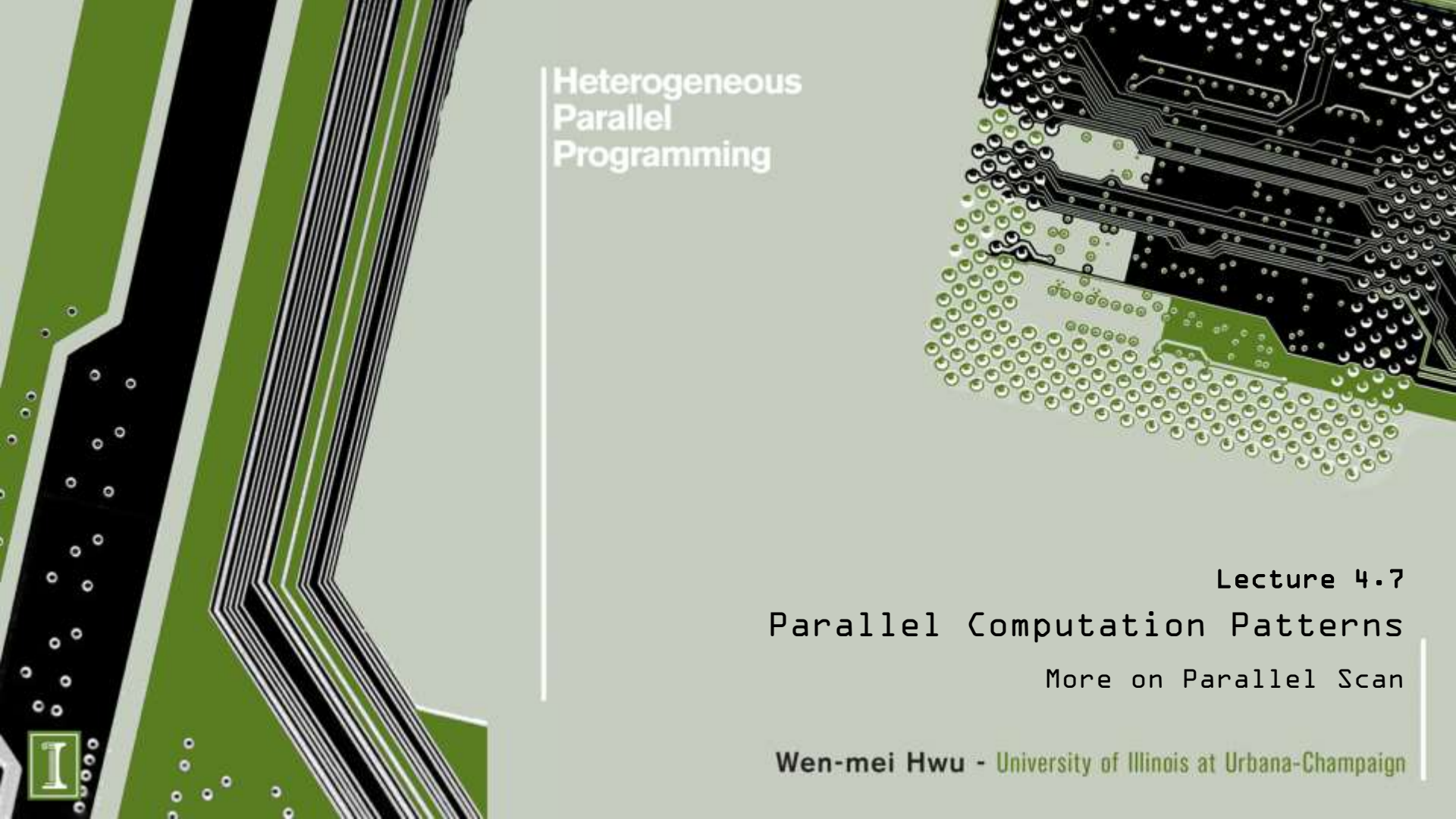

Heterogeneous Parallel Programming

Lecture 4.7

Parallel Computation Patterns

More on Parallel Scan

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Objective

- To learn more about parallel scan
  - Analysis of the work efficient kernel
  - Exclusive scan
  - Handling large input vectors

Work Analysis of the Work Efficient Kernel

- The work efficient kernel executes log(n) parallel iterations in the reduction step
  - The iterations do n/2, n/4,..1 adds
  - Total adds: (n-1) → O(n) work

- It executes log(n)-1 parallel iterations in the post reduction reverse step
  - The iterations do 2-1, 4-1, …. n/2-1 adds
  - Total adds: (n-2) – (log(n)-1) → O(n) work

- Both phases perform up to no more than 2*(n-1) adds

- The total number of adds is no more than twice of that done in the efficient sequential algorithm
  - The benefit of parallelism can easily overcome the 2X work when there is sufficient hardware

Some Tradeoffs

- The work efficient scan kernel is normally more desirable
  - Better Energy efficiency
  - Less execution resource requirement
- However, the work inefficient kernel could be better for absolute performance due to its single-step nature if
  - There is sufficient execution resource

Exclusive Scan Definition

Definition: *The* exclusive scan *operation takes a binary associative operator* $\oplus$, *and an array of n elements*

$$[x_0, x_1, \ldots, x_{n-1}]$$

and returns the array

$$[0, x_0, (x_0 \oplus x_1), \ldots, (x_0 \oplus x_1 \oplus \ldots \oplus x_{n-2})].$$

Example: If $\oplus$ is addition, then the all-prefix-sums operation on the array [3 1 7 0 4 1 6 3], would return [0 3 4 11 11 15 16 22].

Why Exclusive Scan

- To find the beginning address of allocated buffers
- Inclusive and exclusive scans can be easily derived from each other; it is a matter of convenience

[3 1 7 0 4 1 6 3]

Exclusive [0 3 4 11 11 15 16 22]

Inclusive [3 4 11 11 15 16 22 25]

A simple exclusive scan kernel

- Adapt an inclusive, work in-efficient scan kernel
- Block 0:
  - Thread 0 loads 0 into XY[0]
  - Other threads load X[threadIdx.x-1] into XY[threadIdx.x]
- All other blocks:
  - All thread load X[blockIdx.x*blockDim.x+threadIdx.x-1] into XY[threadIdex.x]
- Similar adaption for work efficient scan kernel but pay attention that each thread loads two elements
  - Only one zero should be loaded
  - All elements should be shifted by only one position

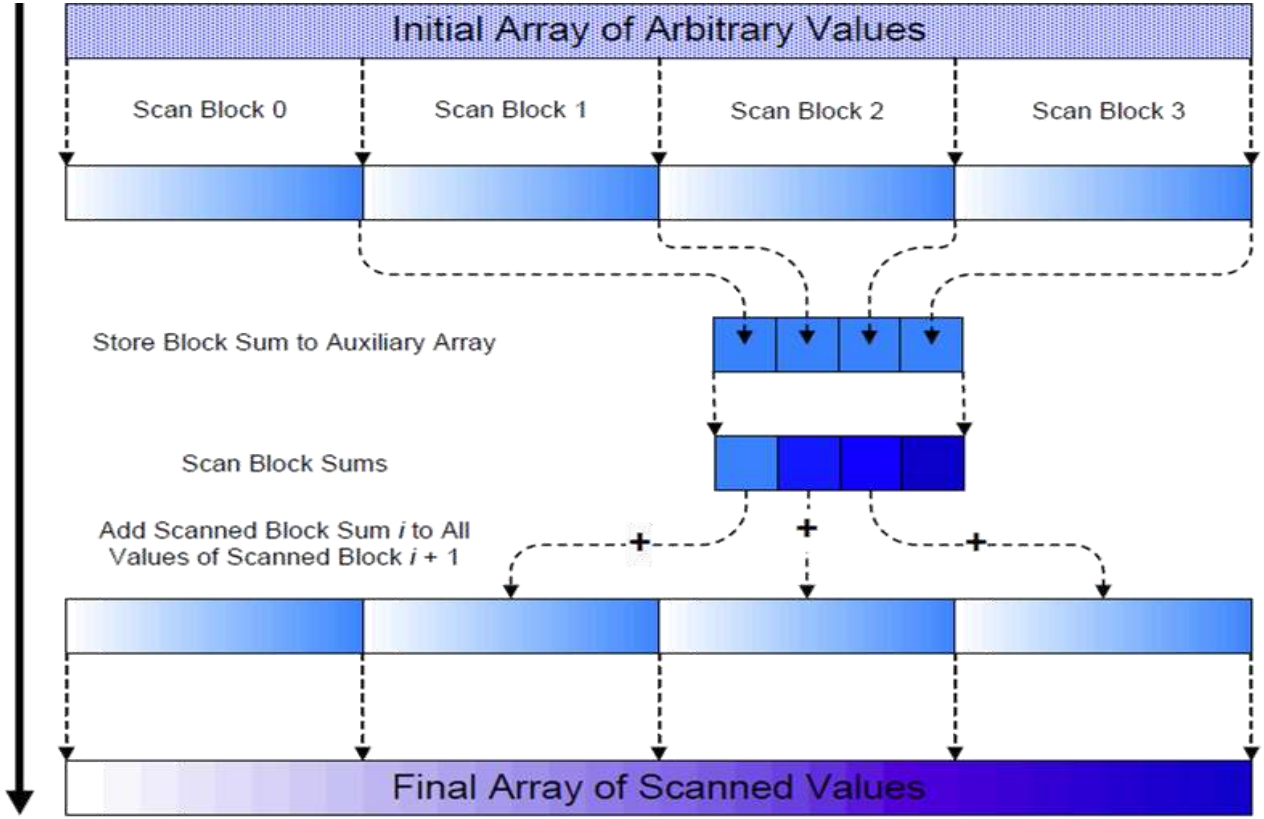
Read the Harris article for a more intellectually interesting approach to exclusive scan kernel implementation.

Handling large Input Vectors

- Build on the work efficient scan kernel
- Have each section of 2*blockDim.x elements assigned to a block
- Have each block write the sum of its section into a Sum[] array indexed by blockIdx.x
- Run the scan kernel on the Sum[] array
- Add the scanned Sum[] array values to the elements of corresponding sections

- Adaptation of work inefficient kernel is similar.

Overall Flow of Complete Scan



To learn more, read
Sections 9.4-9.5