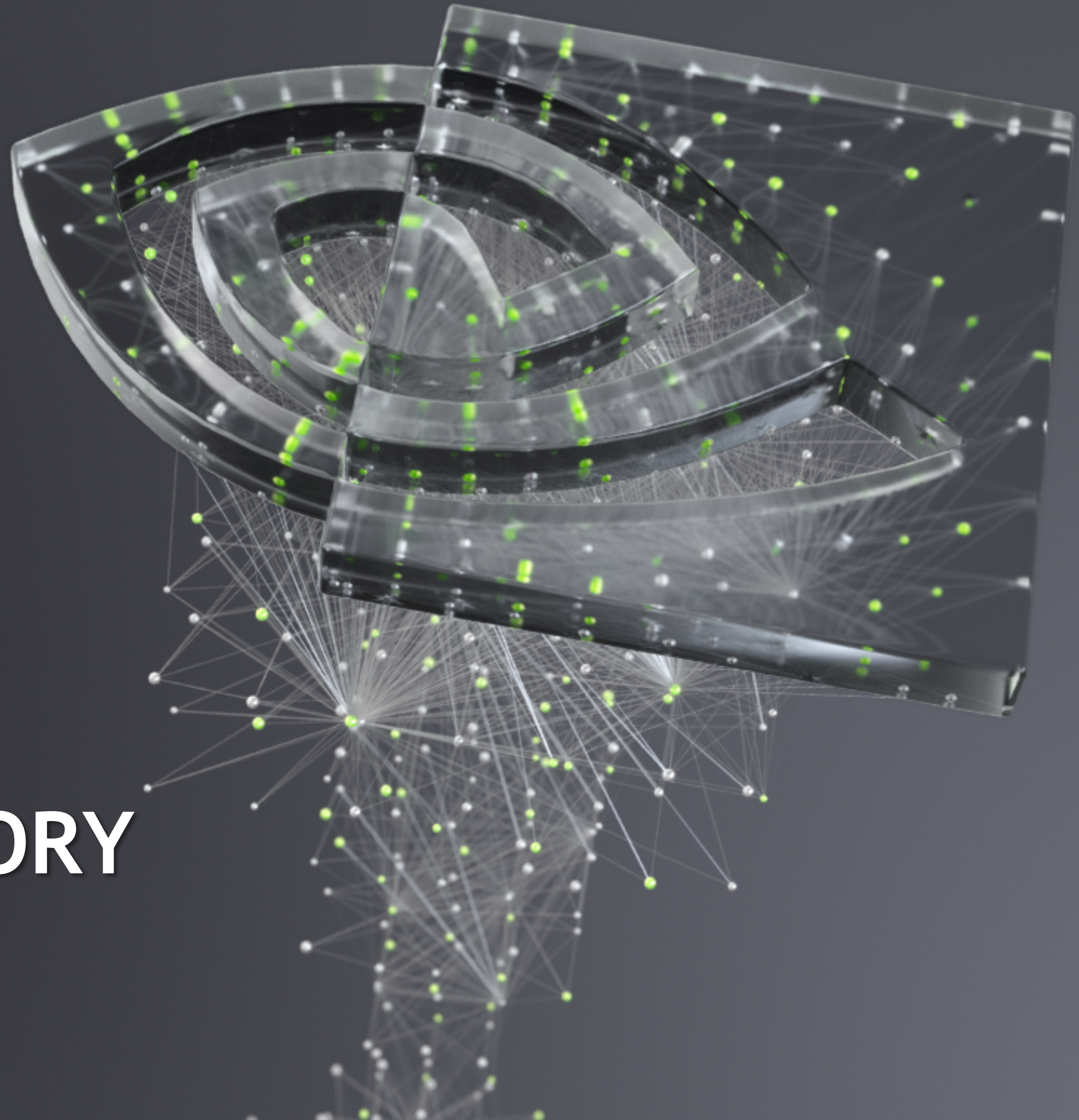


CUDA SHARED MEMORY

NVIDIA Corporation

REVIEW (1 OF 2)

- Difference between *host* and *device*
  - ***Host*** CPU
  - ***Device*** GPU
- Using `__global__` to declare a function as device code
  - Executes on the device
  - Called from the host (or possibly from other device code)
- Passing parameters from host code to a device function

REVIEW (2 OF 2)

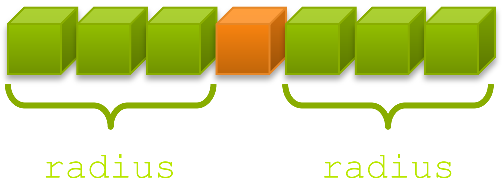
- Basic device memory management
  - `cudaMalloc()`
  - `cudaMemcpy()`
  - `cudaFree()`

- Launching parallel kernels
  - Launch `N` copies of `add()` with `add<<<N,1>>>(…);`
  - Use `blockIdx.x` to access block index

1D STENCIL

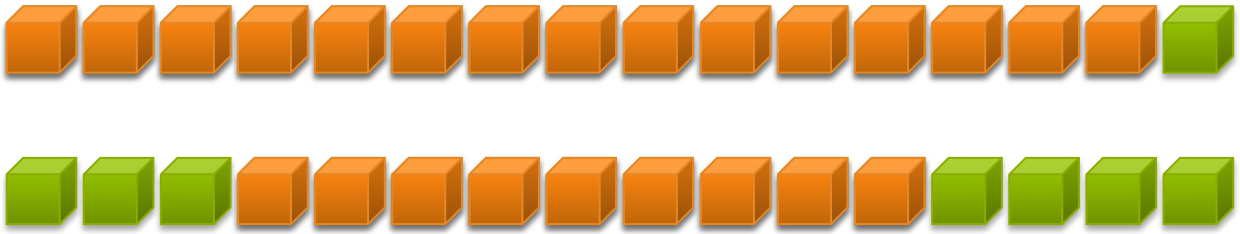
- Consider applying a 1D stencil to a 1D array of elements
  - Each output element is the sum of input elements within a radius

- If radius is 3, then each output element is the sum of 7 input elements:



IMPLEMENTING WITHIN A BLOCK

- Each thread processes one output element
  - `blockDim.x` elements per block
- Input elements are read several times
  - With radius 3, each input element is read seven times

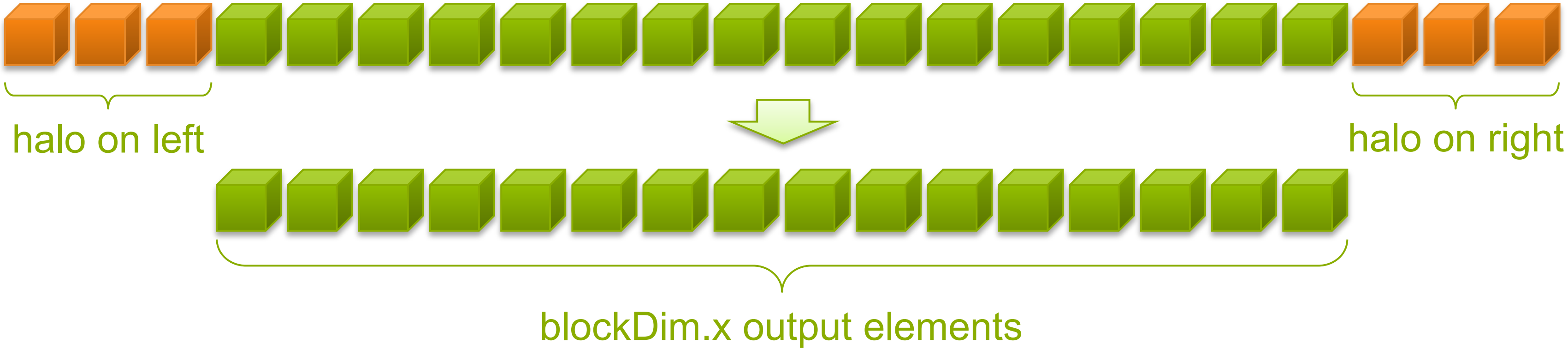


SHARING DATA BETWEEN THREADS

- Terminology: within a block, threads share data via shared memory
- Extremely fast on-chip memory, user-managed
- Declare using `__shared__`, allocated per block
- Data is not visible to threads in other blocks

IMPLEMENTING WITH SHARED MEMORY

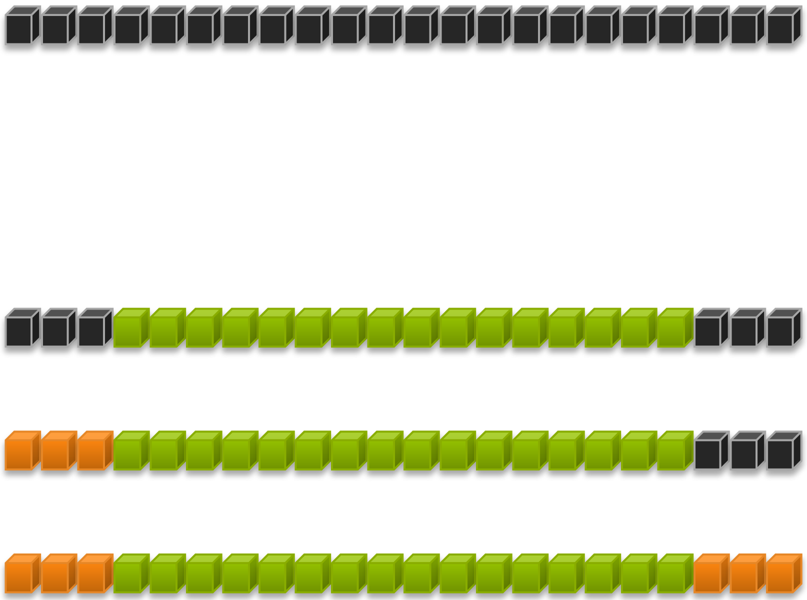
- Cache data in shared memory
  - Read `(blockDim.x + 2 * radius)` input elements from global memory to shared memory
  - Compute `blockDim.x` output elements
  - Write `blockDim.x` output elements to global memory
- Each block needs a halo of `radius` elements at each boundary



STENCIL KERNEL

```
__global__ void stencil_1d(int *in, int *out) {
  __shared__ int temp[BLOCK_SIZE + 2 * RADIUS];
  int gindex = threadIdx.x + blockIdx.x * blockDim.x;
  int lindex = threadIdx.x + RADIUS;

  // Read input elements into shared memory
  temp[lindex] = in[gindex];
  if (threadIdx.x < RADIUS) {
    temp[lindex - RADIUS] = in[gindex - RADIUS];
    temp[lindex + BLOCK_SIZE] =
      in[gindex + BLOCK_SIZE];
  }
```



STENCIL KERNEL

```
  // Apply the stencil
 int result = 0;
  for (int offset = -RADIUS ; offset <= RADIUS ; offset++)
    result += temp[lindex + offset];

  // Store the result
  out[gindex] = result;
}
```

DATA RACE!

- The stencil example will not work…

- Suppose thread 15 reads the halo before thread 0 has fetched

```
temp[lindex] = in[gindex];
    if (threadIdx.x < RADIUS) {
        temp[lindex – RADIUS] = in[gindex – RADIUS];
        temp[lindex + BLOCK_SIZE] = in[gindex + BLOCK_SIZE];
    }
    int result = 0;
    result += temp[lindex + 1];
```

Store at temp[18]

Skipped, threadIdx > RADIUS

Load from temp[19]

__SYNCTHREADS()

- `void __syncthreads();`
- Synchronizes all threads within a block
  - Used to prevent RAW / WAR / WAW hazards
- All threads must reach the barrier
  - In conditional code, the condition must be uniform across the block

STENCIL KERNEL

```
__global__ void stencil_1d(int *in, int *out) {
    __shared__ int temp[BLOCK_SIZE + 2 * RADIUS];
    int gindex = threadIdx.x + blockIdx.x * blockDim.x;
    int lindex = threadIdx.x + radius;

    // Read input elements into shared memory
    temp[lindex] = in[gindex];
    if (threadIdx.x < RADIUS) {
        temp[lindex - RADIUS] = in[gindex - RADIUS];
        temp[lindex + BLOCK_SIZE] = in[gindex + BLOCK_SIZE];
    }
    // Synchronize (ensure all the data is available)
    __syncthreads();
```

STENCIL KERNEL

```
    // Apply the stencil
    int result = 0;
    for (int offset = -RADIUS ; offset <= RADIUS ; offset++)
        result += temp[lindex + offset];

    // Store the result
    out[gindex] = result;
}
```

REVIEW

- Use `__shared__` to declare a variable/array in shared memory
  - Data is shared between threads in a block
  - Not visible to threads in other blocks
- Use `__syncthreads()` as a barrier
  - Use to prevent data hazards

LOOKING FORWARD

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

Deploy Everywhere

Benefits all applications

Examples include:

- Persistent RNNs
- Physics
- Search Algorithms
- Sorting

FOR EXAMPLE: 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
```

NARROWING THE SHARED MEMORY GAP

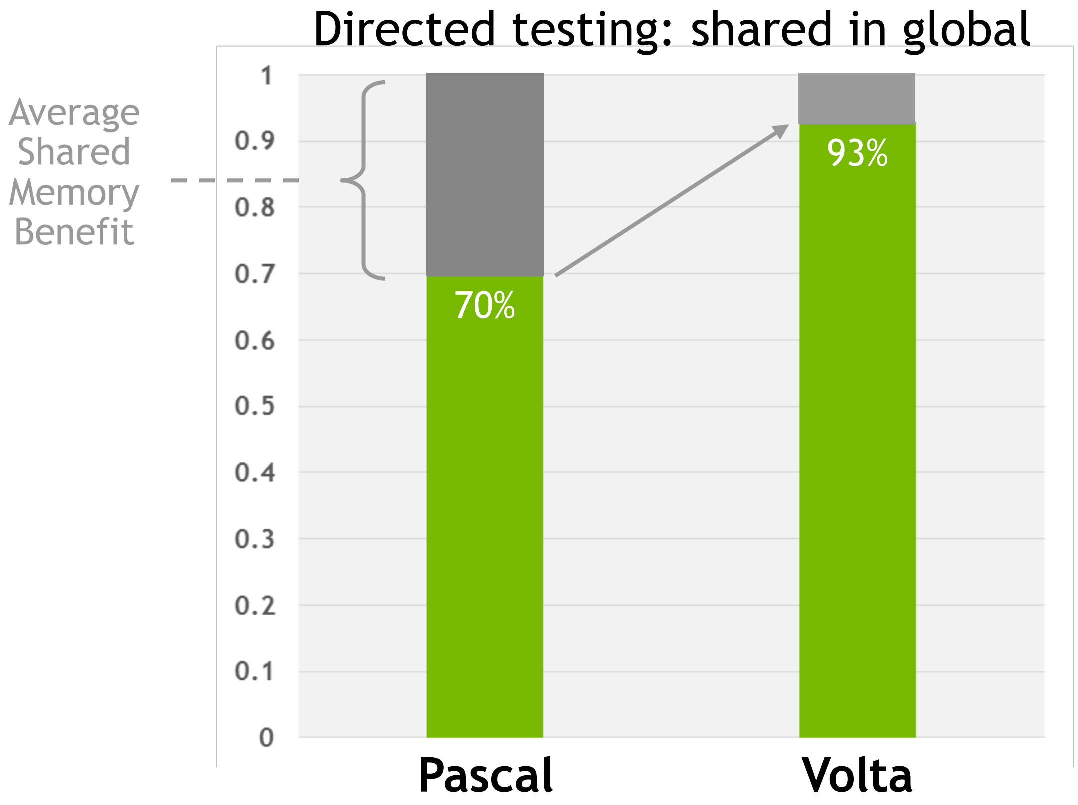
with the GV100 L1 cache

Cache: vs shared

- Easier to use
- 90%+ as good

Shared: vs cache

- Faster atomics
- More banks
- More predictable



FUTURE SESSIONS

- CUDA GPU architecture and basic optimizations
- Atomics, Reductions, Warp Shuffle
- Using Managed Memory
- Concurrency (streams, copy/compute overlap, multi-GPU)
- Analysis Driven Optimization
- Cooperative Groups

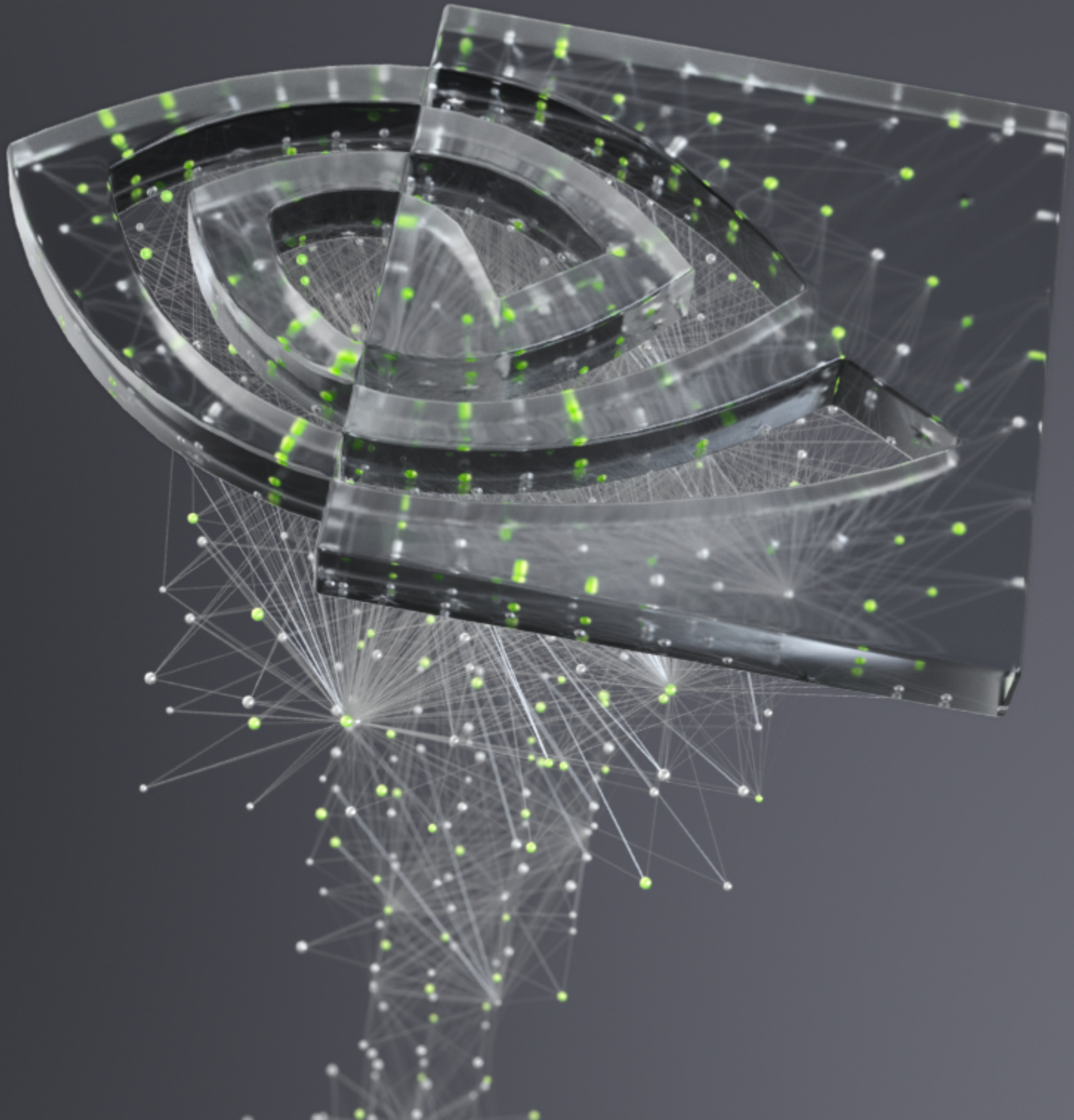
FURTHER STUDY

- Shared memory:
  - https://devblogs.nvidia.com/using-shared-memory-cuda-cc/
- CUDA Programming Guide:
  - https://docs.nvidia.com/cuda/cuda-c-programming-guide/index.html#shared-memory
- CUDA Documentation:
  - https://docs.nvidia.com/cuda/index.html
  - https://docs.nvidia.com/cuda/cuda-runtime-api/index.html (runtime API)

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/hw2/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



QUESTIONS?