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Uni.lu HPC School 2021

PS10b: Introduction to OpenCL Programming

Uni.lu High Performance Computing (HPC) Team

T. Carneiro L. Koutsantonis

University of Luxembourg (UL), Luxembourg

https://hpc.uni.lu/

Introduction: what's OpenCL?

- In **OpenACC** the compiler is responsible for the parallelization…
    - which might not work in all scenarios
    - may not result in the best performance
    - It is not portable

In turn…

- **OpenCL** is a <u>standard</u> for heterogeneous programming
    - multicore CPUs, GPUs (AMD, Intel, ARM),
    - FPGAs, Apple M1, tensor cores, and ARM
- **with minor or no modifications.**

Introduction: portability

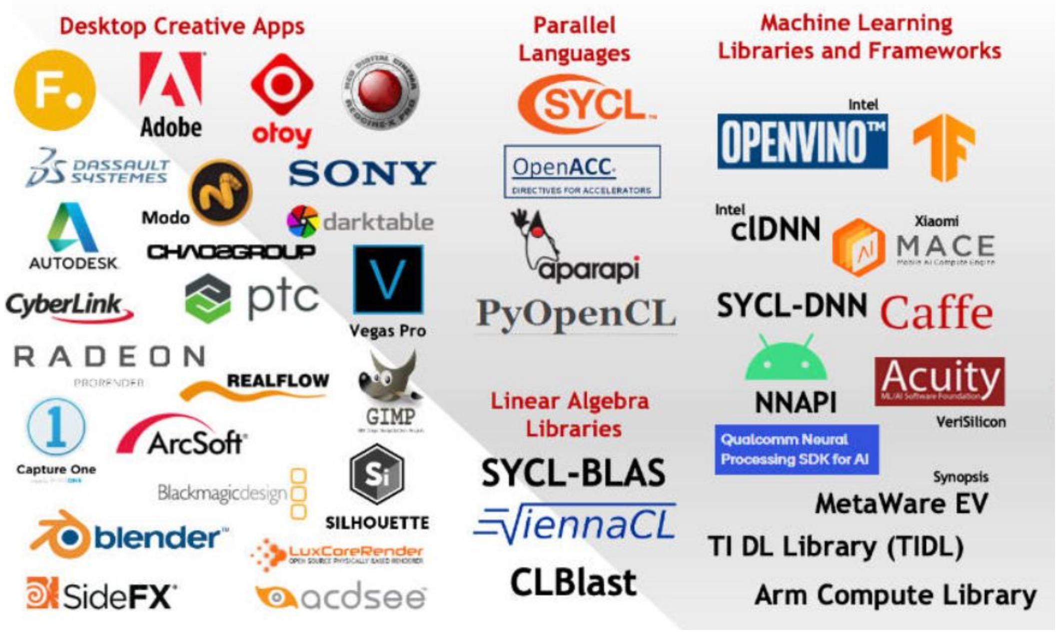
- **OpenCL vs. CUDA - Portability (**)**

vs.

Images from:
https://www.khronos.org/opencl/

Introduction: target audience

- **Target audience of OpenCL:** programmers that aim at programming portable heterogeneous code and that want full control of the parallelization process.
  - **Portability has a price:** OpenCL is <u>much lower level</u> than OpenACC and even then CUDA.



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Have components/ are programmed in OpenCL

Introduction: objectives

- In this tutorial, we teach how to perform the sum of two vectors $C=A+B$ in OpenCL
- **Objectives of the tutorial:**
  - The **main objective** of this tutorial is to introduce for students of the HPC school the heterogeneous programming standard - OpenCL
- **This tutorial covers:**
  - Check for OpenCL-capable device(s);
  - Memory allocation on the device;
  - Data transfer to the device;
  - Retrieve data from the device;
  - Compile C/C++ programs that launch OpenCL kernels.

The OpenCL Platform Model

- **Similar to the CUDA Programming model:**
  - **The code has two parts**: the host and the device parts.
  - **According to the OpenCL specification:** "The model consists of a host (usually the CPU) connected to one or more OpenCL devices (e.g., GPUs, FPGAs).

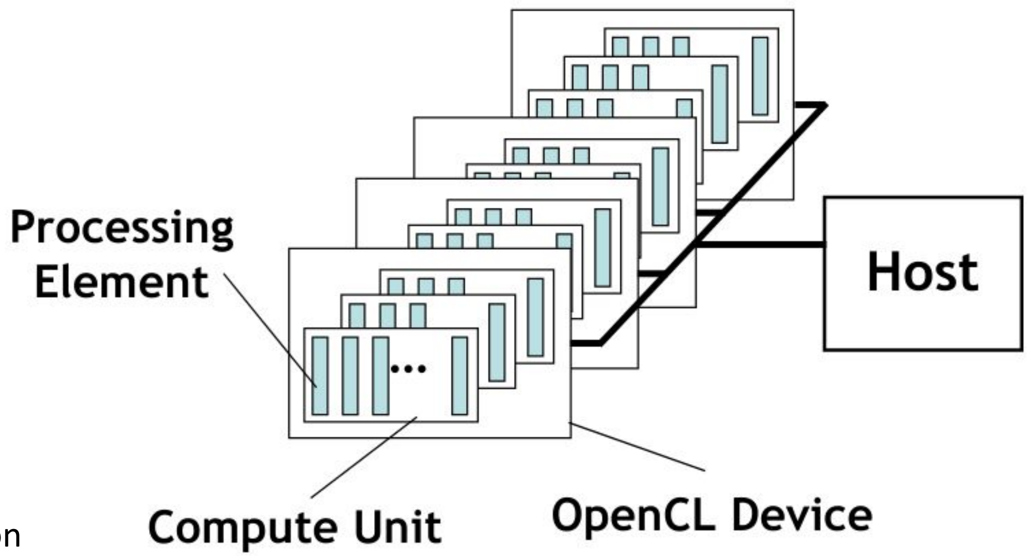

Image from the OpenCL specification 3.0.9

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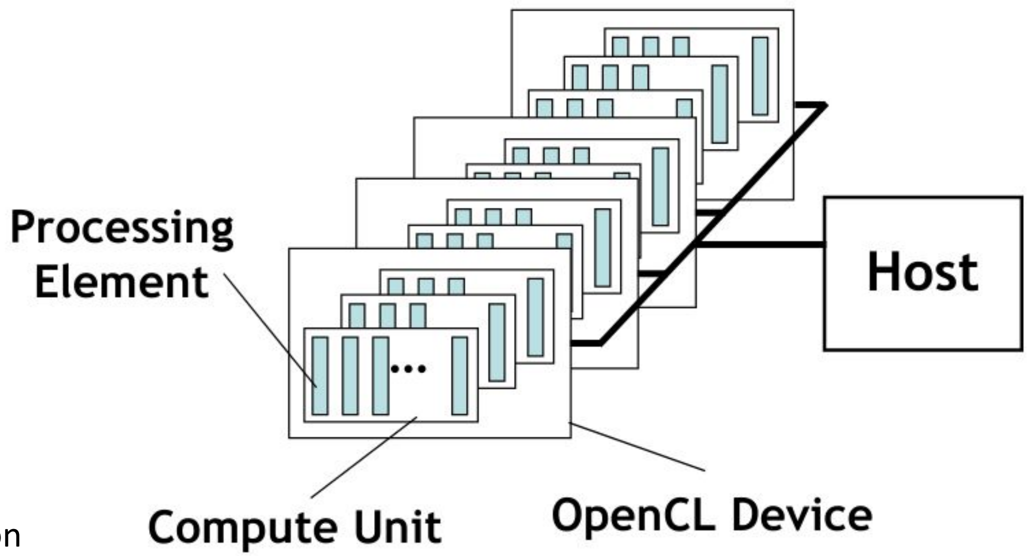


Host: launches the code that is executed on the device(s).

Image from the OpenCL specification 3.0.9

The OpenCL Platform Memory Model

- **Similar to the CUDA programming model:**
  - the host communicates with the *device(s)* through the global memory of the device(s).
  - As in the CUDA programming model, there is a **memory hierarchy** on the device.

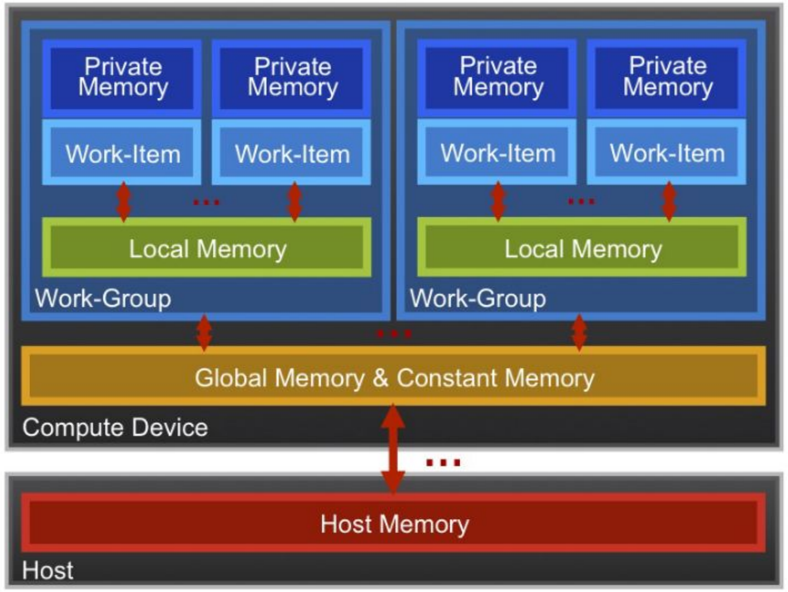
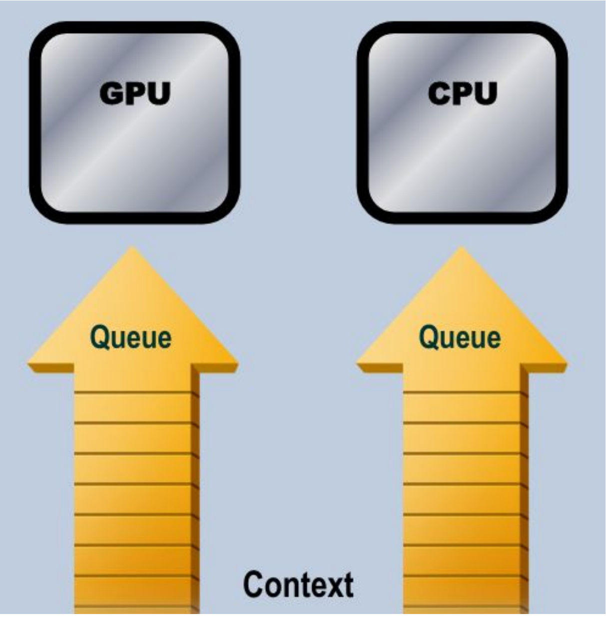


Image from Mattson, T., McIntosh-Smith, S., Koniges, A. *OpenCL: a Hands-on Introduction*

Starting an OpenCL Context

- **Initially, OpenCL needs to initialize a context**
  - Contexts are used by the OpenCL runtime for *managing* command queues, memory, and for executing kernels on one or more devices connected to the the context *(The OpenCL Cookbook)*.

```
cl::Context context(CL_DEVICE_TYPE_DEFAULT);
```



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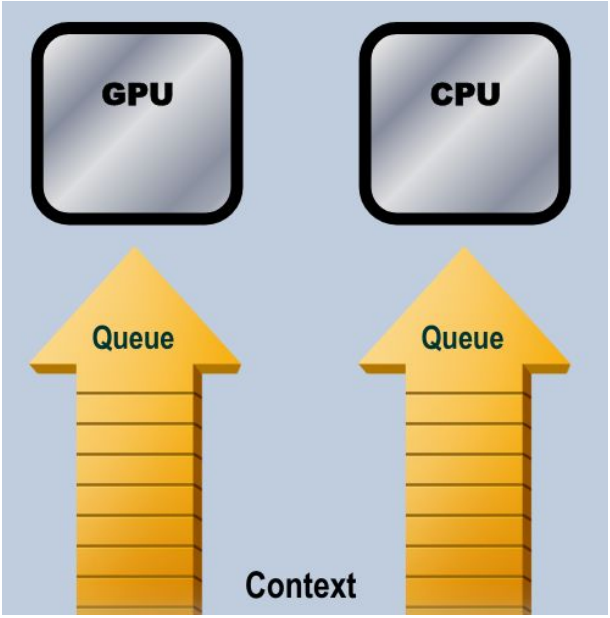

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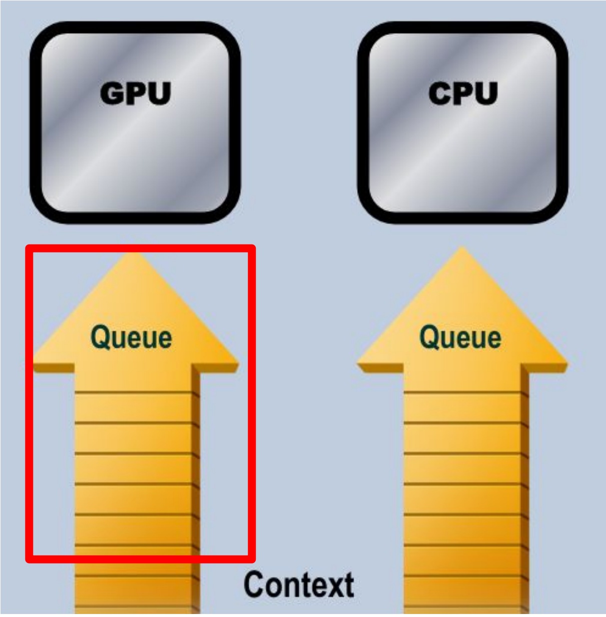
```

- **Then, it is required to initialize a queue:**
  - Push commands to the device.
  - For those who program in CUDA, OpenCL queues

similar to CUDA streams.

```
cl::CommandQueue queue(context);
```



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Allocating Memory on the Device: cl::Buffer

- As the device works with vectors A,B,C, we create three buffers:

```
cl::Buffer A_d(context, CL_MEM_READ_ONLY, sizeof(int) * SIZE);
cl::Buffer B_d(context, CL_MEM_READ_ONLY, sizeof(int) * SIZE);
cl::Buffer C_d(context, CL_MEM_WRITE_ONLY, sizeof(int) * SIZE);
```

- Using the queue, we write to the buffers of A and B to send their values of A and B from the host to the device:

```
queue.enqueueWriteBuffer(A_d, CL_TRUE, 0, sizeof(int) * SIZE, A_h);
queue.enqueueWriteBuffer(B_d, CL_TRUE, 0, sizeof(int) * SIZE, B_h);
```

Online Compilation of the Kernel

- For the sake of greater portability, the kernel is provided as a string:

```
std::string kernel_code =
    "   void kernel simple_add(global const int* A, global const int* B, global int* C){ "
    "       C[get_global_id(0)]=A[get_global_id(0)]+B[get_global_id(0)];                 "
    "   }
```

- Kernels need to return the *void* type.
- The *global* keyword means that the buffer lies on the *global memory*

Building the Kernel

- To build the kernel, we append the kernel string to the program source:

```
cl::Program::Sources sources;
sources.push_back({ kernel_code.c_str(),kernel_code.length() });
```

- Then, we create a program object using the program source as argument:

```
cl::Program program(context, sources);
```

- **Important:** in this tutorial we use the online compilation of the kernel. Thus, compilation errors of the *device* code are known in **execution time**.

```
if (program.build({ default_device }) != CL_SUCCESS)
```

Building the Kernel

- From the *program*, which contains the *simple_add* kernel, we instantiate a kernel object for execution with three *cl:buffers* as arguments:

```
cl::make_kernel<cl::Buffer, cl::Buffer, cl::Buffer> simple_add(cl::Kernel(program, "simple_add"));
```

- Now, we are able to invoke the kernel *simple_add*:

```
cl::NDRange global(SIZE);
simple_add(cl::EnqueueArgs(queue, global), A_d, B_d, C_d).wait();
```

- And retrieve the result by using the *queue*:

```
queue.enqueueReadBuffer(buffer_C, CL_TRUE, 0, sizeof(int) * SIZE, C);
```

Compiling the Code

- It is simple to compile an OpenCL code with *gcc* or *g++*. In short, it is only required to add -lOpenCL flag to the compilation command.

```
$ g++ -lOpenCL exercise1.cpp
```

- **Exercise 1:** what's the output of the first exercice? Is the default OpenCL platform of Iris the NVIDIA platform?
- **Exercise 2:** following the online tutorial, compile *exercise1.cpp* using the NVIDIA implementation of OpenCL (*-I* and *-L*).
- What's the OpenCL platform after compiling *exercise1.cpp* using the NVIDIA implementation of OpenCL?
- ***Obs:*** *solutions are in the online tutorial.*

Conclusions

- OpenCL is an **open standard** for heterogeneous programming.
  - However, it exposes the programmer to **much lower-level** concepts than OpenACC and CUDA.
- Depending on the application, one might get a similar performance compared to OpenCL or CUDA using OpenACC.
- **Thus, the programmer needs to decide whether to follow a lower level approach:**
  - Need for portability - OpenCL;
  - The OpenACC compiler can't accelerate the code properly;
  - The OpenACC code became too complex and it is worth to move to OpenCL or CUDA.

Thank you for your attention!

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University of Luxembourg, Belval Campus
Maison du Nombre, 4th floor
2, avenue de l'Université
L-4365 Esch-sur-Alzette
mail: hpc@uni.lu

https://hpc.uni.lu/

References

- The OpenCL Cookbook
- Tutorial: Simple start with OpenCL and C++
- Khronos OpenCL Working Group. The OpenCL Specification (Oct. 2021)
- Smistad, E. Getting started with OpenCL and GPU Computing, Feb. 22, 2018 (Access on Oct. 28, 2021).
- Mattson, T., McIntosh-Smith, S., Koniges, A. OpenCL: a Hands-on Introduction