Introduction to CUDA & CUDA+OpenGL

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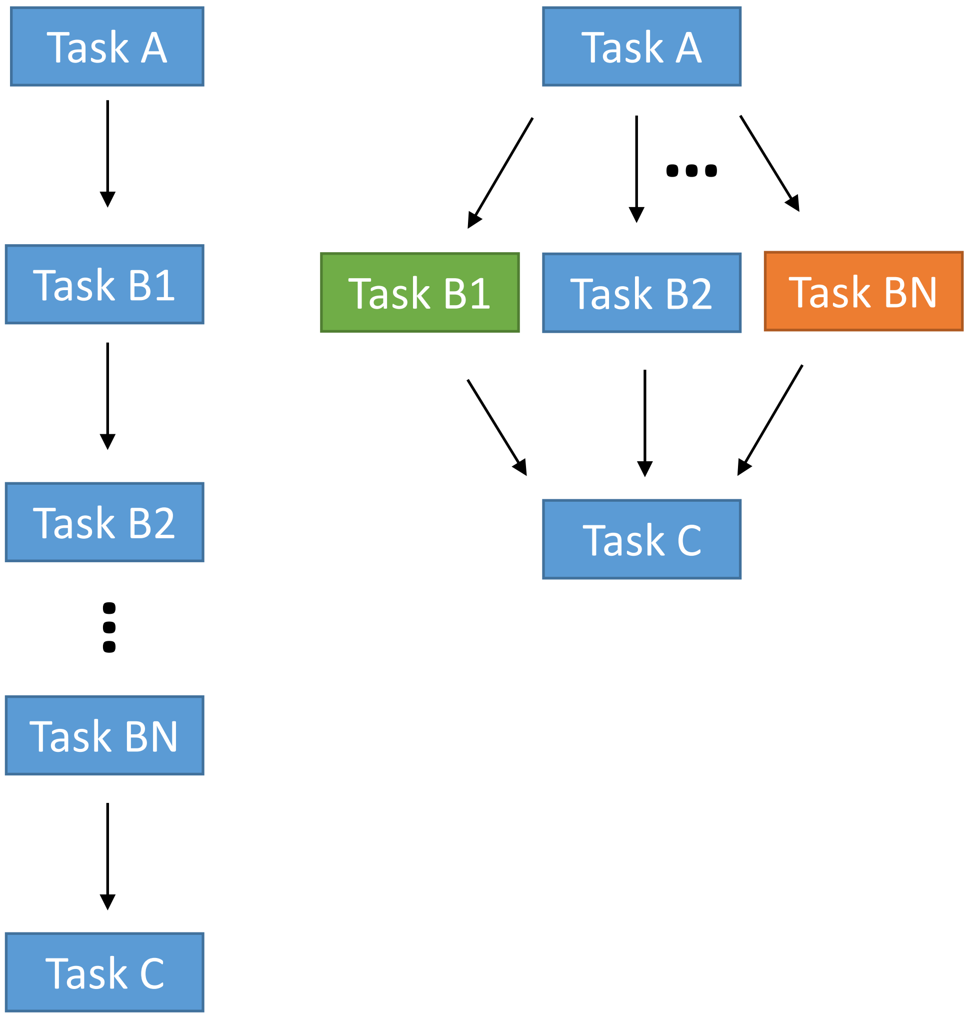
https://github.com/phhaas/CUDASeminar_Intro.git

Parallelization in Computing

- Computing of tasks in parallel on different cores
- Works especially well for problems, where "Divide and Conquer" can be applied
  - Divide one big problem in many smaller subproblems, which are solved individually
  - Merge sort, hierarchical methods, FFT, machine learning, …
  - In physics: MC, multi-body systems, metropolis algorithm, lattice gauge theory, …

Sequentiell vs. Parallel Computing

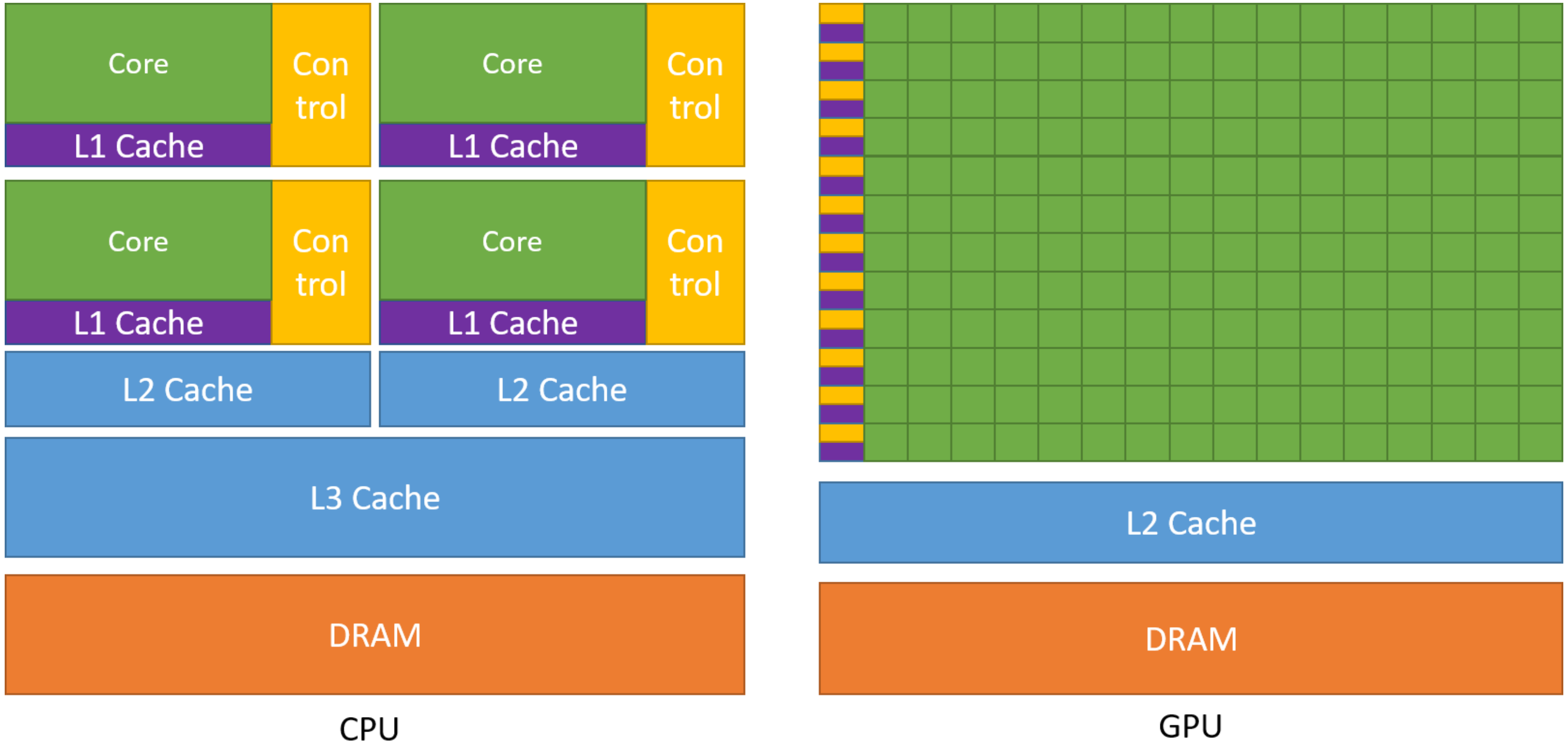


GPU vs. CPU Architecture

- Why do we want to use the GPU for parallelization?

$\Rightarrow$ CPU is designed for few sequential tasks at a time, GPU for many parallel tasks (threads)

$\Rightarrow$ Less complex data flow, more processing



https://docs.nvidia.com/cuda/cuda-c-programming-guide/index.html

CUDA is ..

- a model for general-purpose computing on GPUs (GPGPU)
  - The CPU (host) gets access to additional ressources on the GPU (device)
- a platform to implement GPGPU on NVIDIA GPUs in several programming languages:
  - C, C++, Fortran, …

3 major concepts of CUDA:

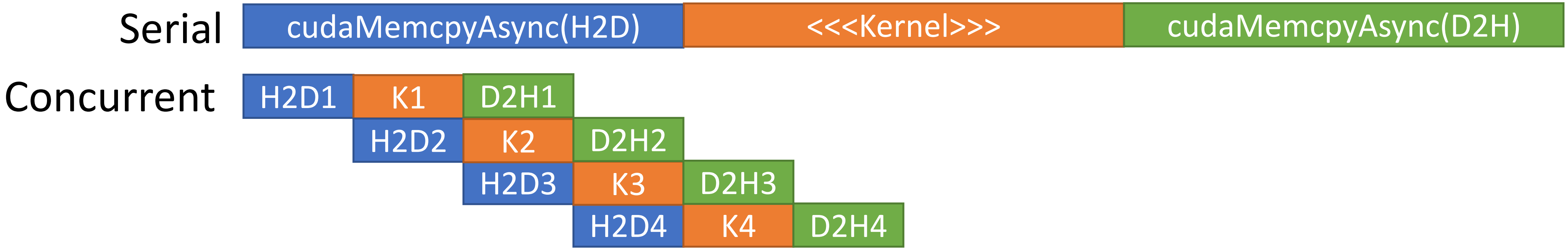
- Kernels
- Thread Hierarchy
- Memory Management

Kernels

- A kernel is similar to a C function, but is intended to be processed on the GPU
- For this only the specifier __global__ is needed:

```
__global__
void helloWorldDevice() {
    printf("Hello world from device!\n");
}
```

- The rest of the code runs on the host, while the kernel launches threads on the device
- Threads are non-blocking, they are processed as fast as possible
- Kernels can also be executed in concurrent streams for further parallelization



Kernels

- To run kernels in N different parallel threads, each thread has its own ID, the threadIdx:

```
__global__
void addVectors(float* in1, float* in2, float* out) {
    //global index
    int i = threadIdx.x;
    out[i] = in1[i] + in2[i];
}

int main() {
    // code executed in CPU

    // vector addition (size N) executed element-wise in N threads on GPU
    addVectors << <1, N >> > (Din1, Din2, Dout);

    // code executed in CPU
}
```

Thread Hierarchy

- A group of N threads is called block with ID blockIdx
- A block runs on one streaming multiprocessor (SM) core

  => Limited threads (1024 for GTX 1080 Ti)
- If the vector size is larger than the limit, one can use M blocks organized in a grid

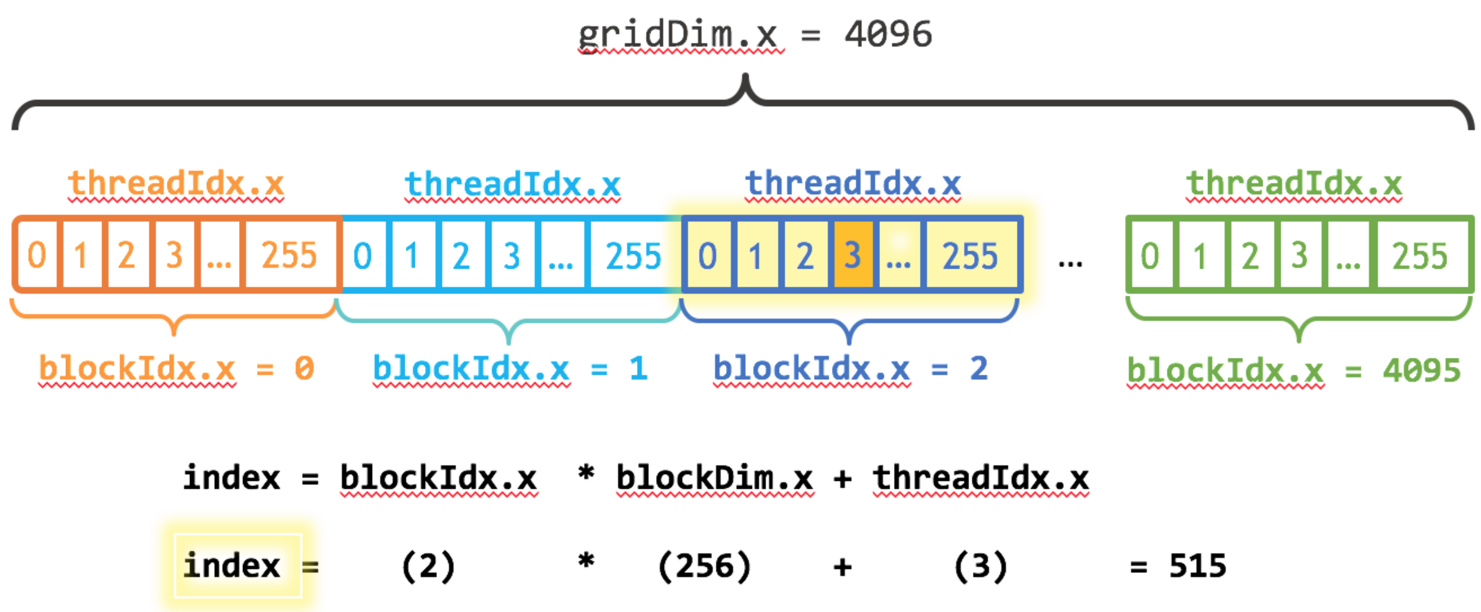
```
__global__
void addVectors(float* x, float* y) {
    // global index
    int i = blockIdx.x * blockDim.x + threadIdx.x;
    y[i] = x[i] + y[i];
}

int main() {
    // ...
    addVectors<<<M, N>>>(x, y)
    // ...
}
```

Thread Hierarchy

- Every block must be independently executable from all others in a grid

  $\Rightarrow$ No constraints on scheduling scheme of the blocks => Scalable
- Index of blocks and threads can also be organised in arrays (2D & 3D)



https://developer.nvidia.com/blog/even-easier-introduction-cuda/

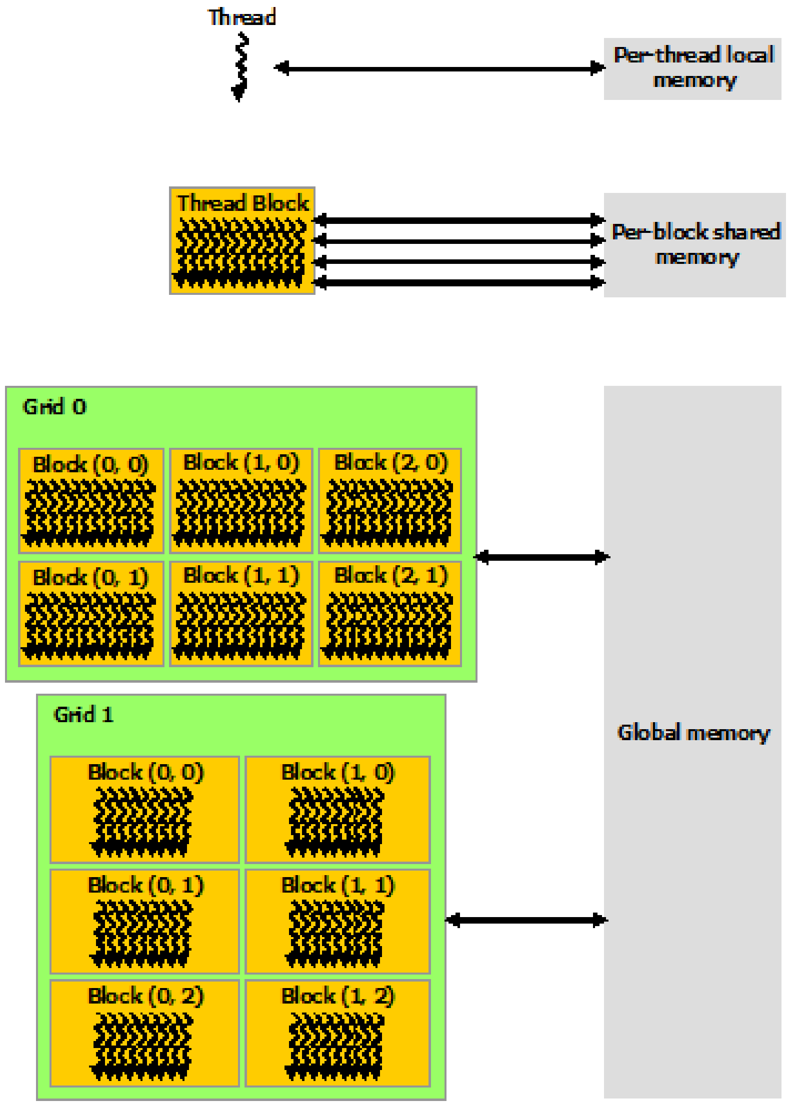
Thread Hierarchy – Warps

- Threads within a block are organised in warps
  - ⇒32 threads for current GPU‘s
- The SM executes all threads in one warp with the same instruction
  - ⇒By using the same instructions, memory access is significantly reduced
  - ⇒If the executed code between threads in a warp take different control paths, they diverge and benefits from warps are lost
    - ⇒ Control divergence

Memory Management

- Memory in CUDA is managed hierarchically:
  - Every thread has local memory
  - All threads of a block have a common shared memory
  - All threads share a global memory
- This device memory is assumed to be indepentent of the one of the host

  $\Rightarrow$ Device memory has to be managed via calls to CUDA, not visible for CPU
- Exception: Managed/Unified Memory visible for both CPU/GPU



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Memory Management – Data Transfer

- Since host and device memory are independent, both have to be managed independently:
  - Allocate host memory:

```
float* XHost = (float*)malloc(N*floatSize);
```

  - Allocate device memory:

```
float* XDevice;
cudaMalloc(&XDevice, N*floatSize);
```

  - Copy from host to device memory:

```
cudaMemcpy(XDevice, XHost, N*floatSize, cudaMemcpyHostToDevice);
```

  - Copy from device to host memory:

```
cudaMemcpy(XHost, XDevice, N*floatSize, cudaMemcpyDeviceToHost);
```

  - Free device memory:

```
cudaFree(XDevice);
```

Memory Management – Synchronisation

- Synchronisation of shared memory (memory in a block):
  - Shared memory is allocated in kernels using the __shared__ specifier:

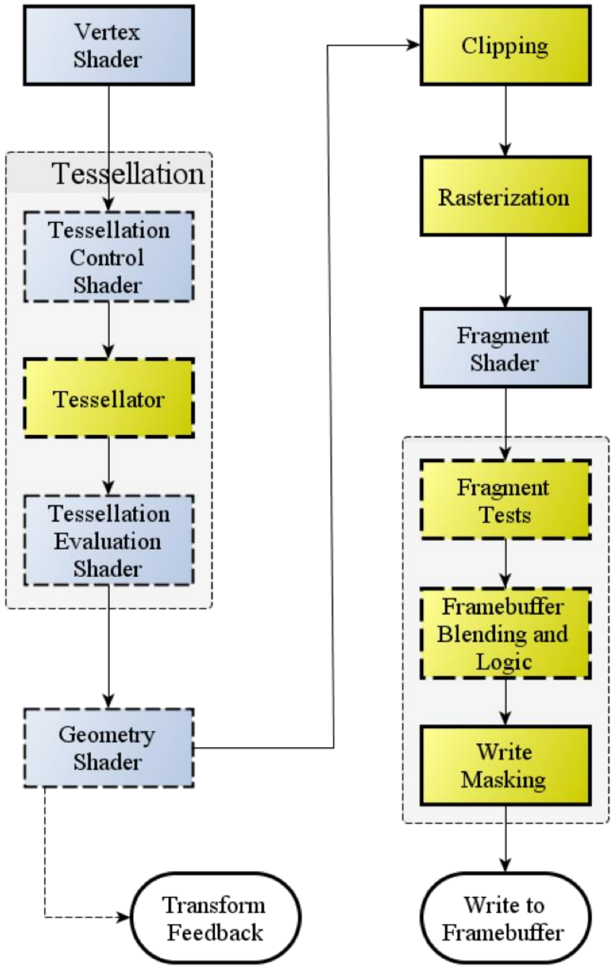
```
__global__
void func(...) {
    __shared__ float shared[N];
    // ..
}
```

  - __syncthreads() forces all threads in a block to wait until all others have cought up
- Synchronisation of host to devices: cudaDeviceSynchronize()

OpenGL

- Open source 3D vector graphics rendering API
- Designed to exploit hardware acceleration (GPU)
- Language bindings for many programming languages
  - C, C++, Fortran, ..
- State-based
- Parts of the OpenGL workflow can be parallelized (blue boxes in the workflow chart)
- Shaders: Applying simple tasks to a large set of elements

  $\Rightarrow$Well suited for parallel computing



https://opengl-notes.readthedocs.io/en/latest/topics/intro/opengl-pipeline.html

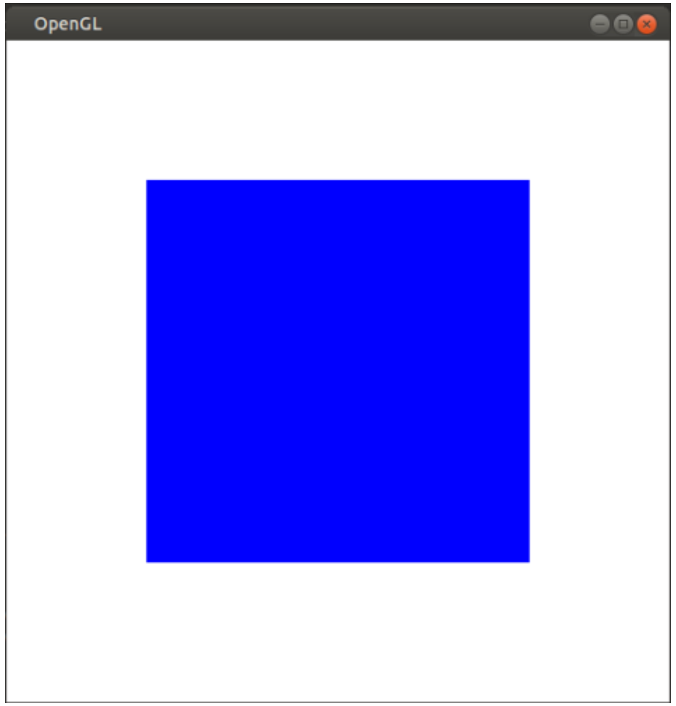
OpenGL

- Initialisation:
  - Set callback functions, display mode, …
- Callback functions:
  - `glutDisplayFunc()`
  - `glutMouseFunc()`
  - `glutMotionFunc()`
  - …
- Rendering loop:
  - `glutMainLoop()`
  - Infinite loop until program is terminated
  - Executes callback `glutDisplayFunc()`
  - Reacts on other callback functions

OpenGL – Simple Drawing

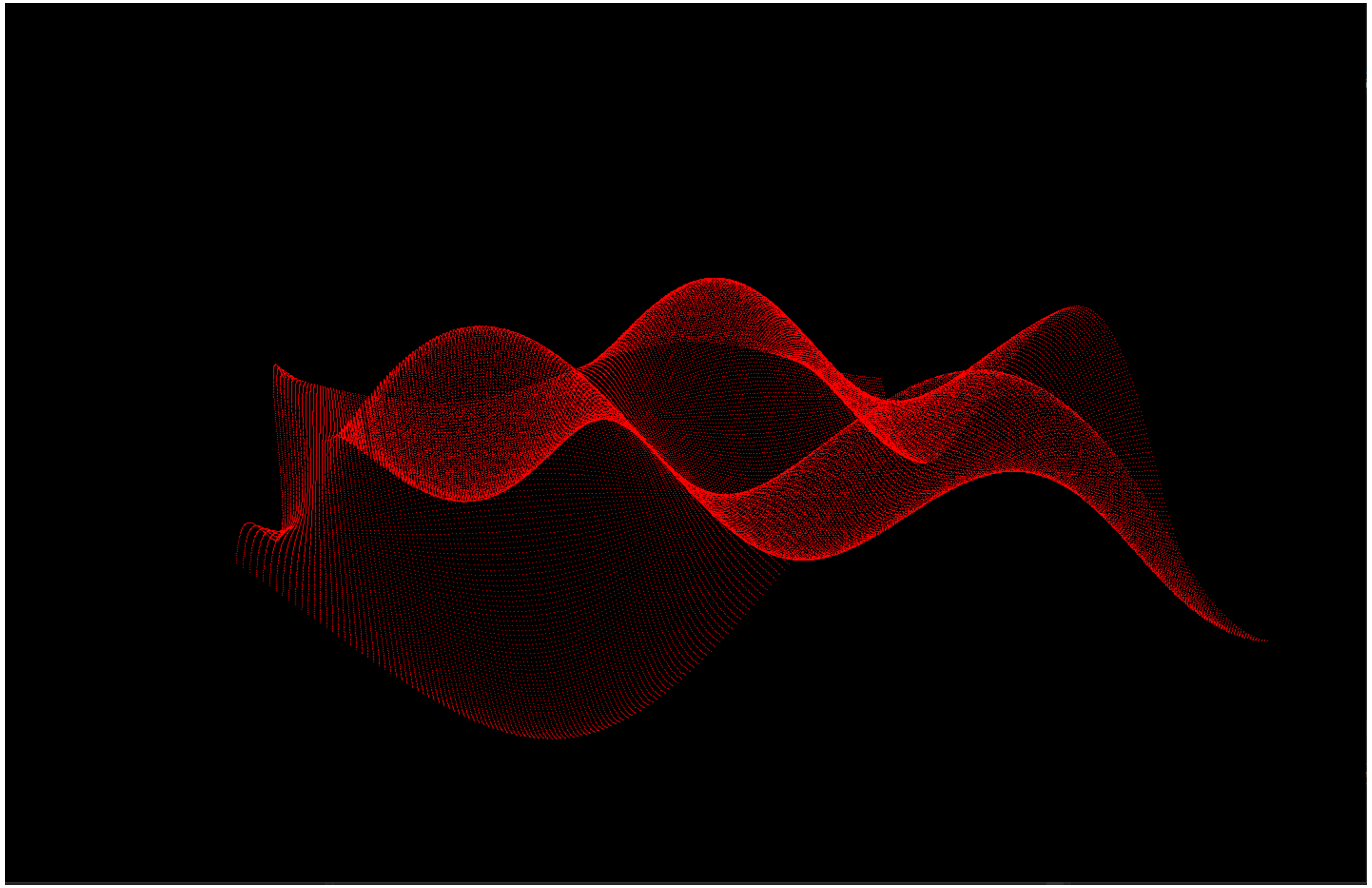
- Drawing a simple rectangle:

```
glBegin(GL_QUADS);  // connects group of 4 vertices to polygon with 4 sides
    glVertex2f(-1.0, -1.0);   // bottom-left vertex
    glVertex2f(-1.0,  1.0);   // top-left vertex
    glVertex2f( 1.0,  1.0);   // top-right vertex
    glVertex2f( 1.0, -1.0);   // bottom-right vertex
glEnd();
```



OpenGL+CUDA Interoperability

- Reduce trafic between CPU and GPU for less PCIe latency
- Example: <CUDA-samples>/2_Graphics/simpleGL



How to get CUDA-samples running?

- Copy sample to your home directory:

```
cp -r /mount/share/cuda-samples/2_Graphics/simpleGL . ; cd simpleGL
```

- Edit "Makefile": e.g.

```
nano Makefile
```

- Edit following lines:

```
CUDA_PATH ?= /usr/local/cuda-11.0      ➞ CUDA_PATH ?= /usr
INCLUDES := -I../../common/inc         ➞ INCLUDES := -I/mount/share/cuda-samples/common/inc
SMS ?= 35 37 50 52 60 61 70 75 80      ➞ SMS ?= <CUDA Capability version number>
```

  - The CUDA Capability version number is printed by calling

```
/mount/share/cuda-samples/deviceQuery
```

Comment out (#) following lines:

```
$(EXEC) mkdir -p bin/$(TARGET_ARCH)/$(TARGET_OS)/$(BUILD_TYPE)
$(EXEC) cp $@ bin/$(TARGET_ARCH)/$(TARGET_OS)/$(BUILD_TYPE)
```

- Run `make`

Sources

- https://docs.nvidia.com/cuda/cuda-c-programming-guide/index.html
- https://developer.nvidia.com/blog/even-easier-introduction-cuda/
- https://www.khronos.org/opengl/wiki_opengl/index.php
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