Intel® DPC++ Compatibility Tool

Migrating CUDA Codes to DPC++
Agenda

• oneAPI Brief Overview
• Intel® DPC++ Compatibility Tool Workflow
• Migration Flow and Vector-Add Example
• Demo Tutorial
  • Simple CUDA* File Project
  • Migrate Multi CUDA Files Project
• Best Known Methods for Migration
• Eclipse and Visual Studio Integration
• Key Takeaways
oneAPI Industry Initiative

Break the Chains of Proprietary Lock-in

Open to promote community and industry collaboration

Enables code reuse across architectures and vendors

The productive, smart path to freedom for accelerated computing from the economic and technical burdens of proprietary programming models.
Intel® oneAPI
Product
Built on Intel’s Rich Heritage of CPU Tools Expanded to XPU
tes

A complete set of advanced compilers, libraries, and porting, analysis and debugger tools

- Accelerates compute by exploiting cutting-edge hardware features
- Interoperable with existing programming models and code bases (C++, Fortran, Python, OpenMP, etc.), developers can be confident that existing applications work seamlessly with oneAPI
- Eases transitions to new systems and accelerators—using a single code base frees developers to invest more time on innovation

Visit software.intel.com/oneapi for more details
Some capabilities may differ per architecture and custom-tuning will still be required. Other accelerators to be supported in the future.

Available Now
Intel® DPC++ Compatibility Tool
Minimizes Code Migration Time

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

~80-90% of code typically migrates automatically.

Inline comments are provided to help developers finish porting the application.

Intel DPC ++ Compatibility Tool Usage Flow

- **Developer’s CUDA Source Code**
- **Compatibility Tool**
- **80-90% Transformed**
- **Human Readable DPC++ with Inline Comments**

Complete Coding & Tune to Desired Performance

DPC++ Source Code
Intel® oneAPI Base Toolkit

Accelerate Data-centric Workloads

A core set of core tools and libraries for developing high-performance applications on Intel® CPUs, GPUs, and FPGAs.

Who Uses It?

- A broad range of developers across industries
- Add-on toolkit users since this is the base for all toolkits

Top Features/Benefits

- Data Parallel C++ compiler, library and analysis tools
- DPC++ Compatibility tool helps migrate existing code written in CUDA
- Python distribution includes accelerated scikit-learn, NumPy, SciPy libraries
- Optimized performance libraries for threading, math, data analytics, deep learning, and video/image/signal processing

Learn More: intel.com/oneAPI-BaseKit
Migrating Vector Add Example
Migrating Simple Example

- `dpct [options] [<source0>... <sourceN>]`
  - Ensure supported CUDA header files are available
    - May use `--cuda-include-path`
- Built-in Usage Information
  - `dpct --help`
Vector-Add Example: Migration with Intel® DPC++ Compatibility Tool

CUDA

```c
#include <cuda.h>
#include <stdio.h>
define VECTOR_SIZE 256

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];
}
```

DPC++

```c
#include <CL/sycl.hpp>
#include <dpct/dpct.hpp>
define VECTOR_SIZE 256

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)];
}
```

```c
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));

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);
```

https://github.com/oneapi-src/oneAPI-samples/tree/master/Tools/Migration/vector-add-dpct
Vector-Add Migration Example (continued)

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

float Result[VECTOR_SIZE] = { };
cudacpy(Result, d_C, VECTOR_SIZE*sizeof(float),
cudacpyDeviceToHost);

cudaFree(d_A);
cudaFree(d_B);
cudaFree(d_C);

for (int i = 0; i < VECTOR_SIZE; i++) {
    if (i % 16 == 0) {
        printf("\n");
    }
    printf("%f ", Result[i]);
}
return 0;
```

```c
q_ct1.submit([&](sycl::handler& cgh) {
    cgh.parallel_for(sycl::nd_range<3>(
        sycl::range<3>(1, 1, VECTOR_SIZE),
        sycl::range<3>(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.memcopy(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);

for (int i = 0; i < VECTOR_SIZE; i++) {
    if (i % 16 == 0) {
        printf("\n");
    }
    printf("%f ", Result[i]);
}
return 0;
```

https://github.com/oneapi-src/oneAPI-samples/tree/master/Tools/Migration/vector-add-dpct
Migrating Needleman Wunsch and HydroC Examples
Migration Flow

Typical preparation steps for simple to complex projects
Intercept Build

- Use intercept-build to create a compilation database
  - For projects that use Make or Cmake
  - Keeps track of compilation options, settings, macro definitions, include paths, etc.
  - Creates a JSON file containing the build commands

- Run “make clean” before “intercept-build”

† Certain CUDA language header files may need to be accessible to the Intel® DPC++ Compatibility Tool
DPCT Basic Options

- `dpct [options] [<source0>... <sourceN>]`

<table>
<thead>
<tr>
<th>DPCT Basic Options</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>--in-root</td>
<td>Path to the root of the source tree to be migrated</td>
</tr>
<tr>
<td>--out-root</td>
<td>Path to root of generated files.</td>
</tr>
<tr>
<td>-p</td>
<td>Path to compile database JSON file</td>
</tr>
<tr>
<td>--process-all</td>
<td>Migraters/copies all files from --in-root directory to the --out-root directory, eliminating need to specify .cu files one by one</td>
</tr>
<tr>
<td>--extra-arg</td>
<td>Specify more Clang compiler options. e.g. dpct --extra-arg=&quot;-std=c++14&quot; -extra-arg=&quot;-l...&quot;</td>
</tr>
<tr>
<td>--format-style</td>
<td>Sets formatting style for output files. e.g. =llvm, =google, =custom (Uses .clang-format file)</td>
</tr>
<tr>
<td>--format-range</td>
<td>Code formatting applied to no code (=none), migrated code (=migrated), or all code (=all)</td>
</tr>
</tbody>
</table>
DPCT Recommended Options

- `dpct [options] [<source0>... <sourceN>]`

### DPCT Options that Ease Migration/Debug

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>--keep-original-code</code></td>
<td>Keep original CUDA code in the comments of generated DPC++ file.</td>
</tr>
<tr>
<td></td>
<td>Allows easy comparison of original CUDA code to generated DPC++ code.</td>
</tr>
<tr>
<td><code>--comments</code></td>
<td>Insert comments explaining the generated code</td>
</tr>
<tr>
<td><code>---always-use-async-handler</code></td>
<td>Always create cl::sycl::queue with the async exception handler</td>
</tr>
</tbody>
</table>

- Many other options available use dpct --help
DPCT Namespace Usage

- DPCT namespace provides helper function and macros to assist the migration of input source code.
  - dpct:
- Implemented in header files (include/dpct)
- Intended to become part of your code.
- Examples: dpct_malloc, dpct_memcpy, get_buffer, get_default_queue, get_default_context
- Not recommended to use these when writing new DPC++ code
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
- Start with a clean project - “make clean” before running “intercept-build make”
- Run `intercept-build make -k` to keep going when some targets can’t be made when generating compilation database
Code Modifications Prior to Migration

- Ensure source files are syntactically correct
- Possibly needed due to differences between clang and nvcc
  1. Namespace qualification maybe needed in certain scenario with clang parser
  2. Additional forward class declarations may be needed by clang
  3. Space within the triple brackets of kernel innovation are tolerated by nvcc but not clang
     - e.g. `cuda_kernel<< <num_blocks, threads_per_block>> >(args...)`
     - See [Compilation CUDA with clang](http://llvm.org) on llvm.org for more details.
Unified Shared Memory (USM) Usage

- DPC++ supports USM that allows pointer-based approach to manage host and device memory.
- USM produces less volume code compare to SYCL buffers
- The Compatibility Tool uses USM by default.
- May be trouble some for non-Intel compilers targeting non-Intel hardware

<table>
<thead>
<tr>
<th>DPCT USM Option</th>
<th>Sets Unified Shared Memory (USM) level.</th>
</tr>
</thead>
<tbody>
<tr>
<td>--usm-level</td>
<td>=Restricted: Use USM (default)</td>
</tr>
<tr>
<td></td>
<td>=none: Uses helper functions and SYCL buffers</td>
</tr>
</tbody>
</table>
Compatibility Tool highlights issues with migration and code comments

/path/to/file:20:1: warning: DPCT10XX:0: text of the warning

//source code line for which warning was generated

See Compatibility Tool – Diagnostics Reference
Code Review or Rewrite Needed

Diagnostic Reference

- Error code logic replaced with (*,0) code or commented out
- Equivalent DPC++ API not available
- CUDA Compute Capability-dependent logic
- Hardware-dependent API (clock())
- Migration not supported for some API
- Execution time measurement logic
- Handling built-in vector type conflicts
- Migration of cuBLAS API (Review arguments list)
Demo: Simple CUDA Project Migration

- Rodinia Benchmark Suite v3.1 – Introduction
- Setting/Verifying the Environment for Intel® DPC++ Compatibility Tool
- Demo
  - Planning for Migration
  - Compatibility Tool Options
  - Migrating Needleman Wunsch Application

http://rodinia.cs.virginia.edu/doku.php


Demo: HydroC - Multi CUDA Files Project Migration

- Setting/Verifying the Environment for Intel® DPC++ Compatibility Tool
- Demo
  - Planning for Migration; Understanding the Application File ...
  - `intercept-build` Options
  - Compatibility Tool Options
  - Migrating HydroC Application

https://github.com/HydroBench/Hydro/tree/master/HydroC/cuHydroC_2DMpi/Src

https://github.com/HydroBench/Hydro

https://github.com/HydroBench/Hydro/blob/master/License.txt
SPECHEM3D_GLOBE

- SPECHEM3D_GLOBE simulates global and regional (continental-scale) seismic wave propagation
- Official repo: https://github.com/geodynamics/specfem3d_globe

<table>
<thead>
<tr>
<th>Language</th>
<th>Files</th>
<th>Blank</th>
<th>Comment</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fortran 90</td>
<td>279</td>
<td>27677</td>
<td>41716</td>
<td>100021</td>
</tr>
<tr>
<td>C</td>
<td>81</td>
<td>3145</td>
<td>5405</td>
<td>20851</td>
</tr>
<tr>
<td>CUDA</td>
<td>88</td>
<td>1410</td>
<td>2286</td>
<td>10841</td>
</tr>
<tr>
<td>Ruby</td>
<td>61</td>
<td>554</td>
<td>192</td>
<td>4365</td>
</tr>
<tr>
<td>make</td>
<td>17</td>
<td>532</td>
<td>817</td>
<td>1887</td>
</tr>
<tr>
<td>C/C++ Header</td>
<td>5</td>
<td>284</td>
<td>370</td>
<td>995</td>
</tr>
<tr>
<td>C++</td>
<td>1</td>
<td>196</td>
<td>229</td>
<td>773</td>
</tr>
<tr>
<td>Markdown</td>
<td>1</td>
<td>31</td>
<td>0</td>
<td>102</td>
</tr>
</tbody>
</table>

**SUM:**
533   33829  51015  139835

SPECFEM3D_GLOBE – Migration to DPC++

**Prepare**

- `$ git clone --recursive --branch devel https://github.com/geodynamics/specfem3d_globe.git`
- `$ ./configure --with-cuda=cuda9 CUDA_LIB=${CUDA_ROOT}/lib64/`  
  `CUDA_INC=${CUDA_ROOT}/include/ MPI_INC=${MPI_ROOT}/include/`  
- `$ intercept-build make -i`

**Migrate**

- `$ dpct -p compile_commands.json`

**Review**

- Review diagnostics messages using reference and manually edit
- Address other not-so-obvious issues
## Diagnostics Messages Breakdown

<table>
<thead>
<tr>
<th>DPCT{diagnostics#} (count)</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPCT1000 (6), DPCT1001 (6), DPCT1003 (11), DPCT1009 (8), DPCT1010 (3), DPCT1024 (2)</td>
<td>Different scenarios for error handling</td>
</tr>
<tr>
<td>DPCT1005 (4), DPCT1012 (4), DPCT1017 (10), DPCT1019 (1), DPCT1022 (1), DPCT1026 (5), DPCT1027 (3), DPCT1051 (4)</td>
<td>Unavailable equivalent API’s in SYCL* (e.g. device versions, certain device properties, timing logic)</td>
</tr>
<tr>
<td>DPCT1039 (9)</td>
<td>Handling atomics (global atomics by default, local will need intervention)</td>
</tr>
<tr>
<td>DPCT1049 (59)</td>
<td>Validating use of work-group sizes</td>
</tr>
</tbody>
</table>
Using plugins with IDE
Eclipse: Gaussian

Refer to software.intel.com/articles/optimization-notice for more information regarding performance & optimization choices in Intel software products.
Visual Studio 2019: Gaussian

Refer to software.intel.com/articles/optimization-notice for more information regarding performance & optimization choices in Intel software products.
Summary

• OneAPI delivers a unified programming model to simplify development across diverse architectures

• Intel DPC++ Compatibility tool assists developers in migrating code written in CUDA to DPC++, increasing developer productivity

• DPC++ is an open specification for a portable, architecture-neutral language for expressing parallelism; it is based on industry standards
References

- [Intel® DPC++ Compatibility Tool Jupyter Tutorial](#)
- [Intel® DPC++ Compatibility Tool](#)
  - [User Guide](#)
  - [Get Started Guide](#)
  - [Release Notes](#)
Are You Ready to Try oneAPI?

1. Identify potential workloads/candidates for testing
   a. Download DPCT and migrate code to DPC++ on-prem, if applicable
   b. Test, tune and optimize your code or test samples in the Intel® DevCloud—a cloud-based development sandbox environment that gives you full access to the latest Intel® hardware and oneAPI software
      https://software.intel.com/devcloud/oneapi

2. Learn more at http://software.intel.com/oneapi the channel to documentation, downloads, access to Intel® Devcloud, and access to support forum
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