Parallel Processing

Unit 3

Dr. Ahmed Sallam

Fundamental GPU Algorithms

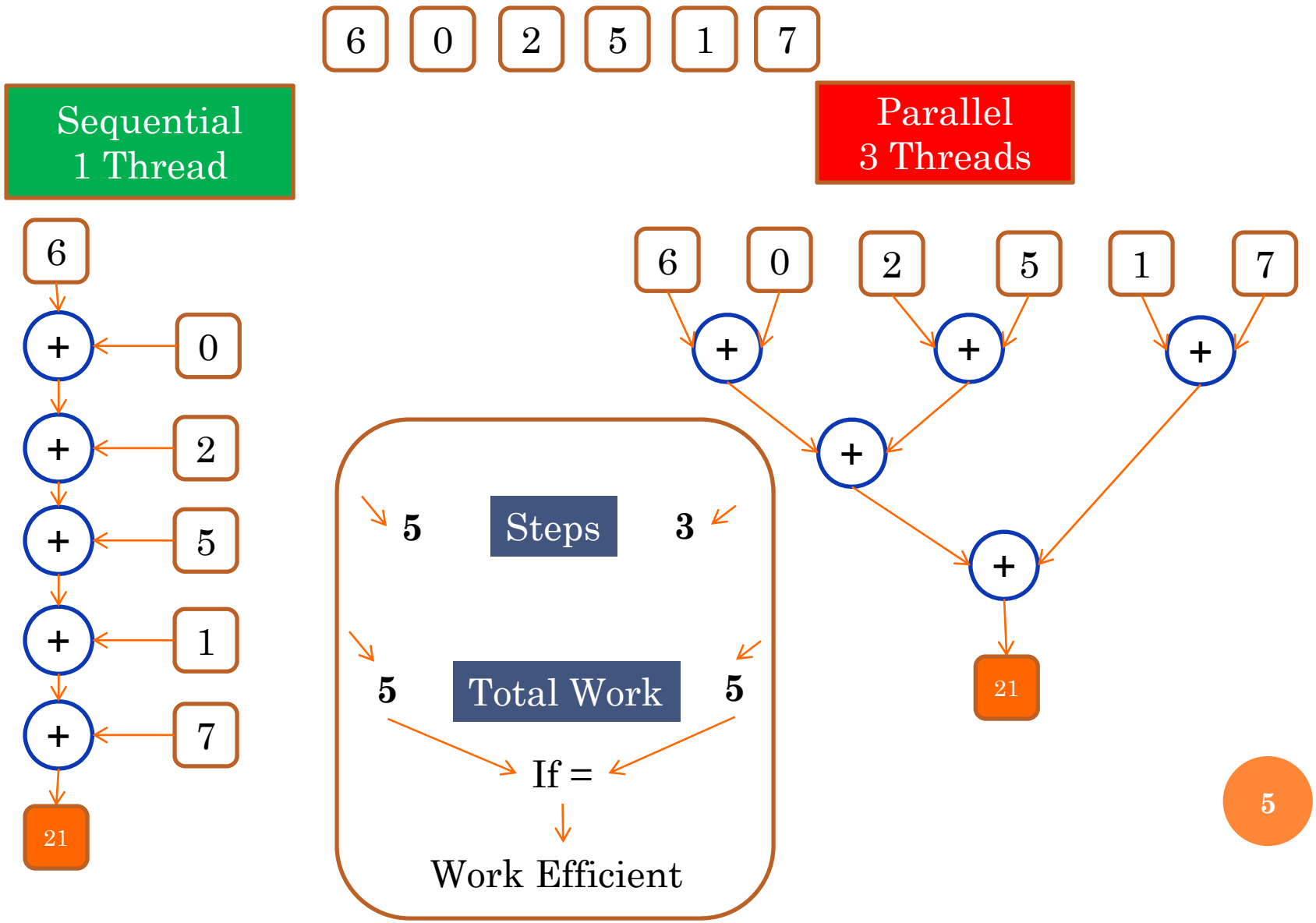
- More Patterns
  - Reduce
  - Scan

OUTLINES

- Efficiency Measure
- Reduce primitive
  - Reduce model
  - Reduce Implementation and complexity analysis
- Scan primitive
  - Scan model
  - Scan Implementation and complexity analysis
- Histogram primitive
  - Histogram with atomic
  - Histogram with atomic and reduce

Efficiency measure

Sequential vs. Parallel efficiency?

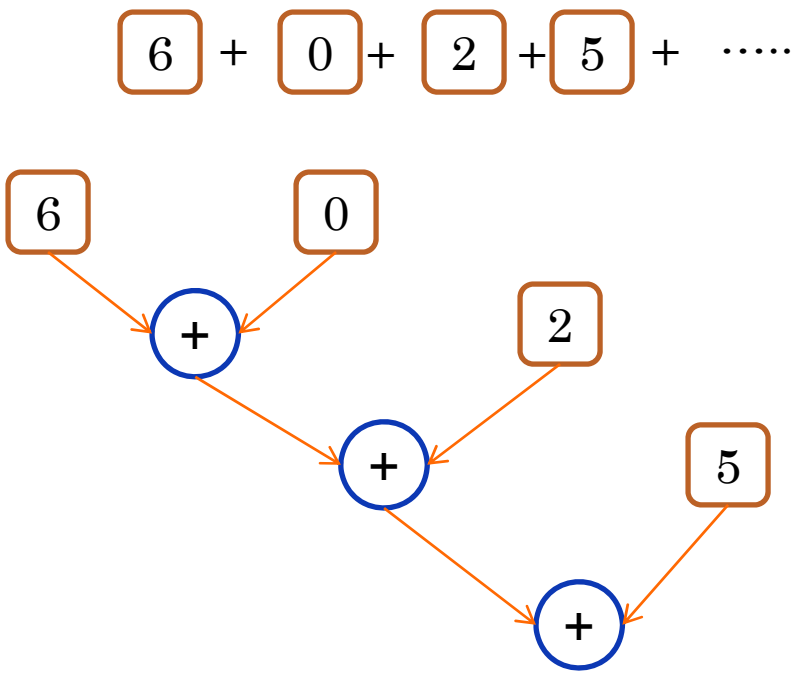


OUTLINES

- Efficiency Measure
- Reduce Algorithm
  - Reduce model
  - Reduce Implementation and complexity analysis
- Scan Algorithm
  - Scan model
  - Scan Implementation and complexity analysis
- Histogram Algorithm
  - Histogram with atomic
  - Histogram with atomic and reduce

Reduce Pattern

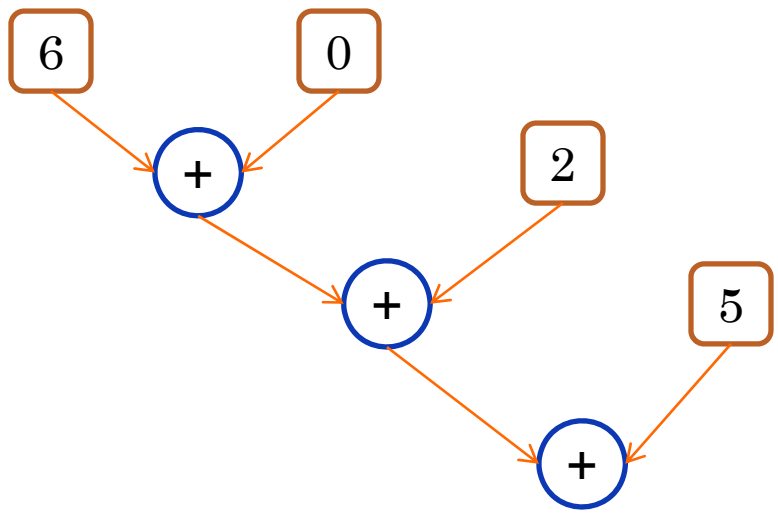
Reduce



Reduce Definition

- Set of elements
- Reduction operator
  - Binary
  - Associative operation

$$\boxed{6} + \boxed{0} + \boxed{2} + \boxed{5} + \cdots\cdots$$

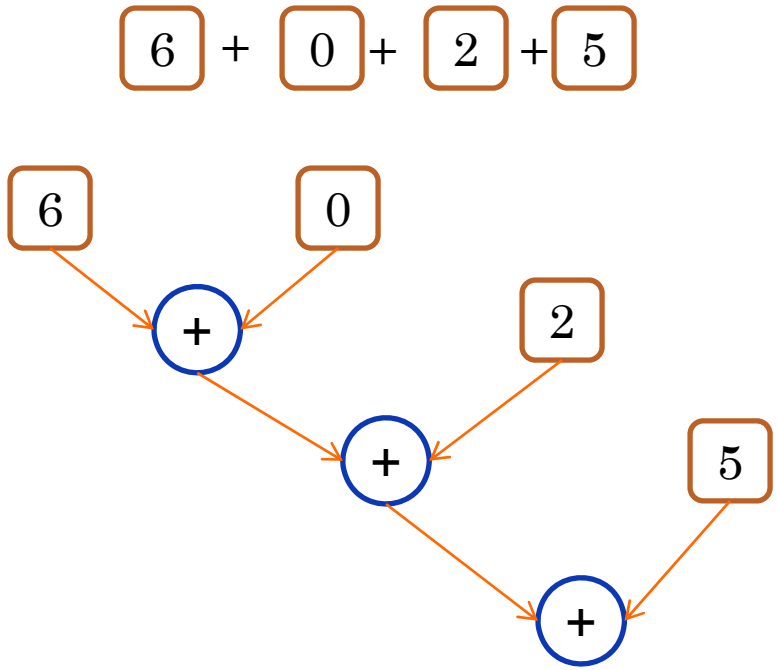


Quiz

- ✓ Multiply (a*b)
- ✓ Minimum
- ❑ Factorial (a!)
- ✓ Logical Or (a||b)
- ✓ Logical And (a&&b)
- ❑ Division (a/b)

Reduce Serial (sequential) implementation

```
sum=0
For (i=1;i<n;i++){
        sum=sum+array[i];
}
return sum;
```



- Steps = 3
- Total work = 3

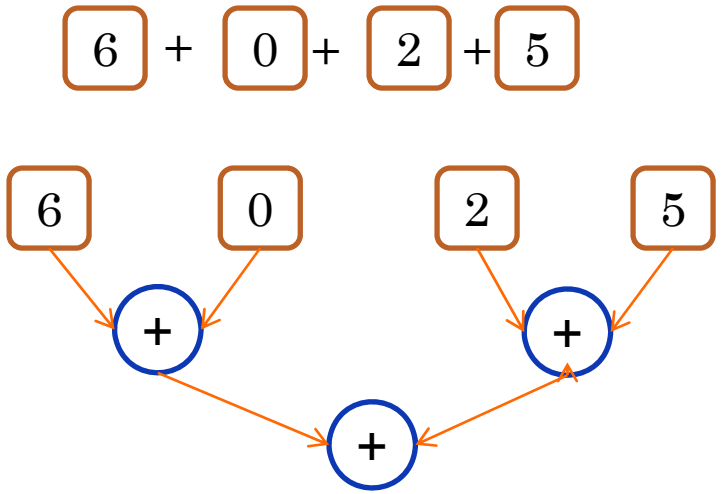
Reduce Serial Complexity

Which is true to reduce n elements?

- ☐ It takes n operation
- ☑ It takes n-1 operation
- ☑ It's work complexity O(n)
- ☑ It's step complexity O(n)

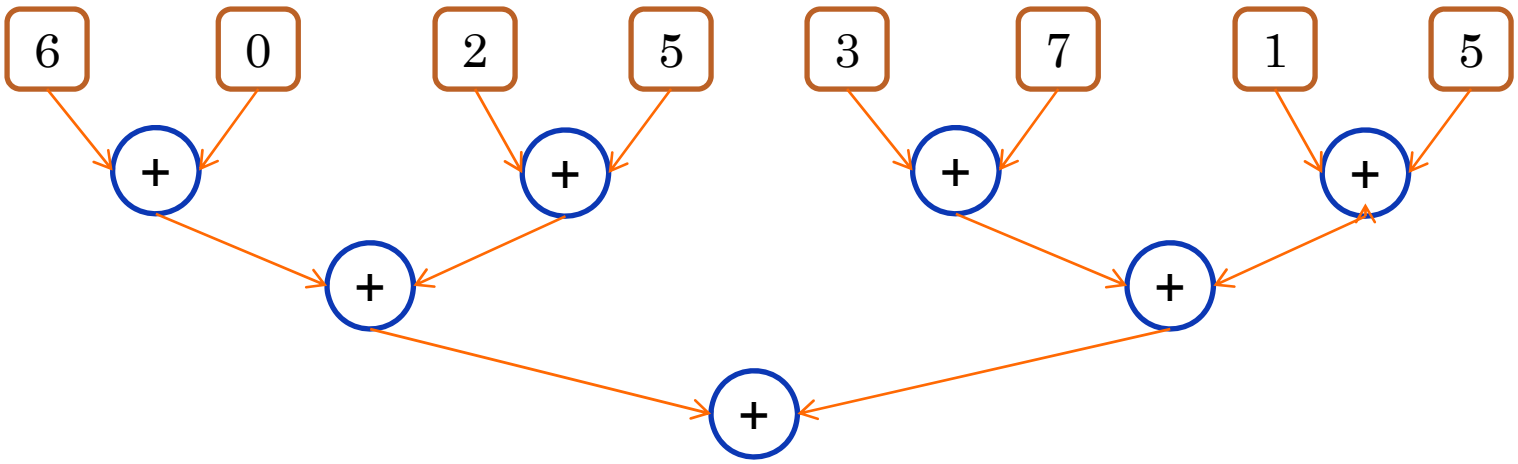
Reduce Parallel implementation

- (a+(b+c))+d) = (a+b)+(c+d)



- Steps = 2
- Total work = 3

Reduce Parallel complexity



N	Steps	Total work
2	1	1
4	2	3
8	3	7
	= lg n	= n-1
	O(log n)	O(n)

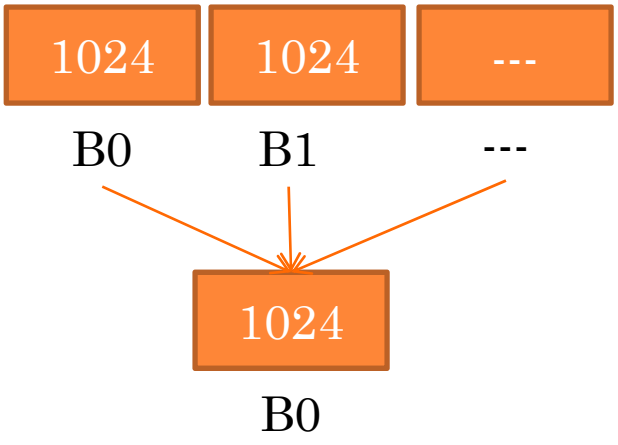
Actually

If we have n elements we need n/2 threads at first step. But this is not possible because we have only p processors

Thus O(log n) is not accurate and we need another calculation this called Brent's theorm

Reduce in action

- Suppose we have 2^20 (~1m) elements
- Stage 1: 1024 block * 1024 thread
- Stage 2: 1 block
- PS: increase performance 3 times by using shared memory



Start

OUTLINES

- Efficiency Measure
- Reduce Algorithm
  - Reduce model
  - Reduce Implementation and complexity analysis
- Scan Algorithm
  - Scan model
  - Scan Implementation and complexity analysis
- Histogram Algorithm
  - Histogram with atomic
  - Histogram with atomic and reduce

Scan Pattern

Scan

- Input: 1 2 3 4
- Op: add
- Output: 1 3 6 10

Transaction	Balance
+10	10
-5	5
+4	9
+3	12

Scan Definition

- Set of elements
- Reduction operator (op)
  - Binary
  - Associative operation (We assume here it's also commutative e.g. x+y=y+x)
- Identity element [I op a= a]

op	I	Because
+	0	a+0=a
*	1	a*1=a
min (unsigned char)	0xFF	min(0xFF,a)=a

Scan Definition cont.

- Exclusive
  - in : 1 0 4 2 3
  - Op= + I= 0
  - Out: 0 1 1 5 7
- Inclusive:
  - in : 1 0 4 2 3
  - Op= + I= 0
  - Out: 1 1 5 7 11

Scan Serial implementation and complexity

```
acc=identity
For (i=1;i<n;i++){
        acc=acc+array[i];
        out[i]=acc;
}
return out;
```

Inclusive

```
acc=identity
For (i=1;i<n;i++){
        out[i]=acc;
        acc=acc+array[i];
}
return out;
```

Exclusive

- Steps = n
- Total work = n

Scan Parallel implementation and complexity

- Inclusive (+ Scan):
  - in : 1 0 4 2 3
  - Out: 1 1 5 7 10

- So if we consider the problem a set of reduce problems with different n then:

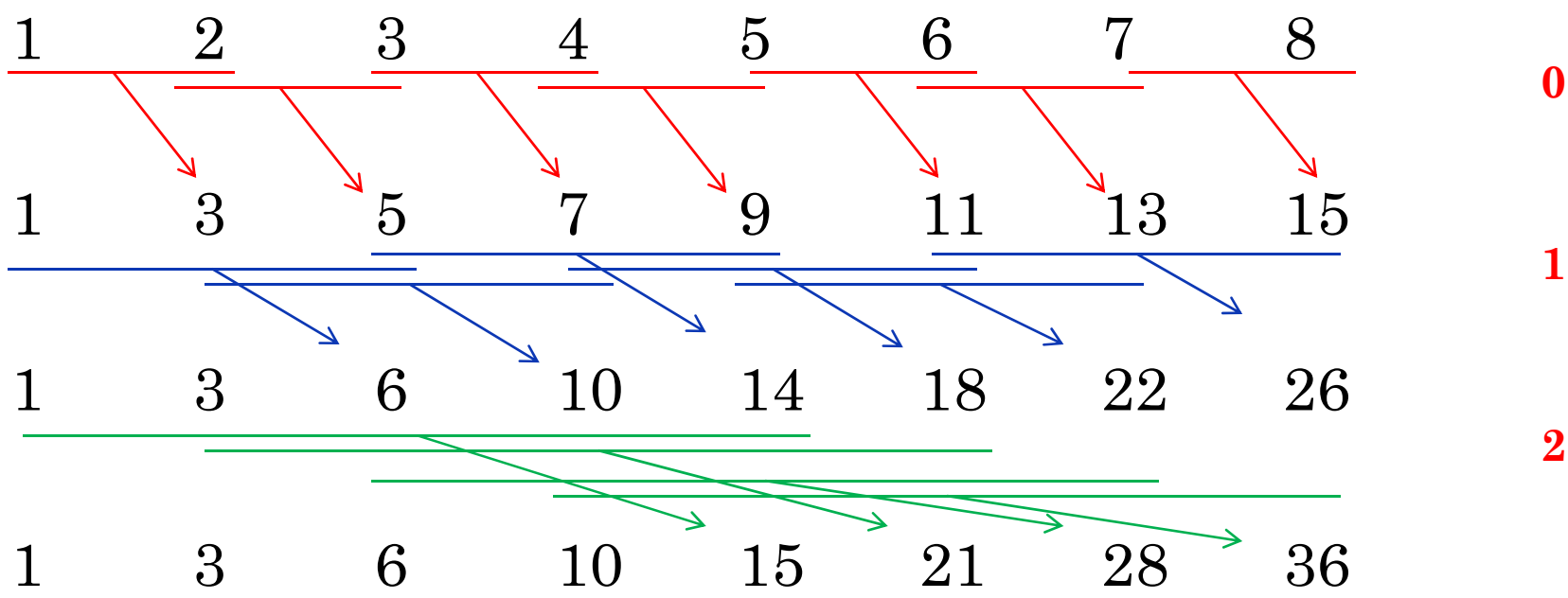
n	Step	Work
1	lg 1	0
2	lg 2	1
…	…	…
n	lg n	n-1
	= O (log n)	= O (n^2)

Scan Parallel implementation and complexity (cont.1)

Method	Step	Work
Hillis & Steele	✓	
Blelloch		✓

Scan Parallel implementation and complexity (cont.2)

- Hillis & Steele (Inclusive sum scan):

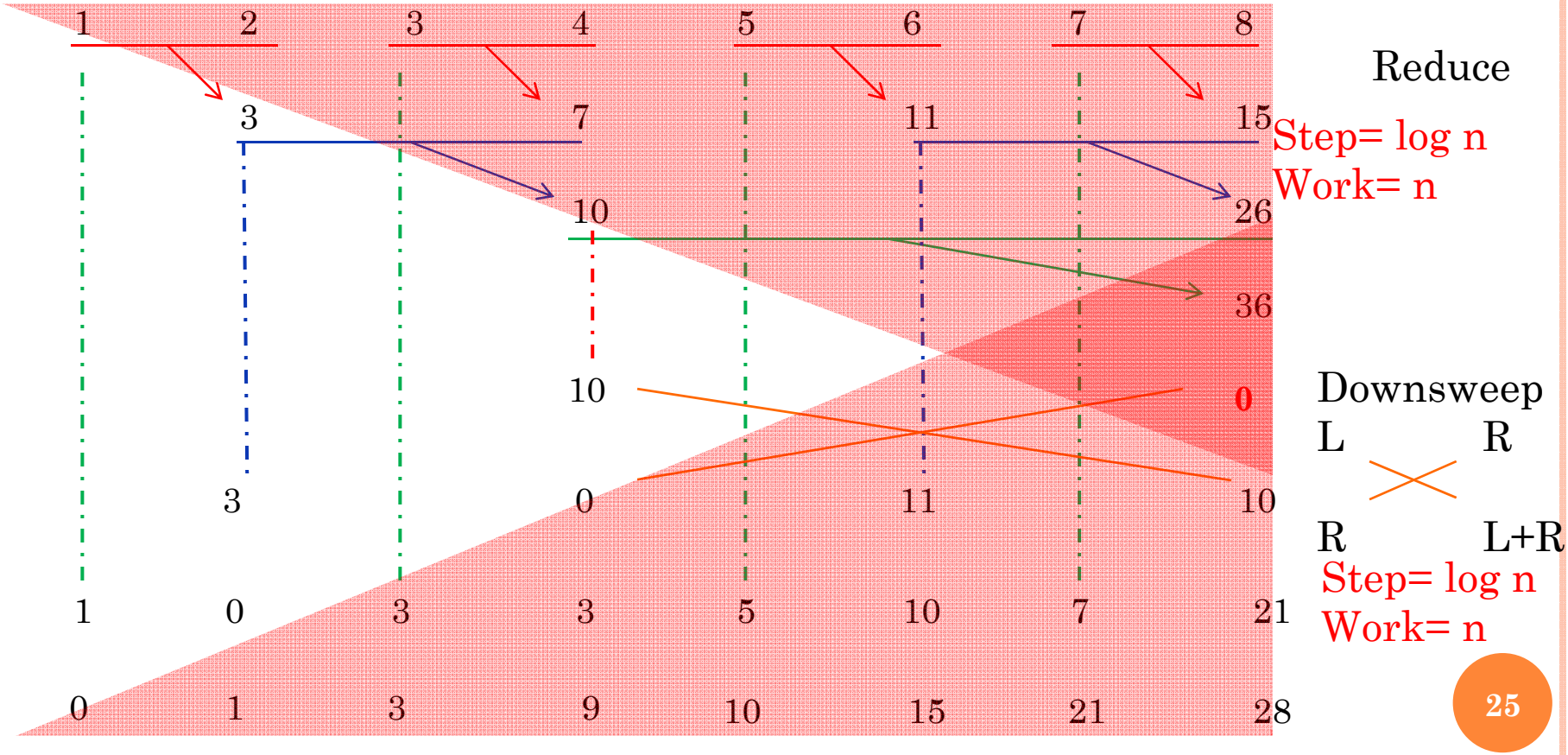


Step= O(log n)

work= matrix = O(n log n)

Scan Parallel implementation and complexity (cont.3)

- Blelloch(Exclusive sum scan):



Quiz

- Which Scan algorithm to use?

	Serial	Hillis & Steele	Blelloch
512 elements 512 processor		✓	
1m elements 512 processor			✓
128k elements 1 processor	✓		

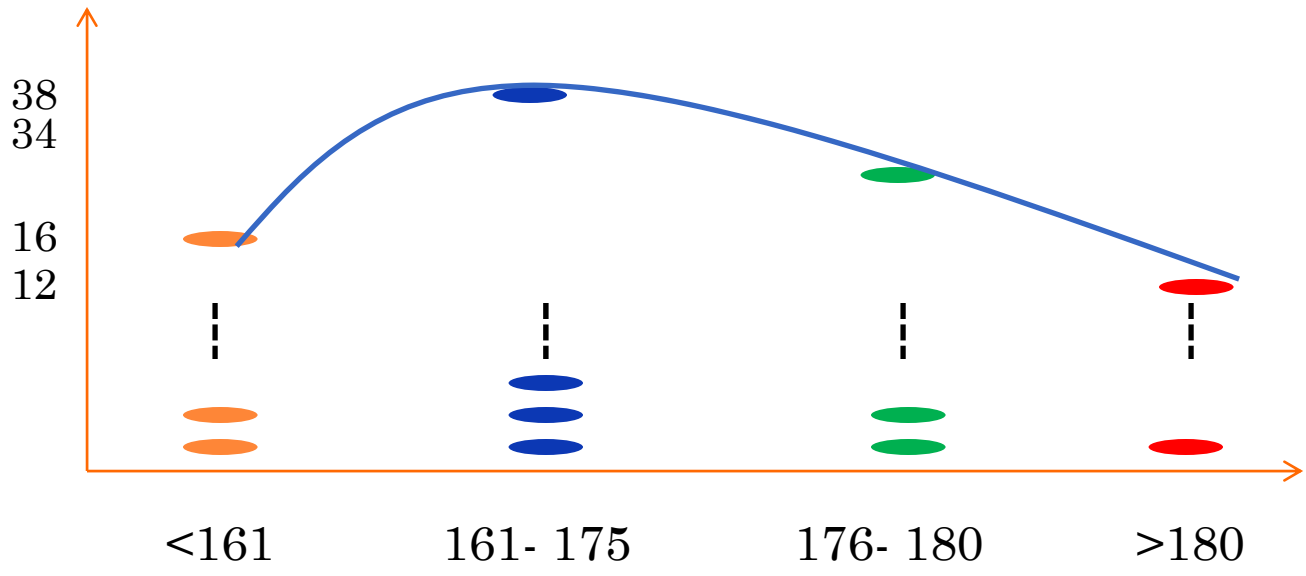
OUTLINES

- Efficiency Measure
- Reduce Algorithm
  - Reduce model
  - Reduce Implementation and complexity analysis
- Scan Algorithm
  - Scan model
  - Scan Implementation and complexity analysis
- Histogram Algorithm
  - Histogram with atomic
  - Histogram with atomic and reduce

HISTOGRAM

HISTOGRAM

- Measure the students height in your class:



- How is shorter than 175?
  - Cumulative distribution (Scan)

HISTOGRAM SERIAL IMPLEMENTATION

```
In: measurements[], n-elements
Out: result[]

For (i=0; i<bin-count; i++)
        result[i]=0;

For (i=0; i< n-elements ; i++)
        result[computeBin(measurements[i])]++
```

Histogram parallel Naïve

```
In: measurements[], n-elements
Out: result[]

For (i=0; i<bin-count; i++)
        result[i]=0;

For (i=0; i< n-elements ; i++)
        result[computeBin(measurements[i])]++
```

- We have synchronization problem

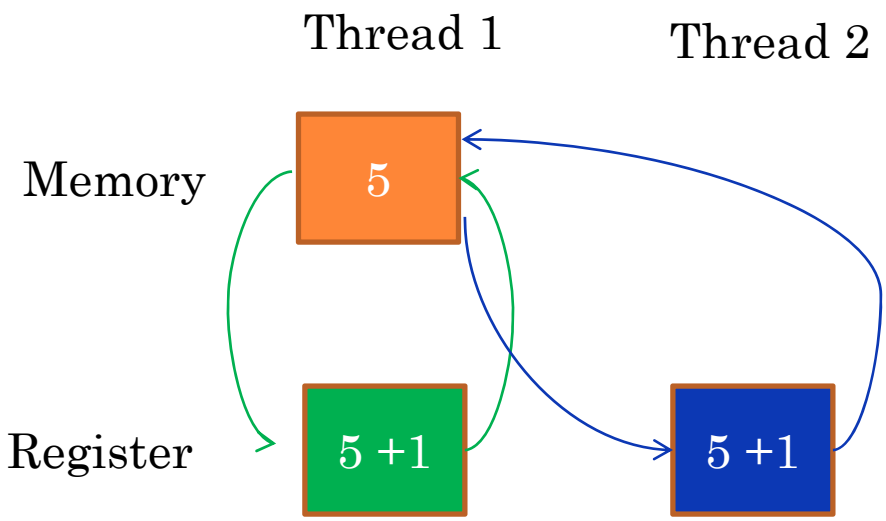
Start

HISTOGRAM PARALLEL NAÏVE (CONT.)

- Example
  - 128 element 8 threads 3 bin

Memory								
	15	15	16	17	16	6	7	8

- Read
- Increment
- Write



Race condition

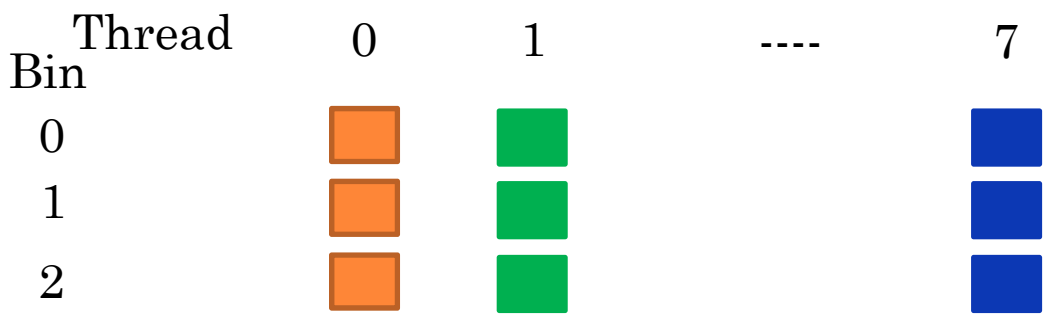
HISTOGRAM PARALLEL SIMPLE

- Use atomic operation
- However this serialize the problem.

Histogram parallel Reduce base

- Example
  - 128 element 8 threads 3 bin

- Use local bins, which means every thread had 3 local bin.

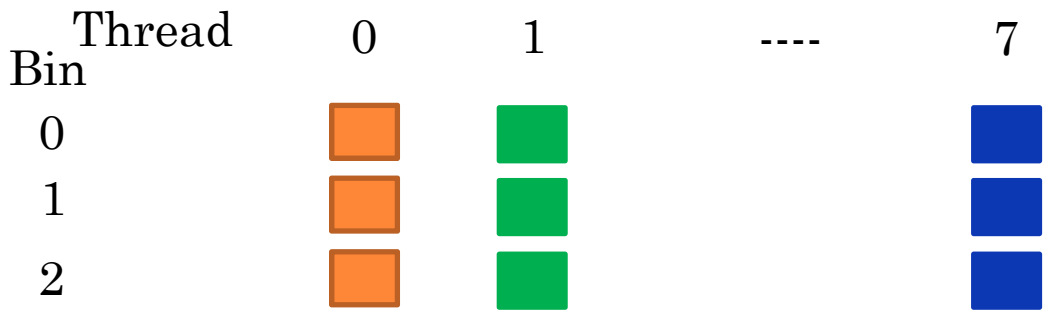


- Each thread accumulate 16 item
- Then apply a reduce back in global memory

Histogram parallel Reduce base

- Example
  - 128 element 8 threads 3 bin

- Use local bins, which means every thread had 3 local bin.



- Each thread accumulate 16 item
- Then apply a reduce back in global memory 3 times for each bin (3 times is bad)

Histogram parallel Sort & Reduce

- Example
  - 128 element 8 threads 3 bin

Memory	1	0	0	2	1	2	1	0			....

- First we sort

Memory	0	0	0	1	1	1	2	2			....

- Then we reduce

OUTLINES

- Efficiency Measure
- Reduce Algorithm
  - Reduce model
  - Reduce Implementation and complexity analysis
- Scan Algorithm
  - Scan model
  - Scan Implementation and complexity analysis
- Histogram Algorithm
  - Histogram with atomic
  - Histogram with atomic and reduce

TONE MAPPING

TONE MAPPING

- Using reduce, scan and histogram