# CUDA – Recap and Higher Dimension Grids

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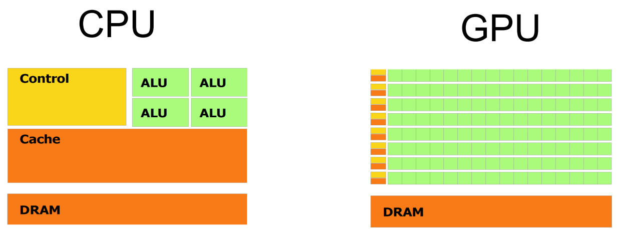
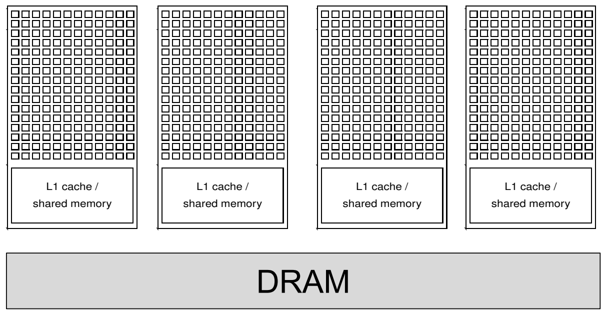
# Recap - What is a GPU?

- A specialized processor initially designed for graphics-like workload (videogames, video processing and CAD)
    - **Lots of cores**, **fewer control units**: very good in compute-heavy applications with little synchronization
- Now present in several supercomputers
    - **Power efficiency**: lot of parallelism but lower clock frequency
- GPU consists of one or more **SMs**, each one comprising **several cores (K80 almost 5k cores!)**





## Recap - What is CUDA?

It is an extension of the C language  that provide basic mechanisms to:

- Create allocate variable on GPU memory

**Question**: Which CUDA function?

- Move data from CPU to GPU memory and vice-versa

**Question:** Which CUDA function?

- Define kernel and launch a kernel

**Question:** Which qualifier I have to use? What is the difference between a kernel and a function.

- Synchronize threads

**Question:** Which CUDA function?

## Recap - Lab

- `HelloWorld` in CUDA

**Problem:** not printing because of the asynchronous nature of the kernel launch

- `saxpy` in CUDA

**Problem**: `ARRAY_SIZE` was not a multiple of `BLOCK_SIZE`

**Problem**: create variable on GPU and move data to/GPU.

*Easy to get it wrong:*

In C, **the size of the data** to be created or moved is **in byte** (Fortran the size is the number of array elements)

# Back to CUDA – CUDA Vector Types

CUDA extends the standard C data types, like `int` and `float`, to be vector with 2, 3 and 4 components, like `int2`, `int3`, `int4`, `float2`, `float3` and `float4`. Other vector types are also supported.

For example, you can declare an integer vector `d` with three components and initialize with 128, 1 and 1 element in the x, y and z direction:

```
int3 d = int3(128, 1, 1);
```

**Question:** does this look reminiscent of something you saw in the lab?

## Access vector types components

CUDA vector types are structures (Fortran: modules) and the 1st, 2nd, 3rd, and 4th components are accessible through the fields .x, .y, .z, and .w (Fortran: %x, %y, %z and %w), respectively.

```
float3 part_pos;
part_pos.z = 1.0f; // is legal
~~part_pos.w = 1.0f;~~ // is illegal: Why?
```

**Question:** What do the `.x` remind you of?

## Type of `blockIdx` and `threadIdx`

CUDA uses the vector type `uint3` for the index variables, `blockIdx` and `threadIdx`. A `uint3` variable is a vector with three unsigned integer components.

We used `threadIdx.x` and `blockIdx.x` to retrieve indices in 1D grid.

## CUDA Type `dim3`

CUDA uses the vector type `dim3` for the dimension variables, `gridDim` and `blockDim`.

The `dim3` type is equivalent to `uint3` with unspecified entries set to 1.

As you probably noticed in the Lab1 for the lab, we could use either:

```
dim3 grid(1,1,1); // 1 block in the grid
dim3 block(32,1,1); // 32 threads per block
```

Or set block and thread per block as scalar quantity in the `<<<   >>>` (execution configuration)

# Why do we need higher dimensions CUDA grids?

Several applications points regularly distributed on a **2D plane**. A first example can be a matrix. A second example involves digital image processing.

A digital raster imagine consists of a collection of **picture elements** (**pixel**) arranged in a uniform 2D rectangular grid with each pixel having an **intensity value**.

**Example of 3x3 .bmp image file** (see lab today)

| Header | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (0,0) | (0,1) | (0,2) | (0,3) | (0,4) | (0,5) | (0,6) | (0,7) | (0,8) |
| (1,0) | (1,1) | (1,2) | (1,3) | (1,4) | (1,5) | (1,6) | (1,7) | (1,8) |
| (2,0) | (2,1) | (2,2) | (2,3) | (2,4) | (2,5) | (2,6) | (2,7) | (2,8) |

## 2D Grid Kernel – Thread per block in x and y

Computing data for an image involves `W` columns and `H` rows, and we can organize the computation into 2D blocks with `TX` threads in the x-direction and `TY` threads in the y-direction.

```
dim3 blockSize(TX, TY); // Equivalent to dim3 blockSize(TX, TY, 1);
```

**Question:** can we use 1D block in a 2D grid?

## 2D Grid Kernel – Number of blocks in x and y

**Questions:** how do we choose the number of blocks in x and y ? If we follow the 1D example, what would be `N` or the `ARRAY_SIZE` equivalent?

We compute the number of blocks (`bx` and `by`) needed in each direction exactly as in the 1D case:

```
int bx = (W + blockSize.x - 1)/blockSize.x ;
int by = (H + blockSize.y - 1)/blockSize.y ;
```

The syntax for specifying the grid size (in blocks) is

```
dim3 gridSize = dim3 (bx, by);
```

## 2D Grid Kernel Launch

We are ready now to launch (no difference with 1D grid):

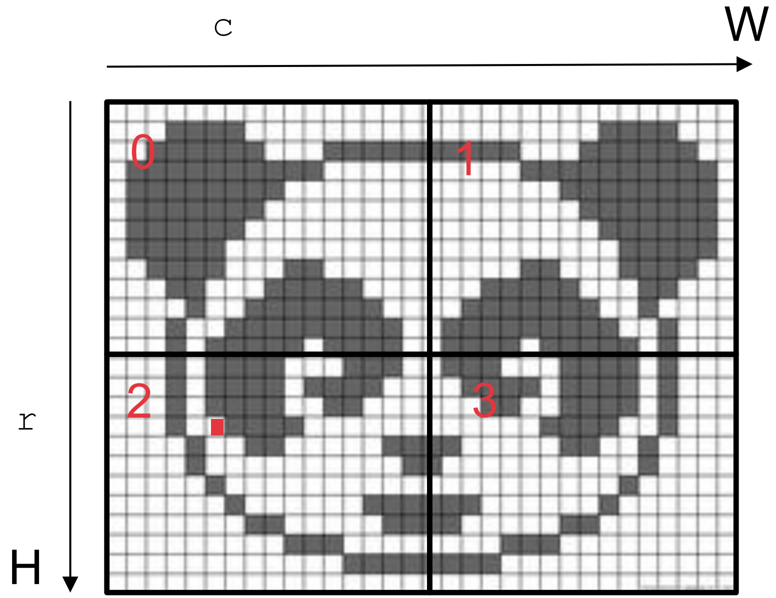
```
kernelName<<<gridSize, blockSize>>>(args)
```

# Determine global indices

To identify our pixel in the image we will use to global indices `c` and `r`.

**Question:** How you calculate `c` and `r` for the red pixel?

```
int c = blockIdx.x*blockDim.x + threadIdx.x;
Int r = blockIdx.y*blockDim.y + threadIdx.y;
```

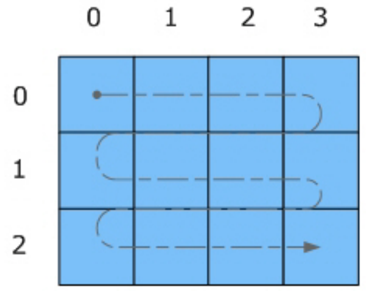


# Flattening global indices to 1D global index

In several cases, it is convenient to express our 2D data as 1D data (flattening): use simply a 1D array of length `W*H`

We place values in the 1D array in **row-major order:** we store the data from row 0, followed by data from row 1 and so on.

Row-major order



**Question:** Why row-major order and not column-major order ?

**Question:** How do you calculate `i`, 1D index? `int i = r*w + c;`

# CUDA code for distance between points in 2D

```
#define W 32
#define H 32
#define TX 8 // number of threads per block along x-axis
#define TY 8 // number of threads per block along y-axis

int divUp(int a, int b) { return (a + b - 1) / b; }
…
int main() {
  float *out = (float*)calloc(W*H, sizeof(float)); // set all the points to 0
  float *d_out = NULL;
  cudaMalloc(&d_out, W*H*sizeof(float));
  float2 pos = { 1.0, 0.0};   // ref. point
  dim3 blockSize(TX, TY);
  dim3 gridSize(divUp(W, TX), divUp(H, TY));
  distanceKernel<<<gridSize, blockSize>>>(d_out, W, H, pos);
  cudaMemcpy(out, d_out, W*H*sizeof(float), cudaMemcpyDeviceToHost);
  cudaFree(d_out);
  free(out);
  return 0;
}
```

## CUDA Kernel and device code

```
__global__ void distanceKernel(float *d_out, int w, int h, float2 pos)
{
  const int c = blockIdx.x * blockDim.x + threadIdx.x; // column
  const int r = blockIdx.y * blockDim.y + threadIdx.y; // row
  const int i = c + r*w;
  if ((c >= w) || (r >= h)) return;
      d_out[i] = distance(c, r, pos); // compute and store result
}


__device__ float distance(int c, int r, float2 pos)
{
  return sqrtf((c - pos.x)*(c - pos.x) + (r - pos.y)*(r - pos.y));
}
```

## 3D GRIDS

3D data set can be thought as image stack composed of **3D voxels** is a volume `W*H*D` (`D` = Depth)

An execution configuration in 3D will require to define the number of threads in the x, y and z direction, i.e TX, TY and TZ

```
dim3 blockSize(TX, TY, TZ);
```

As usual, the block grid size is then calculate depending on the input size:

```
int bx = (W + blockSize.x - 1)/blockSize.x;
int by = (H + blockSize.y - 1)/blockSize.y;
int bz = (D + blockSize.z - 1)/blockSize.z;
```

## Indices 3D

In addition to row (`r`) and column (`c`) global indices, we need a new integer variable to have a global index in the stack (`s` for *stack* or *stratum*):

```
int s = blockIdx.z*blockDim.z + threadIdx.z;
```

The flattened 1D index becomes:

```
int i = c + r*w + s*w*h;
```

## **Question:** CUDA 4D Grids?