COOPERATIVE GROUPS

Bob Crovella, 3/28/2019

AGENDA

Cooperative Groups

- Threadblock Level
- Grid Level
- Multi-Device
- Coalesced Group

Further Study

Homework

COOPERATIVE GROUPS

Cooperative Groups: a flexible model for synchronization and communication within groups of threads.

At a glance

Scalable Cooperation among groups of threads

Flexible parallel decompositions

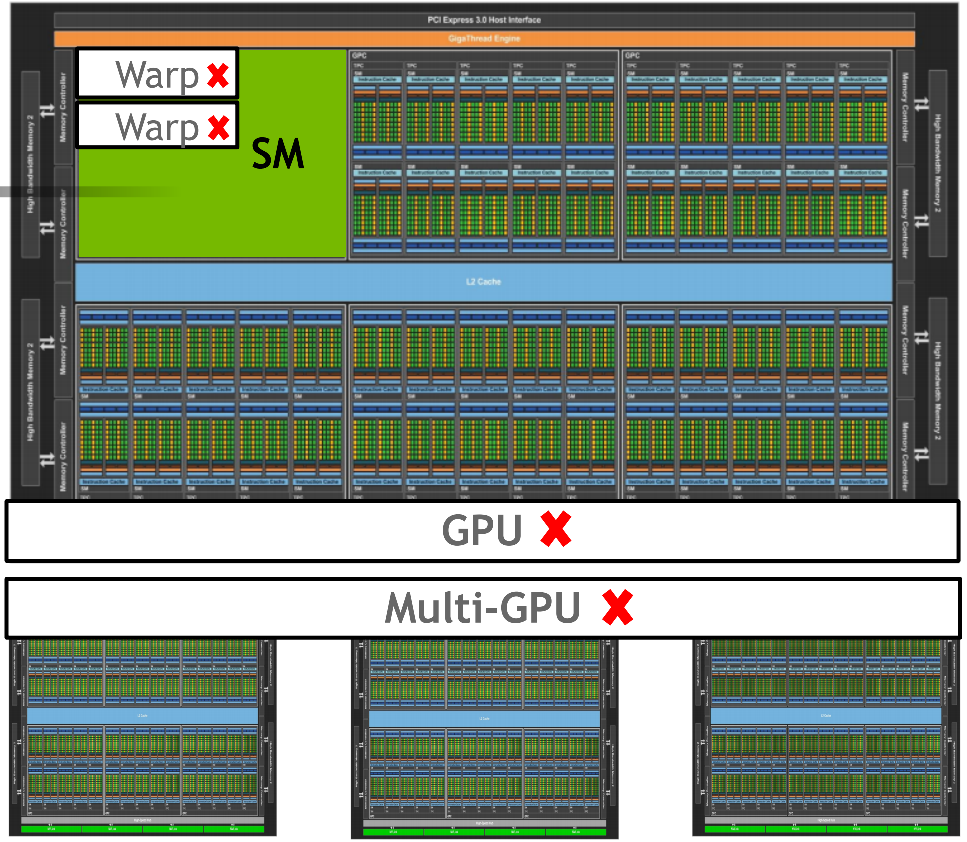
Composition across software boundaries

Obvious benefit: grid-wide sync

Examples include:
- Persistent RNNs
- Reductions
- Search Algorithms
- Sorting

LEVELS OF COOPERATION: PRE CUDA 9.0

`__syncthreads()`: block level synchronization barrier in CUDA



LEVELS OF COOPERATION: CUDA 9.0

For current coalesced set of threads:

```
auto g = coalesced_threads();
```

For warp-sized group of threads:

```
auto block = this_thread_block();
auto g = tiled_partition<32>(block)
```

For CUDA thread blocks:

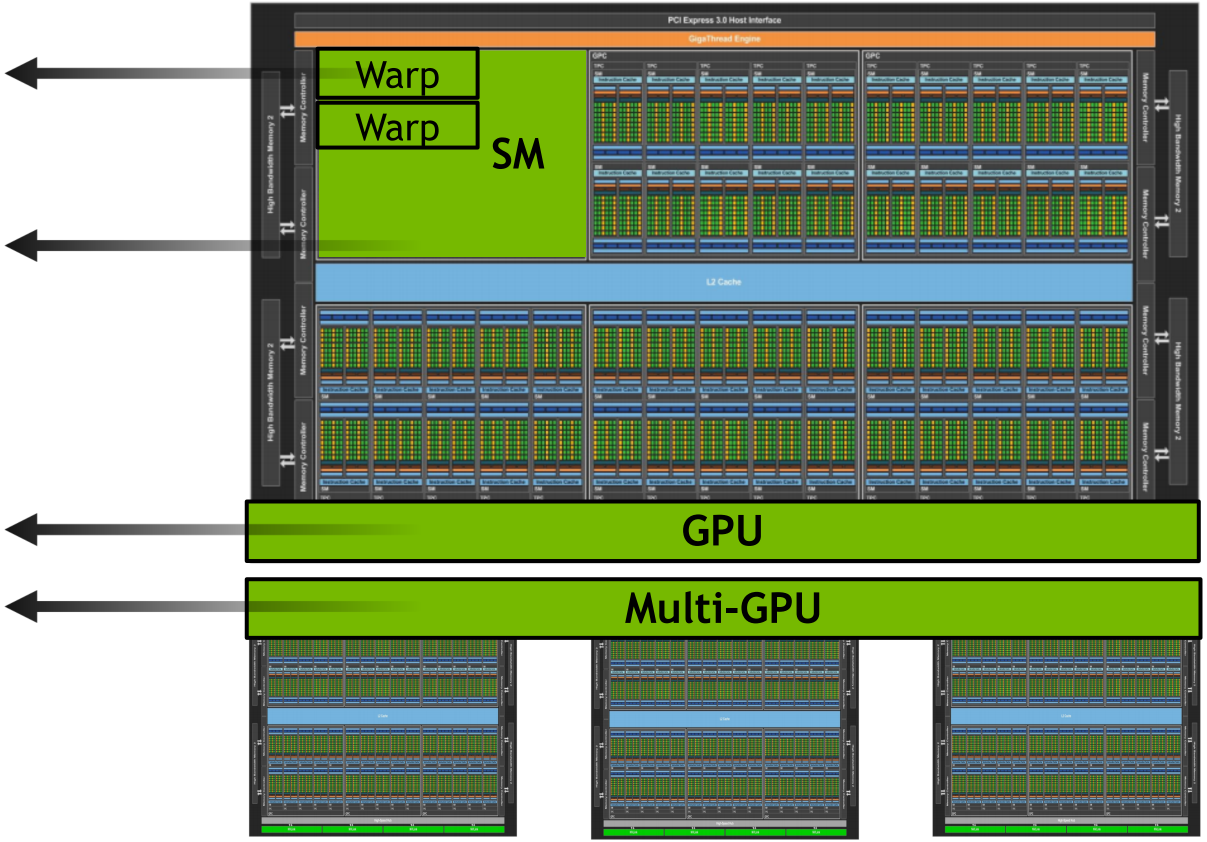
```
auto g = this_thread_block();
```

For device-spanning grid:

```
auto g = this_grid();
```

For multiple grids spanning GPUs:

```
auto g = this_multi_grid();
```



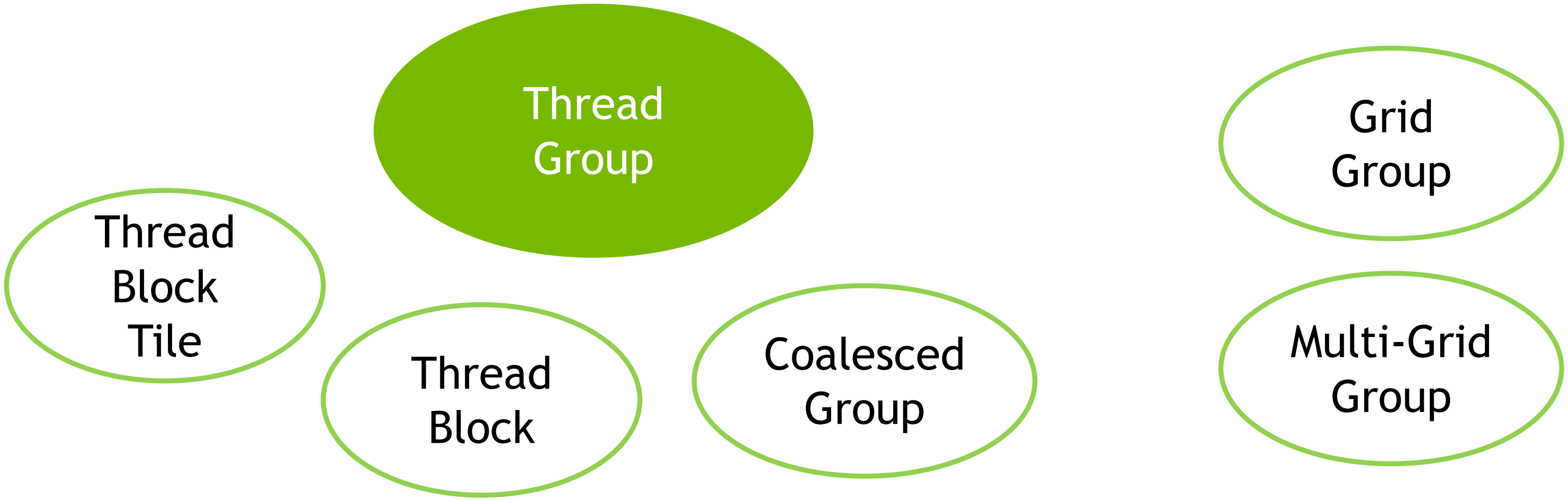
All Cooperative Groups functionality is within a **cooperative_groups::** namespace

THREAD GROUP

Base type, the implementation depends on its construction.

Unifies the various group types into one general, collective, thread group.

We need to extend the CUDA programming model with handles that can represent the groups of threads that can communicate/synchronize



THREAD BLOCK

Implicit group of all the threads in the launched thread block

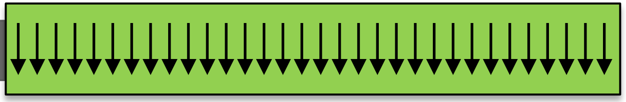
Implements the same interface as thread_group:

```
void sync();                 // Synchronize the threads in the group
unsigned size();             // Total number of threads in the group
unsigned thread_rank();      // Rank of the calling thread within [0, size)
bool is_valid();             // Whether the group violated any API constraints
```

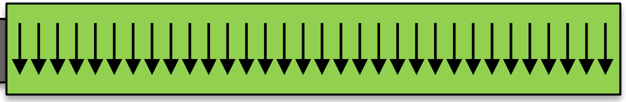
And additional thread_block specific functions:

```
dim3 group_index();          // 3-dimensional block index within the grid
dim3 thread_index();         // 3-dimensional thread index within the block
```

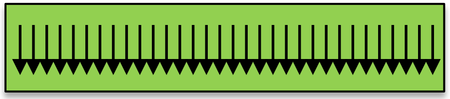
PROGRAM DEFINED DECOMPOSITION

CUDA KERNEL  All threads launched

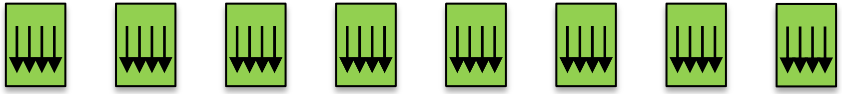
```
thread_block g = this_thread_block();
```

foobar(thread_block g)  All threads in thread block

```
thread_group tile32 = tiled_partition(g, 32);
```



```
thread_group tile4 = tiled_partition(tile32, 4);
```



Restricted to powers of two,
and <= 32 in initial release

GENERIC PARALLEL ALGORITHMS

Per-Block

```
g = this_thread_block();
reduce(g, ptr, myVal);
```

Per-Warp

```
g = tiled_partition(this_thread_block(), 32);
reduce(g, ptr, myVal);
```

```
__device__ int reduce(thread_group g, int *x, int val) {
  int lane = g.thread_rank();
  for (int i = g.size()/2; i > 0; i /= 2) {
    x[lane] = val;       g.sync();
    if (lane < i) val += x[lane + i];  g.sync();
  }
  return val;
}
```

THREAD BLOCK TILE

A subset of threads of a thread block, divided into tiles in row-major order

```
thread_block_tile<32> tile32 = tiled_partition<32>(this_thread_block());
```

```
thread_block_tile<4> tile4 = tiled_partition<4>(this_thread_block());
```

Exposes additional functionality:

```
.shfl()
.shfl_down()
.shfl_up()
.shfl_xor()
```

```
.any()
.all()
.ballot()
.match_any()
.match_all()
```

Size known at compile time = fast!

STATIC TILE REDUCE

Per-Tile of 16 threads

```
g = tiled_partition<16>(this_thread_block());
tile_reduce(g, myVal);
```

```
template <unsigned size>
__device__ int tile_reduce(thread_block_tile<size> g, int val) {
  for (int i = g.size()/2; i > 0; i /= 2) {
    val += g.shfl_down(val, i);
  }
  return val;
}
```

GRID GROUP

A set of threads within the same grid, guaranteed to be resident on the device

New CUDA Launch API to opt-in:

`cudaLaunchCooperativeKernel(…)`

```
__global__ kernel() {
    grid_group grid = this_grid();
    // load data
    // loop - compute, share data
        grid.sync();
        // device wide execution barrier
}
```

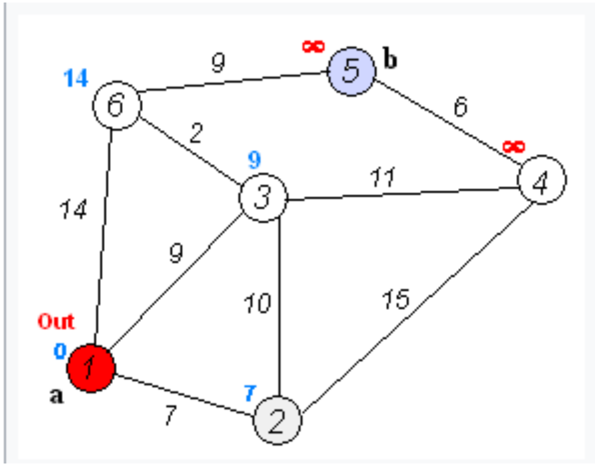
Device needs to support the `cooperativeLaunch` property.

```
cudaOccupancyMaxActiveBlocksPerMultiprocessor(&numBlocksPerSm, kernel, numThreads, 0);
```

GRID GROUP

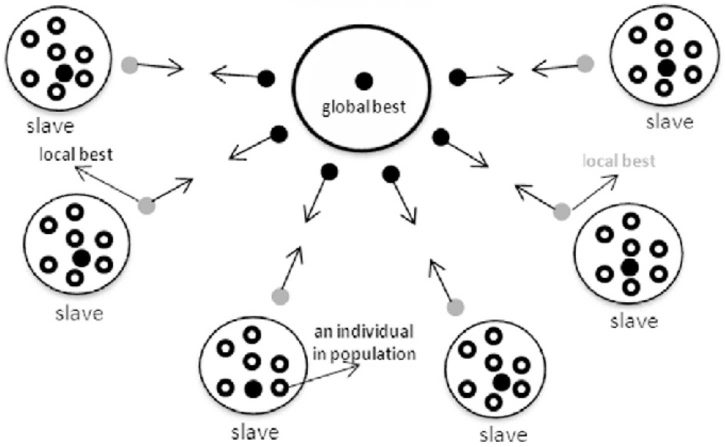
The goal: keep as much state as possible resident

Shortest Path / Search



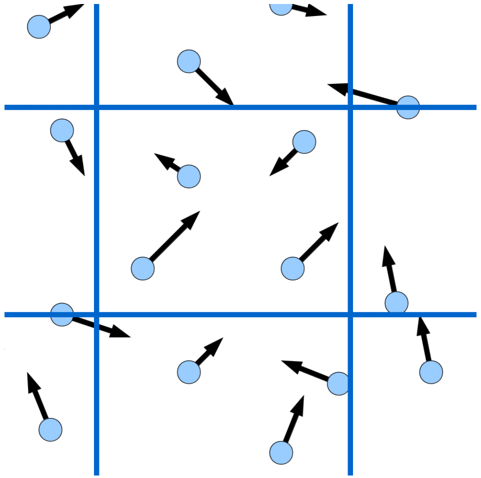
Weight array perfect for persistence
Iteration over vertices? Fuse!

Genetic Algorithms / Master driven algorithms



Synchronization between a master block and slaves

Particle Simulations

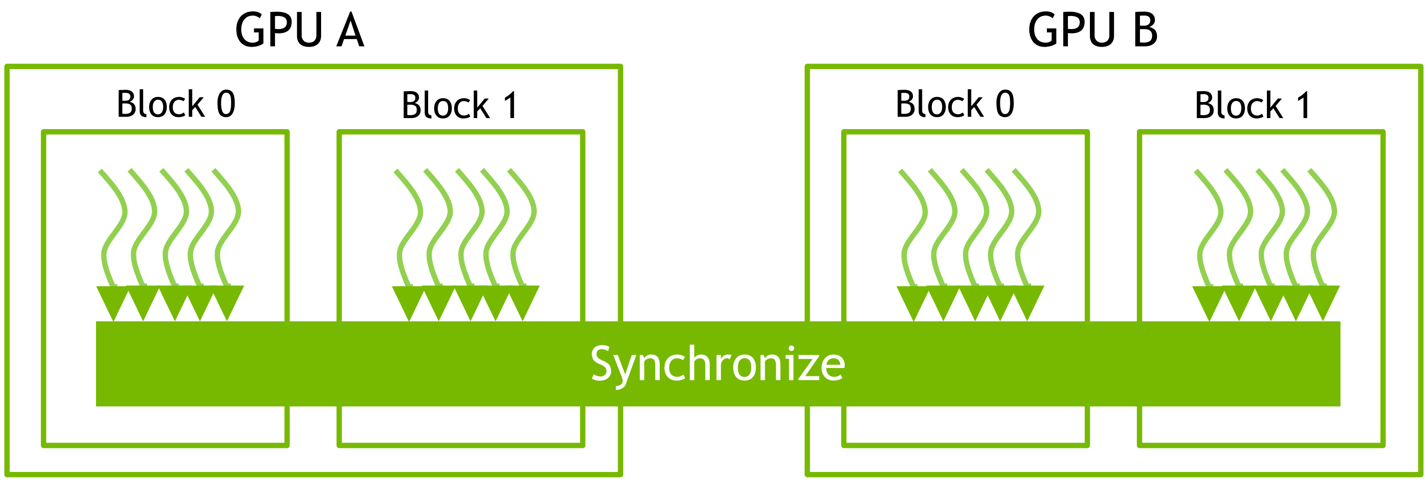


Synchronization between update and collision simulation

MULTI GRID GROUP

A set of threads guaranteed to be resident on the same system, on multiple devices

```
__global__ void kernel() {
    multi_grid_group multi_grid = this_multi_grid();
    // load data
    // loop - compute, share data
        multi_grid.sync();
        // devices are now synced, keep on computing
}
```



MULTI GRID GROUP

Launch on multiple devices at once

New CUDA Launch API to opt-in:

`cudaLaunchCooperativeKernelMultiDevice(…)`

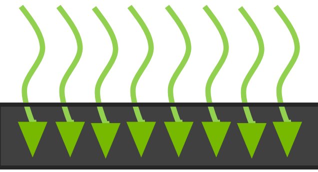
Devices need to support the `cooperativeMultiDeviceLaunch` property.

```
struct cudaLaunchParams params[numDevices];
for (int i = 0; i < numDevices; i++) {
    params[i].func = (void *)kernel;
    params[i].gridDim = dim3(…); // Use occupancy calculator
    params[i].blockDim = dim3(…);
    params[i].sharedMem = …;
    params[i].stream = …; // Cannot use the NULL stream
    params[i].args = …;
}
cudaLaunchCooperativeKernelMultiDevice(params, numDevices);
```

COALESCED GROUP

Discover the set of coalesced threads, i.e. a group of converged threads executing in SIMD

```
coalesced_group active = coalesced_threads();
```



Size: 8

COALESCED GROUP

Discover the set of coalesced threads, i.e. a group of converged threads executing in SIMD

```
coalesced_group active = coalesced_threads();
if () { // start block
    coalesced_group g1 = coalesced_threads();
```

Size: 8

Size: 3

Internal Lane Mask

	1		3				7

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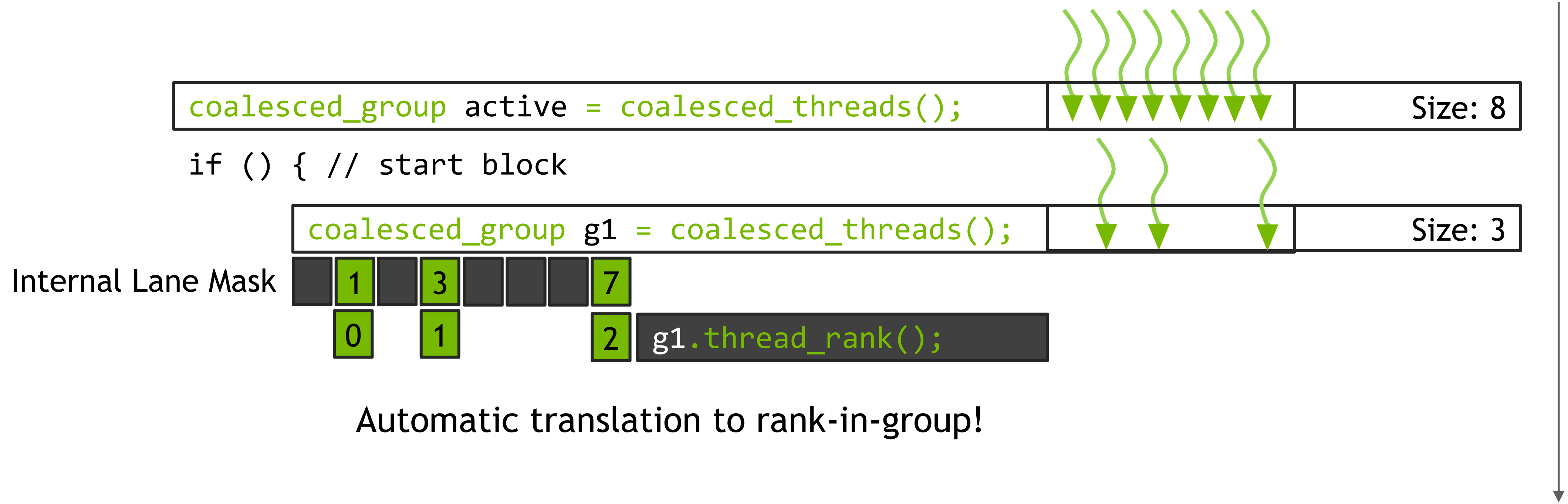

Automatic translation to rank-in-group!

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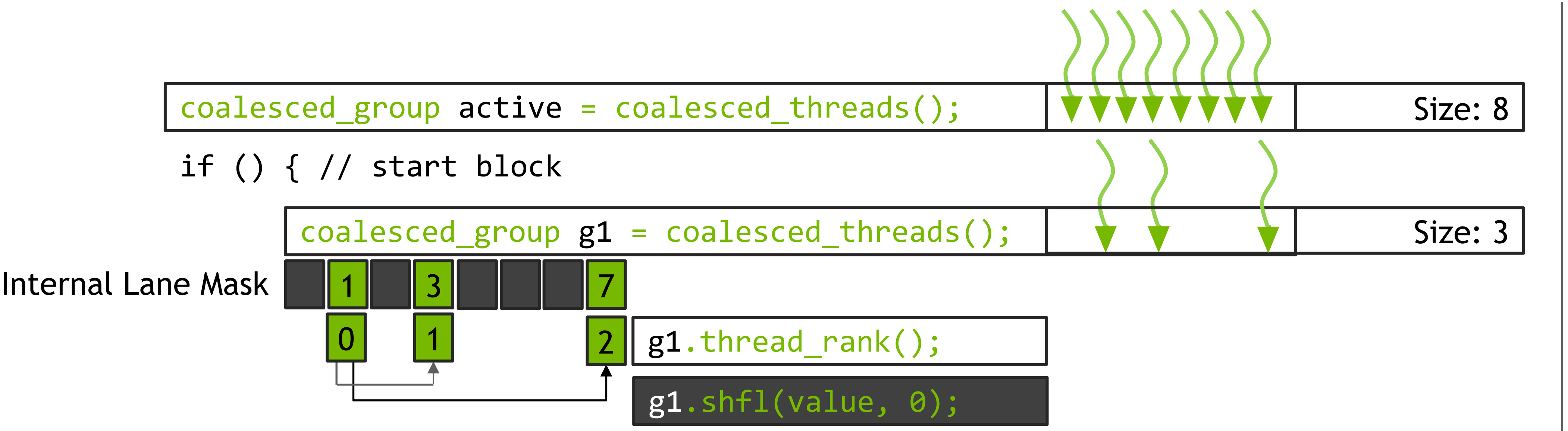

Automatic translation from rank-in-group to SIMD lane!

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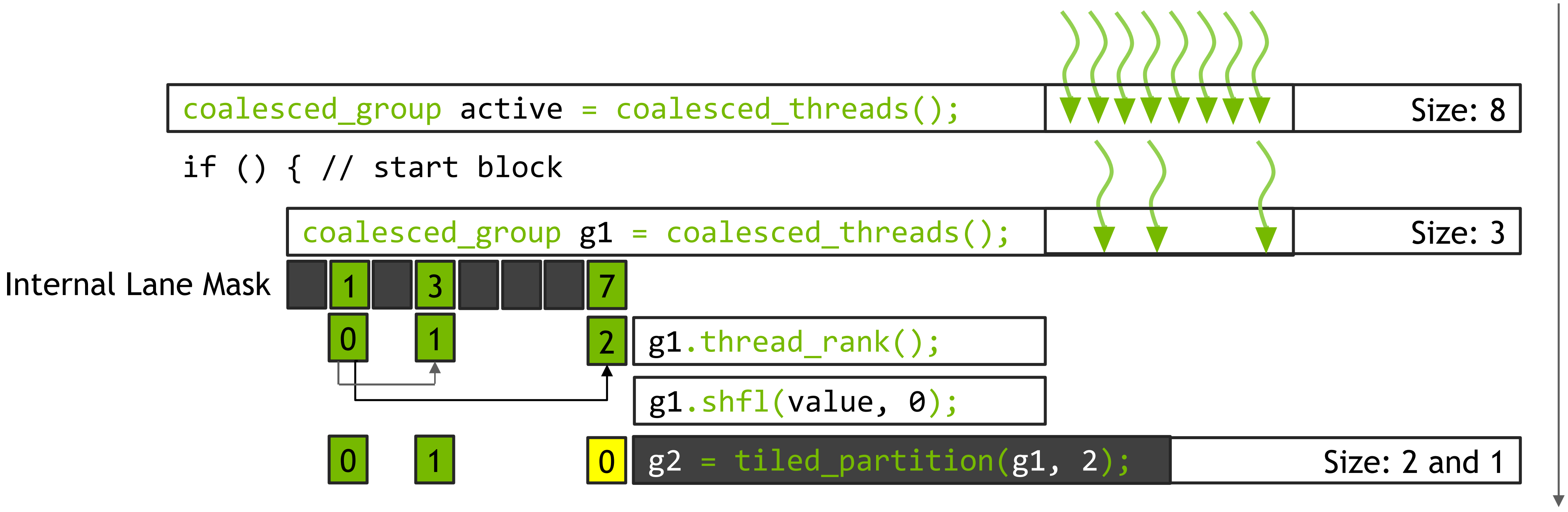

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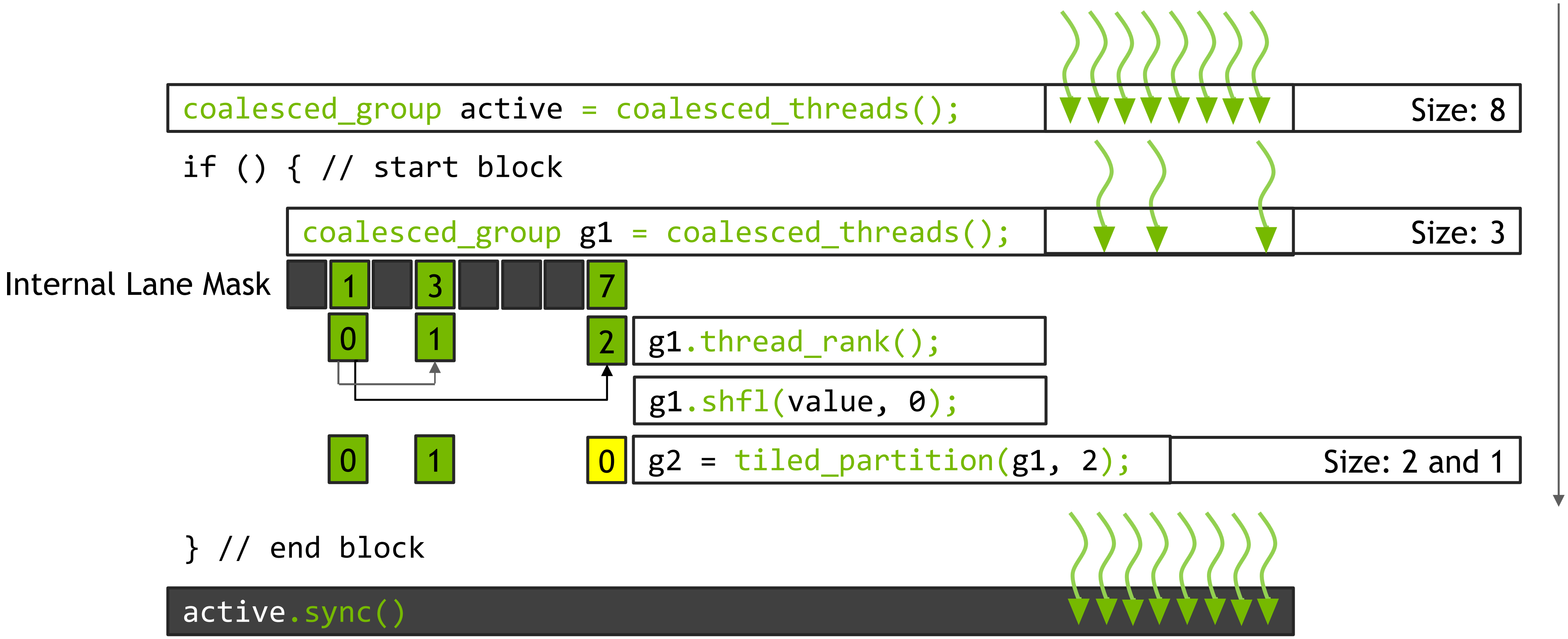

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ATOMIC AGGREGATION

Opportunistic Cooperation Within a Warp

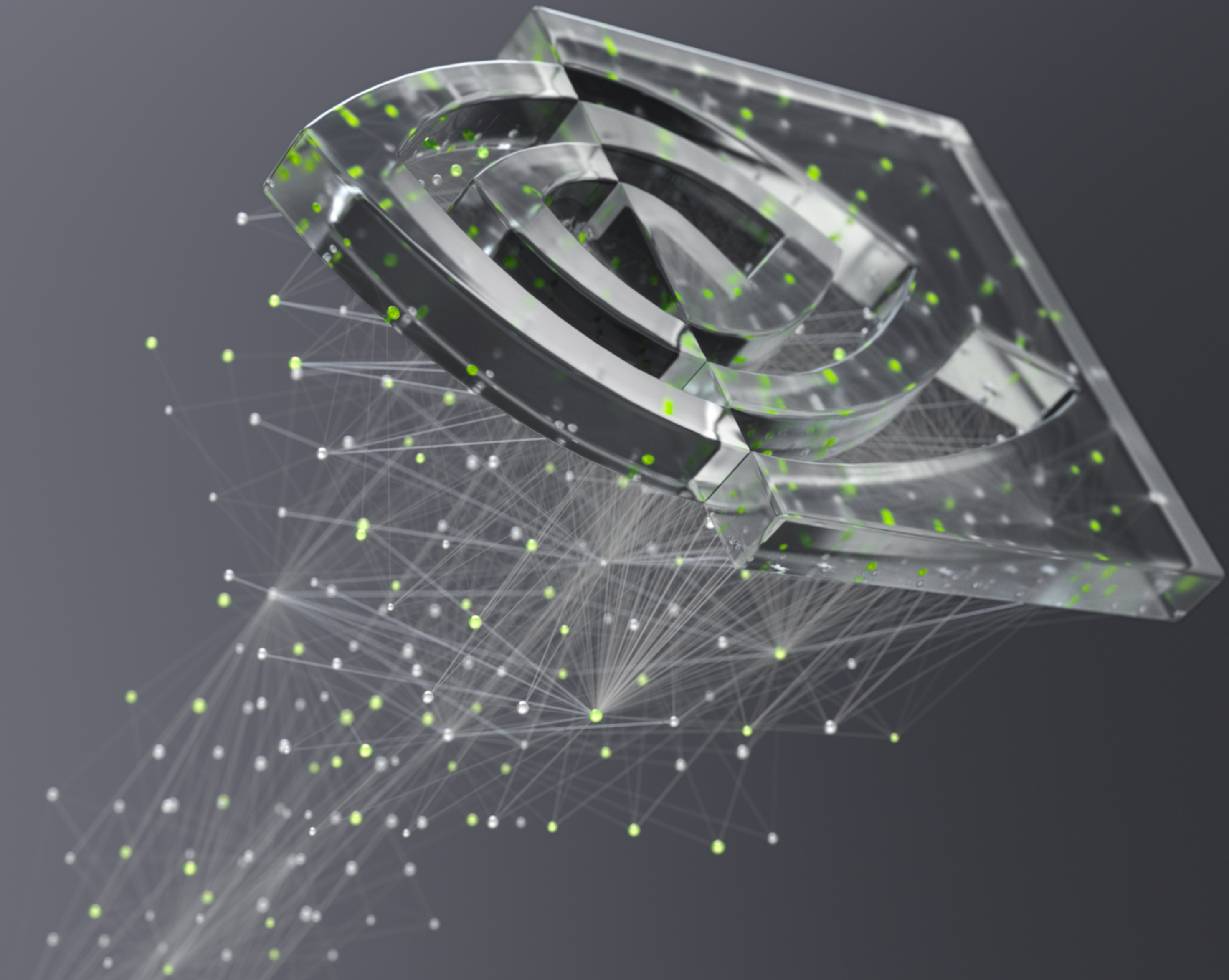
```
inline __device__ int atomicAggInc(int *p)
{
    coalesced_group g = coalesced_threads();
    int prev;
    if (g.thread_rank() == 0) {
        prev = atomicAdd(p, g.size());
    }
    prev = g.thread_rank() + g.shfl(prev, 0);
    return prev;
}
```

FURTHER STUDY

- GTC 2017 On-Demand Recording:
  - http://on-demand.gputechconf.com/gtc/2017/presentation/s7622-Kyrylo-perelygin-robust-and-scalable-cuda.pdf (slides)
  - http://on-demand.gputechconf.com/gtc/2017/video/s7622-perelygin-robust-scalable-cuda-parallel-programming-model.mp4 (recording)
- Sample Codes:
  - conjugateGradientMultiBlockCG, conjugateGradientMultiDeviceCG, reductionMultiBlockCG, warpAggregatedAtomicsCG
- Blog:
  - https://devblogs.nvidia.com/cooperative-groups/
- Programming Guide:
  - https://docs.nvidia.com/cuda/cuda-c-programming-guide/index.html#cooperative-groups
- Persistent kernels, grid sync, RNN state:
  - https://svail.github.io/persistent_rnns/

HOMEWORK

- Log into Summit (ssh username@home.ccs.ornl.gov -> ssh summit)
- Clone GitHub repository:
  - Git clone git@github.com:olcf/cuda-training-series.git
- Follow the instructions in the readme.md file:
  - https://github.com/olcf/cuda-training-series/blob/master/exercises/hw9/readme.md
- Prerequisites: basic linux skills, e.g. ls, cd, etc., knowledge of a text editor like vi/emacs, and some knowledge of C/C++ programming



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