "builders.h"**

**#include <assert.h>**

**void pretty\_gsl\_matrix\_fprintf(FILE\* out, gsl\_matrix\* matrix, const char\* format) {**

**assert(out);**

**assert(matrix);**

**for (size\_t row = 0; row < matrix->size1; row++) {**

**for (size\_t col = 0; col < matrix->size2; col++) {**

**fprintf(out, format, gsl\_matrix\_get(matrix, row, col));**

**}**

**fprintf(out, "\n");**

**}**

**}**

**gsl\_matrix\* BuildKernelMatrix(size\_t rowsAmount, size\_t colsAmount) {**

**size\_t kernelMatrixSize = colsAmount \* rowsAmount;**

**gsl\_matrix\* kernelMatrix = gsl\_matrix\_calloc(kernelMatrixSize, kernelMatrixSize);**

**assert(kernelMatrix);**

**for (size\_t row = 0; row < kernelMatrixSize - colsAmount; row++) {**

**// Set three diagonals.**

**gsl\_matrix\_set(kernelMatrix, row, row, -4.0);**

**gsl\_matrix\_set(kernelMatrix, row, row + 1, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row + 1, row, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row + colsAmount, row, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row, row + colsAmount, 1.0);**

**}**

**for (size\_t row = kernelMatrixSize - colsAmount; row < kernelMatrixSize; row++) {**

**// Set three diagonals.**

**gsl\_matrix\_set(kernelMatrix, row, row, -4.0);**

**gsl\_matrix\_set(kernelMatrix, row, row - 1, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row - 1, row, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row - colsAmount, row, 1.0);**

**gsl\_matrix\_set(kernelMatrix, row, row - colsAmount, 1.0);**

**}**

**#ifdef DEBUG**

**FILE\* out = fopen("kernelmatrix.dat", "w");**

**assert(out);**

**pretty\_gsl\_matrix\_fprintf(out, kernelMatrix, "%lf ");**

**fclose(out);**

**#endif**

**return kernelMatrix;**

**}**

**gsl\_vector\* BuildAnswerVector(size\_t rowsAmount, size\_t colsAmount) {**

**gsl\_vector\* answerVector = gsl\_vector\_calloc(rowsAmount \* colsAmount);**

**assert(answerVector);**

**#ifdef DEBUG**

**FILE\* out = fopen("answervector.dat", "w");**

**assert(out);**

**gsl\_vector\_fprintf(out, answerVector, "%lf ");**

**fclose(out);**

**#endif**

**return answerVector;**

**}**

**gsl\_vector\* BuildCoeffsVector(gsl\_matrix\* gridMatrix) {**

**size\_t vectorSize = gridMatrix->size1 \* gridMatrix->size2;**

**gsl\_vector\* coeffsVector = gsl\_vector\_calloc(vectorSize);**

**assert(coeffsVector);**

**for (size\_t i = 0; i < vectorSize; i++) {**

**gsl\_vector\_set(coeffsVector, i, gsl\_matrix\_get(gridMatrix, i / gridMatrix->size2, i % gridMatrix->size2));**

**}**

**#ifdef DEBUG**

**FILE\* out = fopen("coeffsvector.dat", "w");**

**assert(out);**

**gsl\_vector\_fprintf(out, coeffsVector, "%lf ");**

**fclose(out);**

**#endif**

**return coeffsVector;**

**}**

**gsl\_matrix\* ReadGridMatrix(FILE\* in, size\_t rowsAmount, size\_t colsAmount) {**

**assert(in);**

**gsl\_matrix\* gridMatrix = gsl\_matrix\_calloc(rowsAmount, colsAmount);**

**assert(gridMatrix);**

**if (gsl\_matrix\_fscanf(in, gridMatrix) != 0) {**

**perror("Problem with grid matrix reading.\n");**

**return NULL;**

**}**

**#ifdef DEBUG**

**FILE\* out = fopen("gridmatrix.dat", "w");**

**assert(out);**

**pretty\_gsl\_matrix\_fprintf(out, gridMatrix, "%lf ");**

**fclose(out);**

**#endif**

**return gridMatrix;**

**}**

**builders.h**

**// Copyright 2023 Olimpiev Y. Y.**

**#pragma once**

**#include <gsl/gsl\_matrix.h>**

**#include <gsl/gsl\_vector.h>**

**gsl\_matrix\* BuildKernelMatrix(size\_t rowsAmount, size\_t colsAmount);**

**gsl\_vector\* BuildAnswerVector(size\_t rowsAmount, size\_t colsAmount);**

**gsl\_vector\* BuildCoeffsVector(gsl\_matrix\* gridMatrix);**

**void pretty\_gsl\_matrix\_fprintf(FILE\* out, gsl\_matrix\* matrix, const char\* format);**

**gsl\_matrix\* ReadGridMatrix(FILE\* in, size\_t rowsAmount, size\_t colsAmount);**

**Chache-misses**

➜ sudo perf stat -B -e cache-references,cache-misses ./sequentional/Exec/app matrixes/matrix\_64\_64.dat

Performance counter stats for ./sequentional/Exec/app matrixes/matrix\_64\_64.dat:

1 111 382 427 cache-references

8 727 056 cache-misses # ­ % of all cache refs

10 134 016 961 cycles

20 384 588 162 instructions # 2,01 insn per cycle

2 923 080 539 branches

32 935 faults

8 migrations

4,239754374 seconds time elapsed

4,165050000 seconds user

0,072018000 seconds sys

➜ sudo perf stat -B -e cache-references,cache-misses./parallel\_1/Exec/app matrixes/matrix\_64\_64.dat

Performance counter stats for ./parallel\_1/Exec/app matrixes/matrix\_64\_64.dat:

1 633 534 839 cache-references

17 707 461 cache-misses # 1,084 % of all cache refs

36 420 228 435 cycles

31 848 429 425 instructions # 0,87 insn per cycle

5 010 699 378 branches

32 976 faults

137 migrations

2,200918100 seconds time elapsed

15,094096000 seconds user

0,191266000 seconds sys

➜ sudo perf stat -B -e cache-references,cache-misses ./parallel\_2/Exec/app matrixes/matrix\_64\_64.dat

Performance counter stats for ./parallel\_2/Exec/app matrixes/matrix\_64\_64.dat:

1 161 858 299 cache-references

12 636 088 cache-misses # 1,088 % of all cache refs

25 512 752 687 cycles

22 506 703 189 instructions # 0,88 insn per cycle

3 523 992 111 branches

32 968 faults

116 migrations

1,603124175 seconds time elapsed

10,622744000 seconds user

0,146821000 seconds sys

➜ **lab2** **git:(main)** sudo perf stat -B -e cache-references,cache-misses ./parallel\_2/Exec/app matrixes/matrix\_128\_128.dat

Performance counter stats for./parallel\_2/Exec/app matrixes/matrix\_128\_128.dat:

41 098 152 057 cache-references

440 298 951 cache-misses # 1,071 % of all cache refs

597 362 014 698 cycles

647 994 170 038 instructions # 1,08 insn per cycle

93 965 534 839 branches

524 670 faults

590 migrations

34,703371562 seconds time elapsed

231,163012000 seconds user

2,737971000 seconds sys

➜ sudo perf stat -B -e cache-references,cache-misses ./parallel\_1/Exec/app matrixes/matrix\_128\_128.dat

Performance counter stats for ./parallel\_1/Exec/app matrixes/matrix\_128\_128.dat:

54 821 869 183 cache-references

526 857 902 cache-misses # 0,961 % of all cache refs

866 085 660 708 cycles

924 119 542 409 instructions # 1,07 insn per cycle

135 370 803 516 branches

524 664 faults

1 243 migrations

47,901587199 seconds time elapsed

330,302886000 seconds user

2,618067000 seconds sys