CUDA C/C++ Basics

Supercomputing 2011 Tutorial

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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

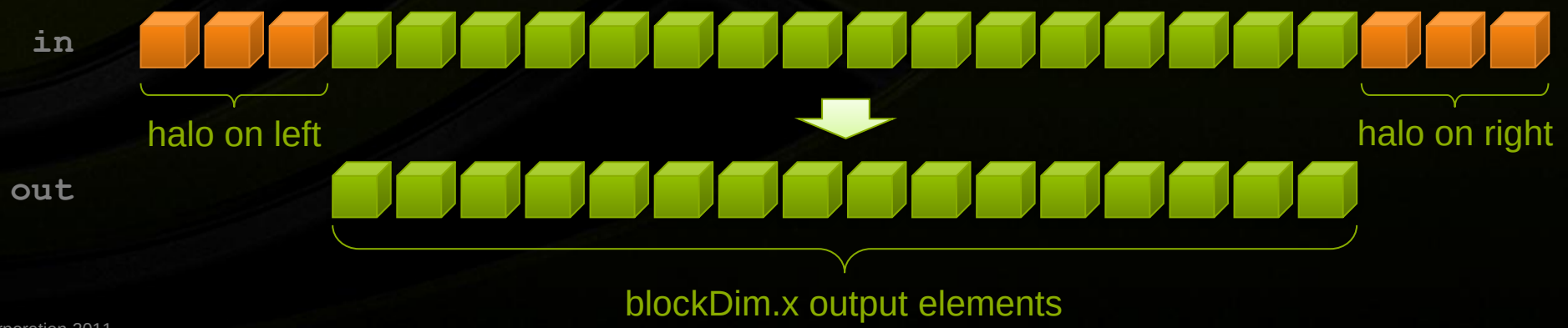
Sharing Data Between Threads

- Terminology: within a block, threads share data via shared memory
- Extremely fast on-chip memory
  - By opposition to device memory, referred to as global memory
  - Like a user-managed cache
- 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

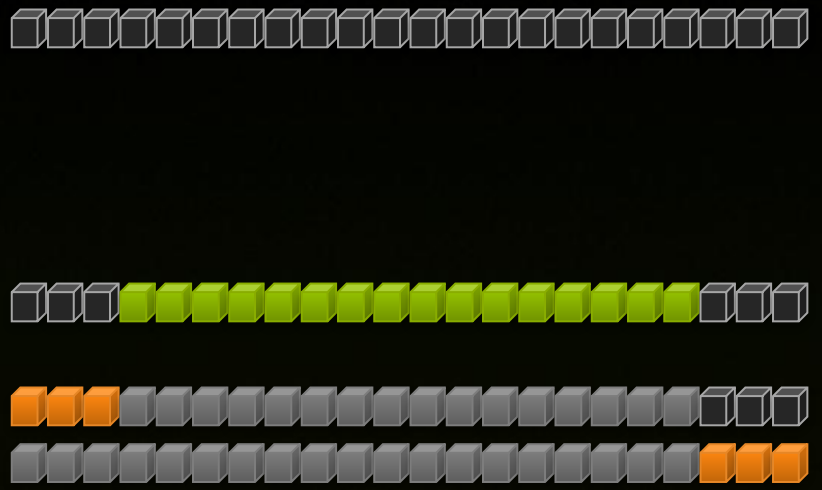
- Each block needs a halo of `radius` elements at each boundary



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 it…

```
...
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;
for (int offset = -RADIUS ; offset <= RADIUS ; offset++)
   result += temp[lindex + offset];
...
```

Store at temp[18]

Skipped since threadId.x > 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 (1 of 2)

- Launching parallel threads
  - Launch `N` blocks with `M` threads per block with `kernel<<<N,M>>>(…);`
  - Use `blockIdx.x` to access block index within grid
  - Use `threadIdx.x` to access thread index within block

- Allocate elements to threads:

```
int index = threadIdx.x + blockIdx.x * blockDim.x;
```

Review (2 of 2)

- 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