# C++ LAYER DIRECTIONS

Michael Garland, May 2018

NVIDIA

# HIGH-PERFORMANCE EXECUTION

Across potentially many nodes

×1000

Parallelism + Asynchrony + Data coordination

# BEYOND PARALLELISM

Provide the things needed for scalable execution

Continue to evolve

Parallelism

Common mechanisms are needed

Asynchrony

Data coordination

# C++ STANDARDIZATION

## What is most important for the Standard Library?

Common concepts which serve to
organize & compose software modules

Iterators are a prime example

# KEY INGREDIENTS

## Concepts needed for structuring libraries & applications

Identify things: pointers, iterators, ranges

Identify place to allocate storage: allocators

Identify where/how to execute : execution policies, executors

Identify dependencies: futures

Identify affinity of workers and data: conforming index spaces

Legend:

| |
|---|
| Existing or proposed |
| Missing ingredients |

# C++17 PARALLEL ALGORITHMS

## Algorithms + Execution Policies

```
for_each(par, begin, end, function);
```

Execution Policy

Specify *how* operation
may execute.

# C++17 PARALLEL ALGORITHMS

## Many useful patterns beyond loops

Parallelizable algorithms in STL

`for_each`

`transform`

`copy_if`

`sort`

`set_intersection`

*etc.*

New additions for parallelism

`reduce`

`exclusive_scan`

`inclusive_scan`

`transform_reduce`

`transform_inclusive_scan`

`transform_exclusive_scan`

# NVIDIA'S THRUST LIBRARY

## CUDA C++ Parallel Algorithms

```
for_each(par, begin, end, function);
```

Device-accessible Data

Device Function

e.g., via unified memory

for GPU execution.

Diverse Control Structures

```
async(...)        for_each(...)

define_task_block(...)      bulk_invoke(...)

your_favorite_control_structure(...)
```

Multiplicative Explosion

Diverse Execution Resources

Operating System Threads

SIMD vector units

Thread pool schedulers

GPU runtime

OpenMP runtime

Fibers

Diverse Control Structures

```
async(...)          for_each(...)

define_task_block(...)      bulk_invoke(...)

your_favorite_control_structure(...)
```

Uniform Abstraction

# Executors

Diverse Execution Resources

Operating System Threads

SIMD vector units

Thread pool schedulers

GPU runtime

OpenMP runtime

Fibers

# EXECUTORS

## Compositional, uniform control of where/how execution occurs

```
auto ex = my_thread_pool.executor(…);
```

Executor

Used to *submit work*
for some operation.

Serves to identify *where*
work will be run.

# EXECUTORS

Compositional, uniform control of where/how execution occurs

```
auto ex = obtain_an_executor(…);

async(ex, ...);

for_each(par.on(ex), ...);

parallel_linear_solver(ex, ...);
```

# C++17 PARALLEL ALGORITHMS

Specified to be synchronous

```
// Input parameters must be available immediately

std::transform(par, x.begin(), x.end(), y.begin(), F);

// … synchronize with transform() and resume this thread …

float sum = std::reduce(par, x.begin(), x.end());

return sum;
```

# ASYNCHRONOUS ALGORITHMS

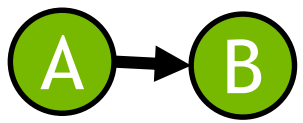
## Need suitable ranges and futures

```
// Inputs x & y are future<RangeType> objects

auto z = async_transform(par, x, y, F);

// … z is also a future<RangeType>; no synchronization here

auto sum = async_reduce(par, z);

return sum.get();
```

# CHAINED ASYNCHRONY

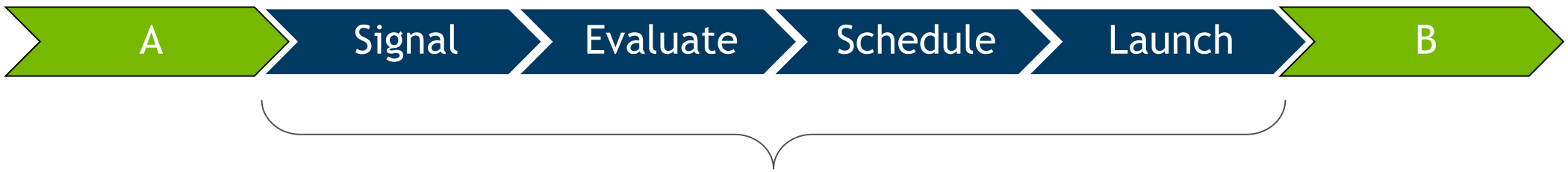
Mediated in C++ by futures and executors

```
auto future = launch(A)
```




*when A completes:* `launch(B, future.get())`

Execution timeline:

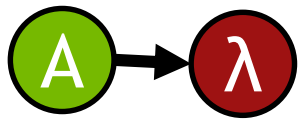


# CHAINED ASYNCHRONY

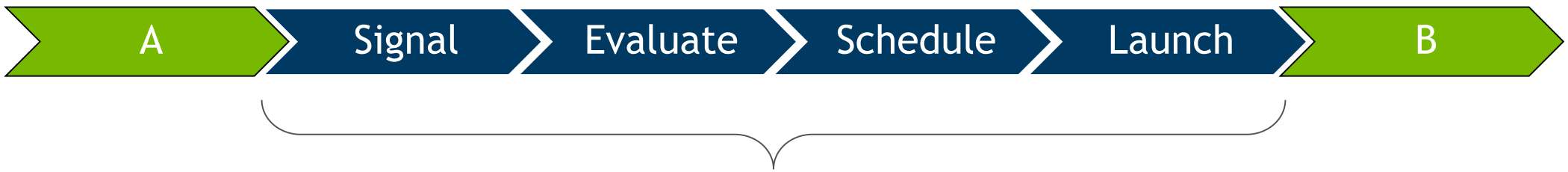
## Don’t hide dependencies

```
auto future = launch(A)
```

*Running code* to decide what to do next:




```
future.then([](…) { ex.execute(B); });
```



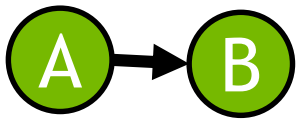

Forces at least some of these stages to run on a thread somewhere

# CHAINED ASYNCHRONY

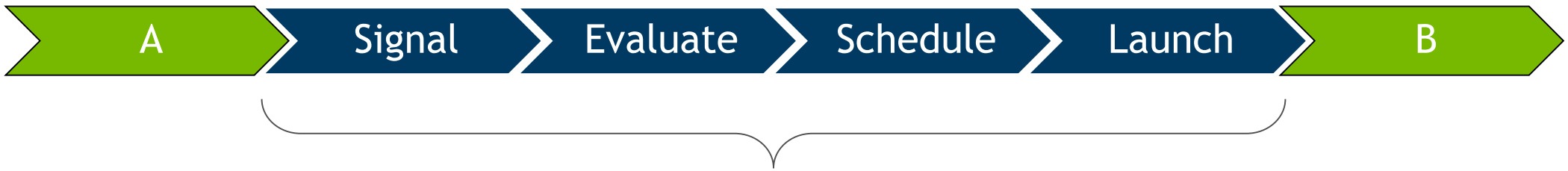
## Expose dependencies

```
auto future = launch(A)
```

*Telling the platform* what to do next:



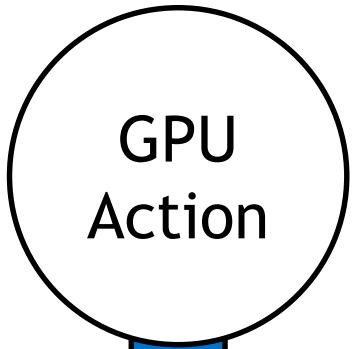

```
ex.then_execute(future, B);
```




Permits more implementations, including hardware mechanisms & construction of task graphs

# PAST

## Singleton actions for immediate submission




**Action**

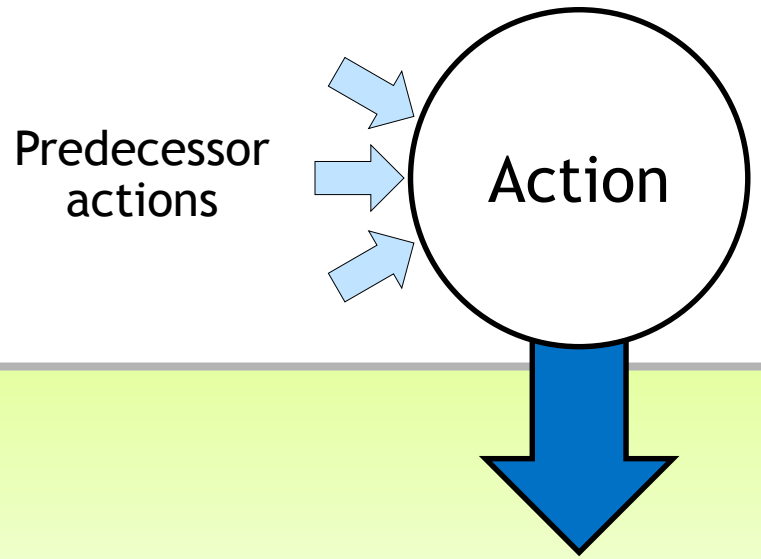
- Task run by collection of threads
- Memory copy
- Memory allocation
- …

**NVIDIA Platform**

Immediately submitted
to specified GPU(s)

# PRESENT

## Actions with predecessors which can be deferred




**NVIDIA Platform**

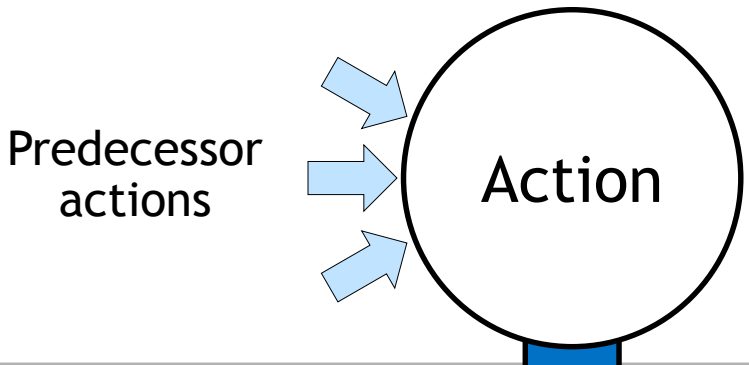
Immediately submitted to specified GPU(s)

— or —

Deferred into a graph

# CUDA GRAPHS

Mechanism for communicating these dependencies to CUDA

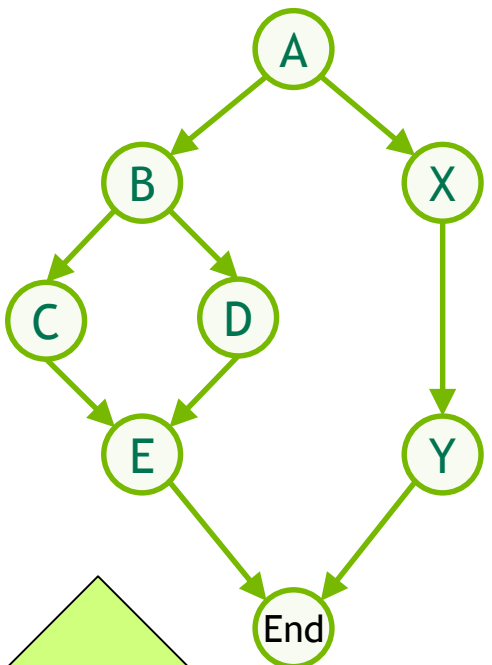


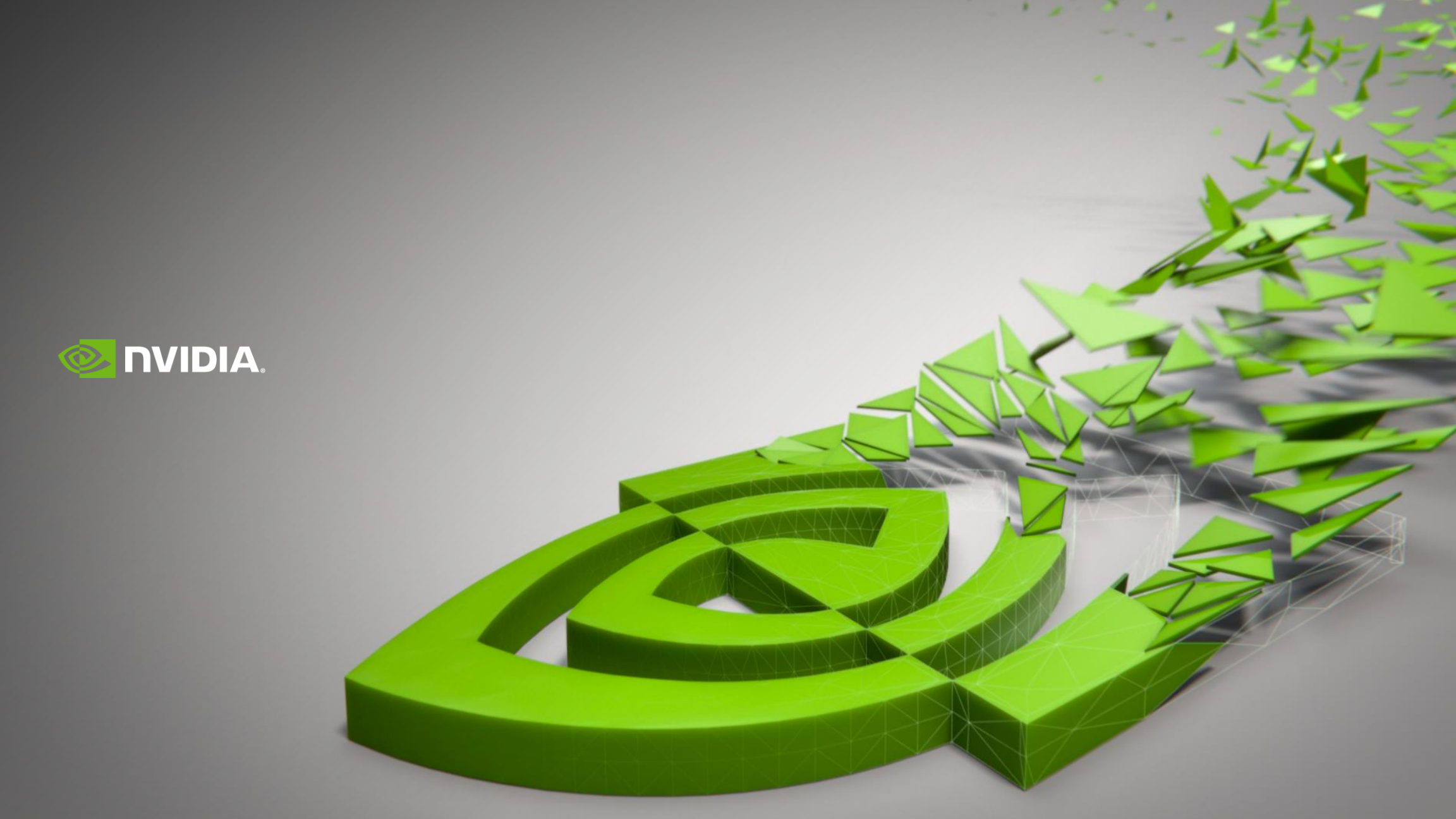

**NVIDIA Platform**

Immediately submitted
to specified GPU(s)

— or —

Deferred into a graph




NVIDIA