Cross-Architecture Programming for Accelerated Compute, Freedom of Choice for Hardware

# Intel® DPC++ Compatibility Tool

June 2023

# Agenda

- Intel® DPC++ Compatibility Tool overview
- vecAdd Migration Example
- Project migration (Rodinia NW)

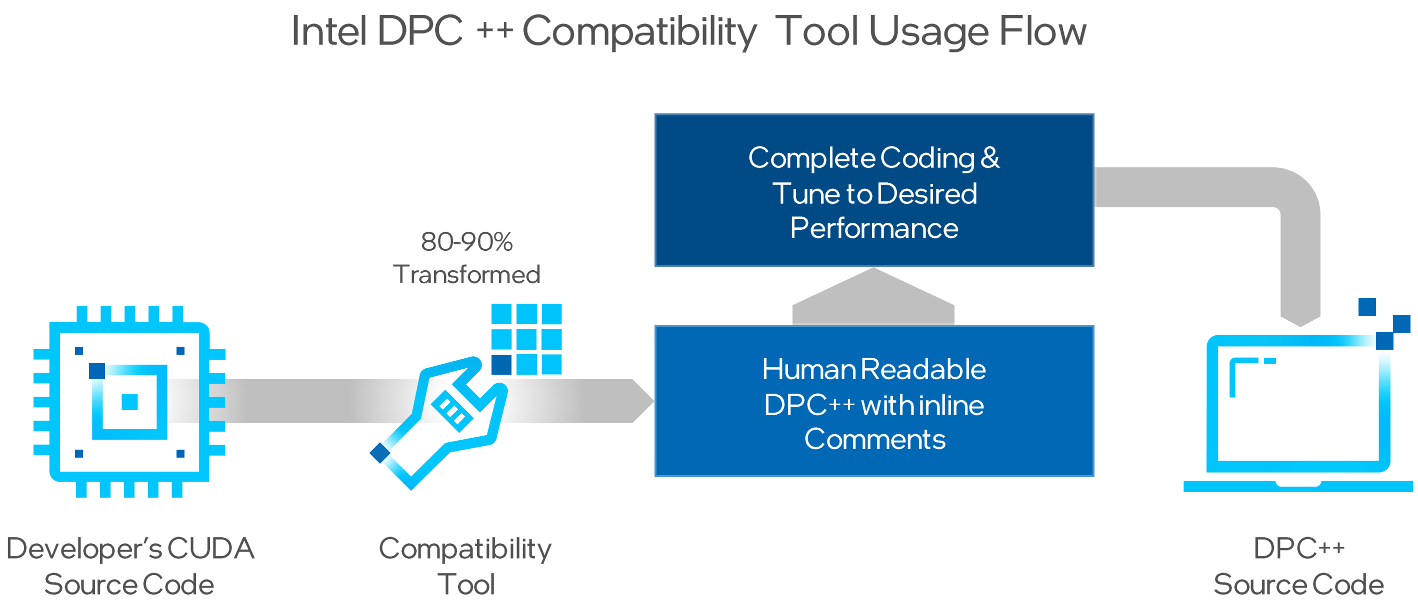
# Intel® DPC++ Compatibility Tool

## Minimizes Code Migration Time

Assists developers migrating code written in CUDA to DPC++ once, generating **human readable** code wherever possible

~90-95% of code typically migrates automatically[1]

Inline comments are provided to help developers finish porting the application




[1]Intel estimates as of September 2021. Based on measurements on a set of 70 HPC benchmarks and samples, with examples like Rodinia, SHOC, PENNANT. Results may vary.

# Open Source CUDA* to SYCL* Code Migration Tool

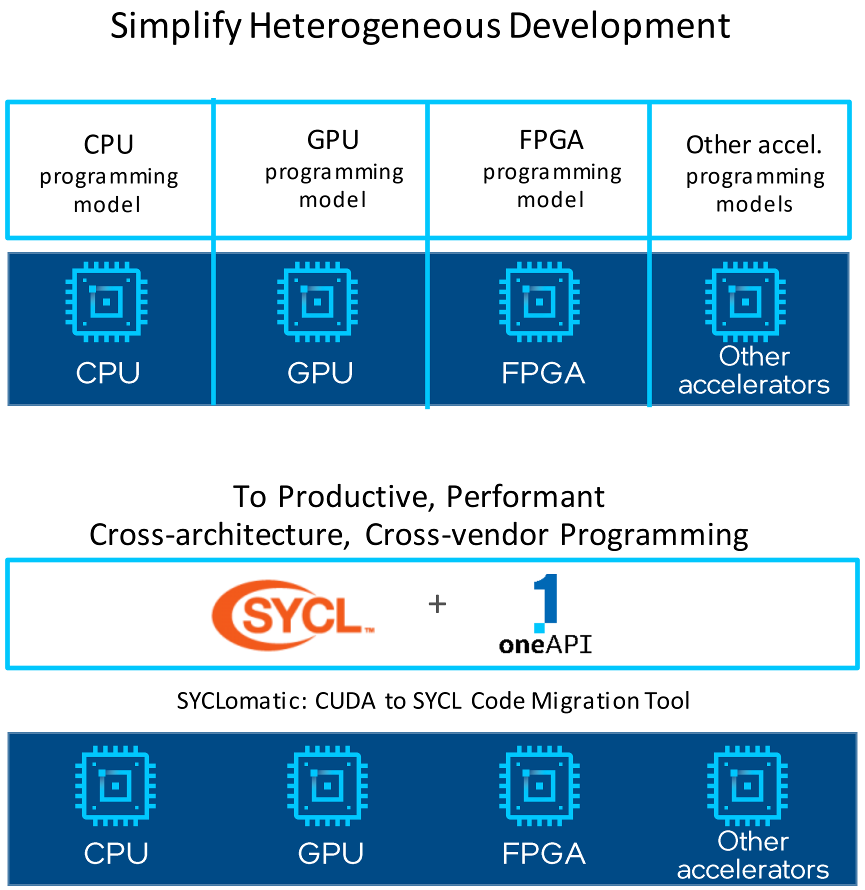
## SYCLomatic

### SYCL with oneAPI open, cross-architecture, standards-based programming

- Allows developers to expand investments across architectures
- Provides choice in hardware & freedom from proprietary, single-vendor lock-in

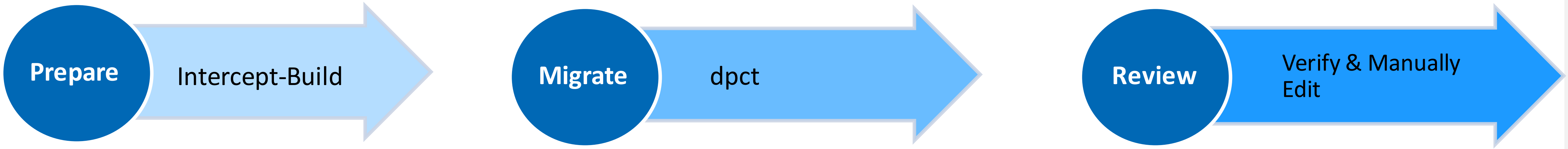
### Intel is open sourcing a CUDA to SYCL migration tool: **SYCLomatic**

- A productive path to create single-source, portable code for hardware targets regardless of vendor
- Simplifies development while delivering performance, reduces time & costs for code maintenance
- A community to share, collaborate & contribute software technologies
- On GitHub:
  - github.com/oneapi-src/SYCLomatic
  - Use the tool, please provide feedback!



# Intel® DPC++ Compatibility Tool

## Migration of Large Code Bases




1. Create a compilation database file

    intercept-build make

2. Migrate your source to DPC++
    dpct -p compile_commands.json
    -in-root=$PROJ_DIR
    -out-root=dpcpp_out *.cu

3. Verify the source for correctness and fix not migrated parts

# ZIB CUDA Code Migration to SYCL Delivers Performance across Architectures

## Freedom of Choice

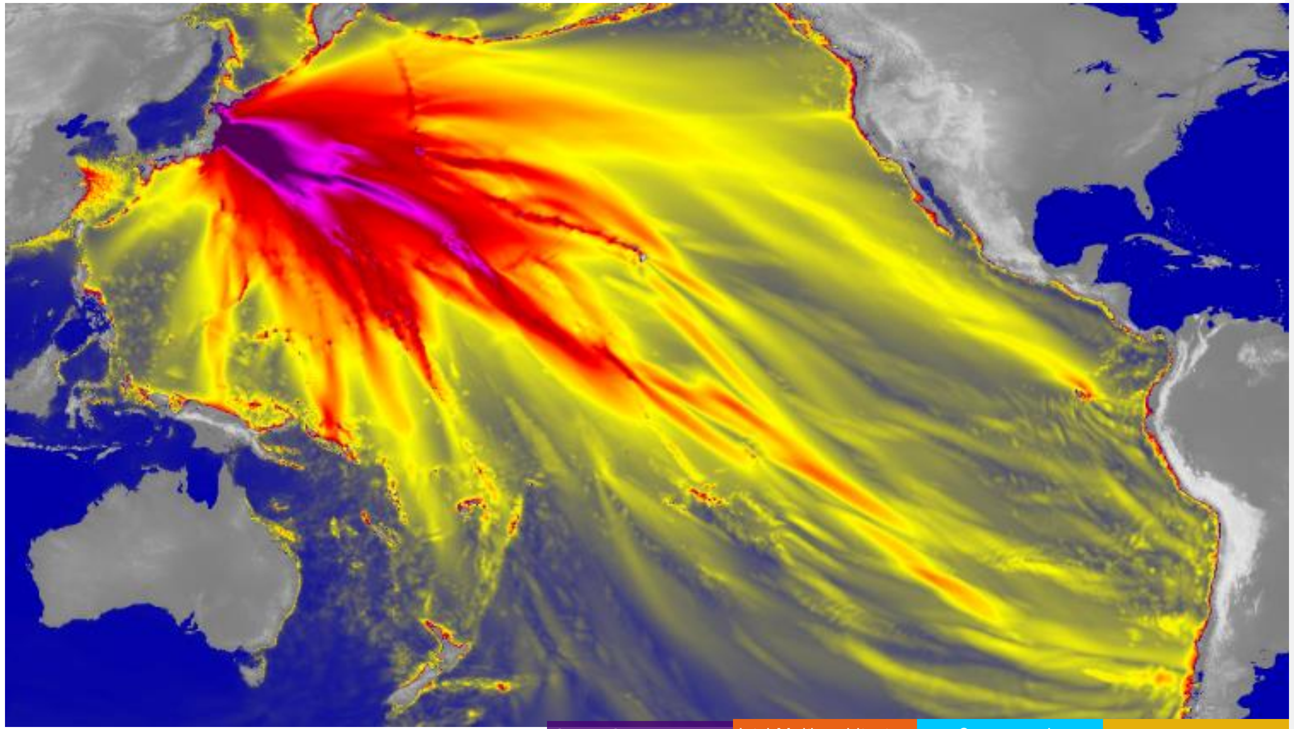
ZUSE INSTITUTE BERLIN

### ZIB ported *easyWave* application from CUDA to SYCL/Data Parallel C++ (DPC++) delivering performance across multi-architectures

- Ported *easyWave* written in CUDA to DPC++ efficiently using the Intel® DPC++ Compatibility Tool
- Achieved strong performance across Intel CPU, GPU and FPGA architectures, and within 5% of CUDA performance on Nvidia P100

Podcast | Video

intel. XEON | Xe | intel. STRATIX 10 | oneAPI | Intel® oneAPI Base Toolkit + FPGA Add-on



Visualization of *easyWave* tsunami simulation application - Courtesy Zuse Institute Berlin (ZIB)

| CUDA Code Migration to DPC++ for Single Source Code | Intel Multi-architecture Deployments (CPU, GPU, FPGA) | Cross-vendor Multi-architecture Deployments | Used Multiple tools in Intel® oneAPI Toolkits |
|---|---|---|---|

github.com/christgau/easywave-sycl

DPC++ is oneAPI's implementation in SYCL.

For details see XPUG presentation: ZIB: oneAPI case study with the tsunami simulation EasyWave from CUDA to DPC++ and back to Nvidia GPUs and FPGAs – Configuration: Compute Domain: approx. 2000 x 1400 cells; 10 hours simulation time. Same code produces valid data on CPU, Intel GPUs, and FPGA. oneAPI performance evolution on DevCloud Coffee Lake Gen9.5 GT2 iGPU using code migrated from CUDA to Data Parallel C++ using the Intel® DPC++ Compatibility tool, build with open source Intel LLVM w/ CUDA support (contribution by Codeplay). Typical application run on Nvidia P100-SXM2-16GB shows migrated DPC++ code runs only 4% slower than CUDA code. Results: Same DPC++ code can target different platforms (almost) without modifications. • Performance is on par with architecture-specific CUDA code. For workloads and configurations visit www.Intel.com/PerformanceIndex.

Results may vary. Intel does not control or audit third-party data. You should consult other sources to evaluate accuracy.

# What’s New?

- Improved conformance with SYCL 2020 specification
- Can use old build logs as input to start migration
- Support of some inline assembly in CUDA code
- Enhanced CUB API migration, Driver API migration in 2022
- --gen-build-script option to automatically create makefiles
- --no-incremental-migration to ignore existing migrated output
- Supported CUDA versions are: 8.0, 9.x, 10.1, 10.2, 11.0 - 11.8, 12.0
- Support for cuFFT*, Thrust, CUB, Driver API migration (partial)
- --use-custom-helper to customize the helper header files for migrated code
- --no-dpcpp-extensions to avoid specific DPC++ in a migrated code
- --use-experimental-features
- --assume-nd-range-dim to control dimensionality preferences

[tinyurl.com/intel-dpct-release-notes](https://tinyurl.com/intel-dpct-release-notes)

# Migration example

Header files → Kernel → Mem alloc → Kernel call → Mem copy → Mem free

```
#include <cuda.h>

#define VECTOR_SIZE 4
__global__ void VectorAddKernel (float *A, float *B, float *C)
{
  A[threadIdx.x] = threadIdx.x + 1.0f;
  B[threadIdx.x] = threadIdx.x + 1.0f;
  C[threadIdx.x] = A[threadIdx.x] + B[threadIdx.x];
}


int main()
{


  float *d_A, *d_B, *d_C;
  cudaMalloc(&d_A, VECTOR_SIZE*sizeof(float));
  cudaMalloc(&d_B, VECTOR_SIZE*sizeof(float));
  cudaMalloc(&d_C, VECTOR_SIZE*sizeof(float));


  VectorAddKernel<<<1, VECTOR_SIZE>>>(d_A, d_B, d_C);


  float Result[VECTOR_SIZE] = { };
  cudaMemcpy(Result, d_C,VECTOR_SIZE*sizeof(float),cudaMemcpyDeviceToHost);

  cudaFree(d_A);
  cudaFree(d_B);
  cudaFree(d_C);
}
```

```
#include <sycl/sycl.hpp>
#include <dpct/dpct.hpp>
#define VECTOR_SIZE 4
void VectorAddKernel (float *A, float *B, float *C, sycl::nd_item<3> item_ct1)
{
  A[item_ct1.get_local_id(2)] = item_ct1.get_local_id(2) + 1.0f;
  B[item_ct1.get_local_id(2)] = item_ct1.get_local_id(2) + 1.0f;
  C[item_ct1.get_local_id(2)] = A[item_ct1.get_local_id(2)] + B[item_ct1.get_local_id(2)];
}


int main()
{
dpct::device_ext &dev_ct1 = dpct::get_current_device();
  sycl::queue &q_ct1 = dev_ct1.default_queue();

  float *d_A, *d_B, *d_C;
  d_A = sycl::malloc_device<float>(VECTOR_SIZE, q_ct1);
  d_B = sycl::malloc_device<float>(VECTOR_SIZE, q_ct1);
  d_C = 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) {
      VectorAddKernel(d_A, d_B, d_C, item_ct1);
    });
  });

  float Result[VECTOR_SIZE] = { };
  q_ct1.memcpy(Result, d_C, VECTOR_SIZE * sizeof(float)).wait();

  sycl::free(d_A, q_ct1);
  sycl::free(d_B, q_ct1);
  sycl::free(d_C, q_ct1);
}
```

tinyurl.com/cuda-sycl-equivalence

intel.

# Queue Selection

```
/// Util function to get the default queue of current device in
/// dpct device manager.
static inline cl::sycl::queue &get_default_queue() {
  return dev_mgr::instance().current_device().default_queue();
}
```

```
cl::sycl::queue &default_queue() { return *_default_queue; }
```

```
 device_ext(const cl::sycl::device &base) : cl::sycl::device(base) {
#ifdef DPCT_USM_LEVEL_NONE
    _default_queue = new cl::sycl::queue(base, exception_handler);
#else
    _default_queue = new cl::sycl::queue(base, exception_handler,
                                cl::sycl::property::queue::in_order());
#endif
    _queues.insert(_default_queue);
    _saved_queue = _default_queue;
  }
```

# General Best Known Methods (BKMs)

- Migrate Incrementally
  - If you see *dpct* generate multiple errors when migrating a long list of CUDA source files in one run, do it one-by-one
- Check that dpct recognized the input code as “valid”
  - default C++ std, macro definitions and include paths
- Start with a clean project - “make clean” before running “intercept-build make”

# Demo

## Pre-requisites on your own system:

- Get the latest oneAPI Base Toolkit:

  https://software.intel.com/content/www/us/en/develop/tools/oneapi/base-toolkit/download.html

- Set the environment, e.g. source /opt/intel/oneapi/setvars.sh

## or use Intel DevCloud https://devcloud.intel.com/oneapi/

NOTE: You need to have CUDA* headers available to migrate the code

# Using Syclomatic on the DevCloud

1. Carefully read and understand the Licence Agreement of Nvidia*
2. Register on the Intel DevCloud: https://devcloud.intel.com/oneapi/
3. Log-in using SSH or the Jupyter Notebook, get a GPU Compute node:

```
qsub -I -l nodes=1:gpu:ppn=2
```

4. Run the following script on your DevCloud node to install the CUDA* headers.
   Note that this is Nvidia's intellectual property, you need to agree to their licence terms.

```
cd $HOME
git clone --recurse-submodules https://gitlab.com/nvidia/headers/cuda.git cuda_tmp
mkdir cudaheaders
for i in $HOME/cuda_tmp/*/*; do cp -r $i $HOME/cudaheaders; done
rm -rf $HOME/cuda_tmp
```

5. Set-up oneAPI environment: `source /opt/intel/inteloneapi/setvars.sh`
6. Tool usage: `dpct --cuda-include-path=$HOME/cudaheaders yoursourcefile.cu`

NOTE: You need to have CUDA* headers available to migrate the code

# vecAdd

- *Download the oneAPI samples:* git clone https://github.com/oneapi-src/oneAPI-samples.git
- *cd vector-add-dpct/src*
- *dpct --cuda-include-path=/home/u136312/include  vector_add.cu*

```
NOTE: Could not auto-detect compilation database for file 'vector_add.cu' in '/home/u136312/oneAPI-samples/Tools/Migration/vector-add-dpct/src' or any parent directory.
The directory "dpct_output" is used as "out-root"
Processing: /home/u136312/oneAPI-samples/Tools/Migration/vector-add-dpct/src/vector_add.cu
/home/u136312/oneAPI-samples/Tools/Migration/vector-add-dpct/src/vector_add.cu:32:14: warning: DPCT1003:0: Migrated API does not return error code. (*, 0) is inserted. You may need to rewrite this code.
    status = cudaMemcpy(Result, d_C, VECTOR_SIZE*sizeof(float), cudaMemcpyDeviceToHost);
             ^
Processed 1 file(s) in -in-root folder "/home/u136312/oneAPI-samples/Tools/Migration/vector-add-dpct/src"

See Diagnostics Reference to resolve warnings and complete the migration:
https://software.intel.com/content/www/us/en/develop/documentation/intel-dpcpp-compatibility-tool-user-guide/top/diagnostics-reference.html
```

- File vector_add.dp.cpp is generated in dpct_output directory

# vecAdd

- *dpct --cuda-include-path=/home/u136312/include --enable-ctad --out-root=test1 vector_add.cu*

  *diff dpct_output/vector_add.dp.cpp test1/vector_add.dp.cpp*

```
32,33c32,33
<       cgh.parallel_for(sycl::nd_range<3>(sycl::range<3>(1, 1, VECTOR_SIZE),
<                                          sycl::range<3>(1, 1, VECTOR_SIZE)),
---
>       cgh.parallel_for(sycl::nd_range(sycl::range(1, 1, VECTOR_SIZE),
>                                       sycl::range(1, 1, VECTOR_SIZE)),
```

- *dpct --cuda-include-path=/home/u136312/include --enable-ctad --out-root=test2 --keep-original-code vector_add.cu*

```
/* DPCT_ORIG __global__ void VectorAddKernel(float* A, float* B, float* C)*/
void VectorAddKernel(float *A, float *B, float *C, sycl::nd_item<3> item_ct1)
{
/* DPCT_ORIG     A[threadIdx.x] = threadIdx.x + 1.0f;*/
    A[item_ct1.get_local_id(2)] = item_ct1.get_local_id(2) + 1.0f;
/* DPCT_ORIG     B[threadIdx.x] = threadIdx.x + 1.0f;*/
    B[item_ct1.get_local_id(2)] = item_ct1.get_local_id(2) + 1.0f;
/* DPCT_ORIG     C[threadIdx.x] = A[threadIdx.x] + B[threadIdx.x];*/
    C[item_ct1.get_local_id(2)] =
        A[item_ct1.get_local_id(2)] + B[item_ct1.get_local_id(2)];
}  ...
  /* DPCT_ORIG     cudaMalloc(&d_A, VECTOR_SIZE*sizeof(float));*/
      d_A = sycl::malloc_device<float>(VECTOR_SIZE, q_ct1);
  /* DPCT_ORIG     cudaMalloc(&d_B, VECTOR_SIZE*sizeof(float));*/
      d_B = sycl::malloc_device<float>(VECTOR_SIZE, q_ct1);
  /* DPCT_ORIG     cudaMalloc(&d_C, VECTOR_SIZE*sizeof(float));*/
      d_C = sycl::malloc_device<float>(VECTOR_SIZE, q_ct1);

  /* DPCT_ORIG     VectorAddKernel<<<1, VECTOR_SIZE>>>(d_A, d_B, d_C);*/
      q_ct1.submit([&](sycl::handler &cgh) {
```

# Rodinia NW

- *cd ~/dpct_demo/oneAPI-samples/Tools/Migration/rodinia-nw-dpct*
- *make clean*

1. *intercept-build make*

cat compile_commands.json

```
[
  {
    "command": "nvcc -c  -o needleman_wunsch_cu  -D__CUDACC__=1 src/needle.cu",
    "directory": "/home/u136312/oneAPI-samples/Tools/Migration/rodinia-nw-dpct",
    "file": "/home/u136312/oneAPI-samples/Tools/Migration/rodinia-nw-dpct/src/needle.cu"
  }
]
```

clang.llvm.org/docs/JSONCompilationDatabase.html

2. *dpct --cuda-include-path=/home/u136312/include -p compile_commands.json --in-root=. --out-root=migration*

warning: DPCT1065:0: Consider replacing sycl::nd_item::barrier() with sycl::nd_item::barrier(sycl::access::fence_space::local_space) for better performance if there is no access to global memory.

…

warning: DPCT1003:0: Migrated API does not return error code. (*, 0) is inserted. You may need to rewrite this code.

warning: DPCT1043:1: The version-related API is different in SYCL. An initial code was generated, but you need to adjust it.

warning: DPCT1009:2: SYCL uses exceptions to report errors and does not use the error codes. The original code was commented out and a warning string was inserted. You need to rewrite this code.

…

warning: DPCT1049:5: The workgroup size passed to the SYCL kernel may exceed the limit. To get the device limit, query info::device::max_work_group_size. Adjust the workgroup size if needed.

# Rodinia NW

- *cp Makefile migration/*
- Replace the CUDA configurations in that new `Makefile` with the following for use with DPC++:

```
CXX = dpcpp
TARGET = needleman_wunsch_dpcpp
SRCS = src/needle.dp.cpp
DEPS = src/needle_kernel.dp.cpp src/needle.h
```

- Compilation out-of-box fails with an error similar to the following:

```
error: assigning to 'int' from incompatible type 'typename info::param_traits<info::device,
(device)4143U>::return_type' (aka 'basic_string<char>’)
```

- Need to address warnings first

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# Addressing Warnings in Migrated Code

warning: DPCT1003:0: Migrated API does not return error code. (*, 0) is inserted. You may need to rewrite this code.

warning: DPCT1043:1: The version-related API is different in SYCL. An initial code was generated, but you need to adjust it.

warning: DPCT1009:2: SYCL uses exceptions to report errors and does not use the error codes. The original code was commented out and a warning string was inserted. You need to rewrite this code.

- remove unnecessary code processing error codes
- need to update the code with correct SYCL device API

needle.dp.cpp

```
int version = 0;
int err_code = 999;
/* ...dpct generated comments... */
err_code = (version = dpct::get_current_device().get_info<sycl::info::device::version>(), 0);
if (err_code != 0)
/* ...dpct generated comments... */
    printf("Error \\"%s\\" checking driver version: %s.\\n",
    "cudaGetErrorName not supported" /*cudaGetErrorName(err_code)*/,
    "cudaGetErrorString not supported" /*cudaGetErrorString(err_code)*/);
else
    printf("CUDA driver version: %d.%d\n", version/1000, version%1000/10);
```

↓

```
std::string version = dpct::get_current_device().get_info<sycl::info::device::version>();
printf("SYCL device version: %s\n", version.c_str());
```

# Addressing Warnings in Migrated Code

Check warning DPCT1049:

```
 /*
DPCT1049:5: The workgroup size passed to the SYCL kernel may exceed the limit.
To get the device limit, query info::device::max_work_group_size. Adjust the
workgroup size if needed.
*/
        q_ct1.submit([&](sycl::handler &cgh) {
            sycl::range<2> temp_range_ct1(17 /*BLOCK_SIZE+1*/,
                                          17 /*BLOCK_SIZE+1*/);
            sycl::range<2> ref_range_ct1(16 /*BLOCK_SIZE*/, 16 /*BLOCK_SIZE*/);
```

*Once migration is completed, compile DPC++ code and run via make commands:*

- *make*
- *make run*
- *./needleman_wunsch_dpcpp 4096 16*

*WG size of kernel = 128*

*Start Needleman-Wunsch*

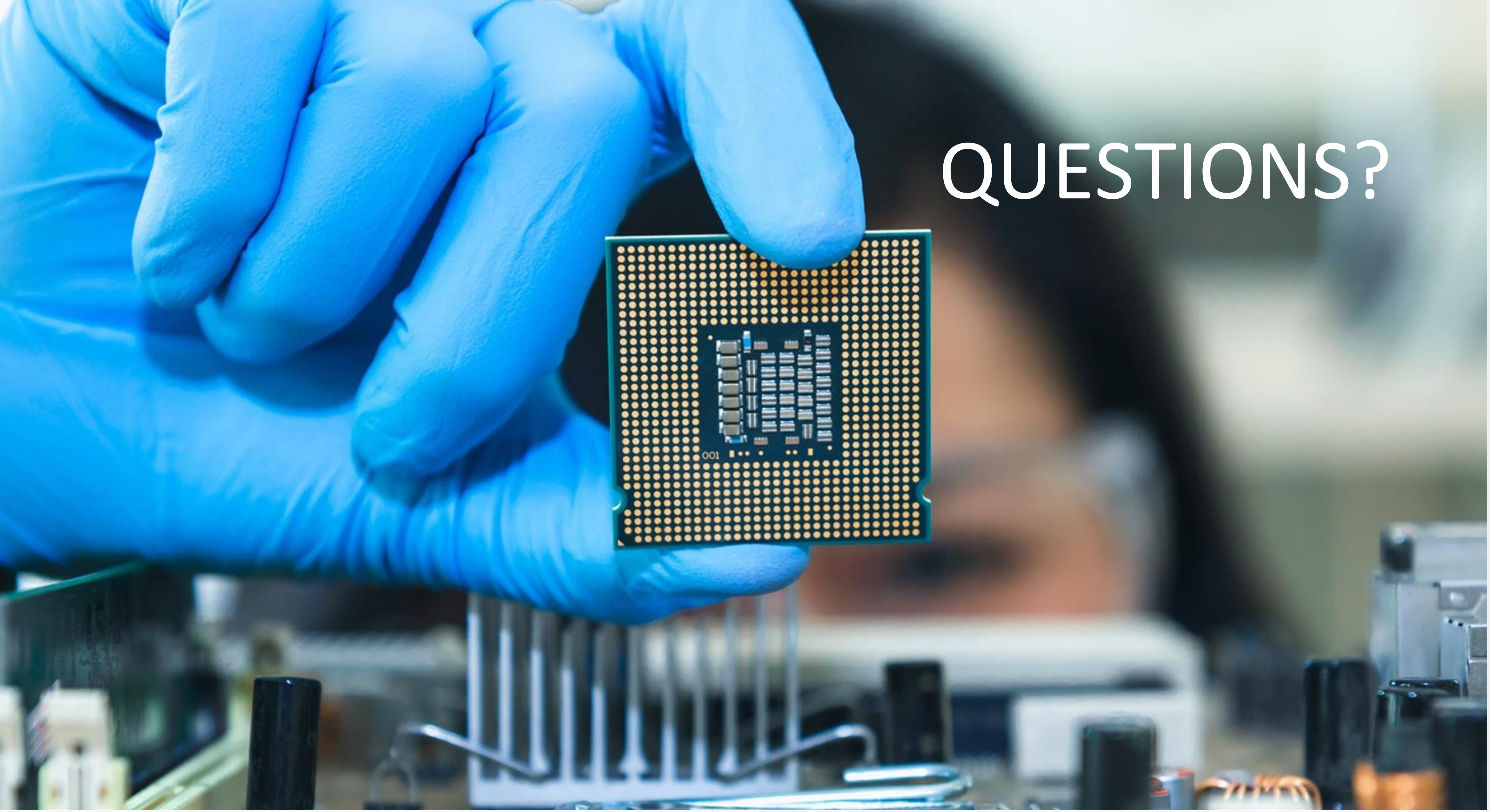
*Processing top-left matrix*

*Processing bottom-right matrix*

# Case Studies

- https://www.oneapi.io/events/devcon2021isc/
  - https://www.oneapi.io/event-sessions/experiences-with-adding-sycl-support-to-gromacs/
  - https://www.oneapi.io/event-sessions/application-optimization-with-cache-aware-roofline-model-and-intel-oneapi-tools/
  - https://www.oneapi.io/event-sessions/porting-namd-oneapi-dpc/
  - https://www.oneapi.io/event-sessions/evaluating-cuda-portability-with-hipcl-dpct/
- https://www.hlrn.de/doc/display/PUB/Joint+NHR@ZIB+-+INTEL+++oneAPI+Workshop
  - easyWave - A Tsunami Simulations Application
  - Ginkgo – a sparse linear algebra library for OneAPI Hardware

# QUESTIONS?



# Notices & Disclaimers