Data Parallel C++
TAB Meeting #2

oneAPI Technical Advisory Board - January 28, 2020

Agenda

1. Review from SC19 TAB meeting
2. Group collectives library direction
3. Simplifying interface for common patterns

1. Review after SC19 TAB Meeting

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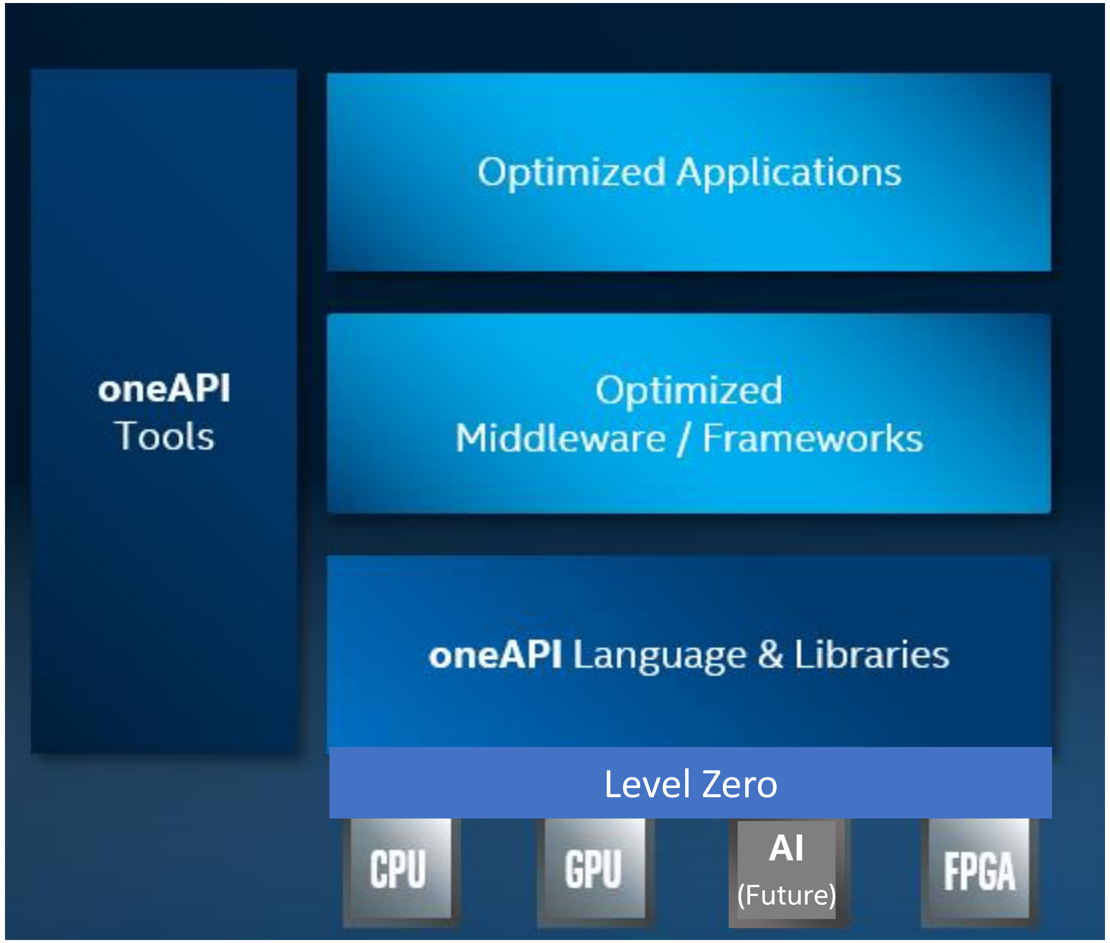
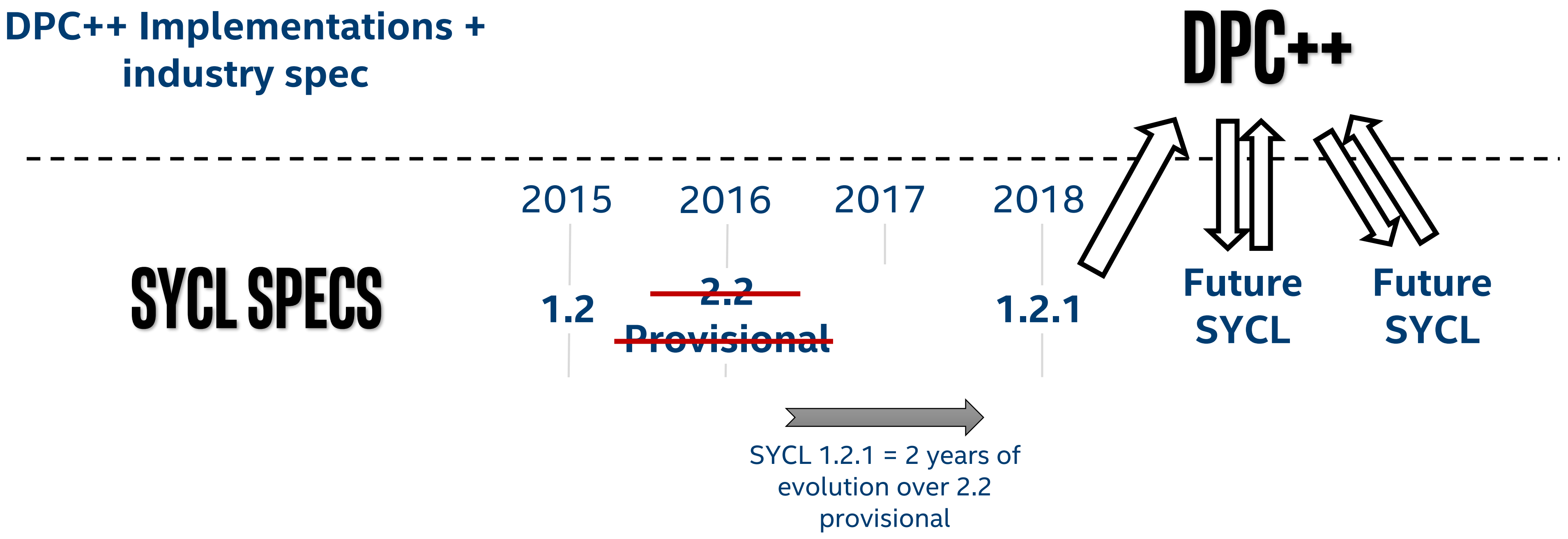
Why DPC++?

- Data Parallel C++
  = ISO C++ and Khronos SYCL and extensions

- Vision:
  - Fast moving open collaboration feeding into SYCL
    - Open source implementation
    - Goal to become upstream LLVM
  - DPC++ extensions aim to become core SYCL, or Khronos extensions
  - DPC++ supports the broader oneAPI ecosystem of standards, including libraries and tooling



Ongoing relationship: DPC++ and SYCL



Today: DPC++ Extensions over SYCL

- Evolving landscape
- SYCL 1.2.1 is public
- A number of published extensions on Intel GitHub
  - DPC++ open source project building first implementation

Extension	Purpose
USM (Unified Shared Memory)	Pointer-based programming
Sub-groups	Cross-lane operations
Reductions	Efficient parallel primitives
Work-group collectives	Efficient parallel primitives
Pipes	Spatial data flow support
Argument restrict	Optimization
Optional lambda name for kernels	Simplification
In-order queues	Simplification
Invocation directly on queue	Simplification
CTAD deduction guides	Simplification
Required WG size	Optimization

Follow up from SC19 Meeting

1. Deterministic reductions
   - Will be adding control for varying scopes of determinism. Some other changes prioritized first
   - Will broadcast when ready for feedback

2. C++ version in SYCL and DPC++
   - We have pushed into next SYCL spec a process for minimum C++ version bumping
   - Open source DPC++ implementation is ToT LLVM - supports very modern C++

3. "Why is the base OpenCL version 1.2 instead of 2.0?"
   - The Khronos SYCL working group has made public two proposals for the next SYCL spec
   - One of these describes generalization of the backend used by SYCL, including OpenCL version
   - https://github.com/KhronosGroup/SYCL-Shared/tree/master/proposals

Follow up from SC19 Meeting (2)

4. “Can we make a language distinction between loops with completely independent iterations?”

- When a functor is passed to **parallel_for**, which takes as its argument **id** instead of **item**, then no collectives (e.g. barrier) are available
  - A user can use this form of kernel functor to signal that iterations/work-items are independent
- Does this already sufficiently address the request for a form of invocation function that has independent iterations?

2. Groups Library

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Group Algorithms Based on C++17 `<algorithm>`

- C++17 algorithms operate over a range defined by a pair of iterators using an execution policy indicating how an algorithm can be parallelized:

```
float x = std::reduce(std::par, data.begin(), data.end(),
                      0, std::plus<>());
```

- SYCL group algorithms operate over work-item data or a range defined by a pair of `multi_ptrs` using a group describing which work-items to use:

```
float x = sycl::reduce(group, data[i], 0, std::plus<>());
float x = sycl::reduce(group, data.begin(), data.end(), 0, std::plus<>());
```

- All members of a group must call algorithm functions together.

Group Algorithms: Example Kernels

```
h.parallel_for(nd_range<1>(32, 32), [=](nd_item<1> it) {
    int item_sum = 0;
    for (int i = it.get_local_id(0); i < 32; i += it.get_local_range(0)) {
      item_sum += input[i];
    }
    group g = it.get_group();
    int group_sum = reduce(g, item_sum, 0, std::plus<>());
    if (it.get_local_id(0) == 0) {
      output = group_sum;
    }
});

h.parallel_for(nd_range<1>(32, 32), [=](nd_item<1> it) {
    group g = it.get_group();
    int group_sum = reduce(g, input, input + 32, 0, std::plus<>());
    if (it.get_local_id(0) == 0) {
      output = group_sum;
    }
});
```

- Examples use only one work-group to keep things simpler.
- First example shows reduction of work-item data.
- Second example shows reduction of data held in memory.

Algorithm Priority

- Initial focus is on matching OpenCL/OpenMP functionality:
  - OpenCL:
    - `any_of, all_of, none_of`
    - `broadcast` (no C++17 algorithm equivalent)
  - OpenMP:
    - `reduce`
    - `exclusive_scan, inclusive_scan`

- We plan to take this extension to Khronos for the next SYCL spec
  – Other algorithms (e.g. `find, sort, shift`) to follow in future extensions.

Towards a Generic Group Abstraction

- Add traits to group class:

```
template <int Dimensions = 1>
class group
{
public:
  typedef id<dimensions> id_type;
  typedef range<dimensions> range_type;
  typedef size_t linear_id_type;
  static constexpr int dimensions = Dimensions;
};
```

- Motivation:
  - Simplifies definition of functions in group algorithms library
  - Groundwork for generic programming supporting other group types (e.g. sub-groups, groups of active work-items, arbitrary user-defined groups)

Function Objects

- Provide transparent (if C++14) function objects for supported operators.
- Function objects supported natively by C++ are defined as aliases:
  - `sycl::plus (+)`
  - `sycl::multiplies (*)`
  - `sycl::bit_and (&), sycl::bit_or (|), sycl::bit_xor (^)`
  - `sycl::logical_and (&&)`
  - `sycl::logical_or (||)`
- New function objects added for common HPC cases:
  - `sycl::minimum`
  - `sycl::maximum`

Summary

- Group algorithms library design reflects our long-term direction:
  - Enables support for STL-like functions at all levels of the hierarchy
  - Step towards group concepts and programming with generic groups

- Your feedback would be much appreciated, specifically on:
  - Alignment with C++17/20 algorithms
  - Algorithm priority

3. Simplifications For Common SYCL Patterns

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Presentation Goals

1. Review SYCL 1.2.1 verbosity in simple example
   - Acknowledge importance of code simplicity, and DPC++ work feeding to SYCL

2. Show direction that we're moving for reduction of verbosity

3. Gather feedback on directions

Generally: Reduce verbosity of code

- Historically
  - SYCL goal has been to enable expressive and generic programming
  - Simple code patterns can be quite verbose

- Pushing now to
  - Simplify developer input for common patterns, while still enabling generic coding

- Multiple directions in work
  - Target fixes to future SYCL specifications directly where possible
    - Presentation at upcoming Khronos F2F
  - Build extensions to prove solutions, and simplify DPC++ code now

Directions

- Multiple simplifications in flight
  1. cl::sycl ⇒ sycl
  2. Optional kernel lambda names
  3. Class template argument deduction (CTAD)
     - buffer<int, 2> b(ptr, range<2>(5, 5)); ⇒ buffer b(ptr, range(5, 5));
  4. Implicit conversion of id to size_t
     - sg.get_local_id()[0] ⇒ sg.get_local_id()
  5. range and nd_range simplifications: Under discussion
     - cgh.parallel_for(range{N}, ... ⇒ cgh.parallel_for(N, ...
  6. queue.parallel_for and variants without submit()
     - Q.parallel_for(R, {prev_event}, [=](id<1> idx) { ... });
  7. Buffer construction: buffer<int> b(v.data(), v.size()); ⇒ buffer b(v);
  8. Enable auto in kernel call

Hello world of SYCL 1.2.1

```
#include <CL/sycl.hpp>
#include <iostream>
constexpr int N = 32;

int main () {
    cl::sycl::buffer<int,1> B(N);

    cl::sycl::queue{}.submit([&](cl::sycl::handler &h) {
        auto a = B.get_access<cl::sycl::access::mode::write>(h);
        h.parallel_for<class mykern>(cl::sycl::range<1>(N), [=](cl::sycl::id<1> i) {
            a[i] = i[0];
        });
    });

    auto a = B.get_access<cl::sycl::access::mode::read>();
    for (int i=0; i<N; ++i) std::cout << a[i] << '\n';

    return 0;
}
```

- Wordy/redundant
- Lots to remember or copy/paste
- Examples are a combo of language + style

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Hello world with implemented simplifications

```
#include <CL/sycl.hpp>
#include <iostream>
constexpr int N = 32;

int main () {
    cl::sycl::buffer<int,1> B(N);

    cl::sycl::queue{}.submit([&](cl::sycl::handlerauto &h) {
        auto a = B.get_access<cl::sycl::access::mode::write>(h);
        h.parallel_for<class mykern>(cl::sycl::range<1>(N), [=](cl::sycl::id<1> i) {
            a[i] = i[0];
        });
    });

    auto a = B.get_access<cl::sycl::access::mode::read>();
    for (int i=0; i<N; ++i) std::cout << a[i] << '\n';

    return 0;
}
```

- Works with DPC++ beta04
- Better, but not there yet
- **Auto handler + default dim buffer** always worked, but people don't use them (and they should)

Hello world with implemented simplifications (2)

```
#include <CL/sycl.hpp>
#include <iostream>
constexpr int N = 32;

int main () {
    sycl::buffer<int> B(N);

    sycl::queue{}.submit([&](auto &h) {
        auto a = B.get_access<sycl::access::mode::write>(h);
        h.parallel_for(sycl::range(N), [=](cl::sycl::id<1> i) {
            a[i] = i[0];
        });
    });

    auto a = B.get_access<sycl::access::mode::read>();
    for (int i=0; i<N; ++i) std::cout << a[i] << '\n';

    return 0;
}
```

- Works with DPC++ beta04
- Better, but not there yet
- Auto handler + default dim buffer always worked, but people don't use them (and they should)

Where we’ll be with changes already in flight

```
#include <CL/sycl.hpp>
#include <iostream>
constexpr int N = 32;

int main () {
    sycl::buffer<int> B(N);

    sycl::queue{}.submit([&](auto &h) {
        auto a = B.get_access<sycl::access::mode::write>(h);
        h.parallel_for(sycl::range(N), [=](cl::sycl::id<1>auto i) {
            a[i] = i[0];
        });
    });

    auto a = B.get_access<sycl::access::mode::read>();
    for (int i=0; i<N; ++i) std::cout << a[i] << ‘\n’;

    return 0;
}
```

- Better, but not there yet
- With USM, significantly shorter still: Q.parallel_for, and no accessor

Where we'll be with changes already in flight (2)

```
#include <CL/sycl.hpp>
#include <iostream>
constexpr int N = 32;

int main () {
    sycl::buffer<int> B(N);

    sycl::queue{}.submit([&](auto &h) {
        auto a = B.get_access<sycl::access::mode::write>(h);
        h.parallel_for(N, [=](auto i) {
            a[i] = i;
        });
    });

    auto a = B.get_access<sycl::access::mode::read>();
    for (int i=0; i<N; ++i) std::cout << a[i] << '\n';

    return 0;
}
```

- Better, but not there yet
- With USM, significantly shorter still: Q.parallel_for, and no accessor
- Major remaining problem = accessors

Example with USM

```
#include <CL/sycl.hpp>
#include <iostream>
constexpr int N = 32;

int main () {
    sycl::queue q;
    int *B = (int *)sycl::malloc_shared(N*sizeof(int), q);

    q.parallel_for(N, [=](auto i) { B[i] = i; }).wait();

    for (int i=0; i<N; ++i) std::cout << B[i] << '\n';

    sycl::free(B, q);
    return 0;
}
```

- Should anything in this USM example be simpler?

Accessor Simplifications

1. Modify enums (simplify)
   - sycl::access::target::global_buffer ⇒ sycl::target::global
   - sycl::access::mode::read ⇒ sycl::access_mode::read

2. Make the enums unnecessary in typical code
   1. Default accessor mode is read_write (conservative)
   2. Optimized modes in accessor name, and not template parameter

+ Maintain backward compatibility

New Accessor Forms

New	SYCL 1.2.1 (Old forms)
accessor	accessor<sycl::access::mode:read_write>
read_accessor	accessor<sycl::access::mode:read>
write_accessor	accessor<sycl::access::mode:write>
discard_write_accessor	accessor<sycl::access::mode:discard_write>
discard_read_write_accessor	accessor<sycl::access::mode:discard_read_write>
atomic_accessor	accessor<sycl::access::mode:atomic>

Most example and tutorial code should use simply “accessor”

New Buffer `get_access` Forms

New	SYCL 1.2.1 (Old forms)
get_accessor	get_access<sycl::access::mode:read_write>
get_read_accessor	get_access<sycl::access::mode:read>
get_write_accessor	get_access<sycl::access::mode:write>
get_discard_write_accessor	get_access<sycl::access::mode:discard_write>
get_discard_read_write_accessor	get_access<sycl::access::mode:discard_read_write>
get_atomic_accessor	get_access<sycl::access::mode:atomic>

Most example and tutorial code should construct “accessor”, not use getters

Hello world with new accessor forms

```
#include <CL/sycl.hpp>
#include <iostream>
constexpr int N = 32;

int main () {
    sycl::buffer<int> B(N);

    sycl::queue{}.submit([&](auto &h) {
        sycl::accessor a(B,h); ~~auto a = B.get_access<sycl::access::mode::write>(h)~~;
        h.parallel_for(N, [=](auto i) {
            a[i] = i;
        });
    });

    sycl::accessor a(B); ~~auto a = B.get_access<sycl::access::mode::read>()~~;
    for (int i=0; i<N; ++i) std::cout << a[i] << '\n';

    return 0;
}
```

Hello world with new accessor forms (2)

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```
#include <CL/sycl.hpp>
#include <iostream>
constexpr int N = 32;

int main () {
    sycl::buffer<int> B(N);

    sycl::queue{}.submit([&](auto &h) {
        sycl::accessor a(B,h);
        h.parallel_for(N, [=](auto i) {
            a[i] = i;
        });
    });

    sycl::accessor a(B);
    for (int i=0; i<N; ++i) std::cout << a[i] << '\n';

    return 0;
}
```

Simple factoring out for examples

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```
#include <CL/sycl.hpp>
#include <iostream>
constexpr int N = 32;
using namespace sycl;

int main () {
    buffer<int> B(N);
    queue Q;

    Q.submit([&](auto &h) {
        accessor a(B,h);
        h.parallel_for(N, [=](auto i) {
            a[i] = i;
        });
    });

    accessor a(B);
    for (int i=0; i<N; ++i) std::cout << a[i] << '\n';

    return 0;
}
```

- This code runs a kernel on a device, and manages execution order and data movement from device to host
- What else here should be simplified?

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2b: Group Library Backup

Broadcast

- ```
  template <typename Group, typename T>
  T broadcast(Group g, T x);
  ```
- ```
  template <typename Group, typename T>
  T broadcast(Group g, T x, Group::linear_id_type
  local_linear_id);
  ```
- ```
  template <typename Group, typename T>
  T broadcast(Group g, T x, Group::id_type local_id);
  ```
  ```

Reduce

- `template <typename Group, typename T, class BinaryOp>`
  `T reduce(Group g, T x, BinaryOp binary_op);`

- `template <typename Group, typename V, typename T, class BinaryOp>`
  `T reduce(Group g, V x, T init, BinaryOp binary_op);`

- `template <typename Group, typename Ptr, class BinaryOp>`
  `Ptr::element_type reduce(Group g, Ptr first, Ptr last, BinaryOp binary_op);`

- `template <typename Group, typename Ptr, typename T, class BinaryOp>`
  `Ptr::element_type reduce(Group g, Ptr first, Ptr last, T init, BinaryOp binary_op);`

Any/All/None

- ```
  template <typename Group>
  bool any_of(Group g, bool predicate);
  ```

- ```
  template <typename Group, typename T, class UnaryPredicate>
  bool any_of(Group g, T x, UnaryPredicate p);
  ```

- ```
  template <typename Group, typename Ptr, class UnaryPredicate>
  bool any_of(Group g, Ptr first, Ptr last, UnaryPredicate p);
  ```
  ```

Exclusive Scan

- ```
  template <typename Group, typename T, class BinaryOp>
  T exclusive_scan(Group g, T x, BinaryOp binary_op);
  ```
- ```
  template <typename Group, typename V, typename T, class BinaryOp>
  T exclusive_scan(Group g, V x, T init, BinaryOp binary_op);
  ```
- ```
  template <typename Group, typename InPtr, typename OutPtr, class BinaryOp>
  OutPtr exclusive_scan(Group g, InPtr first, InPtr last, OutPtr d_first, BinaryOp
  binary_op);
  ```
- ```
  template <typename Group, typename InPtr, typename OutPtr, typename T, class BinaryOp>
  OutPtr exclusive_scan(Group g, InPtr first, InPtr last, OutPtr d_first, T init,
  BinaryOp binary_op);
  ```

Inclusive Scan

- `template <typename Group, typename T, class BinaryOp>`
  `T inclusive_scan(Group g, T x, BinaryOp binary_op);`

- `template <typename Group, typename V, typename T, class BinaryOp>`
  `T inclusive_scan(Group g, V x, BinaryOp binary_op, T init);`

- `template <typename Group, typename InPtr, typename OutPtr, class BinaryOp>`
  `OutPtr inclusive_scan(Group g, InPtr first, InPtr last, OutPtr d_first, BinaryOp binary_op);`

- `template <typename Group, typename InPtr, typename OutPtr, class BinaryOp, typename T>`
  `T inclusive_scan(Group g, InPtr first, InPtr last, OutPtr d_first, BinaryOp binary_op, T init);`