handson_gpu_2020

November 19, 2020

1 Setup Iniziale

1. Attivare il supporto GPU in Runtime->Change Runtime Type->Hardware Accelerator
2. Check if pyCUDA è installato

[ ]:
```
!pip install pycuda
import pycuda
```

2 Esplorare la Bash

[ ]:
```
!ls
!pwd                  #Show position
!cd ..
```

[ ]:
```
!mkdir test_d       #Make directory
!rm -r test_dir/    #Remove directory (-d if empty)
```

[7]:
```
!touch ciao         #Create empty file
!rm ciao
```

[ ]:
```
!gcc --version
!nvcc --version     #Controlla la versione di CUDA installata
```

Look at the following link for more information: https://wiki.ubuntu-it.org/Programmazione/LinguaggioBash

3 Caratteristiche della GPU in uso

Proviamo a capire le caratteristiche della GPU che abbiamo a disposizione.

[10]:
```
!nvidia-smi
```

```
Thu Nov 19 19:26:44 2020
+-----------------------------------------------------------------------------+
| NVIDIA-SMI 455.38       Driver Version: 418.67       CUDA Version: 10.1     |
|-------------------------------+----------------------+----------------------+
| GPU  Name        Persistence-M| Bus-Id        Disp.A | Volatile Uncorr. ECC |
```

```
| Fan  Temp  Perf  Pwr:Usage/Cap|         Memory-Usage | GPU-Util  Compute M. |
|                               |                      |               MIG M. |
|===============================+======================+======================|
|   0  Tesla T4            Off  | 00000000:00:04.0 Off |                    0 |
| N/A   31C    P8     9W /  70W |      10MiB / 15079MiB |      0%      Default |
|                               |                      |                 ERR! |
+-------------------------------+----------------------+----------------------+

+-----------------------------------------------------------------------------+
| Processes:                                                                  |
|  GPU   GI   CI        PID   Type   Process name                  GPU Memory |
|        ID   ID                                                   Usage      |
|=============================================================================|
|  No running processes found                                                 |
+-----------------------------------------------------------------------------+
```

oppure si può usare il modulo pycuda, interrogando le funzioni del driver

[9]:
```python
import pycuda.driver as drv
drv.init()
drv.get_version()
devn=drv.Device.count()
print("N GPU "+str(devn))
devices = []
for i in range(devn):
  devices.append(drv.Device(i))
for sp in devices:
  print("GPU name: "+str(sp.name))
  print("Compute Capability = "+str(sp.compute_capability()))
  print("Total Memory = "+str(sp.total_memory()/(2.**20))+' MBytes')
  attr = sp.get_attributes()
  print(attr)
```

```
N GPU 1
GPU name: <bound method name of <pycuda._driver.Device object at
0x7f48604878b8>>
Compute Capability = (7, 5)
Total Memory = 15079.75 MBytes
{pycuda._driver.device_attribute.ASYNC_ENGINE_COUNT: 3,
pycuda._driver.device_attribute.CAN_MAP_HOST_MEMORY: 1,
pycuda._driver.device_attribute.CLOCK_RATE: 1590000,
pycuda._driver.device_attribute.COMPUTE_CAPABILITY_MAJOR: 7,
pycuda._driver.device_attribute.COMPUTE_CAPABILITY_MINOR: 5,
pycuda._driver.device_attribute.COMPUTE_MODE:
pycuda._driver.compute_mode.DEFAULT,
pycuda._driver.device_attribute.CONCURRENT_KERNELS: 1,
pycuda._driver.device_attribute.ECC_ENABLED: 1,
pycuda._driver.device_attribute.GLOBAL_L1_CACHE_SUPPORTED: 1,
pycuda._driver.device_attribute.GLOBAL_MEMORY_BUS_WIDTH: 256,
```

```
pycuda._driver.device_attribute.GPU_OVERLAP: 1,
pycuda._driver.device_attribute.INTEGRATED: 0,
pycuda._driver.device_attribute.KERNEL_EXEC_TIMEOUT: 0,
pycuda._driver.device_attribute.L2_CACHE_SIZE: 4194304,
pycuda._driver.device_attribute.LOCAL_L1_CACHE_SUPPORTED: 1,
pycuda._driver.device_attribute.MANAGED_MEMORY: 1,
pycuda._driver.device_attribute.MAXIMUM_SURFACE1D_LAYERED_LAYERS: 2048,
pycuda._driver.device_attribute.MAXIMUM_SURFACE1D_LAYERED_WIDTH: 32768,
pycuda._driver.device_attribute.MAXIMUM_SURFACE1D_WIDTH: 32768,
pycuda._driver.device_attribute.MAXIMUM_SURFACE2D_HEIGHT: 65536,
pycuda._driver.device_attribute.MAXIMUM_SURFACE2D_LAYERED_HEIGHT: 32768,
pycuda._driver.device_attribute.MAXIMUM_SURFACE2D_LAYERED_LAYERS: 2048,
pycuda._driver.device_attribute.MAXIMUM_SURFACE2D_LAYERED_WIDTH: 32768,
pycuda._driver.device_attribute.MAXIMUM_SURFACE2D_WIDTH: 131072,
pycuda._driver.device_attribute.MAXIMUM_SURFACE3D_DEPTH: 16384,
pycuda._driver.device_attribute.MAXIMUM_SURFACE3D_HEIGHT: 16384,
pycuda._driver.device_attribute.MAXIMUM_SURFACE3D_WIDTH: 16384,
pycuda._driver.device_attribute.MAXIMUM_SURFACECUBEMAP_LAYERED_LAYERS: 2046,
pycuda._driver.device_attribute.MAXIMUM_SURFACECUBEMAP_LAYERED_WIDTH: 32768,
pycuda._driver.device_attribute.MAXIMUM_SURFACECUBEMAP_WIDTH: 32768,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE1D_LAYERED_LAYERS: 2048,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE1D_LAYERED_WIDTH: 32768,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE1D_LINEAR_WIDTH: 134217728,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE1D_MIPMAPPED_WIDTH: 32768,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE1D_WIDTH: 131072,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_ARRAY_HEIGHT: 32768,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_ARRAY_NUMSLICES: 2048,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_ARRAY_WIDTH: 32768,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_GATHER_HEIGHT: 32768,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_GATHER_WIDTH: 32768,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_HEIGHT: 65536,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_LINEAR_HEIGHT: 65000,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_LINEAR_PITCH: 2097120,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_LINEAR_WIDTH: 131072,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_MIPMAPPED_HEIGHT: 32768,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_MIPMAPPED_WIDTH: 32768,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE2D_WIDTH: 131072,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE3D_DEPTH: 16384,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE3D_DEPTH_ALTERNATE: 32768,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE3D_HEIGHT: 16384,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE3D_HEIGHT_ALTERNATE: 8192,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE3D_WIDTH: 16384,
pycuda._driver.device_attribute.MAXIMUM_TEXTURE3D_WIDTH_ALTERNATE: 8192,
pycuda._driver.device_attribute.MAXIMUM_TEXTURECUBEMAP_LAYERED_LAYERS: 2046,
pycuda._driver.device_attribute.MAXIMUM_TEXTURECUBEMAP_LAYERED_WIDTH: 32768,
pycuda._driver.device_attribute.MAXIMUM_TEXTURECUBEMAP_WIDTH: 32768,
pycuda._driver.device_attribute.MAX_BLOCK_DIM_X: 1024,
pycuda._driver.device_attribute.MAX_BLOCK_DIM_Y: 1024,
```

```
pycuda._driver.device_attribute.MAX_BLOCK_DIM_Z: 64,
pycuda._driver.device_attribute.MAX_GRID_DIM_X: 2147483647,
pycuda._driver.device_attribute.MAX_GRID_DIM_Y: 65535,
pycuda._driver.device_attribute.MAX_GRID_DIM_Z: 65535,
pycuda._driver.device_attribute.MAX_PITCH: 2147483647,
pycuda._driver.device_attribute.MAX_REGISTERS_PER_BLOCK: 65536,
pycuda._driver.device_attribute.MAX_REGISTERS_PER_MULTIPROCESSOR: 65536,
pycuda._driver.device_attribute.MAX_SHARED_MEMORY_PER_BLOCK: 49152,
pycuda._driver.device_attribute.MAX_SHARED_MEMORY_PER_MULTIPROCESSOR: 65536,
pycuda._driver.device_attribute.MAX_THREADS_PER_BLOCK: 1024,
pycuda._driver.device_attribute.MAX_THREADS_PER_MULTIPROCESSOR: 1024,
pycuda._driver.device_attribute.MEMORY_CLOCK_RATE: 5001000,
pycuda._driver.device_attribute.MULTIPROCESSOR_COUNT: 40,
pycuda._driver.device_attribute.MULTI_GPU_BOARD: 0,
pycuda._driver.device_attribute.MULTI_GPU_BOARD_GROUP_ID: 0,
pycuda._driver.device_attribute.PCI_BUS_ID: 0,
pycuda._driver.device_attribute.PCI_DEVICE_ID: 4,
pycuda._driver.device_attribute.PCI_DOMAIN_ID: 0,
pycuda._driver.device_attribute.STREAM_PRIORITIES_SUPPORTED: 1,
pycuda._driver.device_attribute.SURFACE_ALIGNMENT: 512,
pycuda._driver.device_attribute.TCC_DRIVER: 0,
pycuda._driver.device_attribute.TEXTURE_ALIGNMENT: 512,
pycuda._driver.device_attribute.TEXTURE_PITCH_ALIGNMENT: 32,
pycuda._driver.device_attribute.TOTAL_CONSTANT_MEMORY: 65536,
pycuda._driver.device_attribute.UNIFIED_ADDRESSING: 1,
pycuda._driver.device_attribute.WARP_SIZE: 32}
```

oppure anche con il metodo DeviceData()

[13]:
```python
from pycuda import autoinit
from pycuda.tools import DeviceData
specs = DeviceData()
print ('Max threads per block = '+str(specs.max_threads))
print ('Warp size             ='+str(specs.warp_size))
print ('Warps per MP          ='+str(specs.warps_per_mp))
print ('Thread Blocks per MP ='+str(specs.thread_blocks_per_mp))
print ('Registers             ='+str(specs.registers))
print ('Shared memory         ='+str(specs.shared_memory))
```

```
Max threads per block = 1024
Warp size            =32
Warps per MP         =64
Thread Blocks per MP =8
Registers            =65536
Shared memory        =49152
```

4 Esempio GPU in C

Proviamo a scrivere e compilare un programma GPU in C. Notare il comando (magic) all'inizio che serve per salvare il contenuto della cella in un file nel workspace.

[11]:
```
%%writefile VecAdd.cu
# include <stdio.h>
# include <cuda_runtime.h>

// CUDA Kernel
__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];
    }
}

/**
 * Host main routine
 */

int main(void)
{
    int numElements = 15;
    size_t size = numElements * sizeof(float);
    printf("[Vector addition of %d elements]\n", numElements);

    float a[numElements],b[numElements],c[numElements];
    float *a_gpu,*b_gpu,*c_gpu;

    // Generates the input vectors
    for (int i=0;i<numElements;++i){
        a[i] = i*i;
        b[i] = i;
    }

    // Allocate space on the GPU
    cudaMalloc((void **)&a_gpu, size);
    cudaMalloc((void **)&b_gpu, size);
    cudaMalloc((void **)&c_gpu, size);

    // Copy vectors A and B in host memory to the device vectors in device␣
↪memory
    printf("Copy input data from the host memory to the CUDA device\n");
    cudaMemcpy(a_gpu, a, size, cudaMemcpyHostToDevice);
```

```
    cudaMemcpy(b_gpu, b, size, cudaMemcpyHostToDevice);

    // Launch the Vector Add CUDA Kernel
    int threadsPerBlock = 256;
    int blocksPerGrid = (numElements + threadsPerBlock - 1) / threadsPerBlock;
    printf("CUDA kernel launch with %d blocks of %d threads\n", blocksPerGrid,␣
 ↪threadsPerBlock);
    vectorAdd<<<blocksPerGrid, threadsPerBlock>>>(a_gpu, b_gpu, c_gpu,␣
 ↪numElements);

    // Copy the device result vectors to the host result vectors in host memory
    printf("Copy output data from the CUDA device to the host memory\n");
    cudaMemcpy(c, c_gpu, size, cudaMemcpyDeviceToHost);

    // Free device global memory
    cudaFree(a_gpu);
    cudaFree(b_gpu);
    cudaFree(c_gpu);

    for (int i=0;i<numElements;++i ){
        printf("%f \n", c[i]);
    }

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

```
Writing VecAdd.cu
```

[12]:
```
!ls
!nvcc -o VecAdd VecAdd.cu
!./VecAdd
```

```
drive                    handson_gpu_2020.pdf  test_d
handson_gpu_2020.ipynb   sample_data           VecAdd.cu
[Vector addition of 15 elements]
Copy input data from the host memory to the CUDA device
CUDA kernel launch with 1 blocks of 256 threads
Copy output data from the CUDA device to the host memory
0.000000
2.000000
6.000000
12.000000
20.000000
30.000000
42.000000
56.000000
```

```
72.000000
90.000000
110.000000
132.000000
156.000000
182.000000
210.000000
Done
```

5 Implementazione con pycuda

[14]:
```python
from pycuda import autoinit
from pycuda import gpuarray
import numpy as np
```

[15]:
```python
#Generating some initial vectors

aux = range(15)
a = np.array(aux).astype(np.float32)
b = (a*a).astype(np.float32)
c = np.zeros(len(aux)).astype(np.float32)

# Creating copies of the initial vectors on the GPU

a_gpu = gpuarray.to_gpu(a)
b_gpu = gpuarray.to_gpu(b)
c_gpu = gpuarray.to_gpu(c)
```

A.) Modo semplice per operare sui vettori della GPU.

[16]:
```python
c_gpu = a_gpu + b_gpu
print(c_gpu)
```

```
[  0.   2.   6.  12.  20.  30.  42.  56.  72.  90. 110. 132. 156. 182.
 210.]
```

B.) Il secondo modo è quello di utilizzare il metodo elementwise, che applica la stessa "Operation" a tutti gli elementi dei vettori. Il vantaggio è che si possono definire anche operazioni piu' complesse della semplice somma.

[17]:
```python
from pycuda.elementwise import ElementwiseKernel
myCudaFunc = ElementwiseKernel(arguments = "float *a, float *b, float *c",
                               operation = "c[i] = a[i]+b[i]",
                               name = "mySumK")
myCudaFunc(a_gpu,b_gpu,c_gpu)
c_gpu
```

[17]:
```
array([  0.,   2.,   6.,  12.,  20.,  30.,  42.,  56.,  72.,  90., 110.,
       132., 156., 182., 210.], dtype=float32)
```

Altro esempio di operazione tra vettori con Pycuda.

[18]:
```
from pycuda.elementwise import ElementwiseKernel
lin_comb = ElementwiseKernel(
        "float a, float *x, float b, float *y, float *z",
        "z[i] = a*x[i] + b*y[i]",
        "linear_combination")
lin_comb(3.,a_gpu,5.,b_gpu,c_gpu)
c_gpu
```

[18]:
```
array([   0.,    8.,   26.,   54.,   92.,  140.,  198.,  266.,  344.,
        432.,  530.,  638.,  756.,  884., 1022.], dtype=float32)
```

C.) Il terzo modo è il piu' "generico". Si utilizza il metodo SourceModule che permette di definire anche kernel piu' complessi. Con questo modulo si possono importare metodi da file scritti in C.

[20]:
```
from pycuda.compiler import SourceModule

!ls

# Nella stessa cartella del file in C o inserendo il percorso
cudaCode = open("VecAdd.cu","r")
code = cudaCode.read()
myCode = SourceModule(code)                       # Compile the file
importedKernel = myCode.get_function("vectorAdd") # Import of the needed module
```

```
drive                   handson_gpu_2020.pdf  test_d  VecAdd.cu
handson_gpu_2020.ipynb  sample_data           VecAdd
```

definiamo la "geometria" della GPU che vogliamo usare e resettiamo il vettore c_gpu (per essere sicuri sia vuoto)

[21]:
```
nThreadsPerBlock = 256
nBlockPerGrid = 1
nGridsPerBlock = 1

c_gpu.set(c)
c_gpu
```

[21]:
```
array([0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
      dtype=float32)
```

lanciamo il kernel importato passandogli i puntatori dei vettori e la geometria della GPU

[22]:
```
b_gpu.gpudata # restituisce il puntatore nella memoria gpu
importedKernel(a_gpu.gpudata, b_gpu.gpudata, c_gpu.gpudata,
               block=(nThreadsPerBlock,nBlockPerGrid,nGridsPerBlock))
print(c_gpu)
```

```
[  0.   2.   6.  12.  20.  30.  42.  56.  72.  90. 110. 132. 156. 182.
 210.]
```

6 Somma di Matrici

[23]:
```
# Puliamo la memoria
%reset

import numpy as np
from pycuda import gpuarray, autoinit
import pycuda.driver as cuda
from pycuda.tools import DeviceData
from pycuda.tools import OccupancyRecord as occupancy
from matplotlib import pyplot as plt
```

```
Once deleted, variables cannot be recovered. Proceed (y/[n])? y
```

inizializziamo gli array con le dimensioni appropriate e copiamolo sulla gpu

[24]:
```
N = 512
presCPU, presGPU = np.float32, 'float'
#presCPU, presGPU = np.float64, 'double'
a_cpu = np.random.random((N,N)).astype(presCPU)
b_cpu = np.random.random((N,N)).astype(presCPU)
c_cpu = np.zeros((N,N), dtype=presCPU)

a_gpu = gpuarray.to_gpu(a_cpu)
b_gpu = gpuarray.to_gpu(b_cpu)
c_gpu = gpuarray.to_gpu(c_cpu)
```

misuriamo il tempo che ci vuole sull'host per fare la somma

[26]:
```
t_cpu = %timeit -o c_cpu = a_cpu + b_cpu
c_cpu = a_cpu + b_cpu
```

```
10000 loops, best of 3: 166 ţs per loop
```

definiamo il kernel gpu per fare la somma e compilamolo per generare la funzione da usare in python

[27]:
```
from pycuda.compiler import SourceModule

cudaKernel = """
__global__ void matrixAdd(float *A, float *B, float *C)
{
    int tid_x = blockDim.x * blockIdx.x + threadIdx.x;
    int tid_y = blockDim.y * blockIdx.y + threadIdx.y;
    int tid   = gridDim.x * blockDim.x * tid_y + tid_x;
    C[tid] = A[tid] + B[tid];
}
"""
myCode = SourceModule(cudaKernel)
addMatrix = myCode.get_function("matrixAdd")
```

```
# The output of get_function is the GPU-compiled function.
```

Per decidere la geoemtria della GPU, vediamo quanti thread ci sono in un blocco.

[28]:
```
dev = cuda.Device(0)
devdata = DeviceData(dev)
print ("Using device : "+dev.name() )
print("Max threads per block: "+str(dev.max_threads_per_multiprocessor))
```

```
Using device : Tesla T4
Max threads per block: 1024
```

Quindi possiamo usare blocchi 32x32. Le nostre matrici sono 512x512, per cui dobbiamo usare 16x16 blocchi

[29]:
```
cuBlock = (32,32,1)
cuGrid = (16,16,1)
```

abbiamo già compilato il kernel con SourceModule. Ora abbiamo due modi per lanciarlo. O chiamiamo direttamente la funzione (come abbiamo fatto sopra per la somam di vettori)

```
kernelFunction(arg1,arg2, ... ,block=(n,m,l),grid=(r,s,t)
```

oppure usiamo la "preparation"

```
kernelFunction.prepare('ABC..')
# Each letter corresponds to an input data type of the function, i = int, f = float, P = pointe
kernelFunction.prepared_call(grid,block,arg1.gpudata,arg2,...)
# When using GPU arrays, they should be passed as pointers with the attribute 'gpudata'
```

con la preparation è possibile misurare il tempo di esecuzione.

[30]:
```
addMatrix(a_gpu, b_gpu, c_gpu, block=cuBlock, grid=cuGrid)

addMatrix.prepare('PPP')
addMatrix.prepared_call(cuGrid,cuBlock,a_gpu.gpudata,b_gpu.gpudata,c_gpu.
 ↪gpudata)
c = c_gpu.get()
```

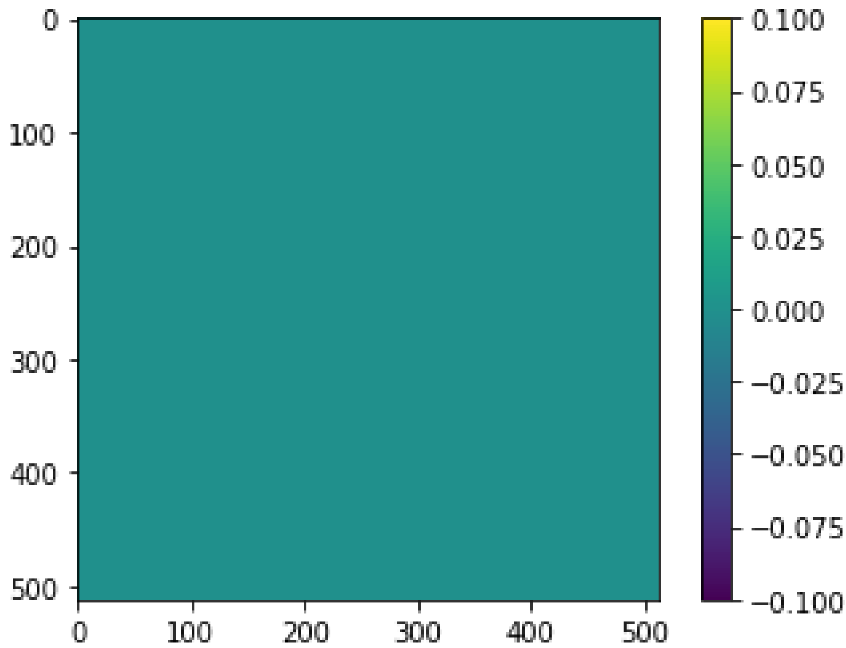
[31]:
```
time2 = addMatrix.prepared_timed_call(cuGrid,cuBlock,a_gpu.gpudata,b_gpu.
 ↪gpudata,c_gpu.gpudata)
time2()
```

[31]: 3.897599875926972e-05

per confrontare meglio, guardiamo i plot e la somma degli scarti

[33]:
```
plt.imshow(c_cpu - c, interpolation='none')
plt.colorbar()

np.sum(np.abs(c_cpu - c))
```

[33]: 0.0



7 Moltiplicazione tra matrici

scriviamo un kernel per la moltiplicazione di matrici

[34]:
```
cudaKernel2 = '''
__global__ void matrixMul(float *A, float *B, float *C)
{
    int tid_x = blockDim.x * blockIdx.x + threadIdx.x; // Row
    int tid_y = blockDim.y * blockIdx.y + threadIdx.y; // Column
    int matrixDim = gridDim.x * blockDim.x;
    int tid   = matrixDim * tid_y + tid_x; // element i,j

    float  aux=0.0f;

    for ( int i=0 ; i<matrixDim ; i++ ){
        //
        aux += A[matrixDim * tid_y + i]*B[matrixDim * i + tid_x] ;

    }

    C[tid] = aux;

}
'''
```

compiliamo e importiamo con SourceModule

[35]:
```
myCode = SourceModule(cudaKernel2)
mulMatrix = myCode.get_function("matrixMul")
```

eseguiamolo con la stessa struttura a blocchi definite per la somma di matrici

[36]:
```
mulMatrix(a_gpu,b_gpu,c_gpu,block=cuBlock,grid=cuGrid)
cc = c_gpu.get()
cc
```

[36]:
```
array([[118.96796 , 128.53334 , 137.8951  , ..., 136.81343 , 133.89436 ,
        127.94641 ],
       [122.9554  , 133.81279 , 143.96031 , ..., 141.14583 , 136.77325 ,
        130.43245 ],
       [112.57934 , 127.36276 , 133.96962 , ..., 134.69655 , 126.64585 ,
        126.39626 ],
       ...,
       [119.63033 , 126.494354, 133.07224 , ..., 135.8559  , 132.20541 ,
        124.66109 ],
       [119.22459 , 129.37212 , 137.39934 , ..., 140.91711 , 131.36617 ,
        129.44757 ],
       [114.62997 , 127.02198 , 133.08858 , ..., 132.60606 , 128.43506 ,
        125.69298 ]], dtype=float32)
```

sulla CPU sarà invece

[37]:
```
dotAB = np.dot(a_cpu, b_cpu)
dotAB
```

[37]:
```
array([[118.96799 , 128.53336 , 137.89502 , ..., 136.8135  , 133.89429 ,
        127.94642 ],
       [122.955475, 133.81274 , 143.96027 , ..., 141.1458  , 136.77321 ,
        130.43245 ],
       [112.579315, 127.362755, 133.96964 , ..., 134.69649 , 126.64586 ,
        126.39632 ],
       ...,
       [119.630356, 126.49432 , 133.0722  , ..., 135.85583 , 132.20549 ,
        124.66108 ],
       [119.22464 , 129.37212 , 137.39932 , ..., 140.91711 , 131.36627 ,
        129.4476  ],
       [114.63002 , 127.02196 , 133.0886  , ..., 132.60608 , 128.43506 ,
        125.69298 ]], dtype=float32)
```

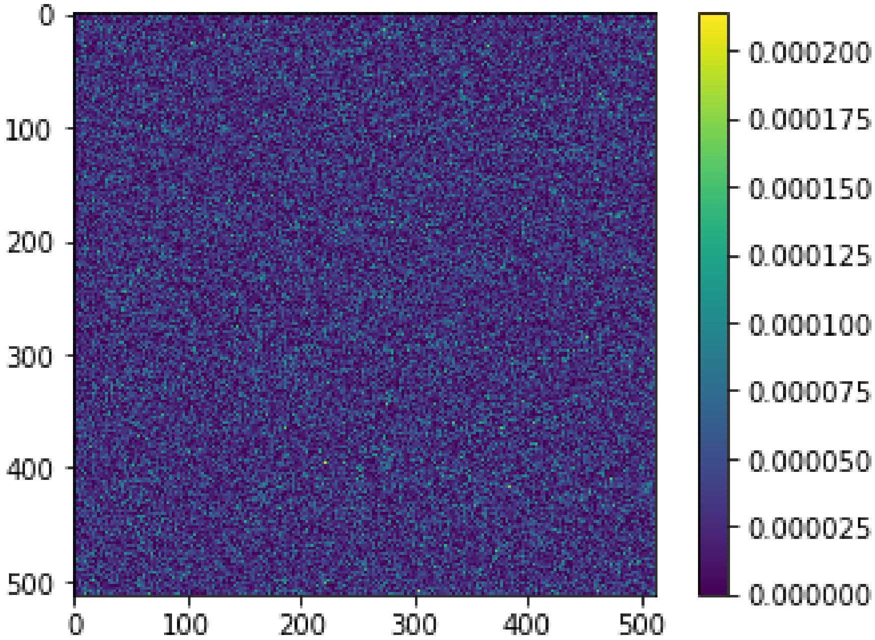
vediamo che il risultato è lo stesso a meno di errore numerico

[44]:
```
diff = np.abs(cc-dotAB)
err = np.sum(diff)/np.min(np.abs(cc))
print(err)
```

```
0.08186958
```

[39]:
```
plt.imshow(diff,interpolation='none')
plt.colorbar()
```

[39]:
```
<matplotlib.colorbar.Colorbar at 0x7f48587172e8>
```



[45]:
```
presCPU, presGPU = np.float64, 'double'
a_cpu = np.random.random((512,512)).astype(presCPU)
b_cpu = np.random.random((512,512)).astype(presCPU)
c_cpu = np.zeros((512,512), dtype=presCPU)
```

[46]:
```
a_gpu = gpuarray.to_gpu(a_cpu)
b_gpu = gpuarray.to_gpu(b_cpu)
c_gpu = gpuarray.to_gpu(c_cpu)
```

[48]:
```
cudaKernel3 = '''
__global__ void matrixMul64(double *A, double *B, double *C)
{
    int tid_x = blockDim.x * blockIdx.x + threadIdx.x; // Row
    int tid_y = blockDim.y * blockIdx.y + threadIdx.y; // Column
    int matrixDim = gridDim.x * blockDim.x;
    int tid   = matrixDim * tid_y + tid_x; // element i,j

    double aux = 0.0;
    for ( int i=0 ; i<matrixDim ; i++ ){
        //
        aux += A[matrixDim * tid_y + i]*B[matrixDim * i + tid_x] ;

    }

    C[tid] = aux;
```

```
}
'''
```

[49]:
```
myCode64 = SourceModule(cudaKernel3)
mulMatrix64 = myCode64.get_function("matrixMul64")
```

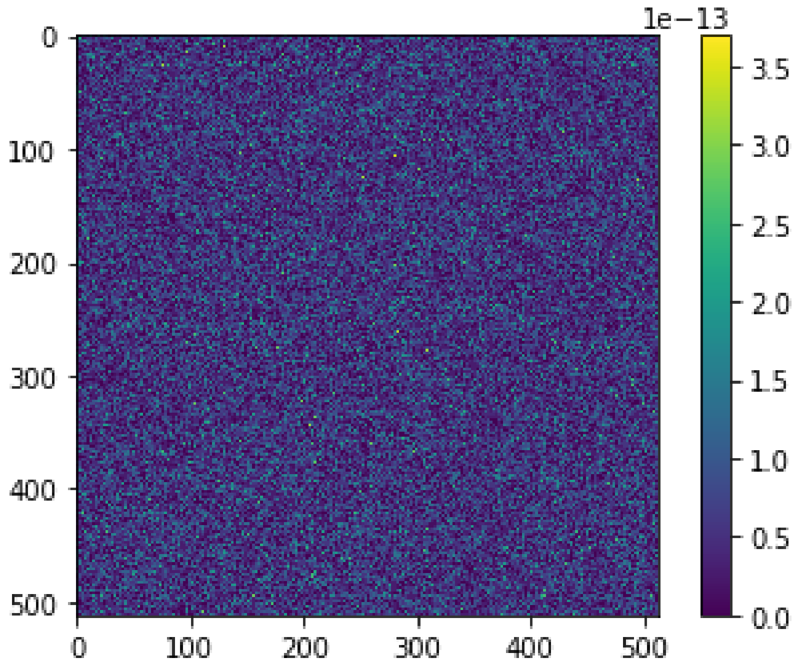
[50]:
```
mulMatrix64(a_gpu,b_gpu,c_gpu,block=cuBlock,grid=cuGrid)
```

[51]:
```
dotAB = np.dot(a_cpu, b_cpu)
```

[52]:
```
diff = np.abs(c_gpu.get()-dotAB)
```

[53]:
```
plt.imshow(diff,interpolation='none')
plt.colorbar()
```

[53]: <matplotlib.colorbar.Colorbar at 0x7f48585257b8>



8 Ancora sulla somma di vettori

[54]:
```
%reset
```

```
Once deleted, variables cannot be recovered. Proceed (y/[n])? y
```

Vogliamo confrontare i tempi per la somma di vettori di dimensione variabile, tra CPU e GPU Iniziamo con la versione CPU

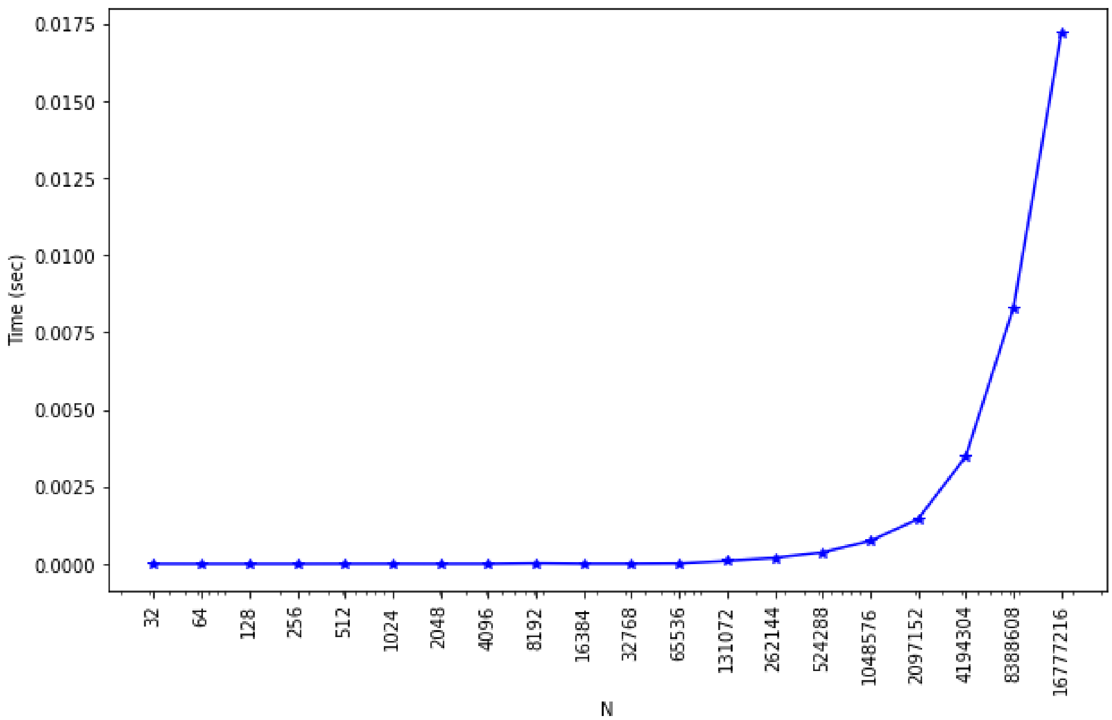
[55]:
```
%matplotlib inline
from matplotlib import pyplot as plt
import numpy as np
from time import time
def myColorRand():
    return (np.random.random(),np.random.random(),np.random.random())
```

[56]:
```
dimension = [2**i for i in range(5,25) ]
myPrec = np.float32
print(dimension)
```

```
[32, 64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384, 32768, 65536, 131072,
262144, 524288, 1048576, 2097152, 4194304, 8388608, 16777216]
```

[57]:
```
nLoops = 100
timeCPU = []
for n in dimension:
    v1_cpu = np.random.random(n).astype(myPrec)
    v2_cpu = np.random.random(n).astype(myPrec)
    tMean = 0
    for i in range(nLoops):
        t = time()
        v = v1_cpu+v2_cpu
        t = time() - t
        tMean += t/nLoops
    timeCPU.append(tMean)
```

[58]:
```
plt.figure(1,figsize=(10,6))
plt.semilogx(dimension,timeCPU,'b-*')
plt.ylabel('Time (sec)')
plt.xlabel('N')
plt.xticks(dimension, dimension, rotation='vertical')
plt.show()
```



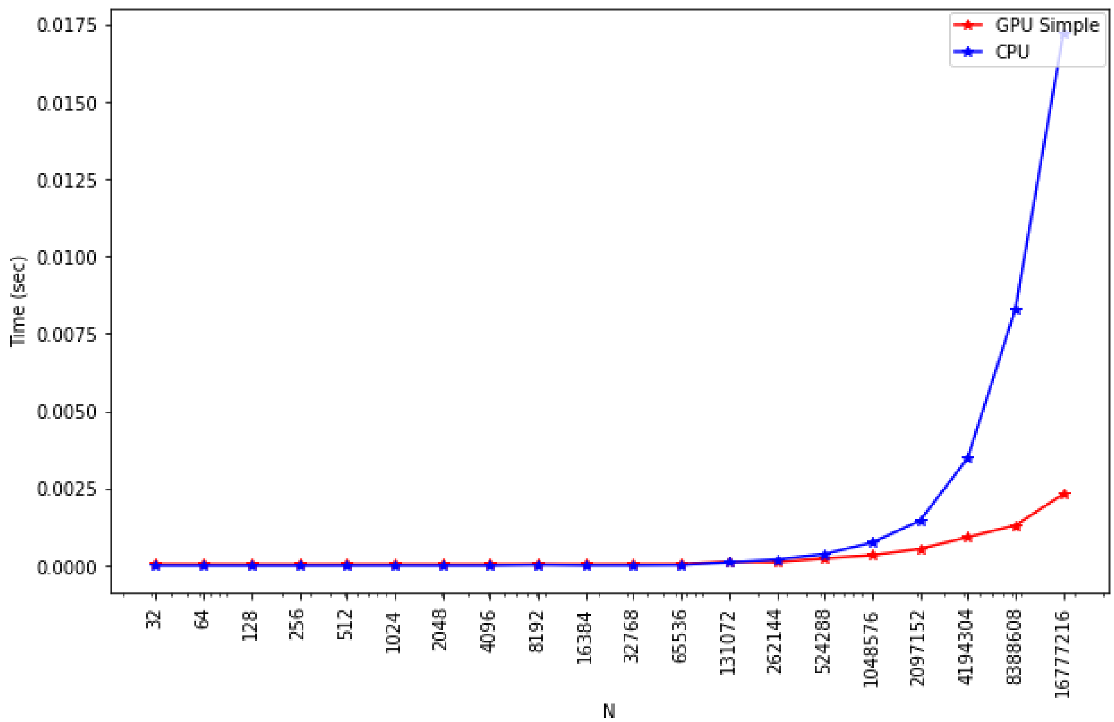
Proviamo a fare la versione GPU. Per prima cosa guardiamo la semplice somma (primo metodo)

[59]:
```
import pycuda
from pycuda import gpuarray
```

[60]:
```
timeGPU1 = []
bandWidth1 = []
for n in dimension:
    v1_cpu = np.random.random(n).astype(myPrec)
    v2_cpu = np.random.random(n).astype(myPrec)
    t1Mean = 0
    t2Mean = 0
    for i in range(nLoops):
        t = time()
        vaux = gpuarray.to_gpu(v1_cpu)
        t = time() -t
        t1Mean += t/nLoops
    bandWidth1.append(t1Mean)
    v1_gpu = gpuarray.to_gpu(v1_cpu)
    v2_gpu = gpuarray.to_gpu(v2_cpu)
    for i in range(nLoops):
        t = time()
        v = v1_gpu+v2_gpu
        t = time() -t
```

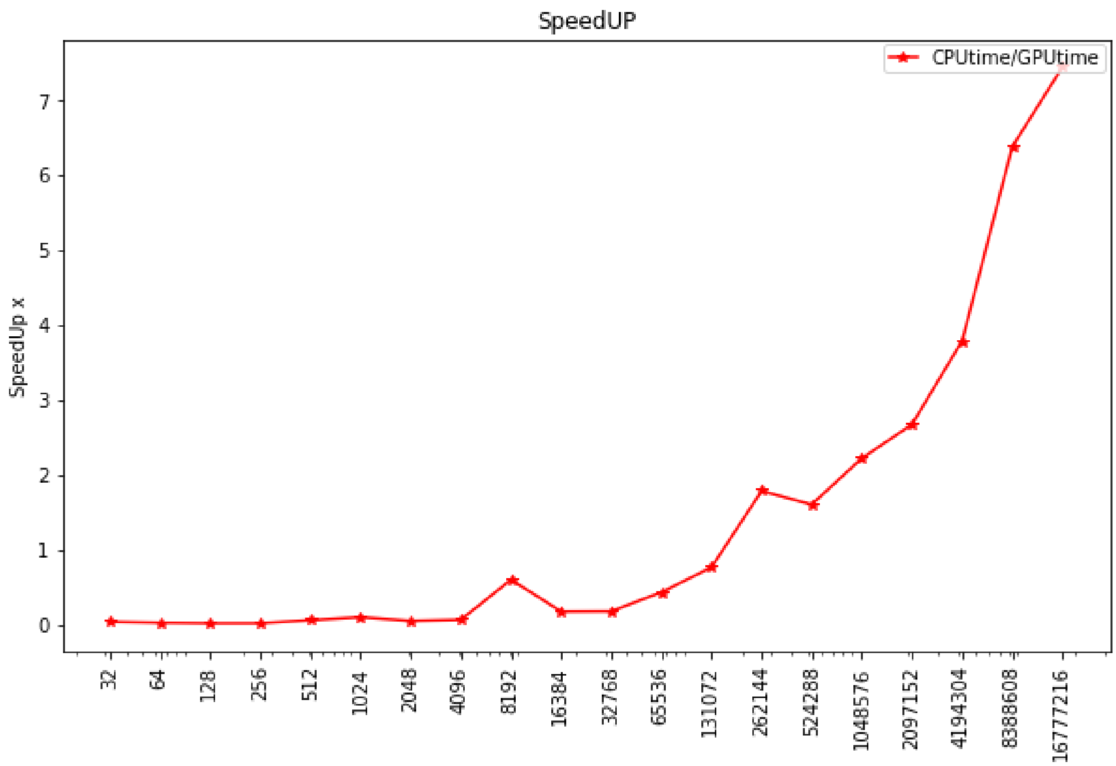
```
        t2Mean += t/nLoops
    timeGPU1.append(t2Mean)
    v1_gpu.gpudata.free()
    v2_gpu.gpudata.free()
    v.gpudata.free()
```

[61]:
```
plt.figure(1,figsize=(10,6))
plt.semilogx(dimension,timeGPU1,'r-*',label='GPU Simple')
plt.semilogx(dimension,timeCPU,'b-*',label='CPU')
plt.ylabel('Time (sec)')
plt.xlabel('N')
plt.xticks(dimension, dimension, rotation='vertical')
plt.legend(loc=1,labelspacing=0.5,fancybox=True, handlelength=1.5,␣
 ↪borderaxespad=0.25, borderpad=0.25)
plt.show()
```



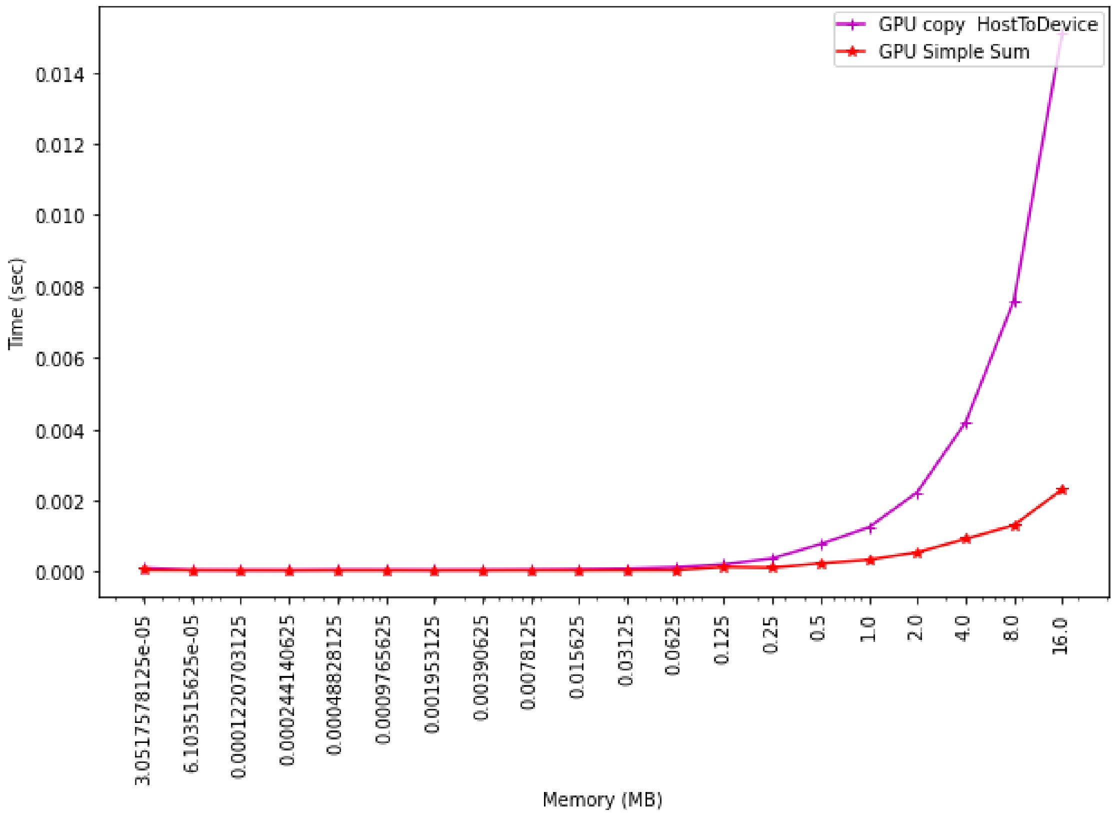
[62]:
```
plt.figure(1,figsize=(10,6))

a = np.array(timeGPU1)
b = np.array(timeCPU)
plt.semilogx(dimension,b/a,'r-*',label='CPUtime/GPUtime')
plt.ylabel('SpeedUp x')
plt.xlabel('N')
plt.title('SpeedUP')
```

```
plt.xticks(dimension, dimension, rotation='vertical')
plt.legend(loc=1,labelspacing=0.5,fancybox=True, handlelength=1.5,␣
 ↪borderaxespad=0.25, borderpad=0.25)
plt.show()
```



proviamo anche a valutare il tempo di trasferimento su GPU

[63]:
```
plt.figure(1,figsize=(10,6))
sizeMB = np.array(dimension)/(2.**20)
plt.semilogx(sizeMB,bandWidth1,'m-+',label='GPU copy  HostToDevice')
plt.semilogx(sizeMB,timeGPU1,'r-*',label='GPU Simple Sum')
plt.ylabel('Time (sec)')
plt.xlabel('Memory (MB)')
plt.xticks(sizeMB, sizeMB, rotation='vertical')
plt.legend(loc=1,labelspacing=0.5,fancybox=True, handlelength=1.5,␣
 ↪borderaxespad=0.25, borderpad=0.25)
plt.show()
```



proviamo ad usare elementwise (secondo metodo)

[64]:
```
from pycuda.elementwise import ElementwiseKernel
myCudaFunc = ElementwiseKernel(arguments = "float *a, float *b, float *c",
                               operation = "c[i] = a[i]+b[i]",
                               name = "mySumK")
```

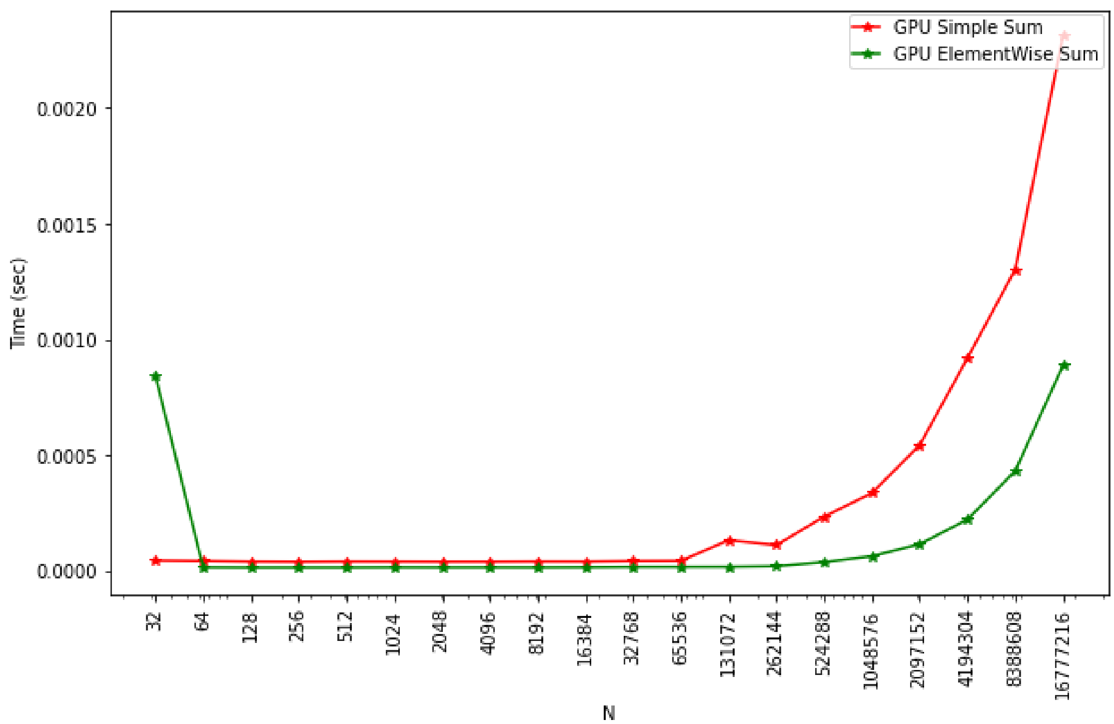
[65]:
```
import pycuda.driver as drv
start = drv.Event()
end = drv.Event()
```

[66]:
```
timeGPU2 = []
for n in dimension:
    v1_cpu = np.random.random(n).astype(myPrec)
    v2_cpu = np.random.random(n).astype(myPrec)
    v1_gpu = gpuarray.to_gpu(v1_cpu)
    v2_gpu = gpuarray.to_gpu(v2_cpu)
    vr_gpu  = gpuarray.to_gpu(v2_cpu)
    t3Mean=0
    for i in range(nLoops):
        start.record()
        myCudaFunc(v1_gpu,v2_gpu,vr_gpu)
        end.record()
```

```
        end.synchronize()
        secs = start.time_till(end)*1e-3
        t3Mean+=secs/nLoops
    timeGPU2.append(t3Mean)
    v1_gpu.gpudata.free()
    v2_gpu.gpudata.free()
    vr_gpu.gpudata.free()
```

[67]:
```
plt.figure(1,figsize=(10,6))
plt.semilogx(dimension,timeGPU1,'r-*',label='GPU Simple Sum')
plt.semilogx(dimension,timeGPU2,'g-*',label='GPU ElementWise Sum')
plt.ylabel('Time (sec)')
plt.xlabel('N')
plt.xticks(dimension, dimension, rotation='vertical')
plt.legend(loc=1,labelspacing=0.5,fancybox=True, handlelength=1.5,␣
 ↪borderaxespad=0.25, borderpad=0.25)
```

[67]: <matplotlib.legend.Legend at 0x7f4858284470>



Implementazione con SourceModule. E′ possibile variare la geometria di griglia e blocchi

[68]:
```
from pycuda.compiler import SourceModule
```

[ ]:
```
presCPU, presGPU = np.float32, 'float'
cudaCode = open("VecAdd.cu","r")
cudaCode = cudaCode.read()
```

```
cudaCode = cudaCode.replace('float',presGPU )
myCode = SourceModule(cudaCode)
vectorAddKernel = myCode.get_function("vectorAdd")
vectorAddKernel.prepare('PPP')
```

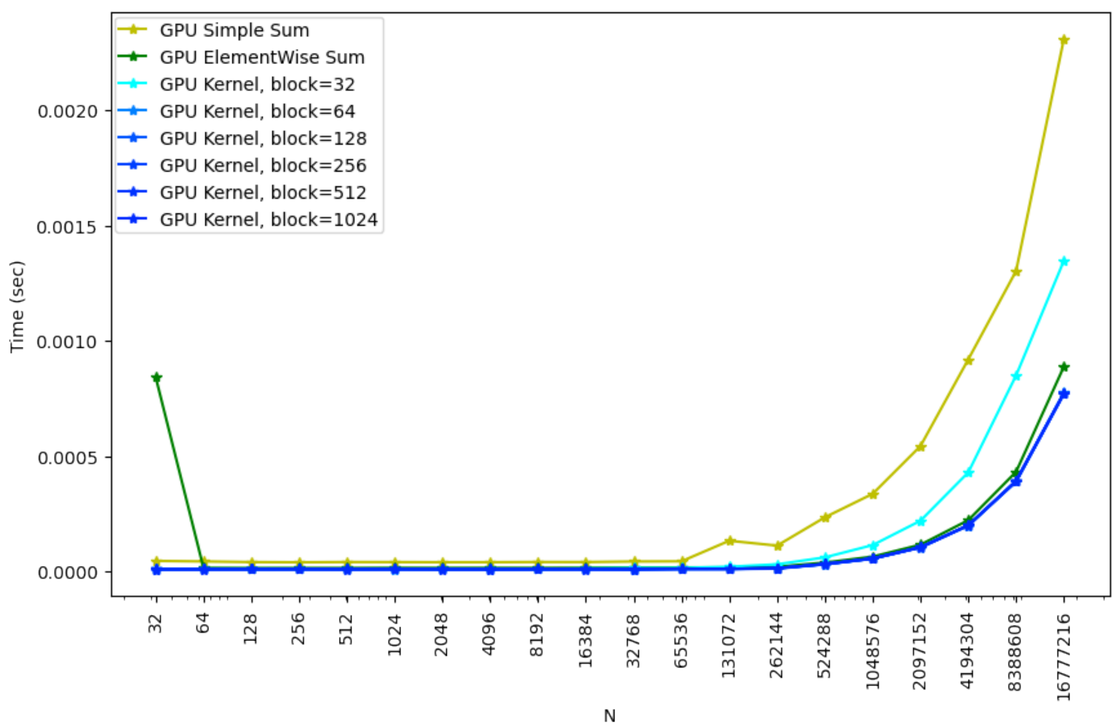
[ ]:
```
timeGPU3 = []
occupancyMesure=[]
for nt in [32,64,128,256,512,1024]:
    aux = []
    auxOcc = []
    for n in dimension:
        v1_cpu = np.random.random(n).astype(myPrec)
        v2_cpu = np.random.random(n).astype(myPrec)
        v1_gpu = gpuarray.to_gpu(v1_cpu)
        v2_gpu = gpuarray.to_gpu(v2_cpu)
        vr_gpu  = gpuarray.to_gpu(v2_cpu)
        cudaBlock = (nt,1,1)
        cudaGrid    = (int((n+nt-1)/nt),1,1)

        cudaCode = open("VecAdd.cu","r")
        cudaCode = cudaCode.read()
        cudaCode = cudaCode.replace('float',presGPU )
        downVar = ['blockDim.x','blockDim.y','blockDim.z','gridDim.x','gridDim.
 ↪y','gridDim.z']
        upVar      = [str(cudaBlock[0]),str(cudaBlock[1]),str(cudaBlock[2]),
                     str(cudaGrid[0]),str(cudaGrid[1]),str(cudaGrid[2])]
        dicVarOptim = dict(zip(downVar,upVar))
        for i in downVar:
            cudaCode = cudaCode.replace(i,dicVarOptim[i])
        #print cudaCode
        myCode = SourceModule(cudaCode)
        vectorAddKernel = myCode.get_function("vectorAdd")
        vectorAddKernel.prepare('PPP')

        print ('Size= '+str(n)+" threadsPerBlock= "+str(nt))
        print (str(cudaBlock)+" "+str(cudaGrid))
        t5Mean = 0
        for i in range(nLoops):
            timeAux = vectorAddKernel.
 ↪prepared_timed_call(cudaGrid,cudaBlock,v1_gpu.gpudata,v2_gpu.gpudata,vr_gpu.
 ↪gpudata)
            t5Mean += timeAux()/nLoops
        aux.append(t5Mean)
        v1_gpu.gpudata.free()
        v2_gpu.gpudata.free()
        vr_gpu.gpudata.free()
    timeGPU3.append(aux)
```

```
    occupancyMesure.append(auxOcc)
```

[ ]:
```
timeGPU3[0]
```

[72]:
```
plt.figure(1,figsize=(10,6),dpi=100)
plt.semilogx(dimension,timeGPU1,'y-*',label='GPU Simple Sum')
plt.semilogx(dimension,timeGPU2,'g-*',label='GPU ElementWise Sum')
count = 0
for nt in [32,64,128,256,512,1024]:
    plt.semilogx(dimension,timeGPU3[count],'-*',label='GPU Kernel, block={0}'.
 ↪format(nt),color=(0,1./(count+1),1))
    count+=1
plt.ylabel('Time (sec)')
plt.xlabel('N')
plt.xticks(dimension, dimension, rotation='vertical')
plt.legend(loc=2,labelspacing=0.5,fancybox=True, handlelength=1.5,␣
 ↪borderaxespad=0.25, borderpad=0.25)
```

[72]:
```
<matplotlib.legend.Legend at 0x7f48582b1240>
```



9 Generare il PDF del Notebook

[73]:
```
!apt-get install texlive texlive-xetex texlive-latex-extra pandoc
!pip install pypandoc
```

```
Reading package lists... Done
Building dependency tree
Reading state information... Done
pandoc is already the newest version (1.19.2.4~dfsg-1build4).
texlive is already the newest version (2017.20180305-1).
texlive-latex-extra is already the newest version (2017.20180305-2).
texlive-xetex is already the newest version (2017.20180305-1).
0 upgraded, 0 newly installed, 0 to remove and 14 not upgraded.
Requirement already satisfied: pypandoc in /usr/local/lib/python3.6/dist-
packages (1.5)
Requirement already satisfied: setuptools in /usr/local/lib/python3.6/dist-
packages (from pypandoc) (50.3.2)
Requirement already satisfied: pip>=8.1.0 in /usr/local/lib/python3.6/dist-
packages (from pypandoc) (19.3.1)
Requirement already satisfied: wheel>=0.25.0 in /usr/local/lib/python3.6/dist-
packages (from pypandoc) (0.35.1)
```

si deve montare il proprio google drive (seguire il link per ottenere la chiave di accesso)

[24]:
```python
from google.colab import drive
drive.mount('/content/drive')
```

```
Mounted at /content/drive
```

si deve copiare il notebook nella directory della macchina virtuale

[25]:
```
!cp "drive/My Drive/Colab Notebooks/handson_gpu_2020.ipynb" ./
```

ora si puo' convertire in pdf

[ ]:
```
!jupyter nbconvert --to PDF "handson_gpu_2020.ipynb"
```

scaricare il file pdf prodotto dal menu files nel pannelo di sinistra (premere il destro sul file e fare download)