Compatibility Tool from CUDA to SYCL (SYCLomatic)

Europar24-Madrid

CGS

July 30, 2024

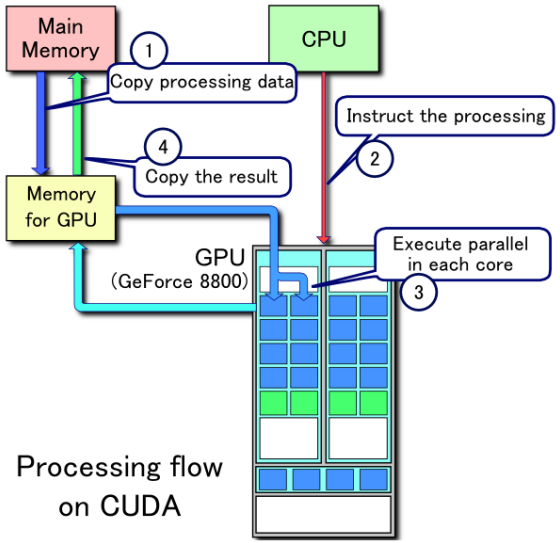
- "Intel® oneAPI Programming Guide", https://www.intel.com/content/www/us/en/develop/documentation/oneapi-programming-guide/top.html
- "Intel® DPC++ Compatibility Tool", https://www.intel.com/content/www/us/en/develop/documentation/oneapi-prhttps://www.intel.com/content/www/us/en/developer/tools/oneapi/dpc-compatibility-tool.html

Outline

Introduction

What's CUDA

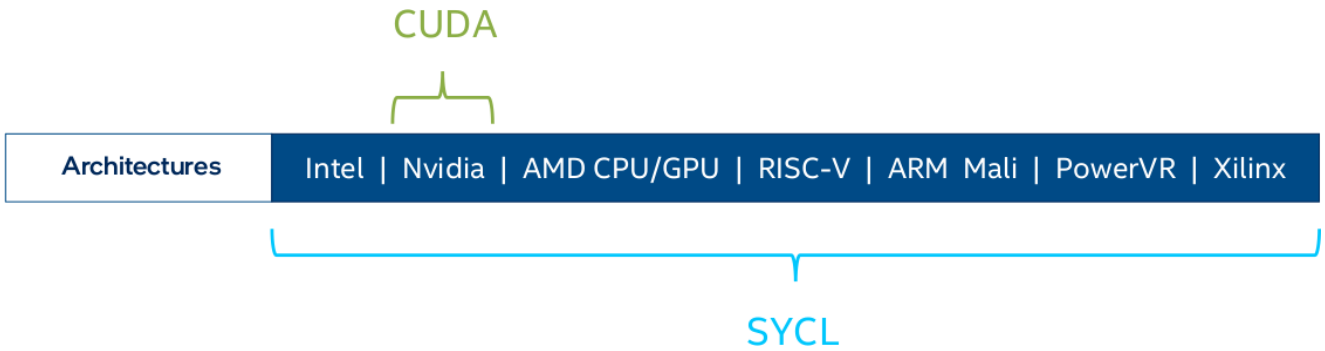
- CUDA (Compute Unified Device Architecture) is primarily known as a programming model for NVIDIA GPUs
- CUDA helps developers accelerate their applications by harnessing the parallel capabilities of NVIDIA GPU accelerators
- More info



Processing flow on CUDA

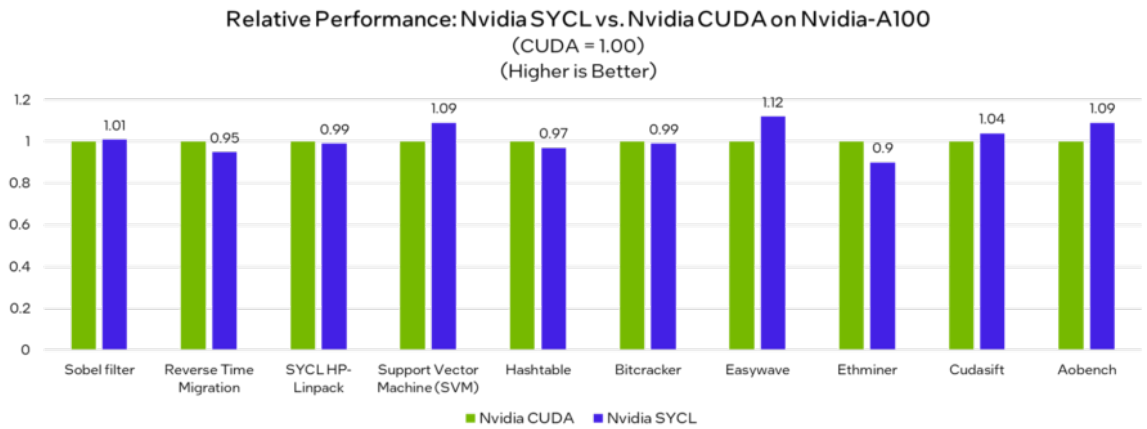
Motivation

- Why migrate code from CUDA?
  - **CUDA**: Supports NVIDIA GPUs
- Why translate it to SYCL?
  - Allows code for heterogeneous processors to be written using modern ISO C++ (at least C++ 17)
  - API for programming both CPUs and GPUs
  - **SYCL**: Supported on Intel, NVIDIA, AMD (CPU & GPUs), RISC-V, ARM-Mali, PowerVR, Xilinx...



Choosing SYCL for Accelerators

- SYCL: Open, based on standards (reminder UXL Foundation)
- Performance across multiple architectures.
- Performance comparable to CUDA on NVIDIA GPUs.
- Code migration possible with SYCLomatic or DPCT



Testing Date: Performance results are **based on testing by Intel as of August 15, 2022** and may not reflect all publicly available updates.

Configuration Details and Workload Setup: Intel® Xeon® Platinum 8360Y CPU @ 2.4GHz, 2 socket, Hyper Thread On, Turbo On, 256GB Hynix DDR4-3200, ucode 0x000363. GPU: Nvidia A100 PCIe 80GB GPU memory. Software: SYCL open source/CLANG 15.0.0, CUDA SDK 11.7 with NVIDIA-NVCC 11.7.64, cuMath 11.7, cuDNN 11.7, Ubuntu 22.04.1. SYCL open source/CLANG compiler switches: -fsycl-targets=nvptx64-nvidia-cuda, NVIDIA NVCC compiler switches: -O3 -gencode arch=compute_80, code=sm_80. Represented workloads with Intel optimizations.

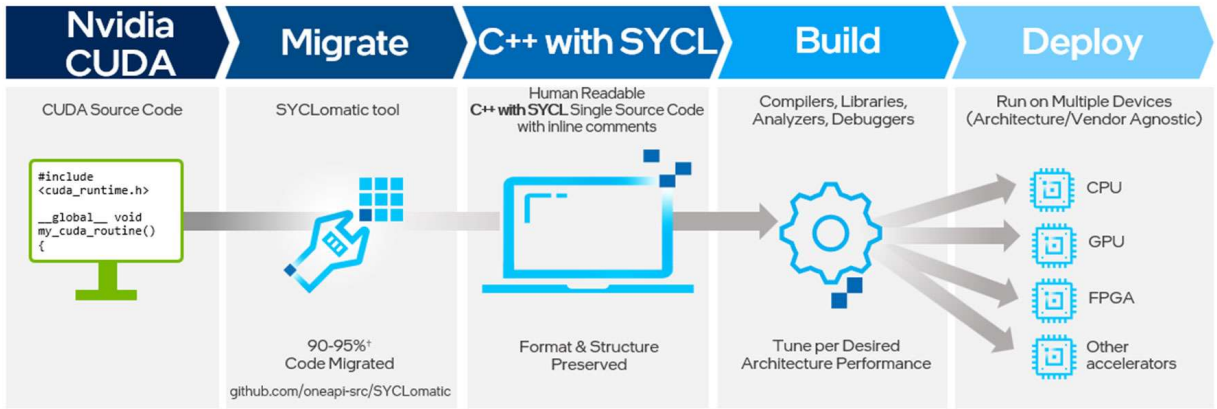
Performance results are based on testing as of dates shown in configurations and may not reflect all publicly available updates. See configuration disclosure for details. No product or component can be absolutely secure.

Performance varies by use, configuration, and other factors. Learn more at www.Intel.com/PerformanceIndex. Your costs and results may vary.

Migration Tool

- SYCLomatic helps developers migrate CUDA code to SYCL
  - Automatically converts between 90-95% of CUDA code to SYCL
  - Developers can complete the process with manual coding or by adapting the code
- Intel® DPC++ Compatibility Tool or DPCT is Intel's implementation available in the Intel® oneAPI Base Toolkit

CUDA‡ to SYCL‡ Code Migration & Development Workflow



† Intel estimates as of March 2023. Based on measurements on a set of 85 HPC benchmarks and samples, with examples like Rodinia, SHOC, PENNANT. Results may vary.
‡ Other names and brands may be claimed as the property of others. SYCL is a trademark of the Khronos Group Inc.

oneAPI

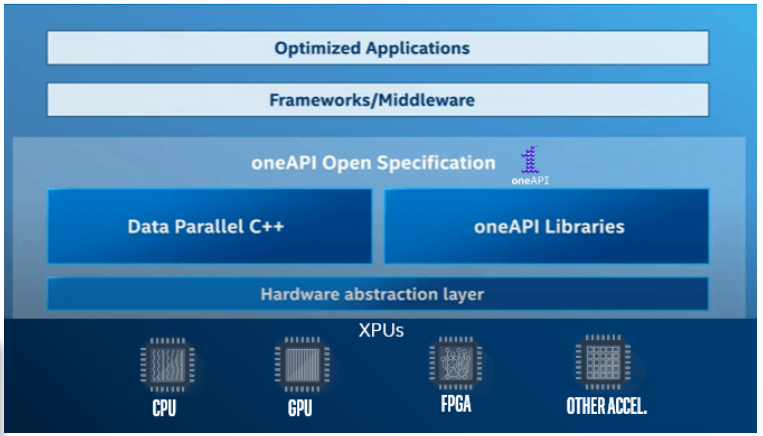
SYCL

- Standard-based language: C++ and SYCL
- Powerful APIs for accelerating domain-specific functions

Solution to unique provider

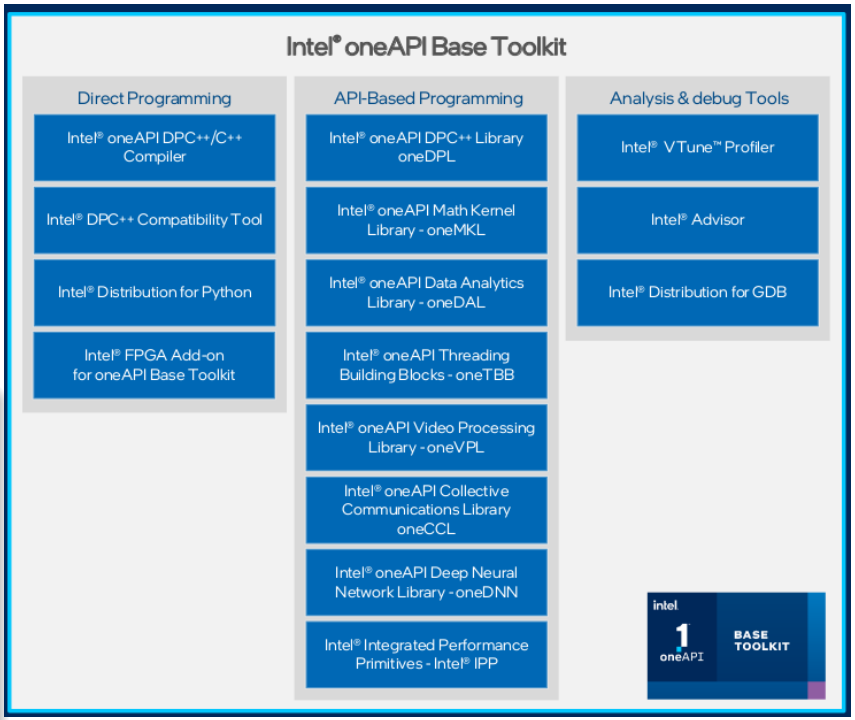
- Open standard to promote community and industry support
- Allows code reuse across different architectures and providers

oneAPI for Cross-Architecture Performance



Compilador DPC++

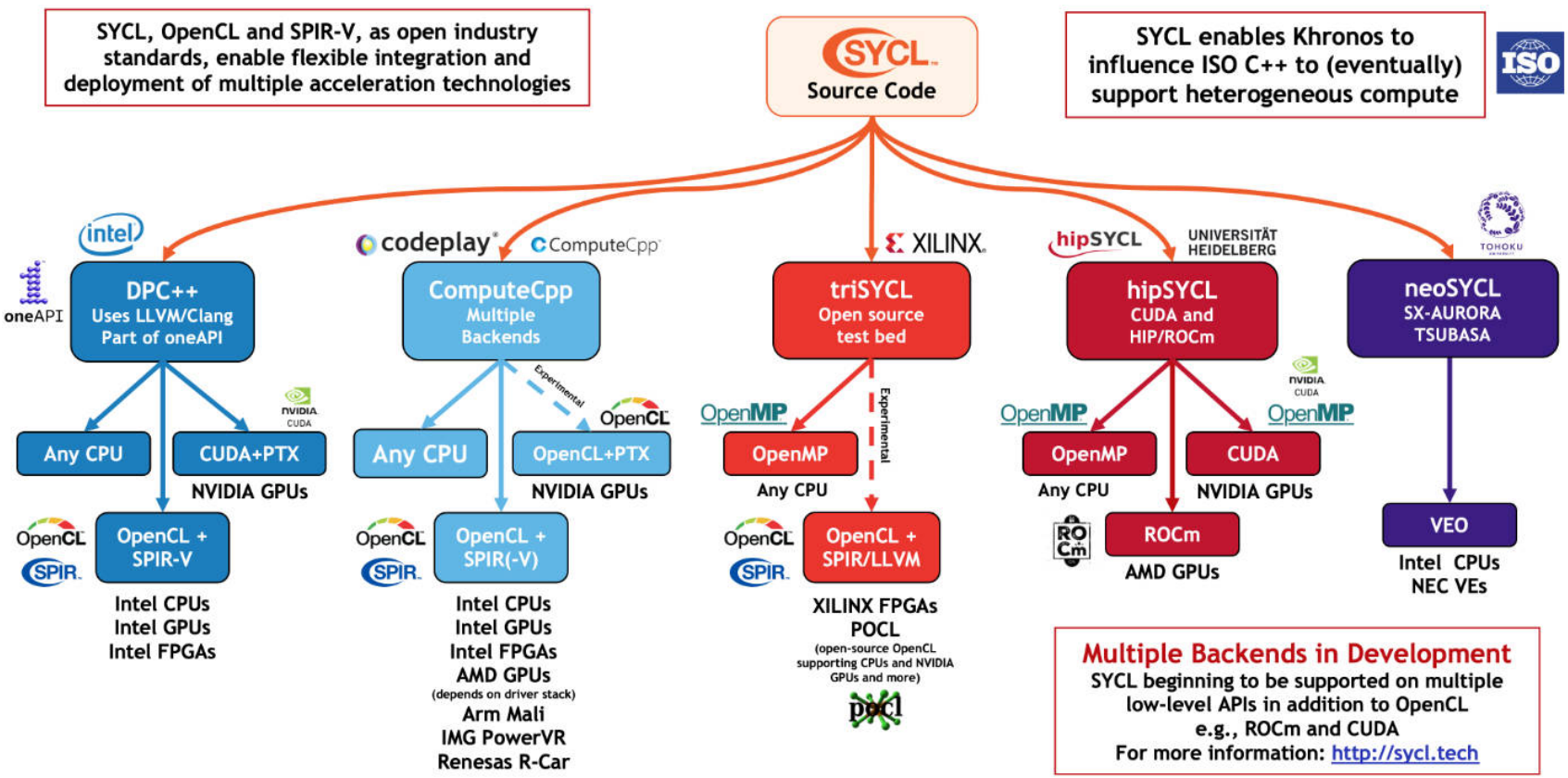
- Basic set of high-performance tools and libraries
- C++ compiler with SYCL support (heterogeneous computing)



Características

- Data Parallel C++ Compiler
- Portability with SYCLomatic
- Python distribution (optimized libraries scikit-learn, NumPy)

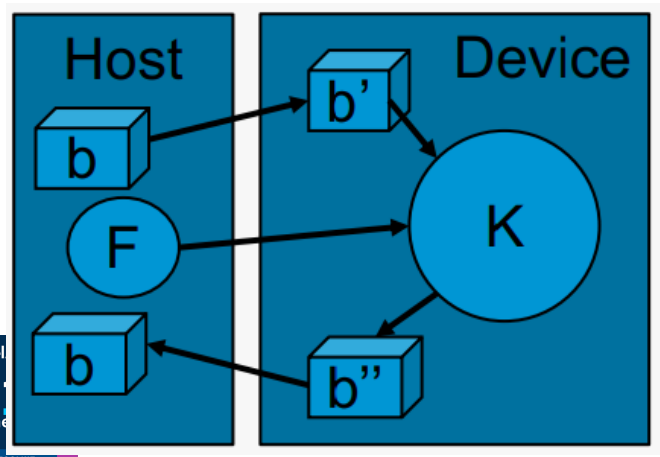
SYCL Implementations



Pseudo-code

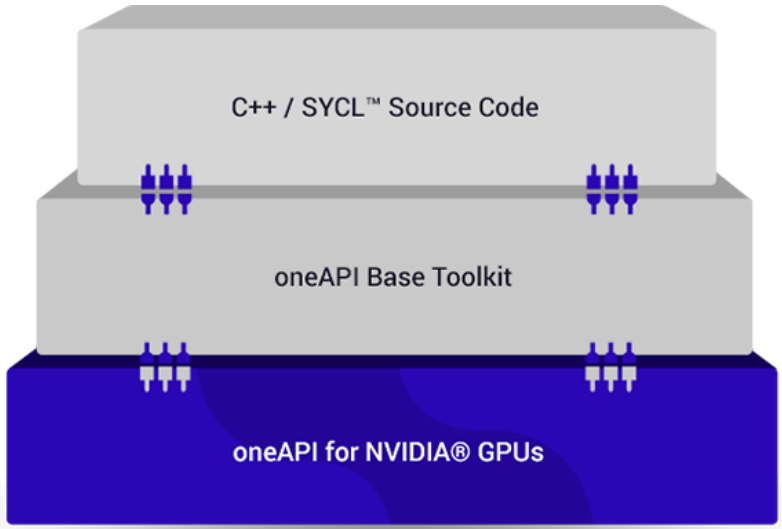
pseudo_code.cpp

```
selector = default_selector()
q = queue(selector)
b = buffer (double, 1000)
q.submit (
    F ( ) {
        a = accessor(b, READ_AND_WRITE)
        K (i) {
            a[i] = a[i] * 2
        }
    }
)
q.wait_and_throw()
a2 = accessor(b, READ_ONLY)
printf("%f", a2[0])
```



Codeplay plugin for NVIDIA GPUs

- Support other vendors such as GPUs from **NVIDIA** or **AMD**
  - Plugins compatibles with the compiler oneAPI DPC++/C++
  - Support plugin for NVIDIA>sm_50
  - Support *beta* plugin for AMD



Compatibility

CUDA-SYCL Migration

- Some equivalences form CUDA and SYCL API

Action	CUDA	SYCL
Header File	`#include<cuda_runtime.h>`	`#include<sycl/sycl.hpp>`
Create a CUDA stream	`cudaStream_t stream1;`	`sycl::queue q;`
Allocate memory on device	`cudaMalloc()`	`sycl::malloc_device()`
Memset on device	`cudaMemsetAsync()`	`q.memset()`
Memcpy from host to device	`cudaMemcpyAsync()`	`q.memcpy()`
Submit kernel to device	`kernel_function <<<NUM_BLOCKS, N>>>();`	`q.parallel_for( sycl::nd_range<1>(N, WG), [=](sycl::nd_item<1> item) { kernel_function(); }); );`
Free device allocation	`cudaFree()`	`sycl::free()`
Synchronize host and device	`cudaStreamSynchronize(stream)`	`q.wait()`

CUDA-SYCL Migration

- Some equivalences form CUDA and SYCL API

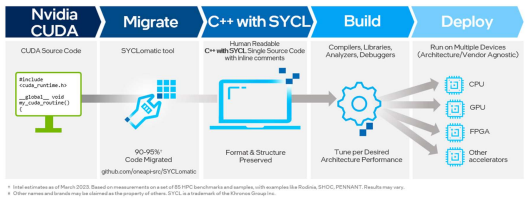
Action	CUDA	SYCL
Shared Local memory	`__shared float local_data[N]`	`sycl::local_accessor<float, 1> local_data(N, h)`
Sycronization	`__syncthreads()`	`sycl::group_barrier(group)`
Atomic Add	`atomicAdd()`	`auto a = sycl::atomic_ref() a.fetch_add()`
Block Thread Index	`threadIdx.x`	`item.get_local_id()`

- It is also possible to translate algebra invocation through cuBLAS with the oneAPI oneMKL library:
  - `cublasSgemm` por `oneapi::mkl::blas::column_major::gemm`

CUDA-SYCL Migration

- Helps developers in migrating code written in CUDA to SYCL[1], generating readable code whenever possible
- 90-95% of the code is automatically migrated[2]
- Provides comments to assist developers in completing the migration

CUDA* to SYCL* Code Migration & Development Workflow



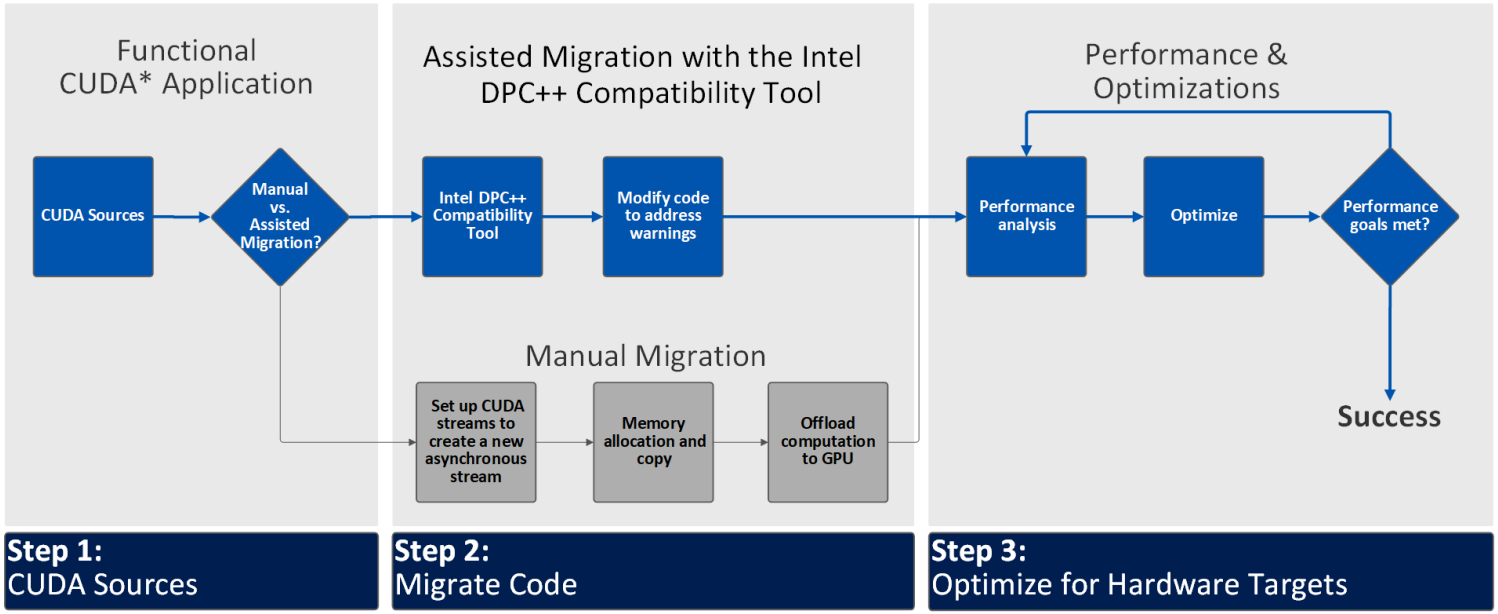
[1] Intel® DPC++ Compatibility Tool from CUDA to SYCL (SY

Compatibility Tool (DPCT/SYCLomatic)

1. Prepare the CUDA source for migration:
   - The DPCT/SYCLomatic compatibility tool searches for CUDA headers
2. Project migration: **execution of the compatibility tool**
   - For simple projects, migrate file by file
   - For complex projects (Microsoft Visual Studio project or Make/Cmake) is recommendable to build database
3. Review converted code:
   - Output files contain annotations to assist in migrating any remaining code that could not be automatically migrated[3]
4. Compilation with Intel® oneAPI DPC++/C++

[3] Developer Guide and Reference https://software.intel.com/content/www/us/en/develop/documentation/intel-dpcpp-compatibility-tool-user-guide/top/diagnostics-reference.html

Compatibility Tool (DPCT/SYCLomatic)



Before starting (DPCT/SYCLomatic)

- Intel® DPC++ Compatibility Tool assist to CUDA code migration to Data Parallel C++ (DPC++)
  - Look at guide and refence information
  - Visit the Resease Notes to find more information

Software Requirements

- Installation of SYCLomatic or use DPCT/SYCLomatic from the Intel oneAPI Base Toolkit
  - Prepare the environment with `source /opt/intel/oneapi/setvars.sh`
- CUDA headers are mandatory
  - `/usr/local/cuda/include`
  - `/usr/local/cuda-x.y/include`, where x.y must be some of the following versions: 8.0, 9.x, 10.1, 10.2, 11.0~11.8, 12.0

SYCLomatic instalation

- Download or clone the Github repository from SYCLomatic, download and export the *PATH*

Terminal #1

```
user@comp~$ nvidia-smi
Mon Nov 13 20:07:34 2023
+-----------------------------------------------------------------------------+
| NVIDIA-SMI 470.223.02   Driver Version: 470.223.02   CUDA Version: 11.4     |
|-------------------------------+----------------------+----------------------+
| GPU  Name        Persistence-M| Bus-Id        Disp.A | Volatile Uncorr. ECC |
| Fan  Temp  Perf  Pwr:Usage/Cap|         Memory-Usage | GPU-Util  Compute M. |
|                               |                      |               MIG M. |
|===============================+======================+======================|
|   0  Tesla K20c          Off  | 00000000:01:00.0 Off |                    0 |
| 30%   26C    P8    16W / 225W |      0MiB /  4743MiB |      0%      Default |
|                               |                      |                  N/A |
+-------------------------------+----------------------+----------------------
+user@comp:~$ mkdir syclomatic
user@comp:~$ cd syclomatic
user@comp:~/syclomatic$ wget https://github.com/oneapi-src/SYCLomatic/releases/download/20231113/linux_release
user@comp:~/syclomatic$ tar -zxvf linux_release.tgz
user@comp:~/syclomatic$ export PATH="/home/$USER/syclomatic/bin:$PATH"
user@comp:~/syclomatic$ c2s --help
USAGE: c2s [options] [<source0> ... <sourceN>]

OPTIONS:

  --always-use-async-handler             - Use async exception handler when creating new sycl::queue with dpc
                                           in addition to default dpct::get_default_queue. Default: off.
  --analysis-scope-path=<dir>            - The directory path for the analysis scope of the source tree that
                                           Default: the value of --in-root.

....
```

DPCT/SYCLomatic usage

- Migrate a single CUDA source file: `c2s test.cu`
- Migrate a single CUDA source file and copy all SYCLomatic auxiliary header files: `c2s test.cu --gen-helper-function`
- Migrate a single CUDA source file to a directory:

  ```
  c2s test.cu --out-root sycl_dir
  ```

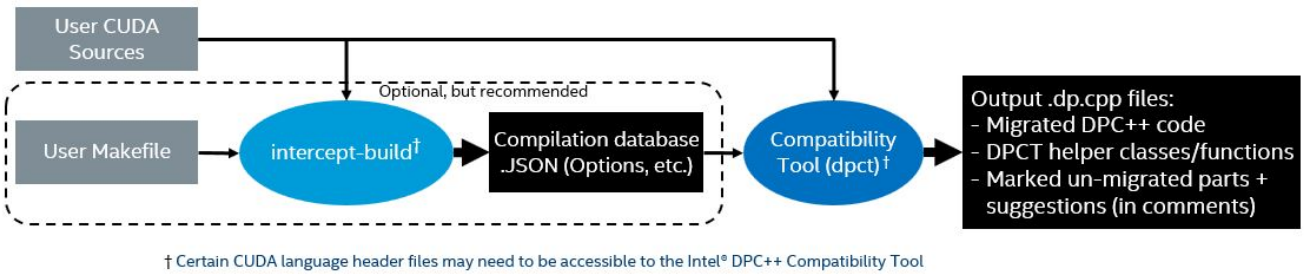
- Migrate a single CUDA source file with a CUDA installation:

  ```
  c2s test.cu --cuda-include-path /tmp/cuda/include
  ```

- Migrate a CUDA project with a makefile:

  `c2s --project-dir /path/to/project`:

  1. `intercept-build make`
  2. `c2s -p compile_command.json`



Warnings (DPCT/SYCLomatic)

- The DPCT compatibility tool identifies parts of the code that may require attention from the programmer.
- Comments in the code indicating compatibility or correctness with DPC++
  - Warnings issues as :

warnings.cpp

```
/path/to/file.hpp:26:1: warning: DPCT1003:0: Migrated API does not return error
     code. (*,0) is inserted. You may need to rewrite this code.
// source code line for which warning was generated
^
```

- More details about the meaning of the warnings can be found in the diagnostic reference guide

Easy project (a single source file)

```cuda
#include <cuda.h>
#include <stdio.h>

const int vector_size = 256;

__global__ void SimpleAddKernel(float *A, int offset)
{
  A[threadIdx.x] = threadIdx.x + offset;

}int main()
{
  float *d_A;
  int offset = 10000;

  cudaMalloc( &d_A, vector_size * sizeof( float ) );
  SimpleAddKernel<<<1, vector_size>>>(d_A, offset);

  float result[vector_size] = { };
  cudaMemcpy(result, d_A, vector_size*sizeof(float), cudaMemcpyDeviceToHost);

  cudaFree( d_A );

  for (int i = 0; i < vector_size; ++i) {
    if (i % 8 == 0) printf( "\n" );
    printf( "%.1f ", result[i] );
  }

  return 0;
}
```

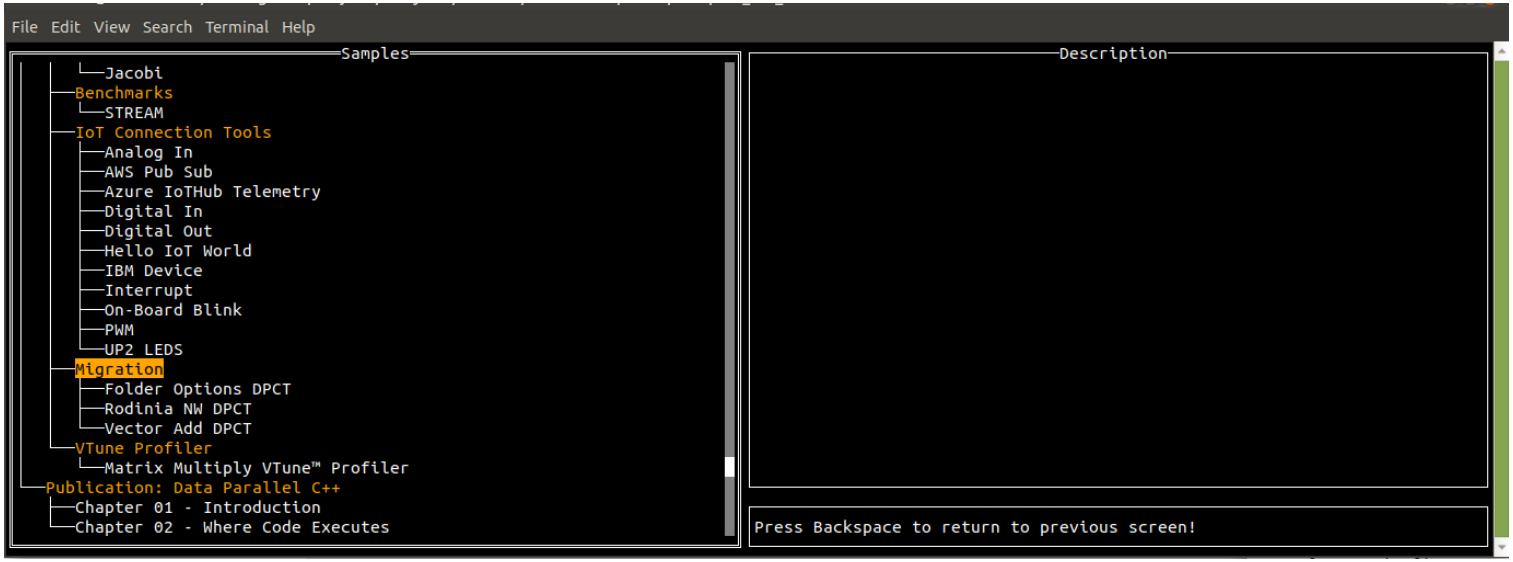
```sycl
#include <CL/sycl.hpp>
#include <dpct/dpct.hpp>
#include <stdio.h>

const int vector_size = 256;

void SimpleAddKernel(float *A, int offset, sycl::nd_item<3> item_ct1)
{
  A[item_ct1.get_local_id(2)] = item_ct1.get_local_id(2) + offset;

}int main()
{
  dpct::device_ext &dev_ct1 = dpct::get_current_device();
  sycl::queue &q_ct1 = dev_ct1.default_queue();
  float *d_A;
  int offset = 10000;

  d_A = sycl::malloc_device<float>(vector_size, q_ct1);
  q_ct1.submit([&](sycl::handler &cgh) {
    cgh.parallel_for(sycl::nd_range(sycl::range(1, 1, vector_size),
                                    sycl::range(1, 1, vector_size)),
                     [=](sycl::nd_item<3> item_ct1) {
                       SimpleAddKernel(d_A, offset, item_ct1);
                     });
  });

  float result[vector_size] = { };
  q_ct1.memcpy(result, d_A, vector_size * sizeof(float)).wait();

  sycl::free(d_A, q_ct1);

  for (int i = 0; i < vector_size; ++i) {
    if (i % 8 == 0) printf( "\n" );
    printf( "%.1f ", result[i] );
  }

  return 0;
}
```

Hands-on

1. Connect to the Intel Developer Cloud
2. In the **Training and Workshops** section
3. ... but we will work on **Migrate from CUDA® to C++ with SYCL®**
   - https://console.cloud.intel.com/training/detail/f82a85e5-acc8-489c-8e1d-0f516c02a662
4. Inside the IDC, open the notebook in the path **Training/HPC/cuda-to-sycl-migration-training/01_SYCL_Migration_Simple_VectorAdd.ipynb**

Other examples

- You can find more examples of migration into GitHub de oneAPI-samples
- ... or using the tool **oneapi-cli**



Multi-source project

- Let's try another example with the **oneapi-cli** tool: folder-options-dpct
- This example consists of three CUDA files (main.cu, util.cu, and util.h) located in two folders (foo and bar):

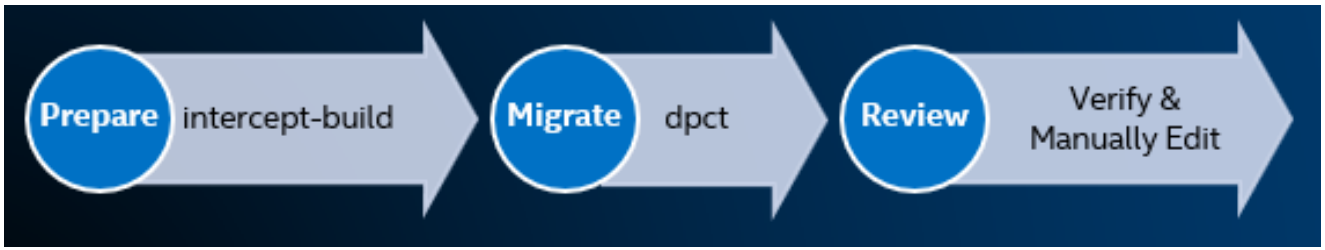
```
foo
 bar
    util.cu
    util.h
 main.cu
```

Steps to perform

1. Code migration with the tool **c2s**
2. Edit and correct the possible issues. It is recommended to check the Diagnostic Reference
3. Compile with DPC++ compile: invoke original *Makefile* in the the target folder but including the **ipcx** as compiler

CUDA Project with Multiple Sources

- Using the DPCT/SYCLomatic tool for multiple sources
  1. Prepare Intercept-build tool: `intercept-build make`
     - Generates a JSON file with all the source files involved in the project
  2. DPCT/c2s tool: `c2s -p compile_commands.json`
  3. Review diagnostic messages[4] using the reference and manually fix other less obvious issues



[4] Developer Guide and Reference https://software.intel.com/content/www/us/en/develop/documentation/intel-dpcpp-compatibility-tool-user-guide/top/diagnostics-reference.html

Hands-on

- Let's try another example with the **oneapi-cli**: *oneAPI-Tools->Migration->Folder Options DPCT*
- Now, we will migrate a CUDA project with a makefile:
  1. `intercept-build make`
  2. `c2s -p compile_command.json`

Terminal #1

```
user@comp~$ intercept-build make
user@comp~$ c2s -p compile_commands.json --cuda-include-path=<CUDAPATH_HEADERS>
user@comp~$ cd dpct_output
user@comp~/dpct_output$ make
```

```
dpct_output/foo
       bar
          util.dp.cpp
          util.h
       main.dp.cpp
```

Hands-on

- It is advisable to inspect the migrated source code and identify possible warnings
  - Revise and check the Diagnostic Reference for more information related to the code **DPCT1015:0**
  - Change `stream_ct1 << "kernel_util,%d\n";` by `stream_ct1 << "kernel_util,"<< c << sycl::endl;` in the util.dp.cpp file
- Modify the Makefile: *CXX = icpx* and add **-fsycl** to *CPPFLAGS* and *LDFLAGS*
- Finally, go to the *result* folder, compile with make, and evaluate the code with *make run*

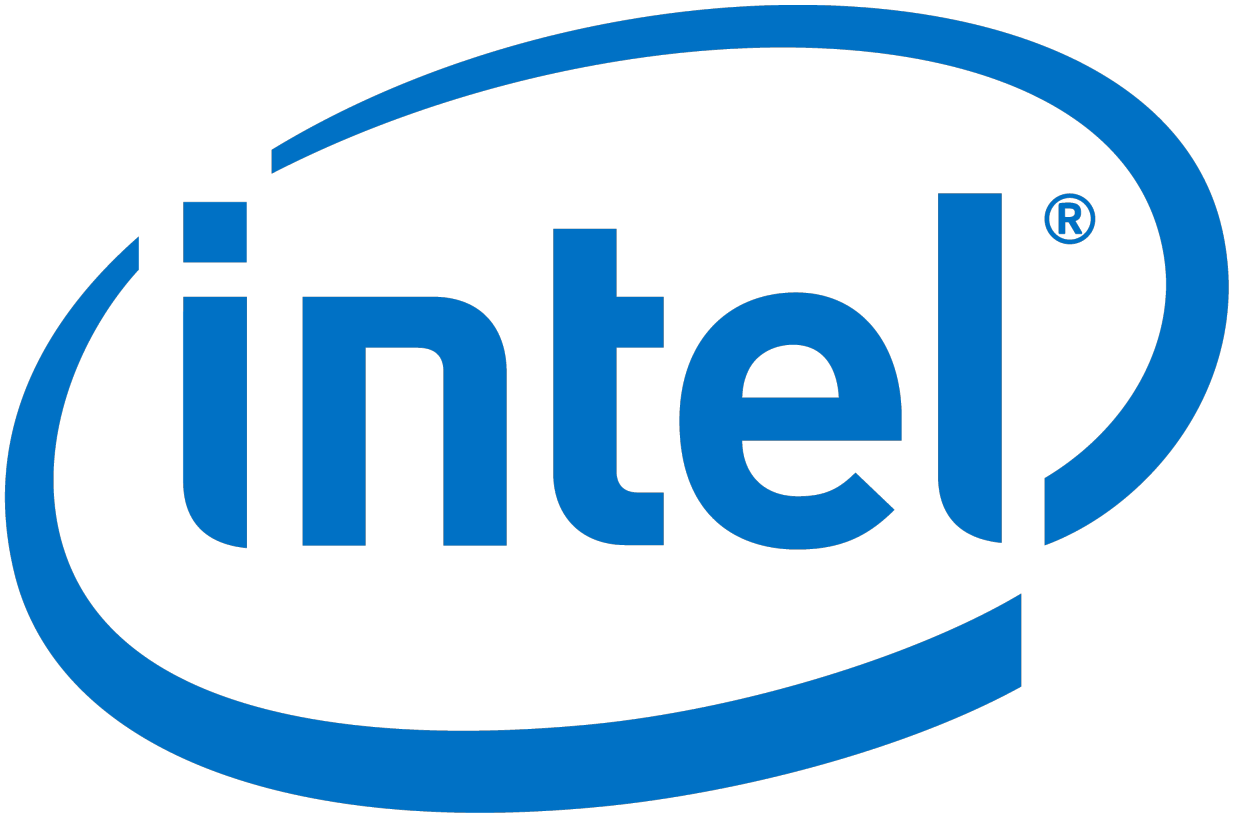
Terminal #1

```
user@comp~/dpct_output$ make
icpx   -I./foo -I./foo/bar -fsycl  -c -o foo/bar/util.dp.o foo/bar/util.dp.cpp
icpx   -I./foo -I./foo/bar -fsycl  -c -o foo/main.dp.o foo/main.dp.cpp
icpx   ./foo/bar/util.dp.o ./foo/main.dp.o -o foo-bar   -fsycl
user@comp~/dpct_output$ make run
./foo-bar
kernel_main!
kernel_util,2
```

More info

Available resources

- Intel oneAPI Base & HPC Toolkit
- Diagnosis reference for SYCLomatic tool
- Some migration experiences and an application cataloged from CUDA to SYCL
- Book **Data Parallel C++: Mastering DPC++ for Programming of Heterogeneous Systems using C++ and SYCL** disponible en el link



Software

Contacto

Thanks for your attention!!!

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