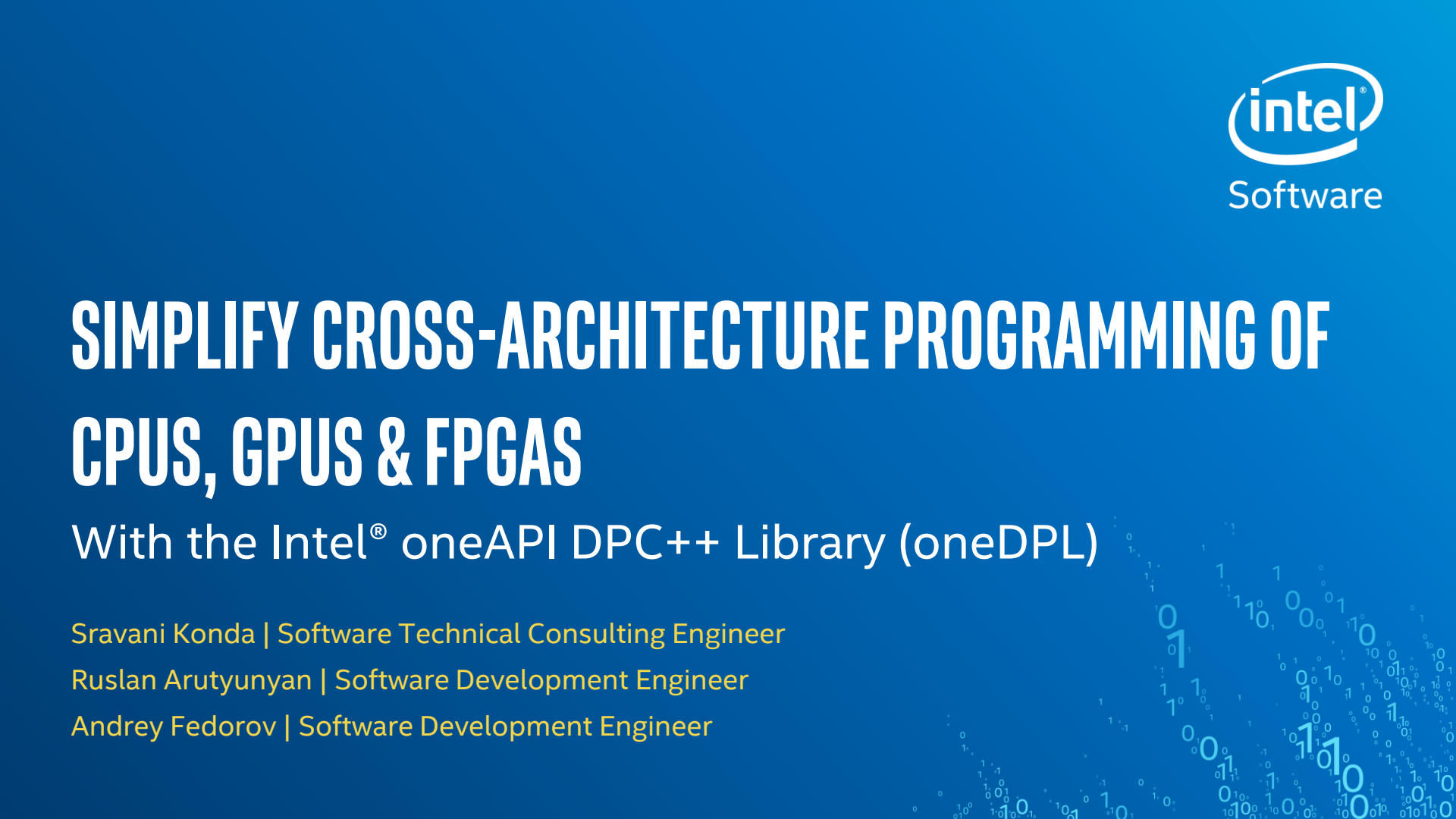


SIMPLIFY CROSS-ARCHITECTURE PROGRAMMING OF CPUS, GPUS & FPGAS

With the Intel® oneAPI DPC++ Library (oneDPL)

Sravani Konda | Software Technical Consulting Engineer
Ruslan Arutyunyan | Software Development Engineer
Andrey Fedorov | Software Development Engineer

Agenda

- Intel® oneAPI DPC++ Library
- C++ Standard APIs for Device Programming
- Parallel STL and its Support for DPC++
- Extension API
- Examples
- Summary

Intel® oneAPI DPC++ Library (oneDPL)

High-Productivity APIs for Heterogeneous Computing - CPUs, GPUs, and FPGAs

APIs are based on familiar standards and libraries - C++ STL, SYCL and Parallel STL, Boost.Compute

Optimized C++ Standard Algorithms - 84 parallelized C++17 algorithms and utilities

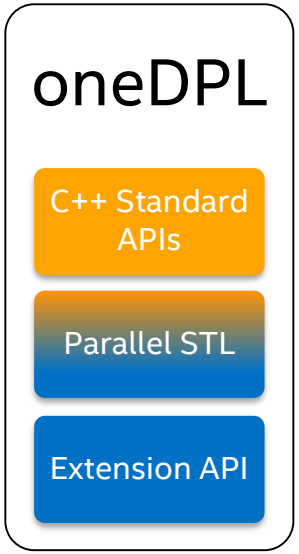
Integrated with Intel® DPC++ Compatibility Tool - Migration of Thrust* APIs

Available on Open Source - https://github.com/oneapi-src/oneDPL

oneDPL Modules

oneDPL consists of 3 Modules

1. C++ STL API functionality
   - Tested C++ Standard APIs that work in DPC++ kernels
2. Parallel STL for DPC++
   - Parallelized C++17 algorithms with DPC++ backend support
3. DPC++ Extension API*
   - Additional library classes and functions



*Extension API is still in beta, the names and semantics might change in future

C++ STD FOR DEVICE PROGRAMMING

C++ Standard Library in DPC++

Host

- Code running on CPU can use everything from STD

Device

- SYCL spec restrictions on C++ features used in device code prevents some std classes/functions from working in device code
  - items using exception
  - dynamic memory allocation
  - virtual functions…

Tested Standard C++ APIs

80+ standard C++ APIs have been tested

- Usage in DPC++ kernels
- Data Transfer from/to host and device

Across 3 major implementations:

1. libstdc++ (GNU): deployed in most Linux distributions
2. libc++ (LLVM): MacOS and FreeBSD
3. MSVC (Microsoft): Windows, shipped with Microsoft Visual Studio

Visit Intel® oneAPI DPC++ Library Guide for a detailed list

Example – std::swap()

```
#include <CL/sycl.hpp>
#include <utility>
#include <iostream>
using namespace cl::sycl;
void kernel_test() {
    sycl::queue deviceQueue;
    sycl::range<1> numOfItems{2};
    sycl::cl_int swap_num[2] = {4, 5};
    std::cout << swap_num[0] << ", " << swap_num[1] << std::endl;
    {
        sycl::buffer<sycl::cl_int, 1> swap_buffer(swap_num, numOfItems);
        deviceQueue.submit([&](sycl::handler& cgh) {
            auto swap_accessor = swap_buffer.get_access<sycl::access::mode::read_write>(cgh);
            cgh.single_task<class KernelSwap>([=] {
                int& num1 = swap_accessor[0];
                int& num2 = swap_accessor[1];
                std::swap(num1, num2);
            });
        });
    }
    std::cout << swap_num[0] << ", " << swap_num[1] << std::endl;
}
int main() {
    kernel_test();
}
```

PARALLEL STL OVERVIEW

Parallel STL Brief Overview

C++17/20 parallel extensions

- Execution policies define how/where to run standard algorithms
- CPU execution: TBB for threading, OpenMP for SIMD
- GPU & accelerators: DPC++ backend support for all algorithms that are part of C++17

Open-source upstream implementation (LLVM) derived from Intel's implementation for CPU

Interface with Execution Policies

- **standard sequential** sort
  sort(v.begin(), v.end());
- **explicitly sequential** sort
  sort(**execution::seq**,v.begin(), v.end());
- permitting **parallel execution**
  sort(**execution::par**,v.begin(), v.end());
- permitting **parallel execution** and **vectorization** as well
  sort(**execution::par_unseq**,v.begin(), v.end());
- permitting **vectorization (C++20)**
  sort(**execution::unseq**,v.begin(), v.end());

Parallel STL in C++

```
#include <algorithm>
#include <execution>
void increment( float *in, float *out, int N ) {
    using namespace std;
    using namespace std::execution;
    transform( par, in, in + N, out, []( float f ) {
        return f+1;
    });
}

template <class ExecutionPolicy, class InputIt, class OutputIt, class
UnaryOp>
OutputIt transform(ExecutionPolicy&& exec, …);
```

Proper overloaded **“transform”** version is resolved by *ExecutionPolicy* type

DPC++ SUPPORT IN PARALLEL STL

Example: Version 0

```
#include <execution>
#include <algorithm>
int main()
{
    std::vector<int> buf(1000);
    std::fill(policy, buf.begin(), buf.end(), 42);
}
```

DPC++ Execution Policies

DPC++ execution policy encapsulates a SYCL queue

The queue defines where the Parallel STL algorithm executes

Policy Usage:

- Include <dpstd/execution> in your code
- Create a policy object by providing a policy type, an (optional) class type for unique kernel name and one of the following constructor arguments
  - A SYCL queue
  - A SYCL device
  - A SYCL device selector
  - An existing policy object
- Pass the created policy object to a Parallel STL algorithm

DPC++ default policy

dpstd::execution::default_policy*

- Predefined object of the device_policy class with default kernel name and default queue.
- Pass directly when invoking an algorithm.

```
std::for_each(default_policy, …);
```

- Create customized policy objects

```
auto policy_a = make_device_policy<class PolicyA>(default_policy);

std::for_each(policy_a, …);
```

* Beta API, the names and semantics might change in future

Example: Version 1

```
#include <CL/sycl.hpp>
#include <dpstd/execution>
#include <dpstd/algorithm>

int main()
{
    std::vector<int> buf(1000);
    std::fill(dpstd::execution::default_policy,
        buf.begin(), buf.end(), 42);
}

// To build: dpcpp <test_name>.cpp -o test
```

Example: Version 2

```
#include <CL/sycl.hpp>
#include <dpstd/execution>
#include <dpstd/algorithm>
#include <dpstd/iterator>
int main()
{
     cl::sycl::buffer<int> buf { 1000 };
     std::fill(dpstd::execution::default_policy,
         dpstd::begin(buf), dpstd::end(buf), 42);

     auto result = std::find(dpstd::execution::default_policy,
         dpstd::begin(buf), dpstd::end(buf), 42);
}
```

'result' type guarantees:

- Is CopyConstructible, CopyAssignable, comparable with operators == and !=
- The following expressions are valid: a + n, a - n, a – b
- get_buffer() method. Returns sycl::buffer

Passing Access Modes to the Backend

```
auto buf_begin = dpstd::begin(buf);
std::fill(policy, buf_begin, buf_begin + 1000, 42);

auto buf_begin =
    dpstd::begin<cl::sycl::access::mode::write>(buf);
std::fill(policy, buf_begin, buf_begin + 1000, 42);
```

Unified Shared Memory in DPC++

- An extension to the standard SYCL memory model
- C++ pointer-based alternative to the buffer programming model
- Enables sharing of memory between the host and device
- Provides explicit and implicit models for managing memory

Unified Shared Memory (USM) Support

```
#include <CL/sycl.hpp>
#include <dpstd/execution>
#include <dpstd/algorithm>
int main()
{
    cl::sycl::queue q;
    const int n = 1000;
    int* d_head = static_cast<int*>(cl::sycl::malloc_device(n*
    sizeof(int), q.get_device(), q.get_context()));
    std::fill(dpstd::execution::make_device_policy(q), d_head,
        d_head + n, 42);
    q.wait();
    cl::sycl::free(d_head, q.get_context());
}
```

USM Support (using USM allocator)

```
#include <CL/sycl.hpp>
#include <dpstd/execution>
#include <dpstd/algorithm>
int main()
{
     cl::sycl::queue q;
     const int n = 1000;
     cl::sycl::usm_allocator<int, cl::sycl::usm::alloc::shared>
         alloc(q.get_context(), q.get_device());


     std::vector<int, decltype(alloc)> vec(n, alloc);
     std::fill(dpstd::execution::default_policy, vec.begin(), vec.end(), 42);

      q.wait();
}
```

EXTENSION API

Extension API

Fancy Iterators:

- counting_iterator
- zip_iterator
- transform_iterator

Utilities:

- identity
- minimum
- maximum

Algorithms:

- reduce_by_segment
- inclusive_scan_by_segment
- exclusive_scan_by_segment
- binary_search
- lower_bound
- upper_bound

EXAMPLES

Gamma correction

Example stages:

- Processing image using standard algorithms
- Processing image using standard algorithms with execution policies
- Processing image using standard algorithms with DPC++

Gamma Correction

```
int main() {
  int width = 2560, height = 1600; // Image size is width x height
  Img<ImgFormat::BMP> image{width, height};
  ImgFractal fractal{width, height};
  // Some code with filling image with created fractal
  // ...









}
```

Gamma Correction

```
int main() {
  int width = 2560, height = 1600; // Image size is width x height
  Img<ImgFormat::BMP> image{width, height};
  ImgFractal fractal{width, height};
  // Some code with filling image with created fractal
  // ...

  // Lambda to process image with gamma = 2
  auto gamma_f = [](ImgPixel &pixel) {
    float v = (0.3f * pixel.r + 0.59f * pixel.g + 0.11f * pixel.b) / 255.0f;
    std::uint8_t gamma_pixel = static_cast<std::uint8_t>(255 * v * v);
    if (gamma_pixel > 255)
      gamma_pixel = 255;
    pixel.set(gamma_pixel, gamma_pixel, gamma_pixel, gamma_pixel);
  };









}
```

Gamma Correction

```
int main() {
  int width = 2560, height = 1600; // Image size is width x height
  Img<ImgFormat::BMP> image{width, height};
  ImgFractal fractal{width, height};
  // Some code with filling image with created fractal
  // ...

  // Lambda to process image with gamma = 2
  auto gamma_f = [](ImgPixel &pixel) {
    float v = (0.3f * pixel.r + 0.59f * pixel.g + 0.11f * pixel.b) / 255.0f;
    std::uint8_t gamma_pixel = static_cast<std::uint8_t>(255 * v * v);
    if (gamma_pixel > 255)
      gamma_pixel = 255;
    pixel.set(gamma_pixel, gamma_pixel, gamma_pixel, gamma_pixel);
  };




    // how to handle the image using gamma_f with help of the algorithms?



}
```

Gamma Correction (std algorithm)

```
int main() {
  int width = 2560, height = 1600; // Image size is width x height
  Img<ImgFormat::BMP> image{width, height};
  ImgFractal fractal{width, height};
  // Some code with filling image with created fractal
  // ...

  // Lambda to process image with gamma = 2
  auto gamma_f = [](ImgPixel &pixel) {
    float v = (0.3f * pixel.r + 0.59f * pixel.g + 0.11f * pixel.b) / 255.0f;
    std::uint8_t gamma_pixel = static_cast<std::uint8_t>(255 * v * v);
    if (gamma_pixel > 255)
      gamma_pixel = 255;
    pixel.set(gamma_pixel, gamma_pixel, gamma_pixel, gamma_pixel);
  };



    auto buffer_begin = image.data(); // iterator to pass image to the algorithm
    auto buffer_end = image.data() + image.width() * image.height(); // iterator to pass image to the algorithm



}
```

Gamma Correction (std algorithm)

```
int main() {
  int width = 2560, height = 1600; // Image size is width x height
  Img<ImgFormat::BMP> image{width, height};
  ImgFractal fractal{width, height};
  // Some code with filling image with created fractal
  // ...

  // Lambda to process image with gamma = 2
  auto gamma_f = [](ImgPixel &pixel) {
    float v = (0.3f * pixel.r + 0.59f * pixel.g + 0.11f * pixel.b) / 255.0f;
    std::uint8_t gamma_pixel = static_cast<std::uint8_t>(255 * v * v);
    if (gamma_pixel > 255)
      gamma_pixel = 255;
    pixel.set(gamma_pixel, gamma_pixel, gamma_pixel, gamma_pixel);
  };



    auto buffer_begin = image.data(); // iterator to pass image to the algorithm
    auto buffer_end = image.data() + image.width() * image.height(); // iterator to pass image to the algorithm
    // call std::for_each
    std::for_each(buffer_begin, buffer_end, gamma_f);

}
```

Gamma Correction (std algorithm with policy)

```
int main() {
  int width = 2560, height = 1600; // Image size is width x height
  Img<ImgFormat::BMP> image{width, height};
  ImgFractal fractal{width, height};
  // Some code with filling image with created fractal
  // ...

  // Lambda to process image with gamma = 2
  auto gamma_f = [](ImgPixel &pixel) {
    float v = (0.3f * pixel.r + 0.59f * pixel.g + 0.11f * pixel.b) / 255.0f;
    std::uint8_t gamma_pixel = static_cast<std::uint8_t>(255 * v * v);
    if (gamma_pixel > 255)
      gamma_pixel = 255;
    pixel.set(gamma_pixel, gamma_pixel, gamma_pixel, gamma_pixel);
  };



    auto buffer_begin = image.data(); // iterator to pass image to the algorithm
    auto buffer_end = image.data() + image.width() * image.height(); // iterator to pass image to the algorithm
    // call std::for_each with par_unseq policy
    std::for_each(std::execution::par_unseq, buffer_begin, buffer_end, gamma_f);

}
```

Gamma Correction (std algorithm with DPC++)

```
int main() {
  int width = 2560, height = 1600; // Image size is width x height
  Img<ImgFormat::BMP> image{width, height};
  ImgFractal fractal{width, height};
  // Some code with filling image with created fractal
  // ...

  // Lambda to process image with gamma = 2
  auto gamma_f = [](ImgPixel &pixel) {
    float v = (0.3f * pixel.r + 0.59f * pixel.g + 0.11f * pixel.b) / 255.0f;
    std::uint8_t gamma_pixel = static_cast<std::uint8_t>(255 * v * v);
    if (gamma_pixel > 255)
      gamma_pixel = 255;
    pixel.set(gamma_pixel, gamma_pixel, gamma_pixel, gamma_pixel);
  };




    // call std::for_each with par_unseq policy
    // std::for_each(std::execution::par_unseq, buffer_begin, buffer_end, gamma_f);

}
```

Gamma Correction (std algorithm with DPC++)

```
int main() {
  int width = 2560, height = 1600; // Image size is width x height
  Img<ImgFormat::BMP> image{width, height};
  ImgFractal fractal{width, height};
  // Some code with filling image with created fractal
  // ...

  // Lambda to process image with gamma = 2
  auto gamma_f = [](ImgPixel &pixel) {
    float v = (0.3f * pixel.r + 0.59f * pixel.g + 0.11f * pixel.b) / 255.0f;
    std::uint8_t gamma_pixel = static_cast<std::uint8_t>(255 * v * v);
    if (gamma_pixel > 255)
      gamma_pixel = 255;
    pixel.set(gamma_pixel, gamma_pixel, gamma_pixel, gamma_pixel);
  };


    buffer<ImgPixel, 1> buf(image.data(), image.width() * image.height()); // buffer to move data and count dependencies


    // call std::for_each with par_unseq policy
    // std::for_each(std::execution::par_unseq, buffer_begin, buffer_end, gamma_f);

}
```

Gamma Correction (std algorithm with DPC++)

```
int main() {
  int width = 2560, height = 1600; // Image size is width x height
  Img<ImgFormat::BMP> image{width, height};
  ImgFractal fractal{width, height};
  // Some code with filling image with created fractal
  // ...

  // Lambda to process image with gamma = 2
  auto gamma_f = [](ImgPixel &pixel) {
    float v = (0.3f * pixel.r + 0.59f * pixel.g + 0.11f * pixel.b) / 255.0f;
    std::uint8_t gamma_pixel = static_cast<std::uint8_t>(255 * v * v);
    if (gamma_pixel > 255)
      gamma_pixel = 255;
    pixel.set(gamma_pixel, gamma_pixel, gamma_pixel, gamma_pixel);
  };


    buffer<ImgPixel, 1> buf(image.data(), image.width() * image.height()); // buffer to move data and count dependencies
    auto buffer_begin = dpstd::begin(buf); // iterator to pass buffer to the algorithm
    auto buffer_end = dpstd::end(buf); // iterator to pass buffer to the algorithm
    // call std::for_each with par_unseq policy
    // std::for_each(std::execution::par_unseq, buffer_begin, buffer_end, gamma_f);

}
```

Gamma Correction (std algorithm with DPC++)

```
int main() {
  int width = 2560, height = 1600; // Image size is width x height
  Img<ImgFormat::BMP> image{width, height};
  ImgFractal fractal{width, height};
  // Some code with filling image with created fractal
  // ...

  // Lambda to process image with gamma = 2
  auto gamma_f = [](ImgPixel &pixel) {
    float v = (0.3f * pixel.r + 0.59f * pixel.g + 0.11f * pixel.b) / 255.0f;
    std::uint8_t gamma_pixel = static_cast<std::uint8_t>(255 * v * v);
    if (gamma_pixel > 255)
      gamma_pixel = 255;
    pixel.set(gamma_pixel, gamma_pixel, gamma_pixel, gamma_pixel);
  };


    buffer<ImgPixel, 1> buf(image.data(), image.width() * image.height()); // buffer to move data and count dependencies
    auto buffer_begin = dpstd::begin(buf); // iterator to pass buffer to the algorithm
    auto buffer_end = dpstd::end(buf); // iterator to pass buffer to the algorithm
    // call std::for_each with DPC++
    std::for_each(dpstd::execution::default_policy, buffer_begin, buffer_end, gamma_f);

}
```

Gamma Correction (std algorithm with DPC++)

```
int main() {
  int width = 2560, height = 1600; // Image size is width x height
  Img<ImgFormat::BMP> image{width, height};
  ImgFractal fractal{width, height};
  // Some code with filling image with created fractal
  // ...

  // Lambda to process image with gamma = 2
  auto gamma_f = [](ImgPixel &pixel) {
    float v = (0.3f * pixel.r + 0.59f * pixel.g + 0.11f * pixel.b) / 255.0f;
    std::uint8_t gamma_pixel = static_cast<std::uint8_t>(255 * v * v);
    if (gamma_pixel > 255)
      gamma_pixel = 255;
    pixel.set(gamma_pixel, gamma_pixel, gamma_pixel, gamma_pixel);
  };

  { // We need to have the scope to transfer data in image after buffer's destruction
    buffer<ImgPixel, 1> buf(image.data(), image.width() * image.height()); // buffer to move data and count dependencies
    auto buffer_begin = dpstd::begin(buf); // iterator to pass buffer to the algorithm
    auto buffer_end = dpstd::end(buf); // iterator to pass buffer to the algorithm
    // call std::for_each with DPC++
    std::for_each(dpstd::execution::default_policy, buffer_begin, buffer_end, gamma_f);
  }
}
```

Extension API

Fancy Iterators:

- counting_iterator
- zip_iterator
- transform_iterator

Utilities:

- identity
- minimum
- maximum

Algorithms:

- reduce_by_segment
- inclusive_scan_by_segment
- exclusive_scan_by_segment
- binary_search
- lower_bound
- upper_bound

Counting Iterator

Boost and Thrust also have counting iterator

This represents current index of sequence we process

Counting Iterator. Example

```
#include<dpstd/iterator>
#include<dpstd/execution>
#include<dpstd/algorithm>

int main() {
    const int n = 10;
    sycl::buffer<int> buf(n);
    auto first_counting = dpstd::counting_iterator<int>(1);

    // fill the sequence with 1, ..., n
    std::copy(dpstd::execution::default_policy, first_counting, first_counting + n, dpstd::begin(buf));

    // check result
    auto host_accessor = buf.get_access<sycl::access::mode::read>();
    std::cout << "Output is: " << std::endl;
    for(int i = 0; i < n; ++i) {
        std::cout << host_accessor[i] << " ";
    }
    return 0;
}
```

Zip Iterator

Boost and Thrust also have zip iterator and make_zip_iterator function

This iterator allows you to process some sequence as one

Zip Iterator. Example

```
#include<dpstd/iterator>
#include<dpstd/execution>
#include<dpstd/algorithm>

int main() {
    const int n = 10;
    sycl::buffer<int> x_buf(n);
    sycl::buffer<int> y_buf(n);
    sycl::buffer<int> z_buf(n);
    auto first_counting = dpstd::counting_iterator<int>(1);

    auto first_zip = dpstd::make_zip_iterator(
        dpstd::begin(x_buf), dpstd::begin(y_buf), dpstd::begin(z_buf));

    auto first_counting_zip = dpstd::make_zip_iterator(
        first_counting, first_counting, first_counting);

    // fill x, y, z sequences with 1, ..., n
    std::copy(dpstd::execution::default_policy, first_counting_zip, first_counting_zip + n, first_zip);
    return 0;
}
```

Summary

- oneDPL consists of 3 Modules: C++ STL API functionality with tested STD APIs; Parallel STL for DPC++; DPC++ Extension API*
- Common APIs that can be used on CPU, GPU, FPGAs
- Simplify parallel programming on heterogeneous architectures
- Integrated with other Intel® oneAPI components - DPC++ Compiler and DPC++ Compatibility Tool
- Available on Open Source - https://github.com/oneapi-src/oneDPL

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