sprawozdanie

June 4, 2023

1 GPU -CUDA

Wykonał: Paweł Kruczkiewicz

Wykonano w środowisku Google Collab na Tesli T4

1.1 Ćw 1

Kod:

```
/* Copyright (c) 2022, NVIDIA CORPORATION. All rights reserved.
 *
 * Redistribution and use in source and binary forms, with or without
 * modification, are permitted provided that the following conditions
 * are met:
 *  * Redistributions of source code must retain the above copyright
 *    notice, this list of conditions and the following disclaimer.
 *  * Redistributions in binary form must reproduce the above copyright
 *    notice, this list of conditions and the following disclaimer in the
 *    documentation and/or other materials provided with the distribution.
 *  * Neither the name of NVIDIA CORPORATION nor the names of its
 *    contributors may be used to endorse or promote products derived
 *    from this software without specific prior written permission.
 *
 * THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS ``AS IS'' AND ANY
 * EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE
 * IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR
 * PURPOSE ARE DISCLAIMED.  IN NO EVENT SHALL THE COPYRIGHT OWNER OR
 * CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL,
 * EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO,
 * PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR
 * PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY
 * OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT
 * (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE
 * OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.
 */

/**
 * Vector addition: C = A + B.
```

```
 *
 * This sample is a very basic sample that implements element by element
 * vector addition. It is the same as the sample illustrating Chapter 2
 * of the programming guide with some additions like error checking.
 */

#include <stdio.h>

// For the CUDA runtime routines (prefixed with "cuda_")
#include <cuda_runtime.h>

#include <helper_cuda.h>
/**
 * CUDA Kernel Device code
 *
 * Computes the vector addition of A and B into C. The 3 vectors have the same
 * number of elements numElements.
 */
__global__ void vectorAdd(const float *A, const float *B, float *C,
                          int numElements) {
  int i = blockDim.x * blockIdx.x + threadIdx.x;

  if (i < numElements) {
    C[i] = A[i] + B[i] + 0.0f;
  }
}

/**
 * Host main routine
 */
int main(void) {
  // Error code to check return values for CUDA calls
  cudaError_t err = cudaSuccess;


  for (int numElements = 10000000; numElements <= 100000000; numElements += 10000000){


  // CudaEvents for time measurements
    cudaEvent_t start, end;
  cudaEventCreate(&start);
  cudaEventCreate(&end);

  // Print the vector length to be used, and compute its size

  size_t size = numElements * sizeof(float);

  // Allocate the host input vector A
```

```
float *h_A = (float *)malloc(size);

// Allocate the host input vector B
float *h_B = (float *)malloc(size);

// Allocate the host output vector C
float *h_C = (float *)malloc(size);

// Verify that allocations succeeded
if (h_A == NULL || h_B == NULL || h_C == NULL) {
  fprintf(stderr, "Failed to allocate host vectors!\n");
  exit(EXIT_FAILURE);
}

// Initialize the host input vectors
for (int i = 0; i < numElements; ++i) {
  h_A[i] = rand() / (float)RAND_MAX;
  h_B[i] = rand() / (float)RAND_MAX;
}

// Allocate the device input vector A
float *d_A = NULL;
err = cudaMalloc((void **)&d_A, size);

if (err != cudaSuccess) {
  fprintf(stderr, "Failed to allocate device vector A (error code %s)!\n",
          cudaGetErrorString(err));
  exit(EXIT_FAILURE);
}

// Allocate the device input vector B
float *d_B = NULL;
err = cudaMalloc((void **)&d_B, size);

if (err != cudaSuccess) {
  fprintf(stderr, "Failed to allocate device vector B (error code %s)!\n",
          cudaGetErrorString(err));
  exit(EXIT_FAILURE);
}

// Allocate the device output vector C
float *d_C = NULL;
err = cudaMalloc((void **)&d_C, size);

if (err != cudaSuccess) {
  fprintf(stderr, "Failed to allocate device vector C (error code %s)!\n",
          cudaGetErrorString(err));
  exit(EXIT_FAILURE);
```

```
}

// Copy the host input vectors A and B in host memory to the device input
// vectors in
// device memory
err = cudaMemcpy(d_A, h_A, size, cudaMemcpyHostToDevice);

if (err != cudaSuccess) {
  fprintf(stderr,
          "Failed to copy vector A from host to device (error code %s)!\n",
          cudaGetErrorString(err));
  exit(EXIT_FAILURE);
}

err = cudaMemcpy(d_B, h_B, size, cudaMemcpyHostToDevice);

if (err != cudaSuccess) {
  fprintf(stderr,
          "Failed to copy vector B from host to device (error code %s)!\n",
          cudaGetErrorString(err));
  exit(EXIT_FAILURE);
}

// Launch the Vector Add CUDA Kernel
for (int threadsPerBlock = 16; threadsPerBlock <= 256; threadsPerBlock *= 2){
int blocksPerGrid = (numElements + threadsPerBlock - 1) / threadsPerBlock;

for (int i = 0; i < 5; i++){
  cudaEventRecord(start);
  vectorAdd<<<blocksPerGrid, threadsPerBlock>>>(d_A, d_B, d_C, numElements);
  cudaEventRecord(end);
  cudaEventSynchronize(end);

  err = cudaGetLastError();

  if (err != cudaSuccess) {
    fprintf(stderr, "Failed to launch vectorAdd kernel (error code %s)!\n",
            cudaGetErrorString(err));
    exit(EXIT_FAILURE);
  }

  // Copy the device result vector in device memory to the host result vector
  // in host memory.
  err = cudaMemcpy(h_C, d_C, size, cudaMemcpyDeviceToHost);

  if (err != cudaSuccess) {
    fprintf(stderr,
            "Failed to copy vector C from device to host (error code %s)!\n",
```

```
                cudaGetErrorString(err));
        exit(EXIT_FAILURE);
      }

      // Verify that the result vector is correct
      for (int i = 0; i < numElements; ++i) {
        if (fabs(h_A[i] + h_B[i] - h_C[i]) > 1e-5) {
          fprintf(stderr, "Result verification failed at element %d!\n", i);
          exit(EXIT_FAILURE);
        }
      }

      float time = 0;
      cudaEventElapsedTime(&time, start, end);
      printf("%d,%d,%f,%d\n", numElements, threadsPerBlock, time, i);
    }
    }
    // Free device global memory
    err = cudaFree(d_A);

    if (err != cudaSuccess) {
      fprintf(stderr, "Failed to free device vector A (error code %s)!\n",
              cudaGetErrorString(err));
      exit(EXIT_FAILURE);
    }

    err = cudaFree(d_B);

    if (err != cudaSuccess) {
      fprintf(stderr, "Failed to free device vector B (error code %s)!\n",
              cudaGetErrorString(err));
      exit(EXIT_FAILURE);
    }

    err = cudaFree(d_C);

    if (err != cudaSuccess) {
      fprintf(stderr, "Failed to free device vector C (error code %s)!\n",
              cudaGetErrorString(err));
      exit(EXIT_FAILURE);
    }

    // Free host memory
    free(h_A);
    free(h_B);
    free(h_C);
  }
    printf("Done\n");
```

```
  return 0;
}
```

[53]:
```
import pandas as pd
import seaborn as sns

sns.set(rc={'figure.figsize':(11.7,8.27)})
```

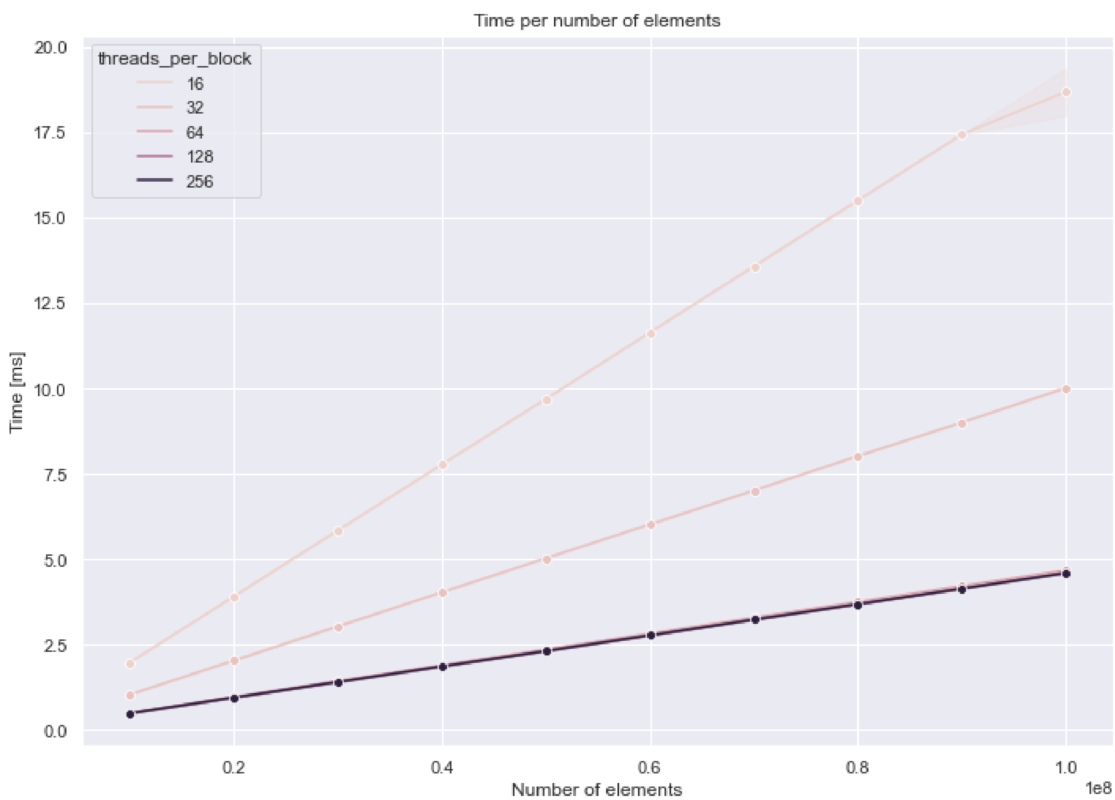
[48]:
```
data = pd.read_csv("data/1.csv")
data.head()
```

[48]:

	number_of_elements	threads_per_block	time	iter
0	10000000	16	1.949024	0
1	10000000	16	1.958880	1
2	10000000	16	1.961888	2
3	10000000	16	1.954432	3
4	10000000	16	1.955776	4

[56]:
```
sns.lineplot(data=data, x="number_of_elements", y="time",␣
↪hue="threads_per_block", marker="o").set(xlabel="Number of elements",␣
↪ylabel="Time [ms]", title="Time per number of elements")
```

[56]:
```
[Text(0.5, 0, 'Number of elements'),
 Text(0, 0.5, 'Time [ms]'),
 Text(0.5, 1.0, 'Time per number of elements')]
```



1.2 Ćw 2

Kod naiwny:

```
%%cu
#include<stdio.h>
#include<stdlib.h>

#define BLOCK_SIZE 32

__global__ void matrix_transpose_naive(int *input, int *output, int n) {

    int indexX = threadIdx.x + blockIdx.x * blockDim.x;
    int indexY = threadIdx.y + blockIdx.y * blockDim.y;
    int index = indexY * n + indexX;
    int transposedIndex = indexX * n + indexY;

    // this has discoalesced global memory store
    output[transposedIndex] = input[index];

    // this has discoalesced global memore load
    // output[index] = input[transposedIndex];
}

__global__ void matrix_transpose_shared(int *input, int *output, int n) {

    __shared__ int sharedMemory [BLOCK_SIZE] [BLOCK_SIZE];

    // global index
    int indexX = threadIdx.x + blockIdx.x * blockDim.x;
    int indexY = threadIdx.y + blockIdx.y * blockDim.y;

    // transposed global memory index
    int tindexX = threadIdx.x + blockIdx.y * blockDim.x;
    int tindexY = threadIdx.y + blockIdx.x * blockDim.y;

    // local index
    int localIndexX = threadIdx.x;
    int localIndexY = threadIdx.y;

    int index = indexY * n + indexX;
    int transposedIndex = tindexY * n + tindexX;

    // reading from global memory in coalesed manner and performing tanspose in shared memory
    sharedMemory[localIndexX][localIndexY] = input[index];
```

```
    __syncthreads();

    // writing into global memory in coalesed fashion via transposed data in shared memory
    output[transposedIndex] = sharedMemory[localIndexY][localIndexX];
}

//basically just fills the array with index.
void fill_array(int *data, int n) {
    for(int idx=0;idx<(n*n);idx++)
        data[idx] = idx;
}

void print_output(int *a, int *b, int n) {
    printf("\n Original Matrix::\n");
    for(int idx=0;idx<(n*n);idx++) {
        if(idx%n == 0)
            printf("\n");
        printf(" %d ",  a[idx]);
    }
    printf("\n Transposed Matrix::\n");
    for(int idx=0;idx<(n*n);idx++) {
        if(idx%n == 0)
            printf("\n");
        printf(" %d ",  b[idx]);
    }
}

int main(void) {
    int *a, *b;
        int *d_a, *d_b; // device copies of a, b, c

    cudaEvent_t start, end;
  cudaEventCreate(&start);
  cudaEventCreate(&end);

  for (int n = 1028; n <= 10280; n += 1028){
    int size = n * n *sizeof(int);

    // Alloc space for host copies of a, b, c and setup input values
    a = (int *)malloc(size); fill_array(a, n);
    b = (int *)malloc(size);

    // Alloc space for device copies of a, b, c
    cudaMalloc((void **)&d_a, size);
    cudaMalloc((void **)&d_b, size);

    // Copy inputs to device
```

```
    cudaMemcpy(d_a, a, size, cudaMemcpyHostToDevice);
    cudaMemcpy(d_b, b, size, cudaMemcpyHostToDevice);

    dim3 blockSize(BLOCK_SIZE,BLOCK_SIZE,1);
    dim3 gridSize(n/BLOCK_SIZE,n/BLOCK_SIZE,1);

    for (int i = 0; i < 5; i++){
    cudaEventRecord(start);
    // matrix_transpose_naive<<<gridSize,blockSize>>>(d_a,d_b,n);
    matrix_transpose_shared<<<gridSize,blockSize>>>(d_a,d_b,n);
    cudaEventRecord(end);
    cudaEventSynchronize(end);

    float time = 0;
    cudaEventElapsedTime(&time, start, end);
    printf("%d,%f,%d\n", n, time, i);
}
    free(a);
    free(b);
      cudaFree(d_a);
    cudaFree(d_b);
  }

    return 0;
}
```

Kod wykorzystujący pamięć współdzieloną:

```
%%cu
#include<stdio.h>
#include<stdlib.h>

#define BLOCK_SIZE 32

__global__ void matrix_transpose_naive(int *input, int *output, int n) {

    int indexX = threadIdx.x + blockIdx.x * blockDim.x;
    int indexY = threadIdx.y + blockIdx.y * blockDim.y;
    int index = indexY * n + indexX;
    int transposedIndex = indexX * n + indexY;

    // this has discoalesced global memory store
    output[transposedIndex] = input[index];

    // this has discoalesced global memore load
    // output[index] = input[transposedIndex];
}

__global__ void matrix_transpose_shared(int *input, int *output, int n) {
```

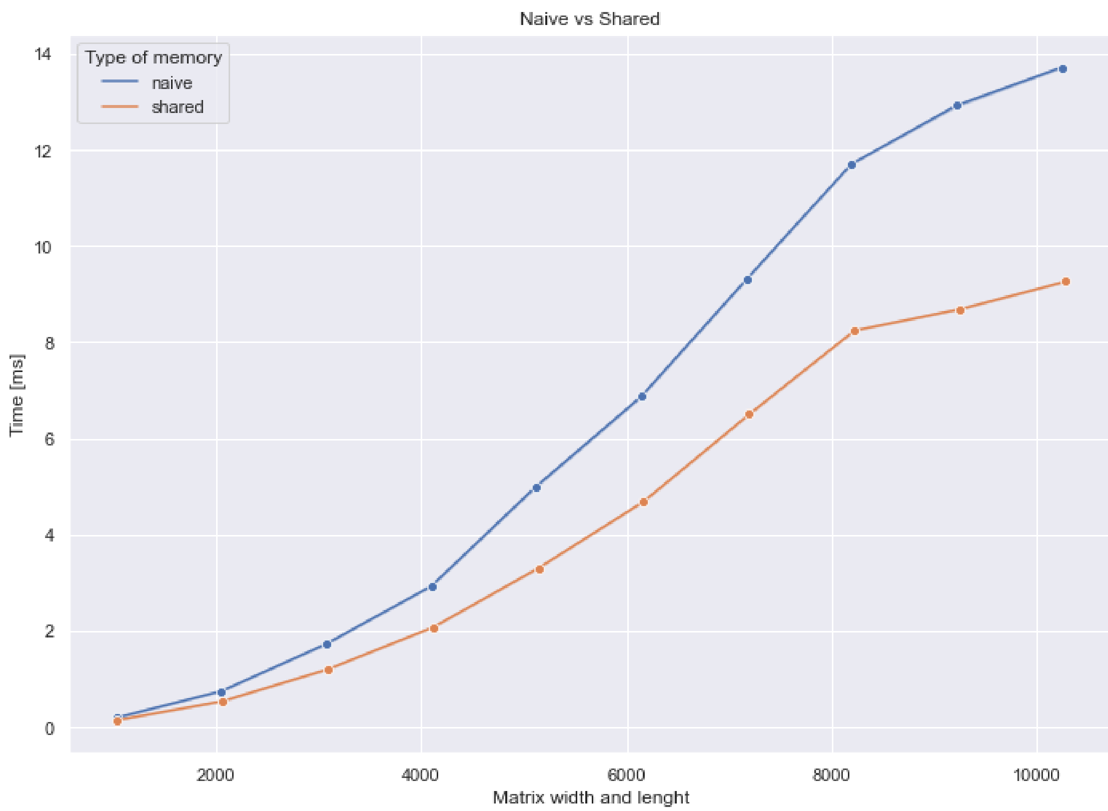
```
    __shared__ int sharedMemory [BLOCK_SIZE] [BLOCK_SIZE];

    // global index
    int indexX = threadIdx.x + blockIdx.x * blockDim.x;
    int indexY = threadIdx.y + blockIdx.y * blockDim.y;

    // transposed global memory index
    int tindexX = threadIdx.x + blockIdx.y * blockDim.x;
    int tindexY = threadIdx.y + blockIdx.x * blockDim.y;

    // local index
    int localIndexX = threadIdx.x;
    int localIndexY = threadIdx.y;

    int index = indexY * n + indexX;
    int transposedIndex = tindexY * n + tindexX;

    // reading from global memory in coalesed manner and performing tanspose in shared memory
    sharedMemory[localIndexX][localIndexY] = input[index];

    __syncthreads();

    // writing into global memory in coalesed fashion via transposed data in shared memory
    output[transposedIndex] = sharedMemory[localIndexY][localIndexX];
}

//basically just fills the array with index.
void fill_array(int *data, int n) {
    for(int idx=0;idx<(n*n);idx++)
        data[idx] = idx;
}

void print_output(int *a, int *b, int n) {
    printf("\n Original Matrix::\n");
    for(int idx=0;idx<(n*n);idx++) {
        if(idx%n == 0)
            printf("\n");
        printf(" %d ",  a[idx]);
    }
    printf("\n Transposed Matrix::\n");
    for(int idx=0;idx<(n*n);idx++) {
        if(idx%n == 0)
            printf("\n");
        printf(" %d ",  b[idx]);
    }
}
```

```
int main(void) {
    int *a, *b;
        int *d_a, *d_b; // device copies of a, b, c

    cudaEvent_t start, end;
  cudaEventCreate(&start);
  cudaEventCreate(&end);

  for (int n = 1028; n <= 10280; n += 1028){
    int size = n * n *sizeof(int);

    // Alloc space for host copies of a, b, c and setup input values
    a = (int *)malloc(size); fill_array(a, n);
    b = (int *)malloc(size);

    // Alloc space for device copies of a, b, c
    cudaMalloc((void **)&d_a, size);
    cudaMalloc((void **)&d_b, size);

    // Copy inputs to device
    cudaMemcpy(d_a, a, size, cudaMemcpyHostToDevice);
    cudaMemcpy(d_b, b, size, cudaMemcpyHostToDevice);

    dim3 blockSize(BLOCK_SIZE,BLOCK_SIZE,1);
    dim3 gridSize(n/BLOCK_SIZE,n/BLOCK_SIZE,1);

    for (int i = 0; i < 5; i++){
    cudaEventRecord(start);
    matrix_transpose_naive<<<gridSize,blockSize>>>(d_a,d_b,n);
    // matrix_transpose_shared<<<gridSize,blockSize>>>(d_a,d_b,n);
    cudaEventRecord(end);
    cudaEventSynchronize(end);

    float time = 0;
    cudaEventElapsedTime(&time, start, end);
    printf("%d,%f,%d\n", n, time, i);
}
    free(a);
    free(b);
      cudaFree(d_a);
    cudaFree(d_b);
  }

    return 0;
}
```

[70]:
```
data2 = pd.read_csv("data/2.csv")
```

[71]:
```python
ax = sns.lineplot(data=data2, y="t", x="n", hue="l", marker="o")
ax.set(title="Naive vs Shared", xlabel="Matrix width and lenght", ylabel="Time␣
↪[ms]")
ax.legend(title="Type of memory")

ax
```

[71]: <AxesSubplot:title={'center':'Naive vs Shared'}, xlabel='Matrix width and lenght', ylabel='Time [ms]'>



[ ]: