# OpenCL exercise 4: Matrix Multiplication

Kaicong Sun

# Local Memory

- Local memory: Shared by all work items of one work group
  - Two work items in the same work group will see the same data
  - Two work items in the different work groups will see different data
- Size: 16kB or 48kB
- Significantly higher memory bandwidth compared to global memory
- Significantly lower latency compared to global memory
  - Random accesses patterns are fast
- Used for:
  - Manually caching data from global memory
  - Storage for data being worked on
- In Cuda: “Shared memory”
  - Has nothing to do with Cuda “Local memory”

# Local Memory Allocation

After compiling the program, the local memory size can not be modified. In other words, the size must be known before compiling. On the kernel side:

- Declare “i” as 32-bit integer in local memory

  ```
  __local int i;
  ```

- Declare “a” as 2D array of unsigned 32-bit integers with a size of 10x15

  ```
  __local uint a[10][15];
  ```

  - “10” and “15” must be compile-time constants

- Wait until all threads have reached this point and prevent any local memory access from being moved across this line

  ```
  barrier(CLK_LOCAL_MEM_FENCE);
  ```

# Dynamic Local Memory Allocation

The size of the local memory is not necessary to be known before compiling. On the kernel side:

- Kernel definition:

```
__kernel void kernel1(__local float* localMem) { ... }
```

- Use inside kernel

```
localMem[i] = 10;
foo = localMem[j];
```

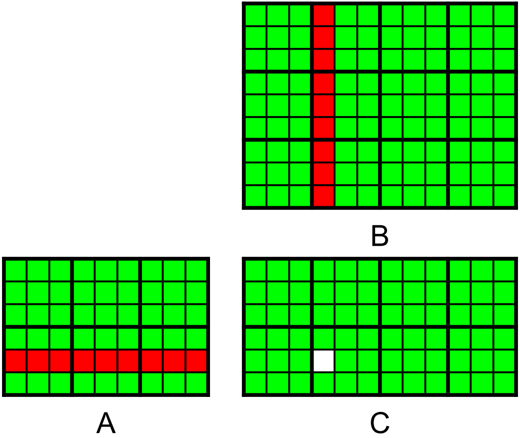
- Calling the kernel

```
kernel1.setArg(0, cl::Local(2*wgX*wgY*sizeof(float)));
queue.enqueueNDRangeKernel(kernel1, ...);
```

- `localMem[]` will contain space for `wgX * wgY` floats

# Matrix Multiplication

- 3 matrices: **A**, **B**, **C**, calculate $C = AB$
- $C_{i,j} = \sum_{k=1}^{n} A_{i,k} B_{k,j}$

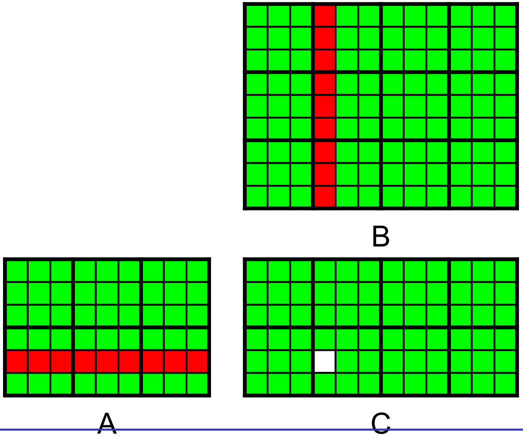


# Host code

```
for (std::size_t j = 0; j < countAY; j++) {
    for (std::size_t i = 0; i < countBX; i++) {
        float sum = 0;
        for (std::size_t k = 0; k < countAX_BY; k++) {
            float a = h_inputA[k + j * countAX_BY];
            float b = h_inputB[i + k * countBX];
            sum += a * b;
        }
        h_outputC[i + j * countBX] = sum;
    }
}
```

# Task 1: Simple GPU implementation

Implement host code on GPU, use one work item for each element in *C* (the result matrix).

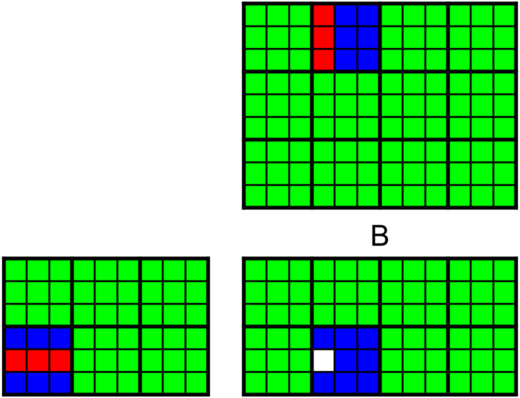


# Task 2: Local memory

Take advantage of local memory to speed up the calculation

- Input Matrices are split into quadratic blocks, size of block = size of work group
- Each work group will:
  - For each input block needed:
    - Load the block from global input buffer *A* into local memory
    - Load the block from global input buffer *B* into local memory
    - Barrier
    - Use the data from local memory to calculate the result
    - Barrier
  - Store the result

# Step 1

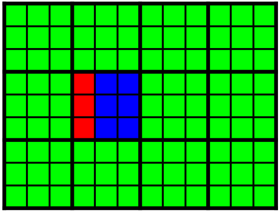


B

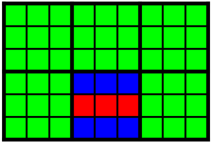
A

C

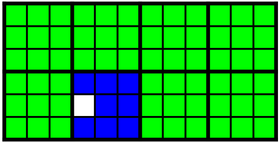
# Step 2



B

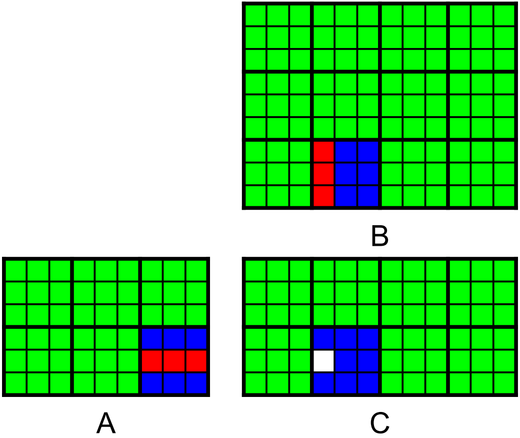


A



C

# Step 3



# Pseudocode

```
for (uint j = 0; j < countAY; j++) {
    for (uint i = 0; i < countBX; i++) {
        float sum = 0;
        int k = get_local_id(0);
        int g = get_local_id(1);
        __local float l_A[WG_SIZE][WG_SIZE];
        __local float l_B[WG_SIZE][WG_SIZE];
        // loop over the submatrices
        for (uint bs = 0; bs < countAX_BY; bs += WG_SIZE) {
            //Copy blocks of d_inputA, d_inputB to local memory
            l_A[g][k] = d_inputA[(k+bs) + j * countAX_BY];
            l_B[g][k] = d_inputB[i + (g+bs) * countBX];

            barrier(CLK_LOCAL_MEM_FENCE);
            for (uint m = 0; m < WG_SIZE; m++)
                sum += l_A[g][m] * l_B[m][k];
            barrier(CLK_LOCAL_MEM_FENCE);
        }
        d_outputC[i + j * countBX] = sum;
    }
}
```

# Hints

- For copying a block of data (with size of block = size of work group) into local memory, each work item has to copy one value
  - Two consecutive work items in X-direction should read two consecutive values from global memory
  - `localMem[get_local_id(1)][get_local_id(0)] = globalMem[x + width * y];`
- To make sure a kernel is only called with a certain work group size:

  ```
  __attribute__((reqd_work_group_size(10, 20, 1)))
  __kernel void kernel1() { ... }
  ```

  Kernel can only be called with a 2D work group with 10x20 elements.

# Task 3/4

Two (optional) tasks:

- Task 3: Make a copy of the kernel of Task 2 and modify it so that it doesn't need any compile-time knowledge of the work group size (i.e. `WG_SIZE`)
  - Will need a dynamically sized local memory area
  - Will be slower than kernel 2

```
matrixMulKernel.setArg(4, cl::Local(2 * wgSize
* wgSize * sizeof(float)));
__local float* l_A = localMem;
__local float* l_B = localMem + get_local_size(0)
* get_local_size(1);
```

- Task 4: Create a kernel similar to kernel 1, but use OpenCL images for *A* and *B*
  - Will be slower than kernel 2 and kernel 3
  - Might be slower or faster than kernel 1