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High Performance Computing Lab

Practical No. 11

Title of practical: Understanding concepts of CUDA Programming

Problem Statement 1:

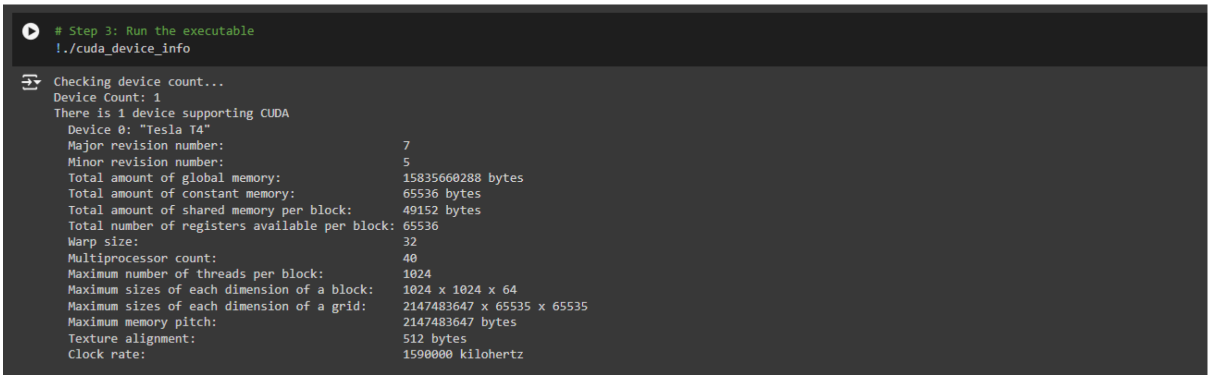
Execute the following program and check the properties of your GPGPU.

```
#include <stdio.h>
#include <stdlib.h>
int main()
{
	int deviceCount;
	cudaGetDeviceCount(&deviceCount);
	if (deviceCount == 0)
	{
	printf("There is no device supporting CUDA\n");
	}
	int dev;
	for (dev = 0; dev < deviceCount; ++dev)
	{
	cudaDeviceProp deviceProp;
	cudaGetDeviceProperties(&deviceProp, dev);
	if (dev == 0)
		{
			if (deviceProp.major < 1)
		{
				printf("There is no device supporting CUDA.\n");
```

```
                }
                else if (deviceCount == 1)
                {
                printf("There is 1 device supporting CUDA\n");
                }
                else
            {
                    printf("There are %d devices supporting CUDA\n",
deviceCount);
                }
    }
    printf("\nDevice %d: \"%s\"\n", dev, deviceProp.name);
    printf("  Major revision number:                    %d\n", deviceProp.major);
    printf("  Minor revision number:                    %d\n", deviceProp.minor);
    printf("  Total amount of global memory:            %d bytes\n",
deviceProp.totalGlobalMem);
    printf("  Total amount of constant memory:          %d bytes\n",
deviceProp.totalConstMem);
    printf("  Total amount of shared memory per block:  %d bytes\n",
deviceProp.sharedMemPerBlock);
    printf("  Total number of registers available per block: %d\n",
deviceProp.regsPerBlock);
    printf("  Warp size:                                %d\n", deviceProp.warpSize);
        printf("  Multiprocessor count:
%d\n",deviceProp.multiProcessorCount );


    printf("  Maximum number of threads per block:      %d\n",
deviceProp.maxThreadsPerBlock);
    printf("  Maximum sizes of each dimension of a block:    %d x %d x %d\n",
deviceProp.maxThreadsDim[0],deviceProp.maxThreadsDim[1],
deviceProp.maxThreadsDim[2]);
    printf("  Maximum sizes of each dimension of a grid:     %d x %d x %d\n",
deviceProp.maxGridSize[0], deviceProp.maxGridSize[1],  deviceProp.maxGridSize[2]);
```

```
        printf("  Maximum memory pitch:                    %d bytes\n",
devicePROP.memPitch);
        printf("  Texture alignment:                       %d bytes\n",
deviceProp.textureAlignment);
        printf("  Clock rate:                              %d kilohertz\n",
deviceProp.clockRate);
        }
}
```

Output:



```
# Step 3: Run the executable
!./cuda_device_info

Checking device count...
Device Count: 1
There is 1 device supporting CUDA
  Device 0: "Tesla T4"
  Major revision number:                         7
  Minor revision number:                         5
  Total amount of global memory:                 15835660288 bytes
  Total amount of constant memory:               65536 bytes
  Total amount of shared memory per block:       49152 bytes
  Total number of registers available per block: 65536
  Warp size:                                     32
  Multiprocessor count:                          40
  Maximum number of threads per block:           1024
  Maximum sizes of each dimension of a block:    1024 x 1024 x 64
  Maximum sizes of each dimension of a grid:     2147483647 x 65535 x 65535
  Maximum memory pitch:                          2147483647 bytes
  Texture alignment:                             512 bytes
  Clock rate:                                    1590000 kilohertz
```

Problem Statement 2:

Write a program to where each thread prints its thread ID along with hello world. Lauch the kernel with one block and multiple threads.

Code:

```
%%writefile cuda_device_info.cu
#include <stdio.h>
#include <cuda_runtime.h>

__global__ void helloWorldKernel() {
   // Get the block ID and thread ID
   int blockId = blockIdx.x;
```

```
    int threadId = threadIdx.x;
    printf("Hello World from block %d, thread %d\n", blockId, threadId);
}

int main() {
    // Launch the kernel with 5 blocks and 10 threads per block
    helloWorldKernel<<<5, 10>>>(); // 5 blocks, 10 threads per block
    cudaDeviceSynchronize(); // Wait for the kernel to finish
    return 0;
}
```

Output:

```
# Step 3: Run the executable
!./cuda_device_info

Hello World from block 4, thread 0
Hello World from block 4, thread 1
Hello World from block 4, thread 2
Hello World from block 4, thread 3
Hello World from block 4, thread 4
Hello World from block 4, thread 5
Hello World from block 4, thread 6
Hello World from block 4, thread 7
Hello World from block 4, thread 8
Hello World from block 4, thread 9
Hello World from block 1, thread 0
Hello World from block 1, thread 1
Hello World from block 1, thread 2
Hello World from block 1, thread 3
Hello World from block 1, thread 4
Hello World from block 1, thread 5
Hello World from block 1, thread 6
Hello World from block 1, thread 7
Hello World from block 1, thread 8
Hello World from block 1, thread 9
Hello World from block 3, thread 0
Hello World from block 3, thread 1
Hello World from block 3, thread 2
Hello World from block 3, thread 3
Hello World from block 3, thread 4
Hello World from block 3, thread 5
Hello World from block 3, thread 6
Hello World from block 3, thread 7
Hello World from block 3, thread 8
Hello World from block 3, thread 9
Hello World from block 2, thread 0
Hello World from block 2, thread 1
Hello World from block 2, thread 2
Hello World from block 2, thread 3
Hello World from block 2, thread 4
Hello World from block 2, thread 5
Hello World from block 2, thread 6
Hello World from block 2, thread 7
Hello World from block 2, thread 8
Hello World from block 2, thread 9
Hello World from block 0, thread 0
Hello World from block 0, thread 1
Hello World from block 0, thread 2
Hello World from block 0, thread 3
Hello World from block 0, thread 4
Hello World from block 0, thread 5
Hello World from block 0, thread 6
Hello World from block 0, thread 7
Hello World from block 0, thread 8
Hello World from block 0, thread 9
```

Analysis:

Block and Thread Structure:

- **There are 5 blocks (numbered 0 to 4), with each block containing 10 threads (numbered 0 to 9).**
- **Each thread within a block prints a message that includes its block and thread ID.**

Execution Order:

- **The output is not in sequential order (i.e., block 0, followed by block 1, and so on). Instead, blocks appear in a seemingly random order (4, 1, 3, 2, and then 0). This is expected behaviour in parallel processing, as blocks are scheduled and executed independently and may complete in any order.**
- **The threads within each block are executed in sequential order from thread 0 to thread 9. This suggests that within each block, thread execution is ordered, but block order is not guaranteed.**

Parallel Processing Analysis:

- **This pattern is a typical outcome of multi-threaded execution in a block-based parallel programming model, such as with CUDA or OpenMP, where the scheduler assigns blocks and threads to available resources, allowing for efficient concurrent execution.**

Interpretation of Output:

- **The interleaving of blocks reflects the flexibility of parallel scheduling, which allows independent tasks (like blocks) to run concurrently without enforcing a strict order.**
- **The consistent order within each block (thread 0 to thread 9) might imply a controlled or synchronized sequence within the block, even if the blocks themselves are scheduled freely across processing units.**

Problem Statement 3:

Write a program to where each thread prints its thread ID along with hello world. Lauch the kernel with multiple blocks and multiple threads.

Code:

```
%%writefile cuda_device_info.cu

#include <stdio.h>

#include <cuda_runtime.h>
```

```
__global__ void helloWorldKernel() {
    // Get the block ID and thread ID within the block
    int blockId = blockIdx.x;
    int threadIdInBlock = threadIdx.x;

    // Get the global thread ID across all blocks
    int globalThreadId = blockId * blockDim.x + threadIdInBlock;

    printf("Hello World from block %d, thread %d (global thread ID: %d)\n", blockId,
threadIdInBlock, globalThreadId);
}

int main() {
    int numBlocks = 2;          // Number of blocks
    int threadsPerBlock = 5;    // Number of threads per block

    // Launch the kernel with multiple blocks and multiple threads
    helloWorldKernel<<<numBlocks, threadsPerBlock>>>();

    // Synchronize the device
    cudaDeviceSynchronize(); // Wait for the kernel to finish

    return 0;
}
```

Output:

```
# Step 2: Compile the code
!nvcc cuda_device_info.cu -o cuda_device_info
```

```
[ ] # Step 3: Run the executable
!./cuda_device_info
```

```
Hello World from block 1, thread 0 (global thread ID: 5)
Hello World from block 1, thread 1 (global thread ID: 6)
Hello World from block 1, thread 2 (global thread ID: 7)
Hello World from block 1, thread 3 (global thread ID: 8)
Hello World from block 1, thread 4 (global thread ID: 9)
Hello World from block 0, thread 0 (global thread ID: 0)
Hello World from block 0, thread 1 (global thread ID: 1)
Hello World from block 0, thread 2 (global thread ID: 2)
Hello World from block 0, thread 3 (global thread ID: 3)
Hello World from block 0, thread 4 (global thread ID: 4)
```

Analysis:

Block and Thread Structure:

- **There are 2 blocks (block 0 and block 1), each with 5 threads.**
- **Threads within each block have local thread IDs from 0 to 4.**
- **Each thread also has a global thread ID, which is a unique identifier across all blocks and threads, calculated as global_thread_id = block_id * num_threads_per_block + thread_id.**

Global Thread ID Calculation:

- **For block 0, thread IDs from 0 to 4 correspond to global thread IDs from 0 to 4.**
- **For block 1, thread IDs from 0 to 4 correspond to global thread IDs from 5 to 9.**
- **This global ID uniquely identifies each thread across all blocks, allowing for a single identifier in the entire grid, useful in indexing and memory operations in parallel processing.**

Execution Order:

- **The output does not follow strict sequential order (block 0 then block 1), likely due to parallel scheduling.**
- **Block 1 messages appear first, followed by block 0, which indicates that block execution can start and finish independently, and block order is not enforced.**

Parallel Execution and Scheduling:

- **The output suggests that while threads within each block execute in a specific order (0 to 4), the blocks themselves may execute in any order due to parallel scheduling.**
- **This unordered block execution reflects parallel processing's non-deterministic scheduling, where independent units (blocks) are scheduled based on resource availability, leading to varied completion times.**

Problem Statement 4:

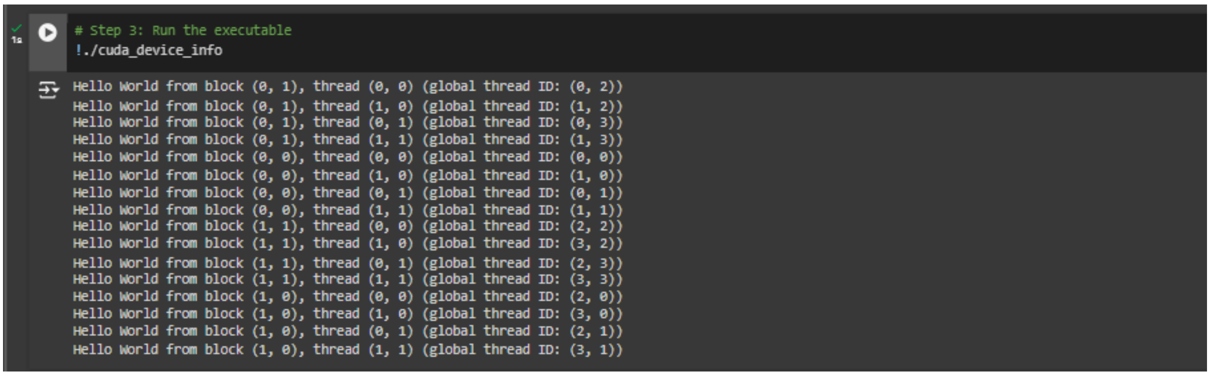
Write a program to where each thread prints its thread ID along with hello world. Lauch the kernel with 2D blocks and 2D threads.

Code:

```
%%writefile cuda_device_info.cu
#include <stdio.h>
#include <cuda_runtime.h>

__global__ void helloWorldKernel() {
   // Get the 2D thread ID within the block
   int threadIdX = threadIdx.x;
   int threadIdY = threadIdx.y;

   // Get the 2D block ID
   int blockIdX = blockIdx.x;
   int blockIdY = blockIdx.y;

   // Get the global thread ID in 2D grid
   int globalThreadIdX = blockIdX * blockDim.x + threadIdX;
   int globalThreadIdY = blockIdY * blockDim.y + threadIdY;

   printf("Hello World from block (%d, %d), thread (%d, %d) (global thread ID: (%d,
%d))\n",
          blockIdX, blockIdY, threadIdX, threadIdY, globalThreadIdX,
globalThreadIdY);
}

int main() {
   dim3 threadsPerBlock(2, 2); // Size of the block (2x2 threads)
   dim3 numBlocks(2, 2);       // Number of blocks (2x2 blocks)
```

```
    // Launch the kernel with 2D blocks and 2D threads
    helloWorldKernel<<<numBlocks, threadsPerBlock>>>();
    cudaDeviceSynchronize(); // Wait for the kernel to finish

    return 0;
}
```

Output:



```
# Step 3: Run the executable
!./cuda_device_info

Hello World from block (0, 1), thread (0, 0) (global thread ID: (0, 2))
Hello World from block (0, 1), thread (1, 0) (global thread ID: (1, 2))
Hello World from block (0, 1), thread (0, 1) (global thread ID: (0, 3))
Hello World from block (0, 1), thread (1, 1) (global thread ID: (1, 3))
Hello World from block (0, 0), thread (0, 0) (global thread ID: (0, 0))
Hello World from block (0, 0), thread (1, 0) (global thread ID: (1, 0))
Hello World from block (0, 0), thread (0, 1) (global thread ID: (0, 1))
Hello World from block (0, 0), thread (1, 1) (global thread ID: (1, 1))
Hello World from block (1, 1), thread (0, 0) (global thread ID: (2, 2))
Hello World from block (1, 1), thread (1, 0) (global thread ID: (3, 2))
Hello World from block (1, 1), thread (0, 1) (global thread ID: (2, 3))
Hello World from block (1, 1), thread (1, 1) (global thread ID: (3, 3))
Hello World from block (1, 0), thread (0, 0) (global thread ID: (2, 0))
Hello World from block (1, 0), thread (1, 0) (global thread ID: (3, 0))
Hello World from block (1, 0), thread (0, 1) (global thread ID: (2, 1))
Hello World from block (1, 0), thread (1, 1) (global thread ID: (3, 1))
```

Analysis:

2D Block and Thread Structure:

- **The setup shows a two-dimensional block structure, where each block is identified by coordinates (x, y).**
- **Each block contains threads arranged in a two-dimensional grid, also identified by (x, y) coordinates.**
- **The format for each output line is:**
  "Hello World from block (block_x, block_y), thread (thread_x, thread_y) (global thread ID: (global_x, global_y))"

Global Thread ID Calculation:

- **Each thread is assigned a unique global thread ID as a coordinate (global_x, global_y), which seems to relate to the block and thread coordinates.**
- **From the output, we can infer a formula where global_x and global_y are determined as follows:**
  - **global_x = block_x * threads_per_block_x + thread_x**

- global_y = block_y * threads_per_block_y + thread_y

- **This formula allows the system to map each thread in its block to a unique global identifier, useful for tasks that need distinct identification across the entire grid.**

Execution Order:

- **The blocks do not follow a sequential order (like (0,0), (0,1), (1,0), (1,1)), suggesting that each block executes independently, as per the scheduling order.**
- **Within each block, however, threads are listed in order, indicating sequential processing within each block, even though blocks themselves may complete at different times.**

Parallel Execution Insights:

- **The independence of block execution shows that the program allows blocks to run in parallel, leveraging the underlying system's scheduling to determine the order.**
- **The sequential nature within each block (order of threads from (0,0) to (1,1)) ensures that operations within a block are synchronized or ordered but allows flexibility across blocks.**

Code:

```
%%writefile cuda_device_info.cu
#include <stdio.h>
#include <cuda_runtime.h>

__global__ void helloWorldKernel() {
   // Get the 2D thread ID within the block
   int threadIdX = threadIdx.x;
   int threadIdY = threadIdx.y;

   // Get the 2D block ID
   int blockIdX = blockIdx.x;
   int blockIdY = blockIdx.y;
```

```
    // Get the global thread ID in 2D grid
    int globalThreadIdX = blockIdX * blockDim.x + threadIdX;
    int globalThreadIdY = blockIdY * blockDim.y + threadIdY;

    // Calculate the 1D global ID
    int globalThreadId1D = (blockIdY * gridDim.x + blockIdX) * (blockDim.x *
blockDim.y) + (threadIdY * blockDim.x) + threadIdX;

    printf("Hello World from block (%d, %d), thread (%d, %d) (global thread ID: (%d,
%d), 1D global ID: %d)\n",
           blockIdX, blockIdY, threadIdX, threadIdY, globalThreadIdX,
globalThreadIdY, globalThreadId1D);
}

int main() {
    dim3 threadsPerBlock(2, 2); // Size of the block (2x2 threads)
    dim3 numBlocks(2, 2);       // Number of blocks (2x2 blocks)

    // Launch the kernel with 2D blocks and 2D threads
    helloWorldKernel<<<numBlocks, threadsPerBlock>>>();
    cudaDeviceSynchronize(); // Wait for the kernel to finish

    return 0;
}
```

Output:

```
[ ] # Step 3: Run the executable
    !./cuda_device_info

Hello World from block (1, 0), thread (0, 0) (global thread ID: (2, 0), 1D global ID: 4)
Hello World from block (1, 0), thread (1, 0) (global thread ID: (3, 0), 1D global ID: 5)
Hello World from block (1, 0), thread (0, 1) (global thread ID: (2, 1), 1D global ID: 6)
Hello World from block (1, 0), thread (1, 1) (global thread ID: (3, 1), 1D global ID: 7)
Hello World from block (1, 1), thread (0, 0) (global thread ID: (2, 2), 1D global ID: 12)
Hello World from block (1, 1), thread (1, 0) (global thread ID: (3, 2), 1D global ID: 13)
Hello World from block (1, 1), thread (0, 1) (global thread ID: (2, 3), 1D global ID: 14)
Hello World from block (1, 1), thread (1, 1) (global thread ID: (3, 3), 1D global ID: 15)
Hello World from block (0, 0), thread (0, 0) (global thread ID: (0, 0), 1D global ID: 0)
Hello World from block (0, 0), thread (1, 0) (global thread ID: (1, 0), 1D global ID: 1)
Hello World from block (0, 0), thread (0, 1) (global thread ID: (0, 1), 1D global ID: 2)
Hello World from block (0, 0), thread (1, 1) (global thread ID: (1, 1), 1D global ID: 3)
Hello World from block (0, 1), thread (0, 0) (global thread ID: (0, 2), 1D global ID: 8)
Hello World from block (0, 1), thread (1, 0) (global thread ID: (1, 2), 1D global ID: 9)
Hello World from block (0, 1), thread (0, 1) (global thread ID: (0, 3), 1D global ID: 10)
Hello World from block (0, 1), thread (1, 1) (global thread ID: (1, 3), 1D global ID: 11)
```

Analysis:

2D Block and Thread Structure:

- **Each line shows a thread within a specific 2D block, identified as (block_x, block_y).**
- **Each thread within a block is located by a 2D coordinate (thread_x, thread_y).**
- **This setup reflects a hierarchical structure where threads are organized in a 2D grid within each block.**

Global Thread ID (2D):

- **The global thread ID (x, y) is a unique identifier that represents each thread's position across all blocks, calculated based on both block and thread positions.**
- **From the output, the calculation for each global coordinate appears to be:**
  - **global_x = block_x * threads_per_block_x + thread_x**
  - **global_y = block_y * threads_per_block_y + thread_y**
- **This mapping allows each thread to have a unique position in a 2D plane that spans all blocks.**

1D Global ID:

- **The 1D global ID provides a unique linear (1D) identifier for each thread, which is likely calculated by flattening the 2D grid into a single-dimensional array.**
- **The formula appears to follow a row-major order:**
  - **1D global ID = global_x * total_grid_y + global_y**
- **This conversion simplifies referencing and accessing each thread, especially in applications requiring a linear index (e.g., indexing in arrays).**

Execution Order:

- **The blocks are processed in a non-sequential order, suggesting that block execution depends on system scheduling and is not strictly sequential.**

- **Within each block, threads are listed in a fixed order (typically row-by-row), indicating that threads within a block are processed sequentially.**

Parallel Execution Insights:

- **The non-deterministic execution order of blocks indicates parallelism, where the execution of different blocks is independent, allowing for concurrent processing.**
- **This layout is particularly efficient for large-scale parallel computing tasks where each block can operate independently, while each thread within a block can handle sub-tasks of the larger process.**