Parallel Algorithms Patterns: Scan

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SLIDES ADAPTED FROM

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REZAUL A. CHOWDHURY - CSE 613: PARALLEL PROGRAMMING

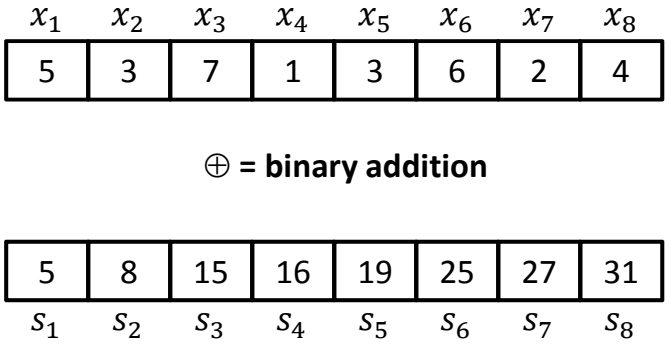
Bibliography

Section 3.3.5 of Structured Parallel Programming, Michael McCool, Arch D. Robison and James Reinders. Morgan Kaufmann (2012)

Parallel Prefix Sum with CUDA, Mark Harris, https://www.mimuw.edu.pl/~ps209291/kgkp/slides/scan.pdf

Scan or Prefix Sum

Scan: computes all partial reduction of a collection



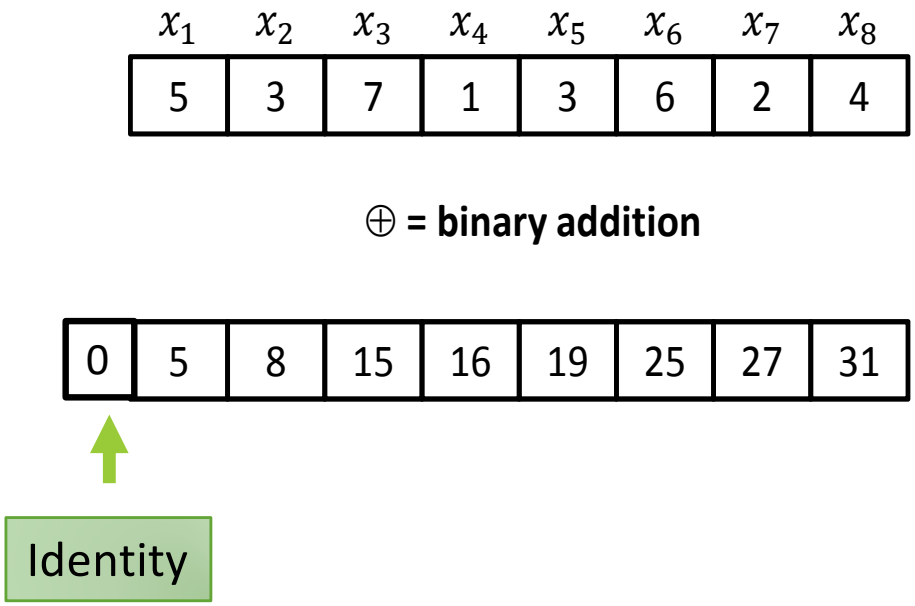
For every output in a collection, a reduction of the input up to that point is computed

If the function being used is associative, the scan can be parallelized

Parallelizing a scan is not obvious at first, because of dependencies to previous iterations in the serial loop

A parallel scan will require more operations than a serial version

Exclusive Scan



Contraction Technique

1. **Reduce**: reduce the original problem to a smaller problem
2. **Conquer**: solve the smaller problem (often recursively)
3. **Expand**: use the solution to the smaller problem to obtain a solution for the original larger problem

Contraction
Scan or Prefix Sum in CPU

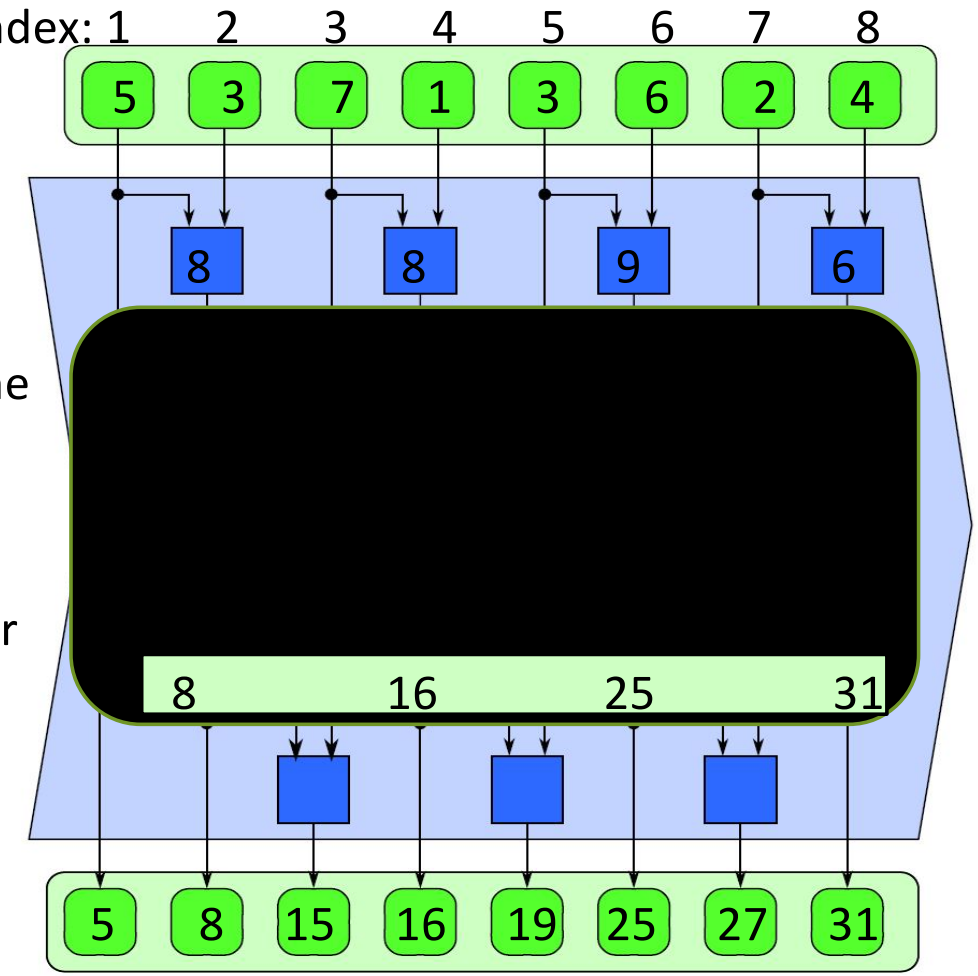
```
prefix_sum(array) {
 if  array.size() == 1 then result[1] = array[1]
  else
    parallel for  i = 1 to array.size()/2 do
      aux[i] = array[2*i-1] + array[2*i]
    aux = prefix_sum(aux)
    parallel for  i = 1 to array.size() do
      if i = 1 then result[1] = array[1]
     else if i = even then result[i] = aux[i/2]
             else result[i] = aux[(i-1)/2] + array[i]
  return result
}
```

Solve problem by processing the result of solving a smaller instance of the problem

Contraction
Scan or Prefix Sum

Black box solves the smaller problem

Result is the aux vector of the upper function



Contraction
Scan or Prefix Sum

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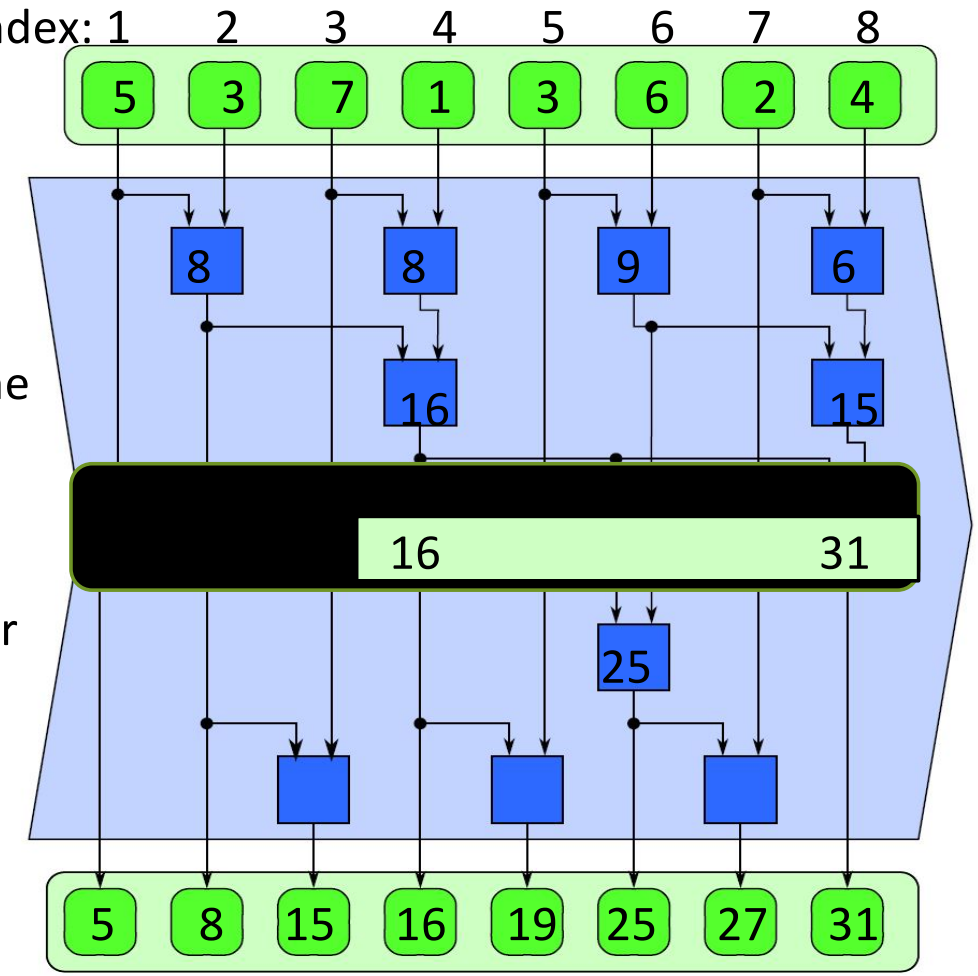
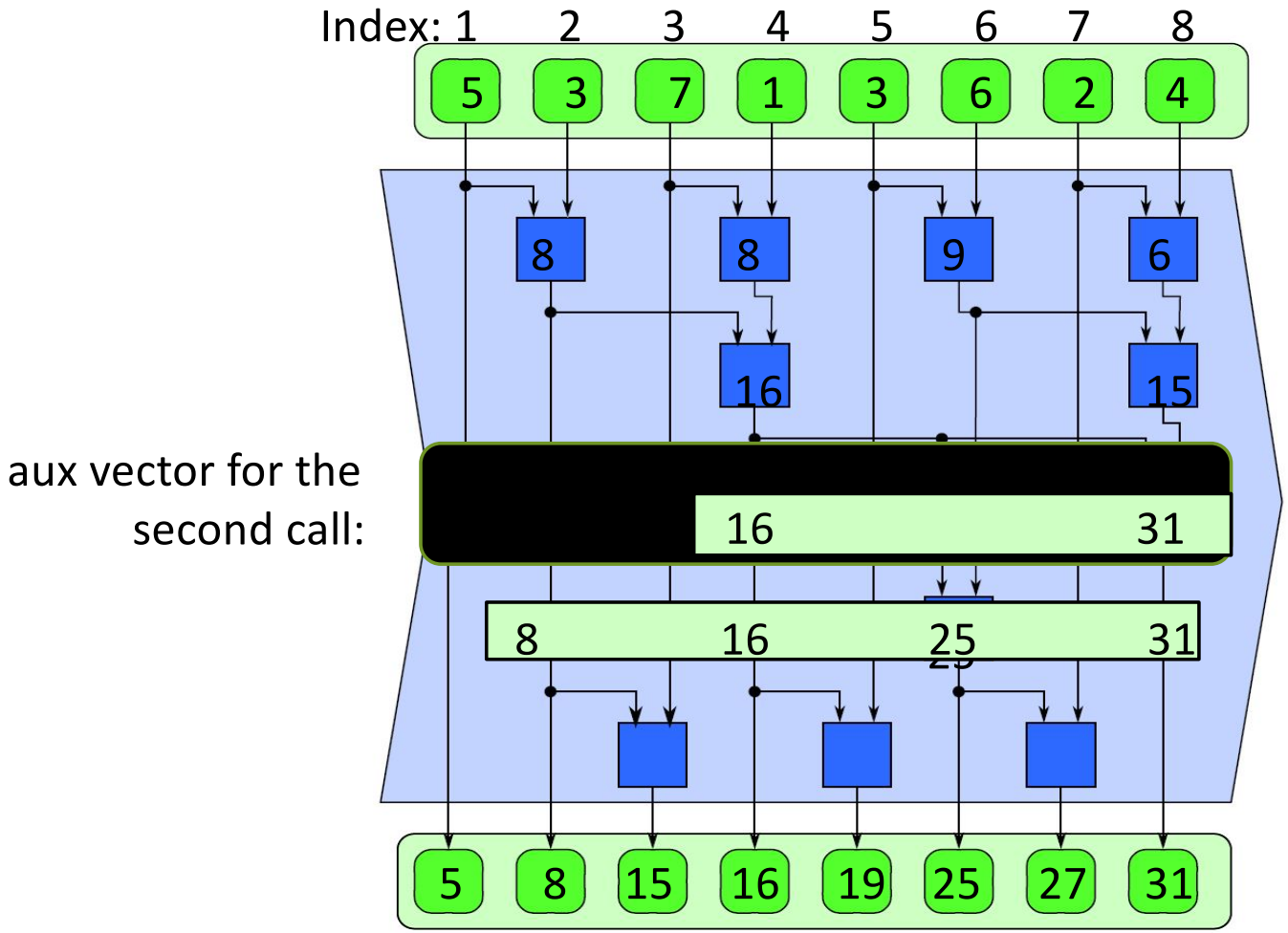
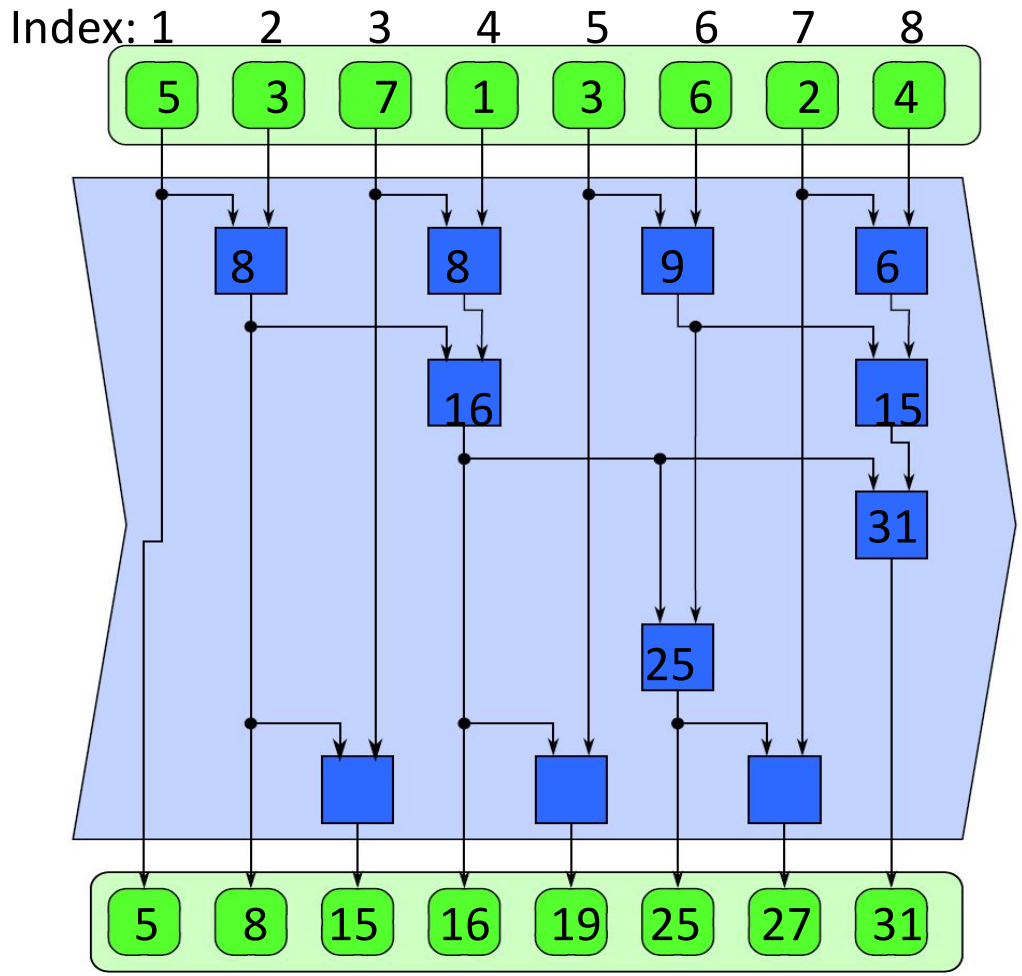


Contraction
Scan or Prefix Sum



Contraction
Scan or Prefix Sum



A GPU Implementation in a Single Block

Two phases:

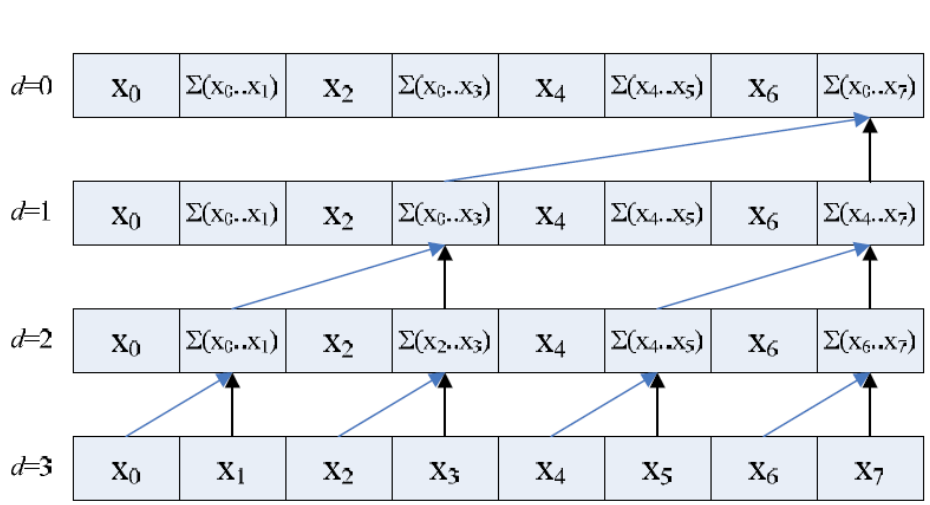
- up-sweep (reduce)
- down-sweep

Thread number: NUM_ELEMENTS /2

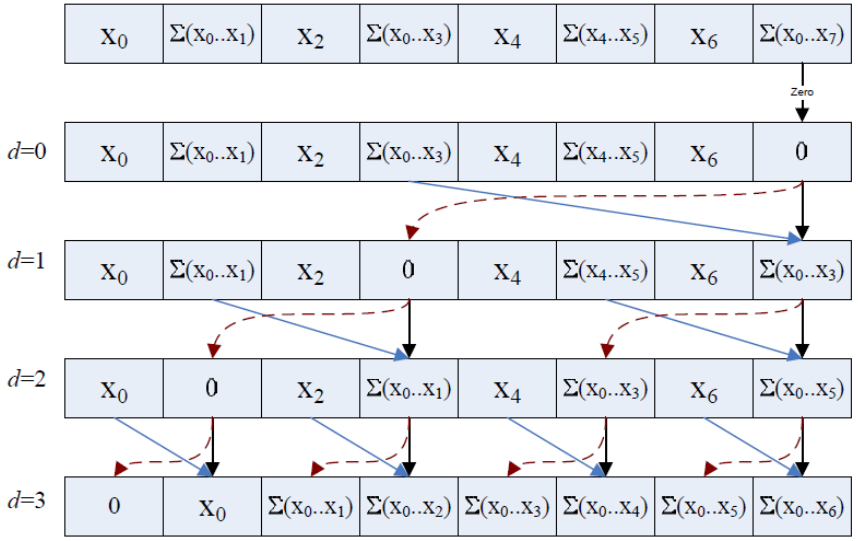
Shared memory size: NUM_ELEMENTS

A GPU Implementation in a Single Block

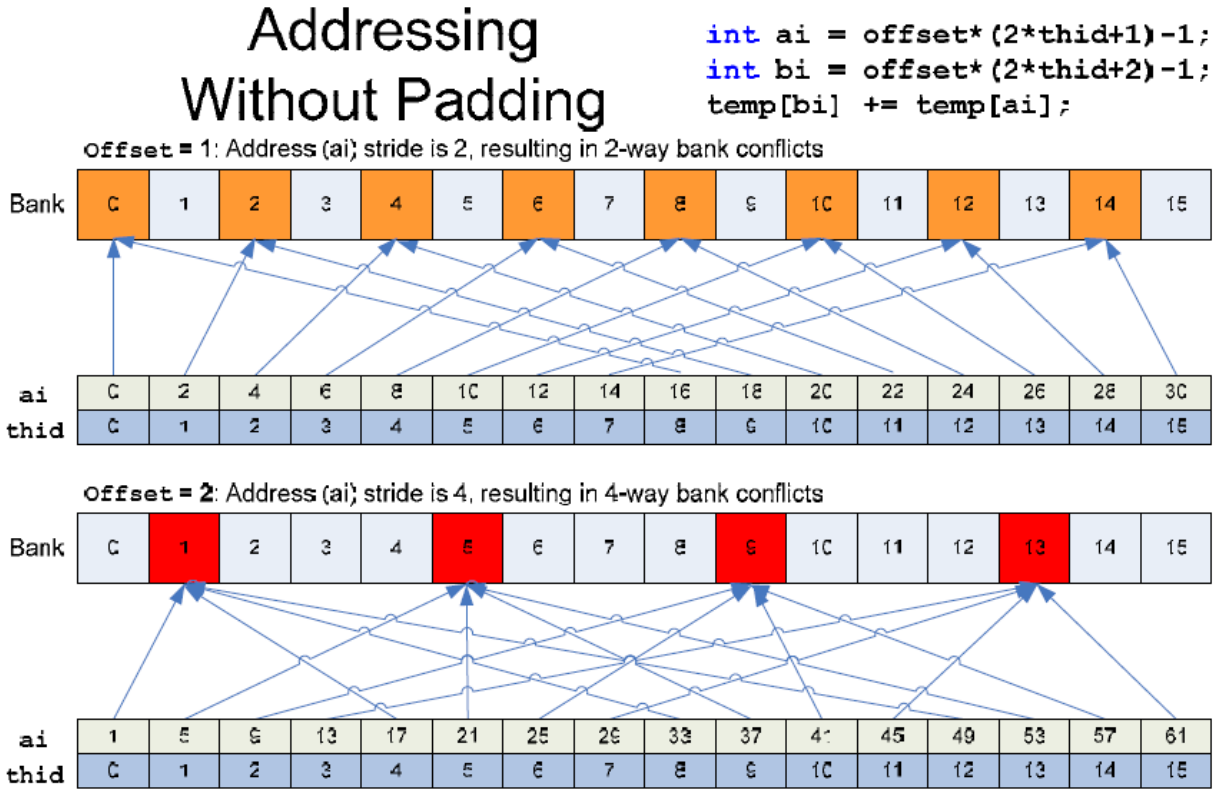
UP-SWEEP



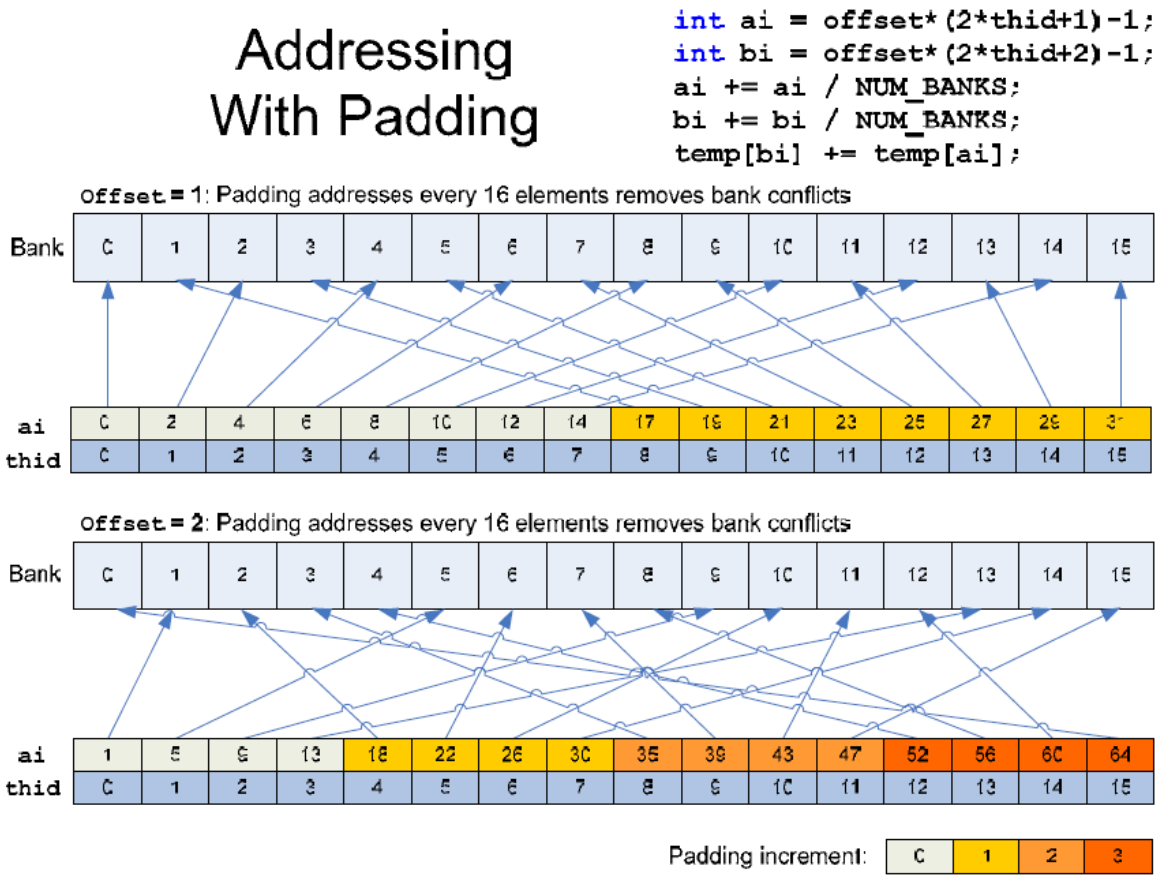
DOWN SWEEP



Avoiding Bank Conflicts



Avoiding Bank Conflicts



Arrays of Arbitrary Size