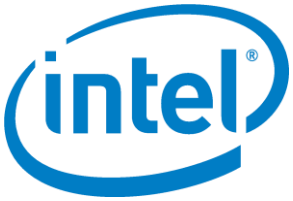


oneAPI Ultrasound Beamforming Library

Getting Started Guide

June 2022

Legal Notices and Disclaimers

Document Number:

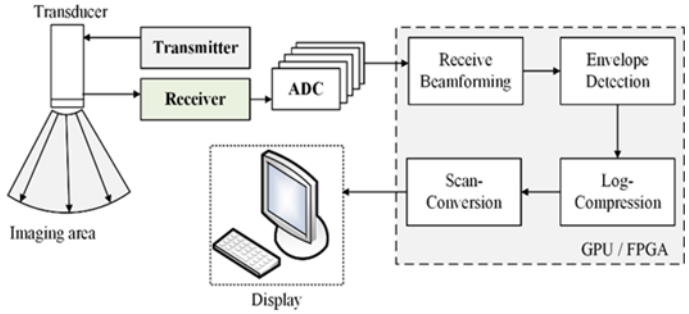
Contents

Revision History

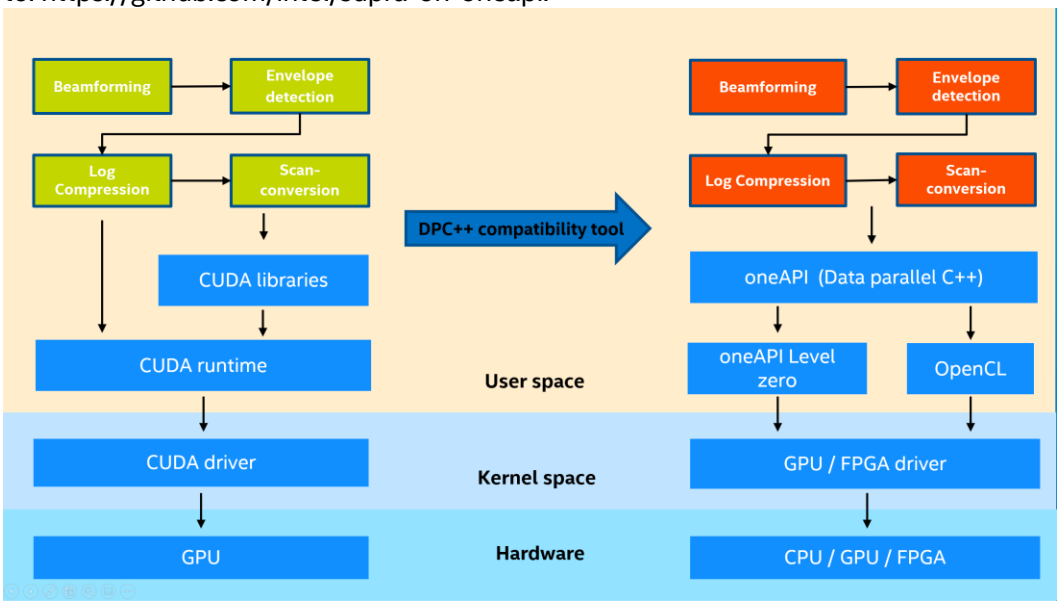
Date	Revision	Description
June 2022	1.0	Initial Release

1.0 Introduction

This project contains ultrasound software beamforming samples, which process ultrasound raw data into images human readable. The project use Intel oneAPI to do computation acceleration with Intel GPU and FPGA.



This project is focusing on the kernel functions of the workflow of ultrasound beamforming process, including Receive Beamforming, Envelope Detection, Log Compression and Scan Conversion. The kernel functions are developed and rewritten based on Supra(https://github.com/IFL-CAMP/supra). We have released a project for migrating origial Supra CUDA code to standard DPC++. For more details, please refer to: https://github.com/intel/supra-on-oneapi.



The purpose of this project is for extracting and rewriting the kernel code for easy utilization and running on Intel GPU and FPGA devices.

1.1 How to use this document

If you would like to setup software Beamforming application to make it run on an Intel device, please follow **Chapter2. Host System Setup**, and **Chapter3. oneAPI Ultrasound Beamforming Library Setup**.

1.2 Terminology

Table 1. Terminology

Term	Description
oneAPI	oneAPI is a cross-industry, open, standards-based unified programming model that delivers a common developer experience across accelerator architectures—for faster application performance, more productivity, and greater innovation. Please refer to https://www.oneapi.com/. Intel® oneAPI products will deliver the tools needed to deploy applications and solutions across the architectures. Please refer to https://software.intel.com/content/www/us/en/develop/tools/oneapi.html
SUPRA	An open-source pipeline for fully software defined ultrasound processing for real-time applications. Covering everything from beamforming to output of B-Mode images, SUPRA can help reproducibility of results and allows modifications to the image acquisition.
DPC++	At the core of the oneAPI specification is DPC++, an open, cross-architecture language built upon the ISO C++ and Khronos SYCL standards.
Intel® DPC++ Compatibility Tool	The Intel® DPC++ Compatibility Tool assists in migrating your existing CUDA code to Data Parallel C++ (DPC++) code. Refer to https://software.intel.com/content/www/us/en/develop/tools/oneapi/components/dpc-compatibility-tool.html

2.0 Host System Setup

In this section, we'll explain how to set up your development system and necessary software packages.

The preferred (and tested) development host platform is PC with Ubuntu 18.04 & 20.04. The PC could have an Intel processor with integrated graphics, a discrete graphics card, or an Intel FPGA. Also you could test the project on Intel Devcloud.

2.1 Run with Devcloud

The Intel DevCloud is a development sandbox to learn about and test programming cross architecture applications with OpenVino, High Level Design (HLD) tools – oneAPI, OpenCL, HLS – and RTL. Devcloud for OneAPI can be used for running and testing this project and you could choose to use Intel FPGA or Intel GPU. Please refer to https://devcloud.intel.com/oneapi to view the details of how to use Devcloud.

2.2 Set up your own development system

If you have your own Intel acceleration devices including Intel CPU with integrated GPU, Intel discrete GPU and Intel FPGA. Run the project on your own development machine is an option. If you do not have any acceleration devices, you could also use Intel CPU as a FPGA emulator to view beamforming results.

Sample	Acceleration Device
1st	Intel® i7-8700K CPU with Intel(R) UHD Graphics 630
	/Intel® i7-1165G7 CPU with Intel® Iris® Xe Graphics
2nd	Intel® Programmable Acceleration Card with Intel Arria® 10 GX FPGA (Data Producer)
	Intel® i7-8700K CPU with Intel(R) UHD Graphics 630
	/Intel® i7-1165G7 CPU with Intel® Iris® Xe Graphics
3nd	Intel® Programmable Acceleration Card with Intel Arria® 10 GX FPGA

2.2.1 Install Basic Packages

```
$ sudo apt-get install cmake cmake-gui libtbb-dev git
build-essential clang
```

2.2.2 Install Intel oneAPI Toolkits

Please refer to Intel(R) oneAPI installation guide: https://software.intel.com/content/www/us/en/develop/articles/installation-guide-for-intel-oneapi-toolkits.html.

Choose the version following your FPGA model type to add FPGA additional package, and refer to https://www.intel.com/content/www/us/en/developer/articles/release-notes/intel-oneapi-dpcpp-fpga-add-on-release-notes.html.

3.0 oneAPI Ultrasound Beamforming Library Setup

3.1 Get oneAPI Ultrasound Beamforming Library Source Code

Download the source code from GitHub.

```
$ git clone https://github.com/intel/ oneAPI-Ultrasound-Beamforming-Library.git
```

3.2 Initialize oneAPI Env

After downloading source code, we could start compile it. Initialize one API environment:

```
$ source /opt/intel/inteloneapi/setvars.sh

::  initializing environment ...
   advisor -- latest
   ccl -- latest
   compiler -- latest
   daal -- latest
   debugger -- latest
   dev-utilities -- latest
   dpcpp-ct -- latest
   intelpython -- latest
   ipp -- latest
   mkl -- latest
```

```
   mpi -- latest
   oneDNN -- latest
   tbb -- latest
   vpl -- latest
   vtune -- latest
:: oneAPI environment initialized ::
```

3.3 Ultrasound Beamforming on Intel GPU

3.3.1 Build

Enter the project folder.

```
$ cd oneAPI-Ultrasound-Beamforming-Library/gpu
```

Create a directory `build` at the `gpu` directory:

```
$ mkdir build
$ cd build
```

In this repo, we just call the oneAPI feature to avoid moving data back and forth between host and device as ZMC(Zero memory copy, just an abbreviation to describe the feature in this repo). The detail of the feature could be found in https://www.intel.com/content/www/us/en/develop/documentation/oneapi-gpu-optimization-guide/top/memory/host-device-memory.html. And the feature is only used for Intel integrated GPU to make no memory copy operation between host and Intel integrated GPU. If you want to test the GPU performance, select whether to use ZMC feature (set to use ZMC by default), run `cmake` using the command:

```
$ cmake .. -DUSE_ZMC=ON/OFF
```

Then run make using the command:

```
$ make -j4
```

Note: ZMC(Zero Memory Copy) can be only used with Intel integrated GPU. Please switch `USE_ZMC = OFF` if using Intel discrete graphics card.

3.3.2 Run the program

Download data to `build` directory.

```
$ mkdir data
$ cd data
$ wget https://f000.backblazeb2.com/file/supra-sample-data/mockData_linearProbe.zip
$ unzip mockData_linearProbe.zip
$ cd ..
```

If just test the GPU performance for easy testing, run the command:

```
$ src/easy_app data/linearProbe_IPCAI_128-2.mock data/linearProbe_IPCAI_128-2_0.raw
```

Note: If you run it on Intel discrete GPU, you need to run `export IGC_EnableDPEmulation=1` before running above command.

3.3.3 See the result and performance

Comsuming time of each kernel's calculation could be seen in the terminal.

Visual `*.png` results are stored in `res` directory. You could also specify the directory to store result by running the command:

```
$ src/easy_app data/linearProbe_IPCAI_128-2.mock data/linearProbe_IPCAI_128-2_0.raw <directory to store results>
```

3.4 Ultrasound Beamforming on Intel GPU with Intel FPGA as Data Producer

In real application scenarios, FPGA is often used to connect the ultrasound probe to collect data. So we simulated using FPGA as a data producer to provide data for GPU. Of course, a simple application is also provided to test software beamforming on the GPU in Chapter 3.3. We have tested and valided data producer on Intel® Programmable Acceleration Card with Intel Arria® 10 GX FPGA.

3.4.1 Build

Enter the project folder.

```
$ cd oneAPI-Ultrasound-Beamforming-Library/gpu
```

Create a directory `build` at the `gpu` directory:

```
$ mkdir build
$ cd build
```

In this repo, we just call the oneAPI feature to avoid moving data back and forth between host and device as ZMC(Zero memory copy, just an abbreviation to describe the feature in this repo). The detail of the feature could be found in https://www.intel.com/content/www/us/en/develop/documentation/oneapi-gpu-optimization-guide/top/memory/host-device-memory.html. And the feature is only used for Intel integrated GPU to make no memory copy operation between host and Intel integrated GPU. If you want to test the GPU performance, select whether to use ZMC feature (set to use ZMC by default), run `cmake` using the command:

```
$ cmake .. -DUSE_ZMC=ON/OFF
```

Then run make using the command:

```
$ make -j4
```

If you want to compile FPGA binary or using FPGA emulator to emulate data producer to send data, run `cmake` using the command:

```
$ cmake .. -DUSE_ZMC=ON/OFF -DCOMPILE_FPGA=ON
```

then run `make` using the command if a new FPGA binary is needed to be compiled:

```
$ make fpga -j4
```

If you want to use FPGA emulator, use the command:

```
$ make fpga_emu -j4
```

Note: ZMC(Zero Memory Copy) can be only used with Intel integrated GPU. Please switch `USE_ZMC = OFF` if using Intel discrete graphics card.

3.4.2 Run the program

Download data to `build` directory.

```
$ mkdir data
$ cd data
$ wget https://f000.backblazeb2.com/file/supra-sample-
data/mockData_linearProbe.zip
$ unzip mockData_linearProbe.zip
$ cd ..
```

If just test the GPU performance for easy testing, run the command:

```
$ src/easy_app data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw
```

Note: If you run it on Intel discrete GPU, you need to run `export IGC_EnableDPEmulation=1` before running above command.

If you compile an FPGA emulator version to test, run the command:

```
$ src/fpga_producer.emu data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw
```

And for the comsumer app, use the command in another terminal:

```
$ src/ultrasound data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw
```

If you compile an FPGA hardware version to test, run the command:

```
$ src/fpga_producer.fpga data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw
```

And for the comsumer app, use the command in another terminal:

```
$ src/ultrasound data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw
```

3.4.3 See the result and performance

Comsuming time of each kernel's calculation could be seen in the terminal.

Visual `*.png` results are stored in `res` directory. You could also specify the directory to store result by running the command:

```
$ src/ultrasound data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw <directory to store results>
```

3.5 Ultrasound Beamforming Standalone Kernels on Intel FPGA

Ultrasound Beamforming Standalone Kernels on Intel FPGA code has been tested and valided on Intel® Programmable Acceleration Card with Intel Arria® 10 GX FPGA.

3.5.1 Build

Enter the project folder.

```
$ cd oneAPI-Ultrasound-Beamforming-Library/fpga/standalone
```

Create a directory `build` at the `standalone` directory:

```
$ mkdir build
$ cd build
```

To compile for the Intel® PAC with Intel Arria® 10 GX FPGA, run `cmake` using the command :

```
$ cmake ..
```

Alternatively, to compile for the Intel® FPGA PAC D5005 (with Intel Stratix® 10 SX), run `cmake` using the command:

```
$ cmake .. -DFPGA_BOARD=intel_s10sx_pac:pac_s10
```

You can also compile for a custom FPGA platform. Ensure that the board support package is installed on your system. Then run `cmake` using the command:

```
$ cmake .. -DFPGA_BOARD=<board-support-package>:<board-variant>
```

Compile the design through the generated `Makefile`. The following build targets are provided, matching the recommended development flow:

Compile for emulation (compiles quickly, targets emulated FPGA device):

```
$ make emu
```

Generate the optimization report:

```
$ make report
```

Compile for FPGA hardware (takes longer to compile, targets FPGA device):

```
$ make fpga
```

3.5.2 Run the program

Download data to `build` directory.

```
$ mkdir data
$ cd data
$ wget https://f000.backblazeb2.com/file/supra-sample-
data/mockData_linearProbe.zip
$ unzip mockData_linearProbe.zip
$ cd ..
```

If you compile an FPGA emulator version to test, run the command:

```
$ ./ultrasound.fpga_emu data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw
```

If you compile an FPGA hardware version to test, run the command:

```
$ ./ultrasound.fpga data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw
```

3.5.3 See the result and performance

Comsuming time of each kernel's calculation could be seen in the terminal.

Visual `*.png` results are stored in `res` directory. You could also specify the directory to store result by running the command:

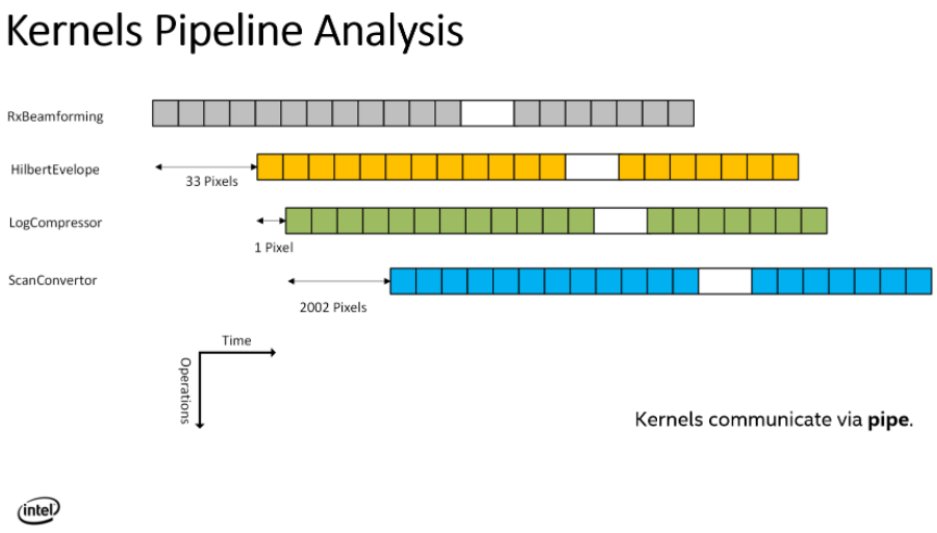
```
$ ./ultrasound.fpga data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw <directory to store results>
```

Or

```
$ ./ultrasound.fpga_emu data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw <directory to store results>
```

3.6 FPGA pipeline lib code

Ultrasound Beamforming Standalone Kernels on Intel FPGA code has been tested and valided on Intel® Programmable Acceleration Card with Intel Arria® 10 GX FPGA. Pipelining the kernels can improve the efficiency and performance of the beamforming algorithm on FPGAs. You can refer to the link to learn more about oneAPI dpcpp optimization on Intel FPGA.
https://software.intel.com/content/dam/develop/external/us/en/documents/oneapi-dpcpp-fpga-optimization-guide.pdf.



3.6.1 Build

Enter the project folder.

```
$ cd oneAPI-Ultrasound-Beamforming-Library/fpga/pipeline
```

Create a directory `build` at the `pipeline` directory:

```
$ mkdir build
$ cd build
```

To compile for the Intel® PAC with Intel Arria® 10 GX FPGA, run `cmake` using the command. If you want to store the results of each kernel(storing by default and you can choose not to set this option),

```
$ cmake .. -DSTORE=ON
```

Or

```
$ cmake .. -DSTORE=OFF
```

Alternatively, to compile for the Intel® FPGA PAC D5005 (with Intel Stratix® 10 SX), run `cmake` using the command:

```
$ cmake .. -DFPGA_BOARD=intel_s10sx_pac:pac_s10 -DSTORE=ON/OFF
```

You can also compile for a custom FPGA platform. Ensure that the board support package is installed on your system. Then run `cmake` using the command:

```
$ cmake .. -DFPGA_BOARD=<board-support-package>:<board-variant> -
DSTORE=ON/OFF
```

You can choose `FAKEDATA` building option on/off to valid the performance without DDR bandwith limit. By default, the program will use real raw data to do calculations. If set `-DFAKEDATA=ON`, there will not be DDR bandwidth limit to decrease the throughput of the pipelined program and fake input data will be used. So if using `FAKEDATA`, run `cmake` using the command:

```
$ cmake .. -DFAKEDATA=ON -DSTORE=OFF/ON
```

Compile the design through the generated `Makefile`. The following build targets are provided, matching the recommended development flow:

Compile for emulation (compiles quickly, targets emulated FPGA device):

```
$ make emu
```

Generate the optimization report:

```
$ make report
```

Compile for FPGA hardware (takes longer to compile, targets FPGA device):

```
$ make fpga
```

3.6.2 Run the program

Download data to `build` directory.

```
$ mkdir data
$ cd data
$ wget https://f000.backblazeb2.com/file/supra-sample-
data/mockData_linearProbe.zip
$ unzip mockData_linearProbe.zip
$ cd ..
```

If you compile an FPGA emulator version to test, run the command:

```
$ ./ultrasound.fpga_emu data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw
```

If you compile an FPGA hardware version to test, run the command:

```
$ ./ultrasound.fpga data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw
```

3.6.3 See the result and performance

Comsuming time of each kernel's calculation could be seen in the terminal.

Visual `*.png` results are stored in `res` directory. You could also specify the directory to store result by running the command:

```
$ ./ultrasound.fpga data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw <directory to store results>
```

Or

```
$ ./ultrasound.fpga_emu data/linearProbe_IPCAI_128-2.mock
data/linearProbe_IPCAI_128-2_0.raw <directory to store results>
```