GPU and Heterogeneous Systems – A.Y. 2021-22

Scuola di Ingegneria Industriale e dell'Informazione
Instructor: Prof. Antonio Miele

January 27, 2023 – **FIRST PART OF THE EXAM**

Surname:	Name:	Person Code:

Question	**1**	**2**	**3**	**4**	**5**	**OVERALL**
Max score	**3**	**3**	**3**	**3**	**3**	**15**
Score						

Instructions:

- **Duration: 40 minutes**
- This first part of the exam is "closed book". The students are not allowed to consult any course material and notes.
- No extra devices (e.g., phones, iPad) are allowed. Please, shut down and store any electronic device.
- Students are not allowed to communicate with any other ones.
- Students can write in pen or pencil, any color, but avoid writing in red.
- Any violation of the above rules will lead to the invalidation of the test.

Question 1
Explain which are the three features of the graphics pipeline that have been parallelized in the GPU architecture.

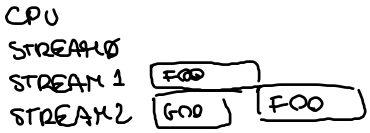
Question 2
Draw the Gantt chart of the execution of the various functions in the following three cases.

(a) Assume that `foo` execution is shorter than `cpuFoo` one.

```
foo<<<blocks, threads>>>();
cpuFoo();
foo<<<blocks, threads>>>();
cudaEventRecord(event1);
cudaEventSynchronize(event1);
cpuFoo();
```

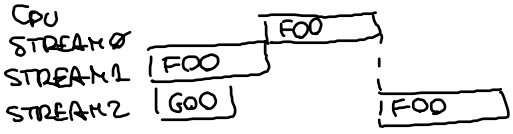
(b) Assume that `foo` execution is longer than `goo` one.

```
cudaStreamCreate(&stream1);
cudaStreamCreate(&stream2);
foo<<<blocks, threads, 0, stream1>>>();
cudaEventRecord(event1, stream1);
goo<<<blocks, threads, 0, stream2>>>();
cudaStreamWaitEvent(stream2, event1);
foo<<<blocks, threads, 0, stream2>>>();
```



(c) Assume that `foo` execution is longer than `goo` one.

```
cudaStreamCreate(&stream1);
cudaStreamCreate(&stream2);
foo<<<blocks, threads, 0, stream1>>>();
goo<<<blocks, threads, 0, stream2>>>();
foo<<<blocks, threads>>>();
foo<<<blocks, threads, 0, stream2>>>();
```



Question 3
Briefly describe CUDA memory model; for each component specify name, type of usage, type of access (read/write or read only) and scope.

Question 4
Describe the main strategies to accelerate the Smith-Waterman algorithm in CUDA.

Question 5

In the following snippet of code, how many times will `foo()` and `goo()` be executed? Motivate the answer.

```
#pragma acc parallel num_gangs(16)
{
  #pragma acc loop gang
  for (int i=0; i<32; i++) {
    goo(i);
  }
  foo();
}
```

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January 27, 2023 – **SECOND PART OF THE EXAM**

Surname:	Name:	Personal Code:

Question	**1**	**2**	**3**	**OVERALL**
Max score	**5**	**6**	**5**	**16**
Score				

Instructions:

- **Duration: 1 hour and 15 minutes**
- This second part of the exam is "open book". The students are allowed to use any material and notes.
- The students are allowed to use the laptop and the tablet. No extra devices (e.g., phones) are allowed. Please, shut down and store not allowed electronic devices.
- Students are not allowed to communicate with any other one or use Internet.
- Students can write in pen or pencil, any color, but avoid writing in red.
- Students can also use the laptop to code the test solution. In this case, please pay attention to the instructor's instructions to submit the test solution.
- Any violation of the above rules will lead to the invalidation of the test.

Question 1
Implement two CUDA functions to accelerate the bodyForce() and updateBodyPositions() functions.

Question 2
Modify the main function to execute the simulation on the GPU by calling previously defined kernels.

Question 3
Describe how you would modify the bodyForce() to use the shared memory.

The source code can be downloaded from: https://miele.faculty.polimi.it/nbody.c

```
/* In physics, the n-body simulation is the simulation of the motion of a set of M
different objects due to the gravitational interaction among them. The following
program implement an N-body simulation. Each object to be simulated is modeled
by means of the Body_t struct that contains fields for the position and the speed
in a 3D space; data of N different objects is stored in an Body_t array.
The simulation starts by computing randomly  the initial position and speed of each
object. Then a number of time steps are simulated; at each time step the bodyForce()
function computes the new speed of each object due to the gravitational interaction
and updateBodyPositions() functions computes the new position of each object.
*/

#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#include <sys/time.h>

#define SOFTENING 1e-9f

typedef struct {
  float x, y, z, vx, vy, vz;
} Body_t;

double get_time();
void randomizeBodies(float *data, int n);
void bodyForce(Body_t *p, float dt, int n);
void updateBodyPositions(Body_t *p, float dt, int n);


void randomizeBodies(float *data, int n) {
  for (int i = 0; i < n; i++) {
    data[i] = 2.0f * (rand() / (float)RAND_MAX) - 1.0f;
  }
}

void bodyForce(Body_t *p, float dt, int n) {
  for (int i = 0; i < n; i++) {
    float Fx = 0.0f, Fy = 0.0f, Fz = 0.0f;

    for (int j = 0; j < n; j++) {
      float dx = p[j].x - p[i].x;
      float dy = p[j].y - p[i].y;
      float dz = p[j].z - p[i].z;
      float distSqr = dx*dx + dy*dy + dz*dz + SOFTENING;
      float invDist = 1.0f / sqrtf(distSqr);
      float invDist3 = invDist * invDist * invDist;

      Fx += dx * invDist3;
      Fy += dy * invDist3;
      Fz += dz * invDist3;
    }

    p[i].vx += dt*Fx;
    p[i].vy += dt*Fy;
    p[i].vz += dt*Fz;
  }
}

void updateBodyPositions(Body_t *p, float dt, int n) {
  for (int i = 0 ; i < n; i++) {
    p[i].x += p[i].vx*dt;
    p[i].y += p[i].vy*dt;
    p[i].z += p[i].vz*dt;
  }
}
```

```
int main(const int argc, const char** argv) {
  int nBodies = 30000;
  if (argc > 1) nBodies = atoi(argv[1]);

  const float dt = 0.01f; // time step
  const int nIters = 10;  // simulation iterations

  double cpu_start, cpu_end;

  Body_t *p = (Body_t*)malloc(nBodies*sizeof(Body_t));

  randomizeBodies((float*)p, 6*nBodies); // Init position / speed data

  cpu_start = get_time();
  for (int iter = 1; iter <= nIters; iter++) {
    bodyForce(p, dt, nBodies); // compute interbody forces
    updateBodyPositions(p, dt, nBodies); // integrate position
  }
  cpu_end = get_time();
  double avgTime = (cpu_end - cpu_start) / nIters;

  printf("%d Bodies: average %0.3f Billion Interactions / second\n", nBodies, 1e-9 *
nBodies * nBodies / avgTime);
  free(p);

  return 0;
}

// function to get the time of day in seconds
double get_time() {
  struct timeval tv;
  gettimeofday(&tv, NULL);
  return tv.tv_sec + tv.tv_usec * 1e-6;
}
```