# Exploring Irregular Memory Access Applications on the GPU

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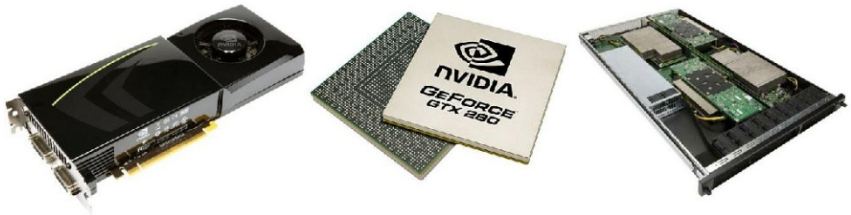
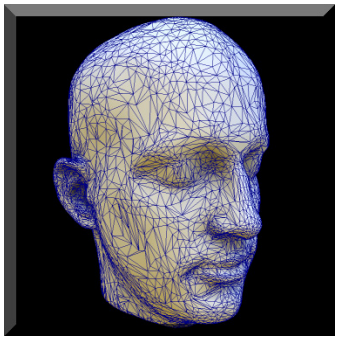
# Graphics Processing Units (GPUs)

- Dedicated co-processors that handle display output.
- Increasingly programmable and powerful
- Latest GPUs have over 1 TFLOP of peak performance
- CUDA
  - Hardware Architecture
  - Programming Model
  - API to Program the GPU in a C-like environment







# Irregular Algorithms

- Algorithms which have irregular memory access patterns
- Difficult to implement  and parallelize with high performance on current generation architectures
  - Does not "play nice" with the memory hierarchy
    - Cache/Virtual Memory Issues
  - Eg: List Ranking, Tree Computations etc.

# The List Ranking Problem

- Classic Irregular Algorithm
- Find the position of every element in a linked list
- Becomes Irregular when list elements are scattered in memory
  - Difficult to parallelize
- Many applications in Graph Problems
  - Tree Computations, Biconnected Components etc.

# Solving the Problem

- Many Algorithms for Parallelization
  - Pointer Jumping Technique
  - Randomized Approaches
  - Sparse Ruling Set Approaches

# Contributions of this Thesis

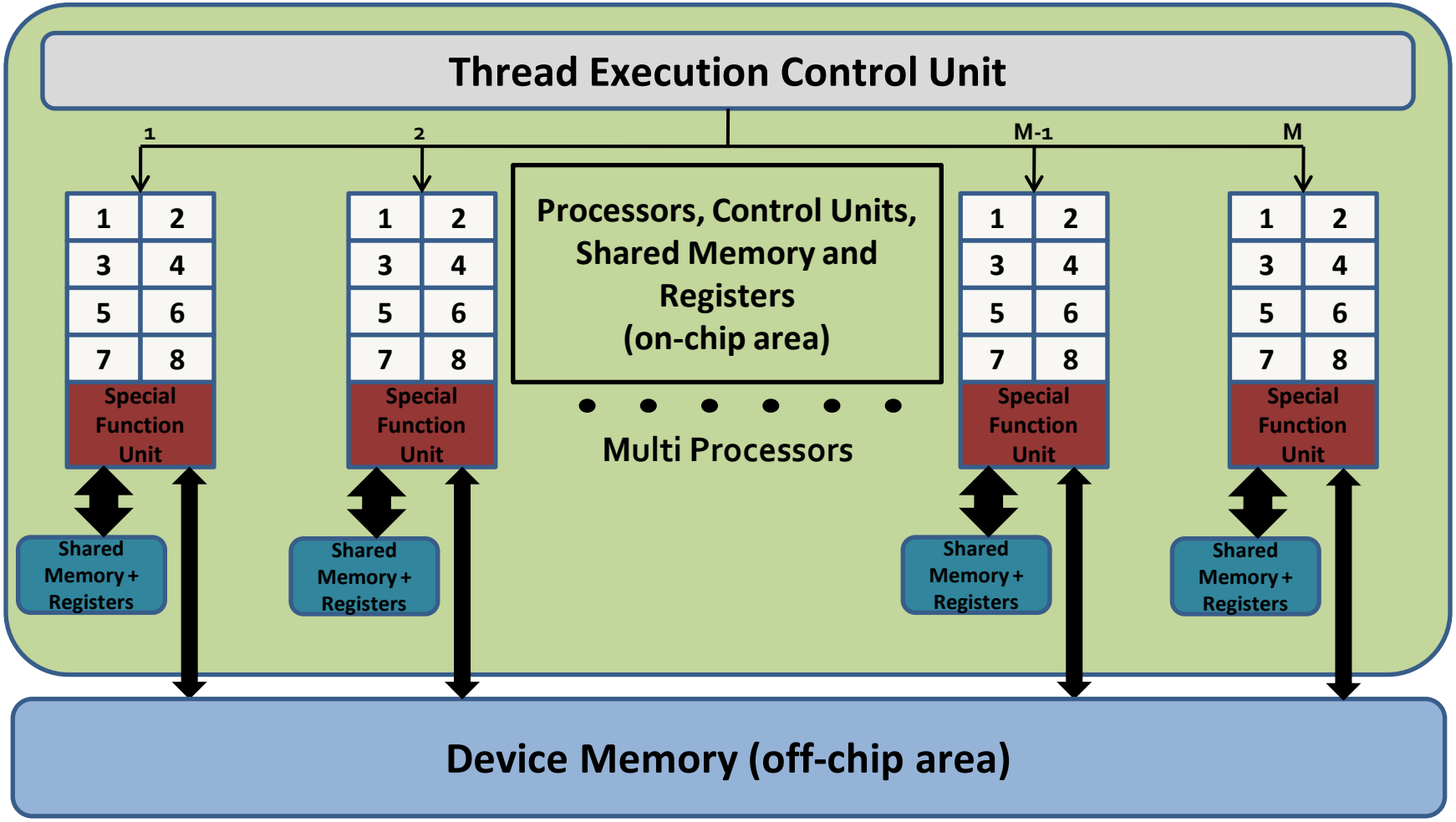
- Pointer Jumping Technique for the GPU
- Wyllie's Algorithm and variants for the GPU
- A work-optimal, recursive algorithm for the GPU
- Applications of List Ranking
  - Euler Tour Construction and Tree Computations on the GPU
- Performance Analysis and Behavior of such Irregular Algorithms on the GPU

# Introduction and Background

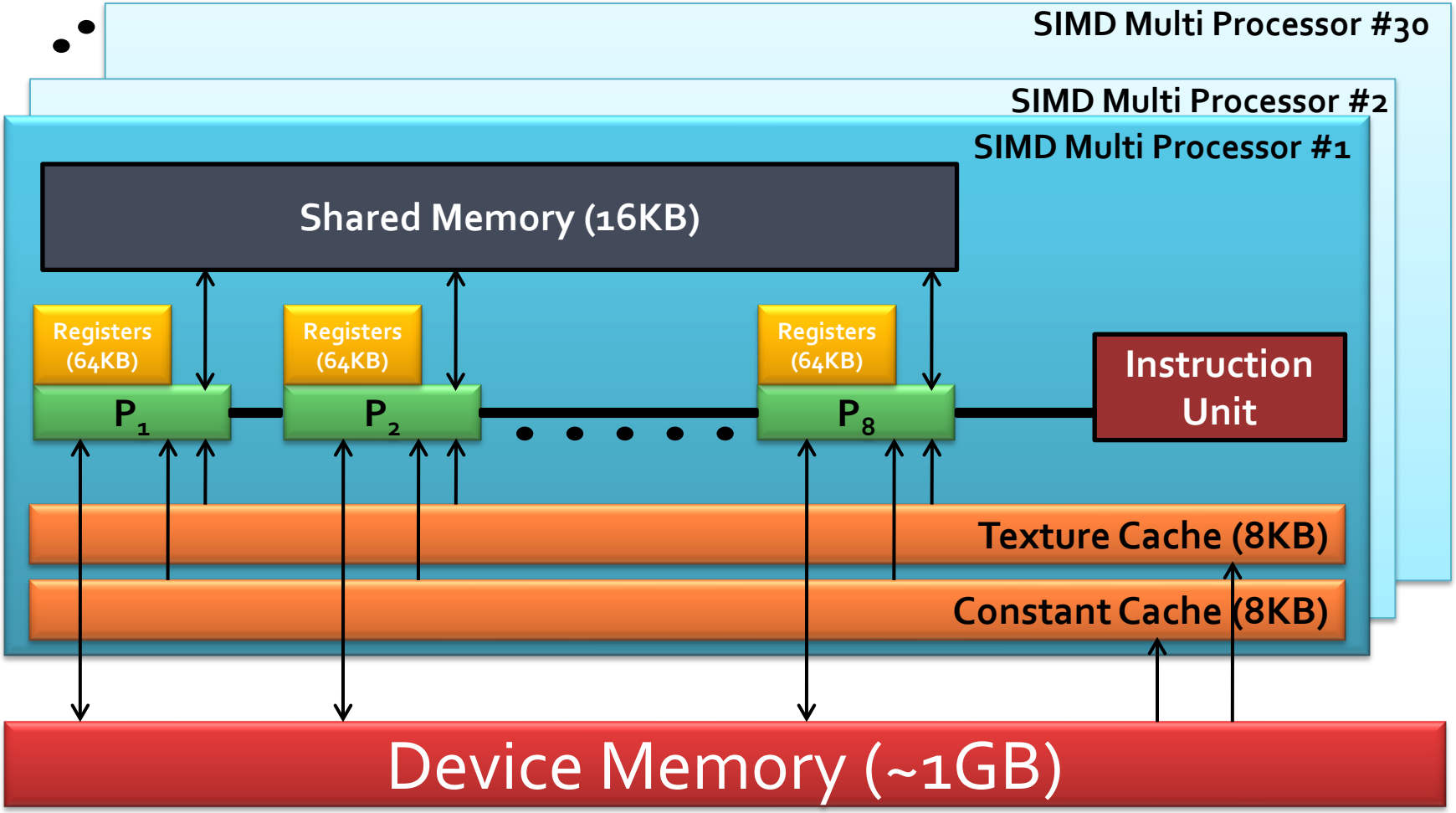
# GPU by the Numbers (GTX280)

- 240 cores
- 4-stage pipeline on each core
- 960 threads in flight at any given time.
- Memory allocated for a set of 8 Cores (SM)
  - 64K Registers
  - 16 KB Shared Memory
  - 8K Constant Cache
  - 8K Texture Cache

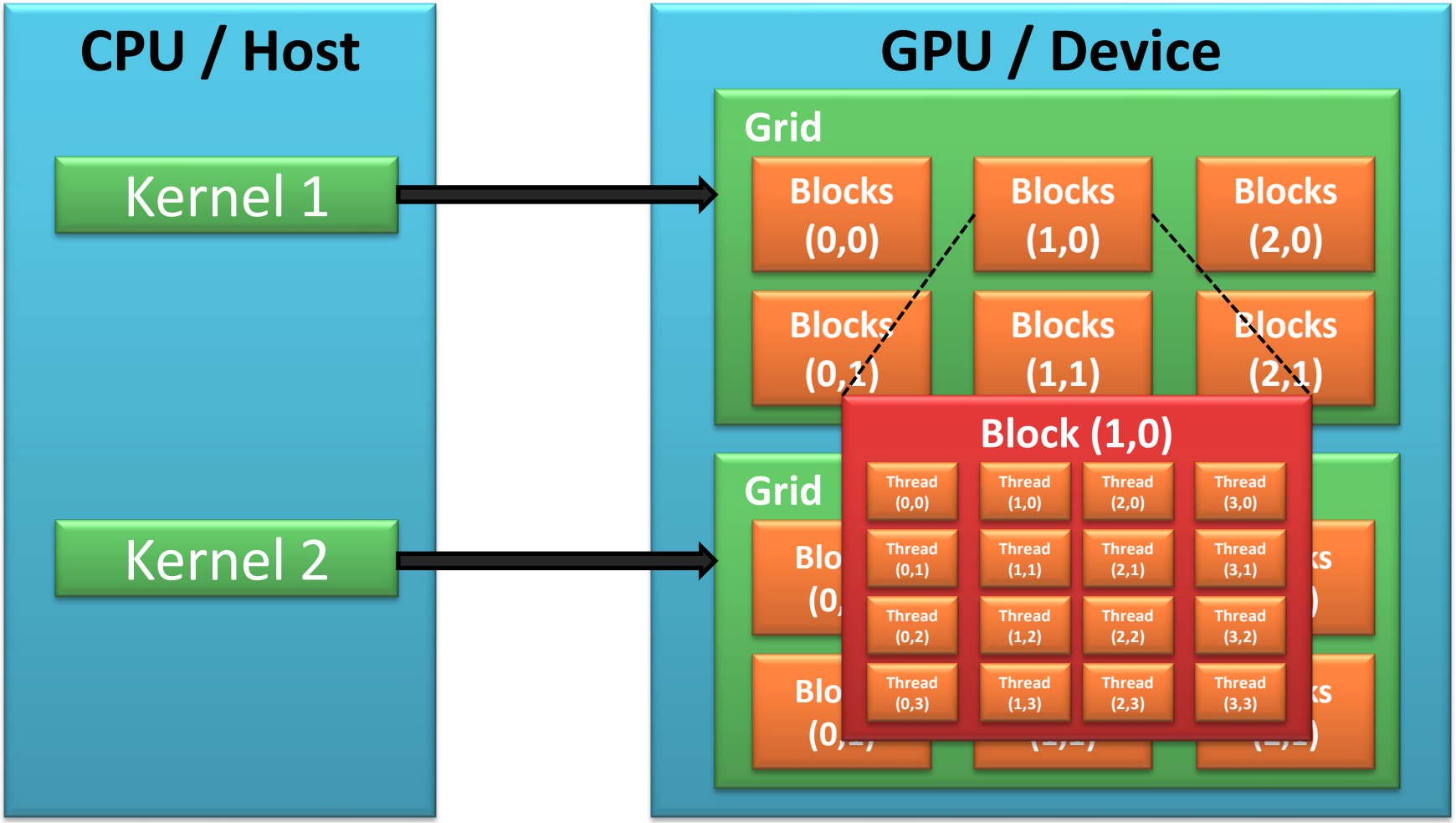
# GPU Architecture



# CUDA Hardware Architecture



# CUDA Software Architecture



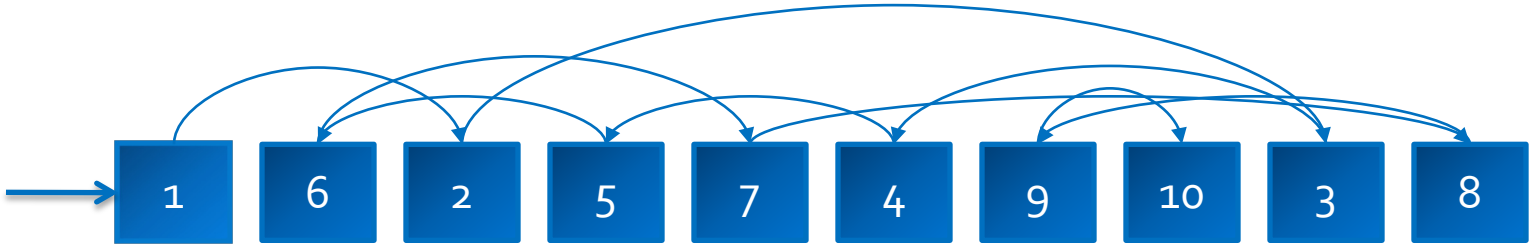
# Data-Parallel Primitives on the GPU

- Primitives on GPU to use for larger problems
  - Scan by Mark Harris et. al
  - Reduce Operations by NVIDIA
  - Efficient Sorting on GPU
- List Ranking is a primitive for lots of graph problems!

# List Ranking

- Simple Problem (Sequentially Speaking)
  - Difficult to Parallelize
- Can be done on ordered or random lists:


Ordered List




Unordered List

# List Ranking Algorithms

| Algorithm | Time | Work | Constants | Space |
|---|---|---|---|---|
| Serial | $O(n)$ | $O(n)$ | small | $c$ |
| Wyllie[16] | $O(\frac{n \log n}{p} + \log n)$ | $O(n \log n)$ | small | $n + c$ |
| Randomized[36, 37] | $O(\frac{n}{p} + \log n)$ | $O(n)$ | medium | $> 2n$ |
| PRAM Optimal [32, 33] | $O(\frac{n}{p} + \log n)$ | $O(n)$ | large | $> n$ |
| Miller-Reid[34] | $O(\frac{n}{p} + \log^2 n)$ | $O(n)$ | small | $5p + c$ |
| Helman-JáJá [17] | $O(\frac{n}{p} + \log n)$ | $O(n)$ | small | $n + \log n + c$ |

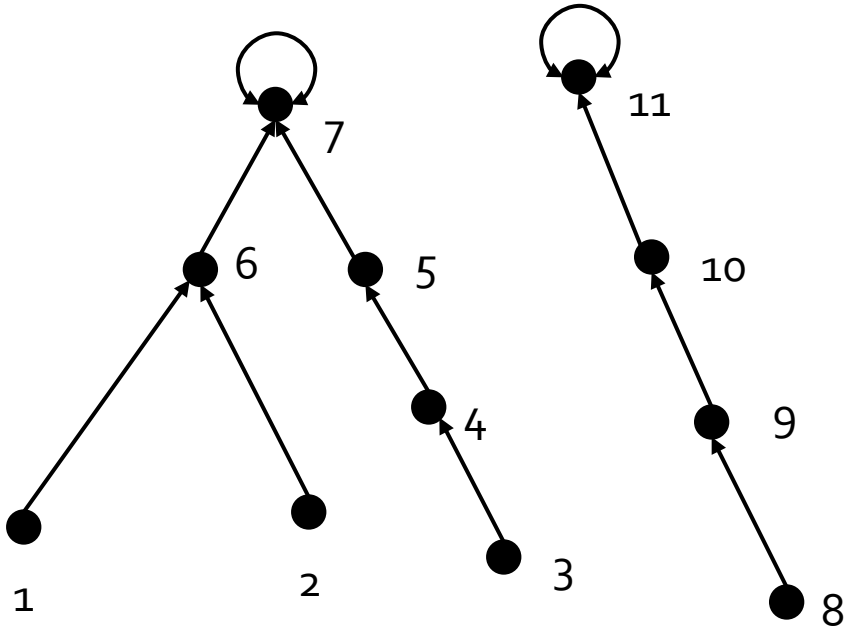
# Applications of List Ranking

- Euler Tour Technique
- Load Balancing
- Tree Contraction
- Expression Evaluation
- Planar Graph Embedding
- Etc..

# Pointer Jumping and Wyllie's Algorithm on the GPU

# Pointer Jumping

- A basic technique in parallel computing.
  - Processing Data in Rooted Directed Trees



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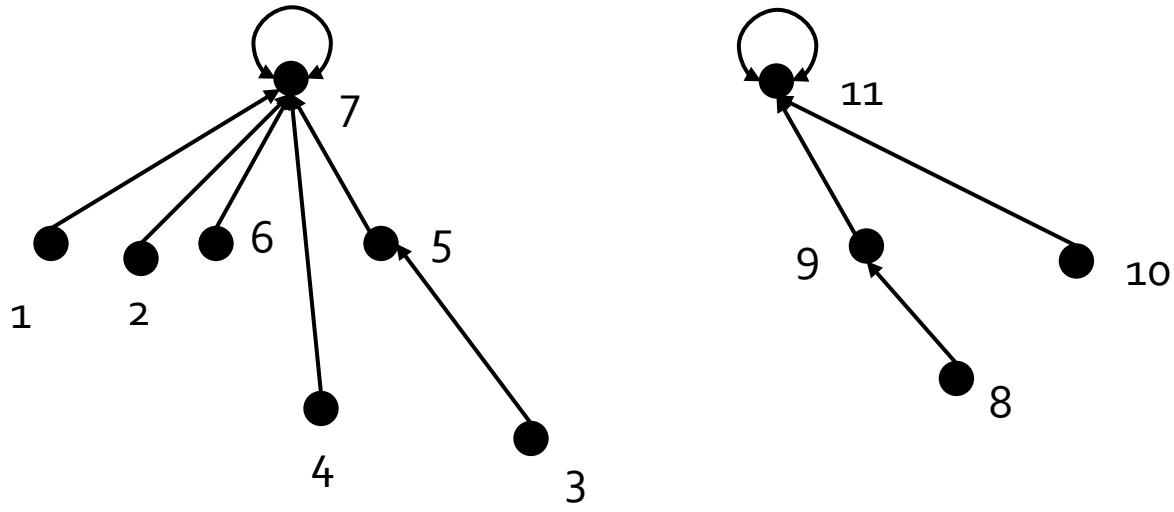

# Pointer Jumping

- A basic technique in parallel computing.
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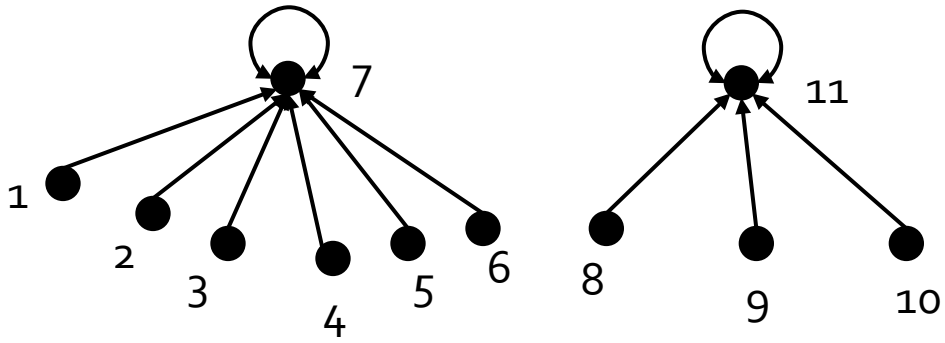


# The Algorithm

**Algorithm 2** Pointer Jumping

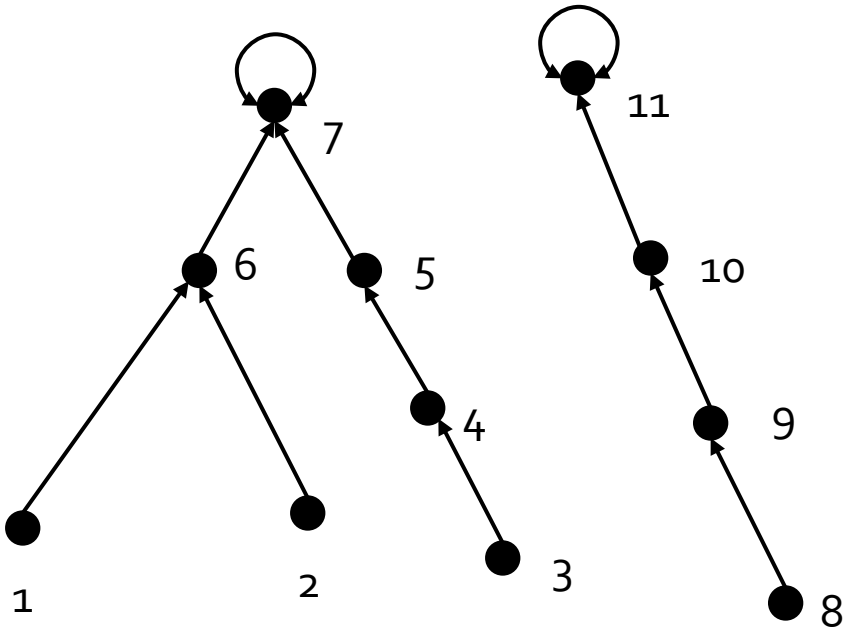
**Input:** A forest of rooted directed trees.

**Output:** For each vertex $i$, the root $S(i)$ of the tree containing $i$

```
1: for 1 ≤ i ≤ n do in parallel
2:     while S(i) is not end of list do
3:         Set S(i) = S(S(i))
4:     end while
5: end for
```

# Pointer Jumping on the GPU

- From PRAM to the GPU
  - One thread per element
  - Successor Array Implementation




| 6 | 6 | 4 | 5 | 7 | 7 | 7 | 9 | 10 | 11 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |

# Wyllie's Algorithm

- Use pointer jumping repeatedly for each element of a linked list in Parallel
  - Update Rank and Successor simultaneously

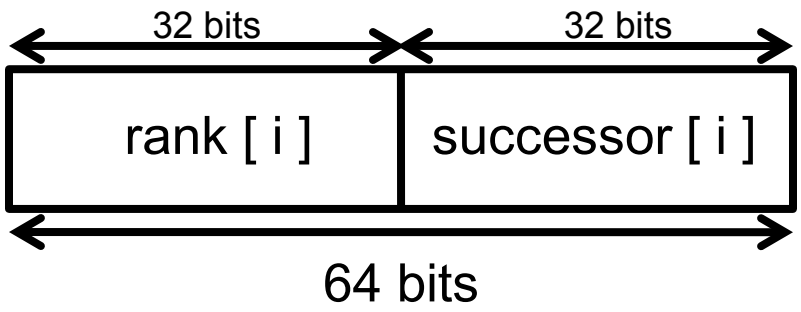
**Algorithm 3** Wyllie's Algorithm

**Input:** An array $S$, containing successors of $n$ nodes and array $R$ with ranks initialized to 1
**Output:** Array $R$ with ranks of each element of the list with respect to the head of the list

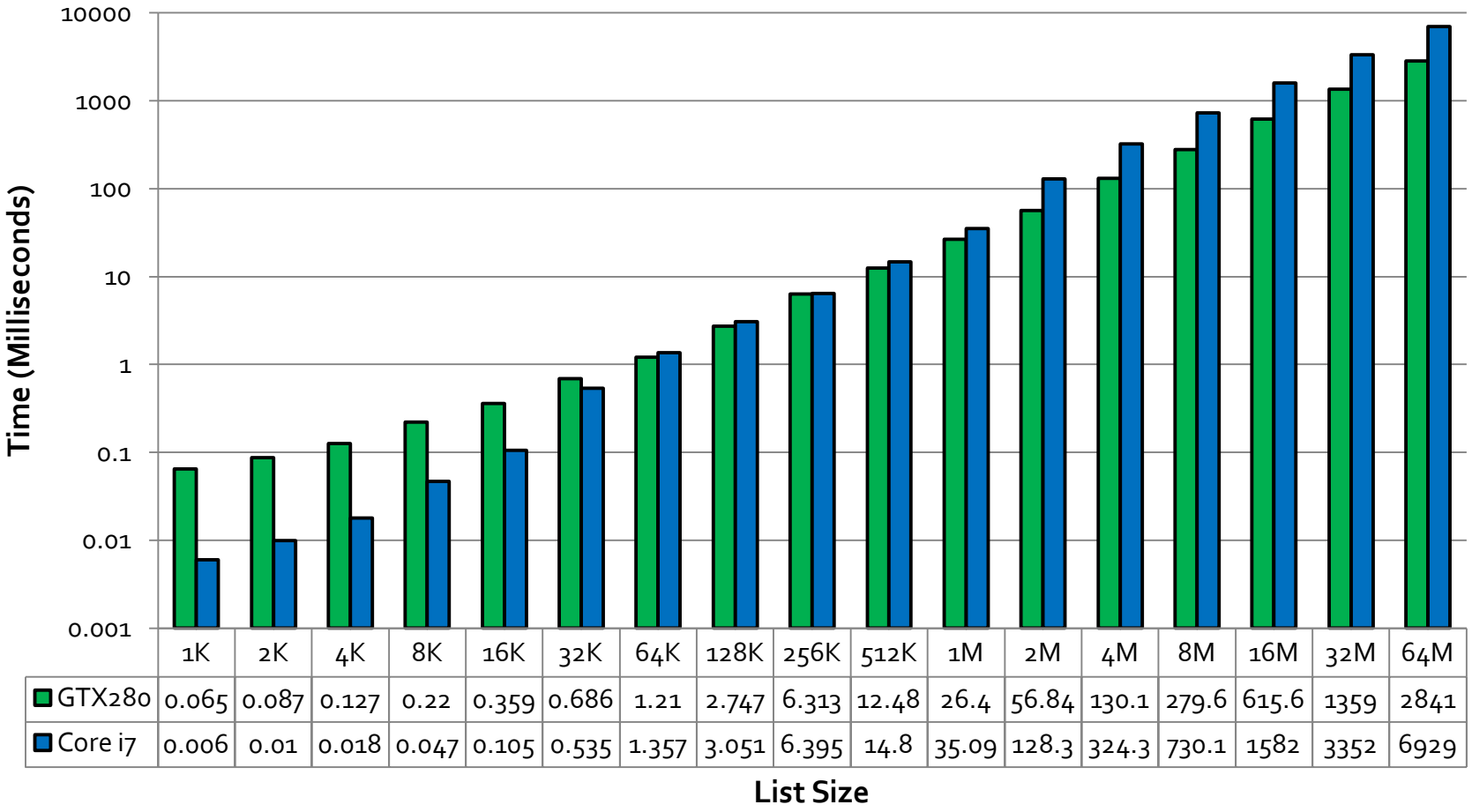
```
1: for each element in S do in parallel
2:     while S[i] and S[S[i]] are not the end of list do
3:         R[i] = R[i] + R[S[i]]
4:         S[i] = S[S[i]]
5:     end while
6: end for
```

# Wyllie's Algorithm on the GPU

- Implemented in CUDA
  - One Thread per list element
  - Synchronize the write operation (rank and successor fields of an element should be written to simultaneously)
  - Pack the two numbers into a 64-bit long integer



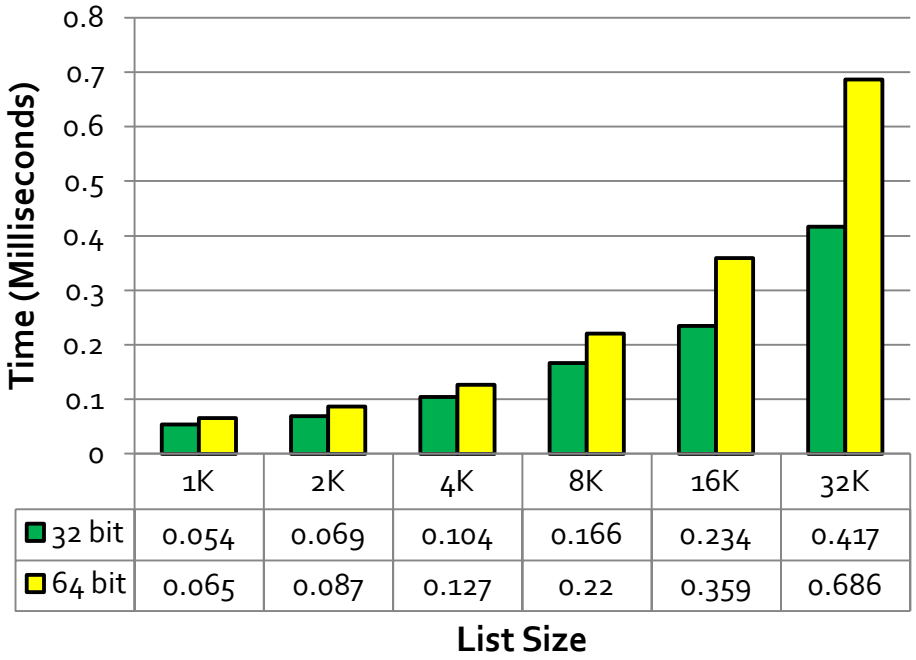
# Results of Wyllie's Algorithm




| | 1K | 2K | 4K | 8K | 16K | 32K | 64K | 128K | 256K | 512K | 1M | 2M | 4M | 8M | 16M | 32M | 64M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GTX280 | 0.065 | 0.087 | 0.127 | 0.22 | 0.359 | 0.686 | 1.21 | 2.747 | 6.313 | 12.48 | 26.4 | 56.84 | 130.1 | 279.6 | 615.6 | 1359 | 2841 |
| Core i7 | 0.006 | 0.01 | 0.018 | 0.047 | 0.105 | 0.535 | 1.357 | 3.051 | 6.395 | 14.8 | 35.09 | 128.3 | 324.3 | 730.1 | 1582 | 3352 | 6929 |

# Optimization I – 32-bit Packing

- For lists of size $< 2^{16}$
  - Pack rank and successor in a 32-bit integer
  - Potential applications in Sparse Forests




| | 1K | 2K | 4K | 8K | 16K | 32K |
|---|---|---|---|---|---|---|
| 32 bit | 0.054 | 0.069 | 0.104 | 0.166 | 0.234 | 0.417 |
| 64 bit | 0.065 | 0.087 | 0.127 | 0.22 | 0.359 | 0.686 |

# Optimization II – Lock-Step

- The original algorithm has n threads working on n elements, each thread doing O(log n) work in the PRAM model
  - GPU is not fully PRAM-compliant -thread execution is asynchronous
- Force synchronous behavior by jumping once in the kernel and forcing a global synchronization.

# Optimization II – Lock-Step

**Algorithm 4** CPU-Orchestrated Wyllie's Algorithm

**Input:** An array of nodes $N$, each with fields $rank$ $next$ and $finished$.

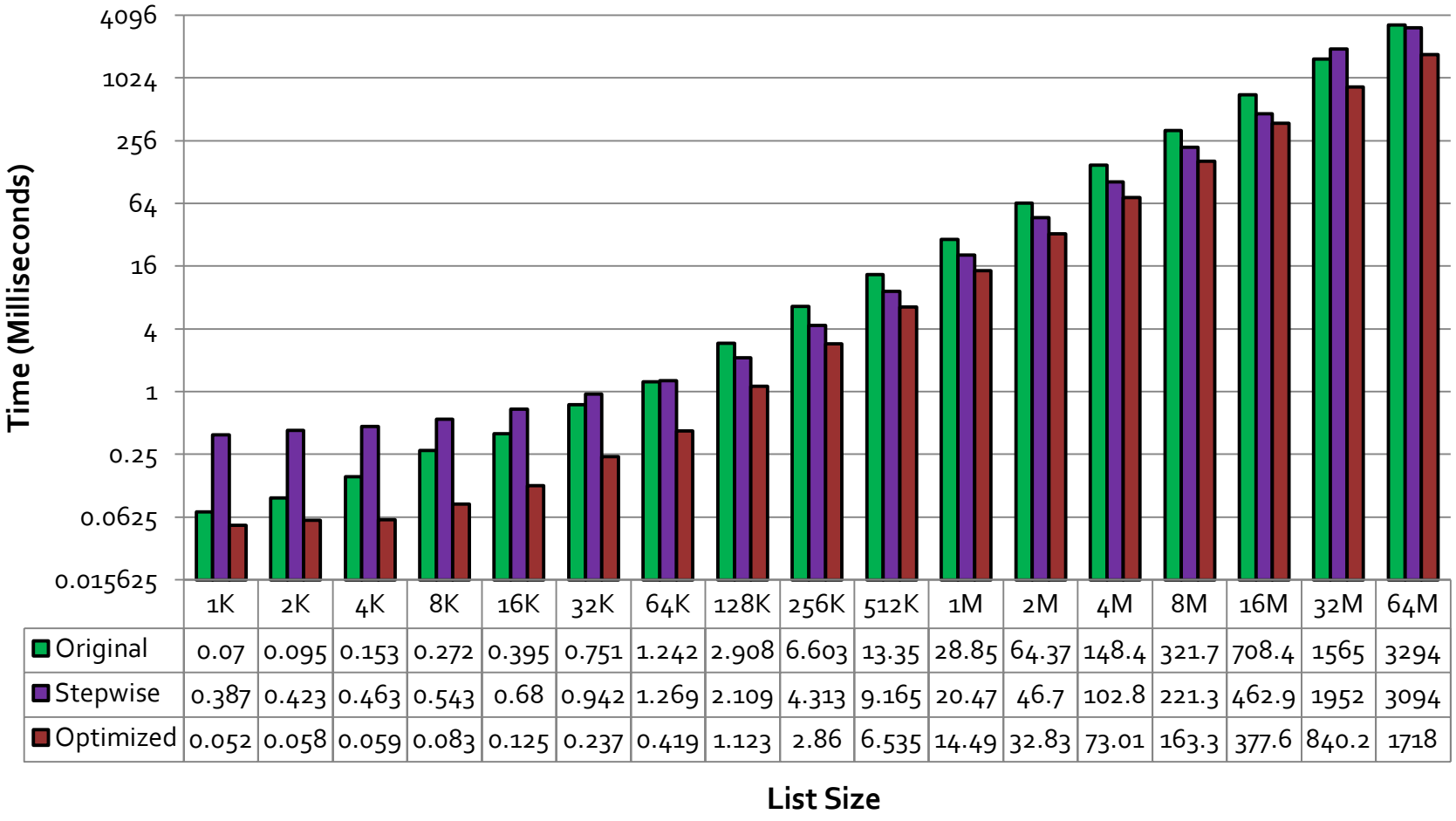
**Output:** $N$ with all the node ranks updated

```
1: Set done = 0 in global memory
2: while some thread has set done = 0 do in parallel
3:     Set done = 1
4:     Load the node in N designated to this thread in local register r1
5:     if r1.finished = 0 then
6:         Load the successor node in local register r2
7:         if r2.finished = 0 then
8:             Set r1.next = r2.next
9:             done = 0
10:        end if
11:        Set r1.rank = r1.rank + r2.rank
12:        Synchronize and store the node in N designated to this thread with r1
13:    end if
14: end while
```

# Optimization III – Reduced Memory Operations

- Threads would load an element and it's successor even if it's pointing to end of list
  - Modify Kernel to load elements as needed.
  - Block-Synchronize to force eligible threads to access memory more efficiently

# Comparison of the Methods



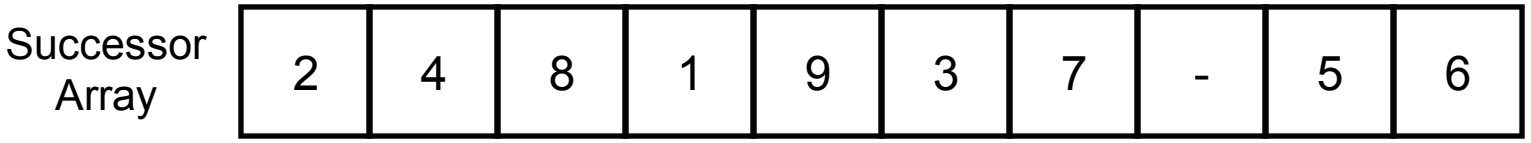

| | 1K | 2K | 4K | 8K | 16K | 32K | 64K | 128K | 256K | 512K | 1M | 2M | 4M | 8M | 16M | 32M | 64M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Original | 0.07 | 0.095 | 0.153 | 0.272 | 0.395 | 0.751 | 1.242 | 2.908 | 6.603 | 13.35 | 28.85 | 64.37 | 148.4 | 321.7 | 708.4 | 1565 | 3294 |
| Stepwise | 0.387 | 0.423 | 0.463 | 0.543 | 0.68 | 0.942 | 1.269 | 2.109 | 4.313 | 9.165 | 20.47 | 46.7 | 102.8 | 221.3 | 462.9 | 1952 | 3094 |
| Optimized | 0.052 | 0.058 | 0.059 | 0.083 | 0.125 | 0.237 | 0.419 | 1.123 | 2.86 | 6.535 | 14.49 | 32.83 | 73.01 | 163.3 | 377.6 | 840.2 | 1718 |

# Where is the performance bottleneck?

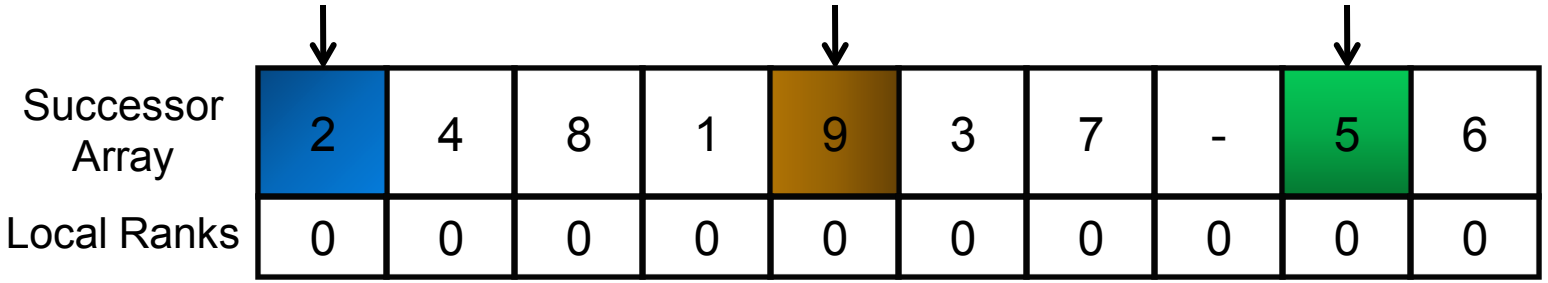
- Wyllie's Algorithm is not optimal in PRAM model
  - $O(n \log n)$ work for something that can be done in $O(n)$
- Expensive synchronization on GPU (64 bit packing and write operations)
- Random Reads from Global Memory
  - ~400-600 GPU cycles of read latency for each element
- There has to be a better way!
  - Is there a better algorithm?

# Helman-JaJa algorithm

- Designed for SMPs – Sparse Ruling Set approach
  - Mark a number of elements as 'splitters'
  - Traverse the list from multiple points by each thread using the splitters as a starting point
  - Store ranks w.r.t splitter position for each element
  - Stop when you hit another splitter (as marked in first step)
  - Construct new, smaller list for global ranks
  - Rank the new list and add the list prefixes to each element of the list




Step 1. Select **Splitters** at equal intervals




Step 2. **Traverse** the List until the next splitter is met and **increment** local ranks as we progress

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Successor Array | 2 | 4 | 8 | 1 | 9 | 3 | 7 | - | 5 | 6 |
| Local Ranks | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 |

Step 2. **Traverse** the List until the next splitter is met and **increment** local ranks as we progress

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Successor Array | 2 | 4 | 8 | 1 | 9 | 3 | 7 | - | 5 | 6 |
| Local Ranks | 0 | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 0 | 1 |

Step 2. **Traverse** the List until the next splitter is met and **increment** local ranks as we progress

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Successor Array | 2 | 4 | 8 | 1 | 9 | 3 | 7 | - | 5 | 6 |
| Local Ranks | 0 | 3 | 1 | 2 | 0 | 1 | 2 | 3 | 0 | 1 |

Step 3. **Stop** When all elements have been assigned a local rank

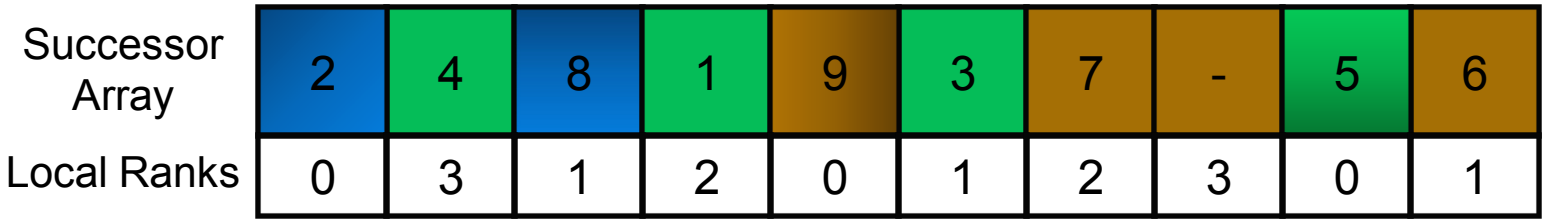
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Successor Array | 2 | 4 | 8 | 1 | 9 | 3 | 7 | - | 5 | 6 |
| Local Ranks | 0 | 3 | 1 | 2 | 0 | 1 | 2 | 3 | 0 | 1 |

Step 4. **Create** a new list of splitters which contains a **prefix value** that is equal to the local rank of it's predecessor

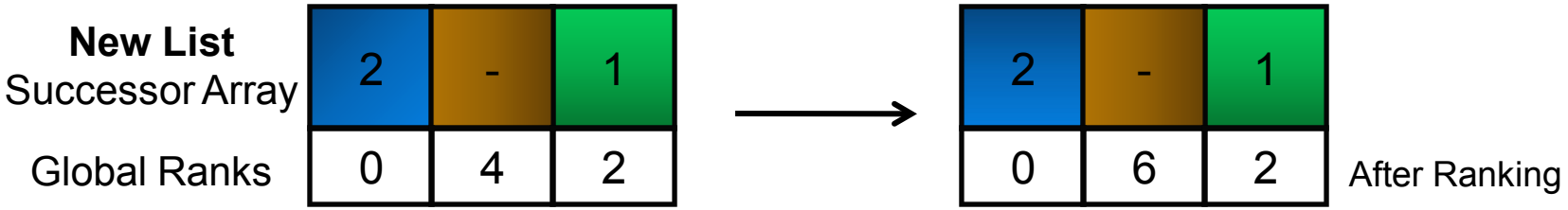
| Successor Array | 2 | 4 | 8 | 1 | 9 | 3 | 7 | - | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|
| Local Ranks | 0 | 3 | 1 | 2 | 0 | 1 | 2 | 3 | 0 | 1 |

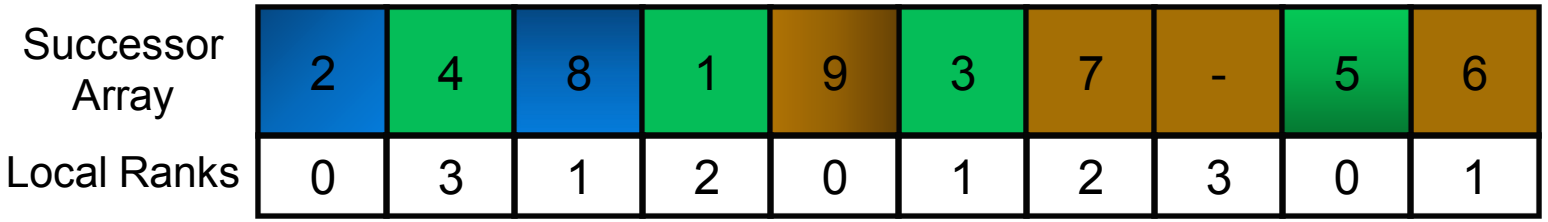
Step 4. **Create** a new list of splitters which contains a **prefix value** that is equal to the local rank of it's predecessor

| **New List** Successor Array | 2 | - | 1 |
|---|---|---|---|
| Global Ranks | 0 | 4 | 2 |

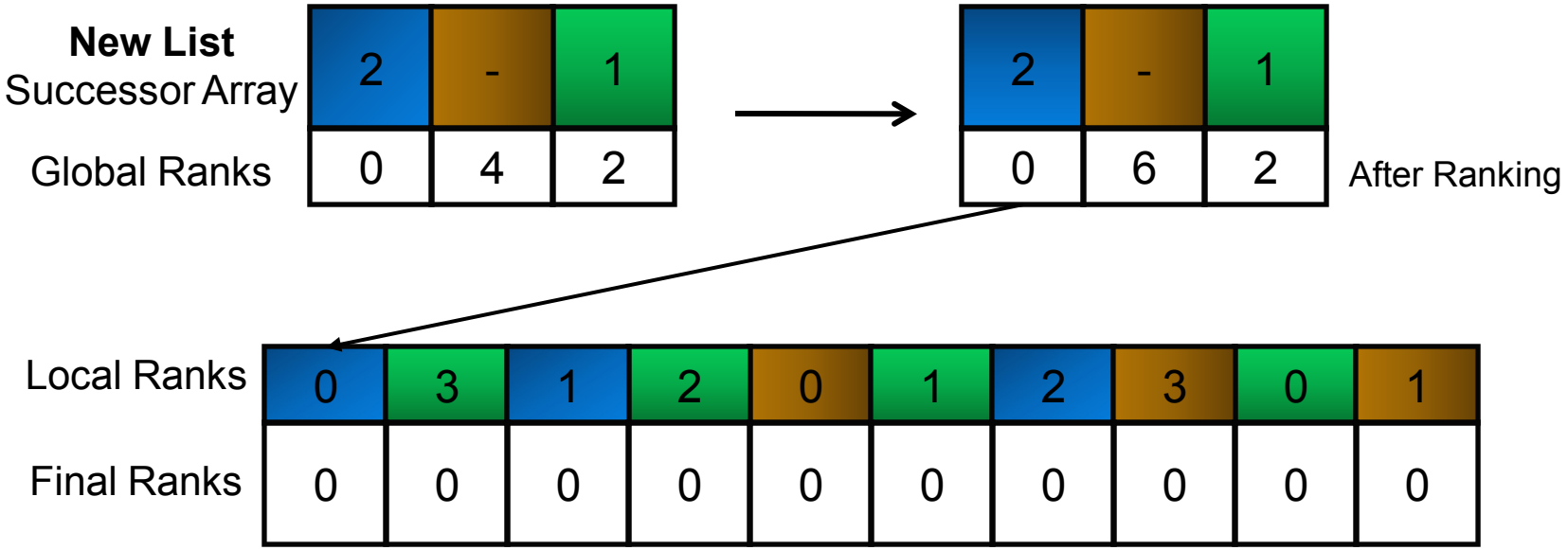


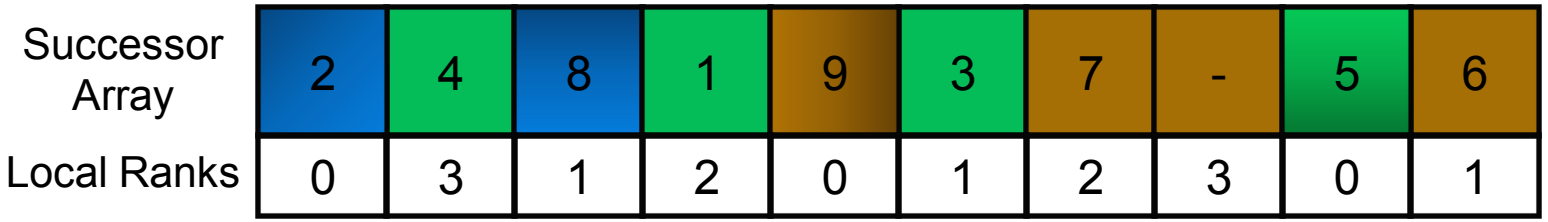

Step 5. Scan the global ranks array **sequentially**






Step 6. Add the global ranks to the corresponding local ranks to get the final rank of the list.



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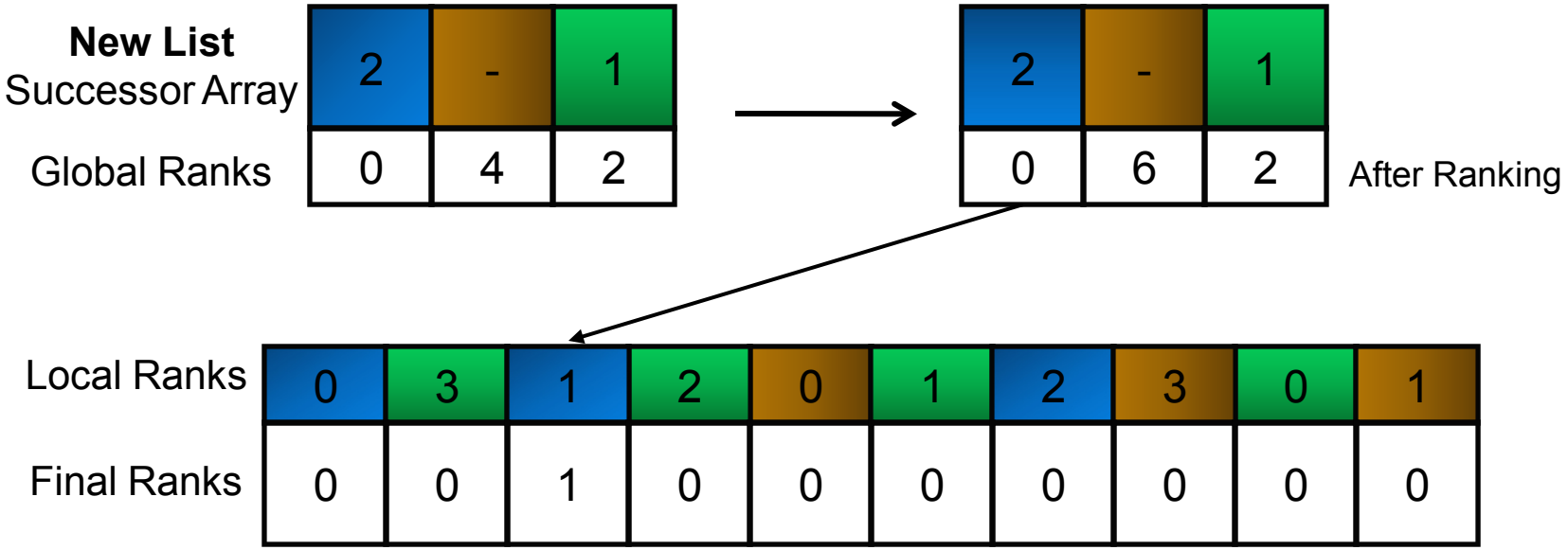

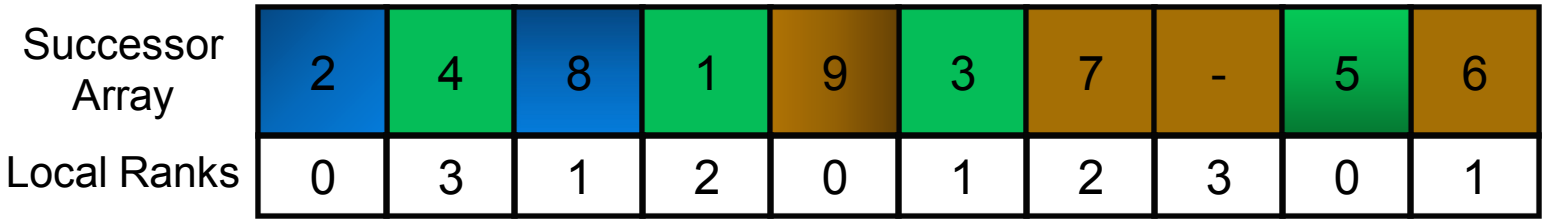


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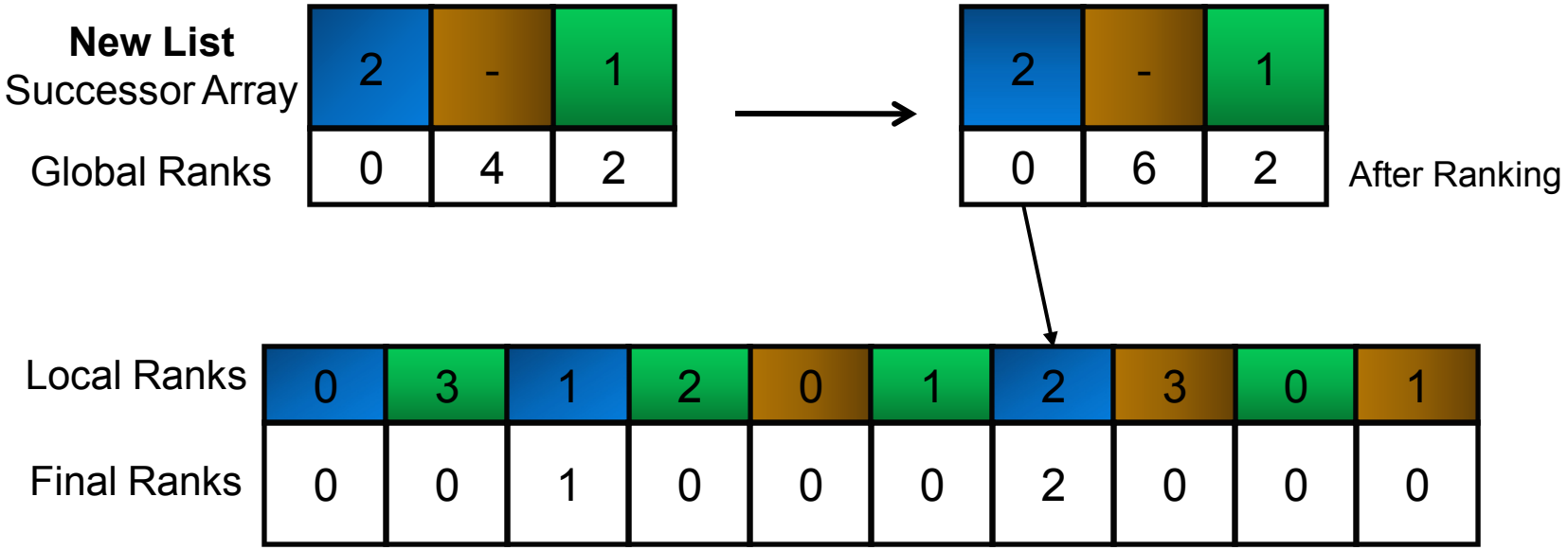

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
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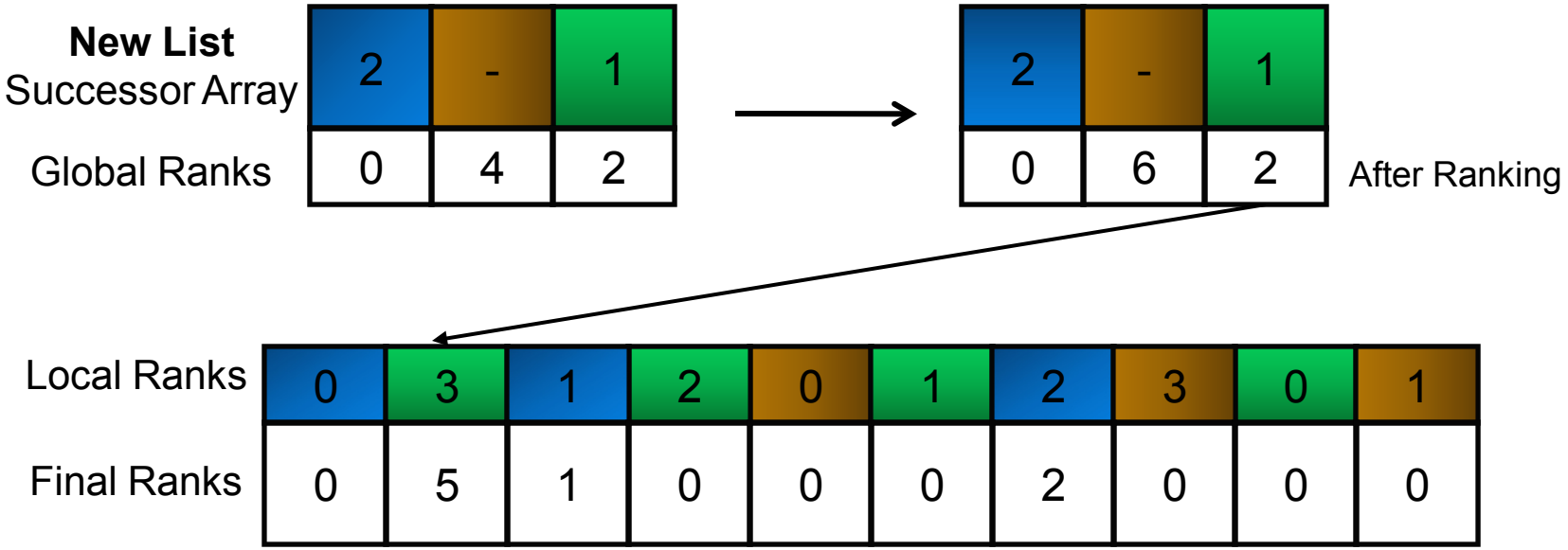

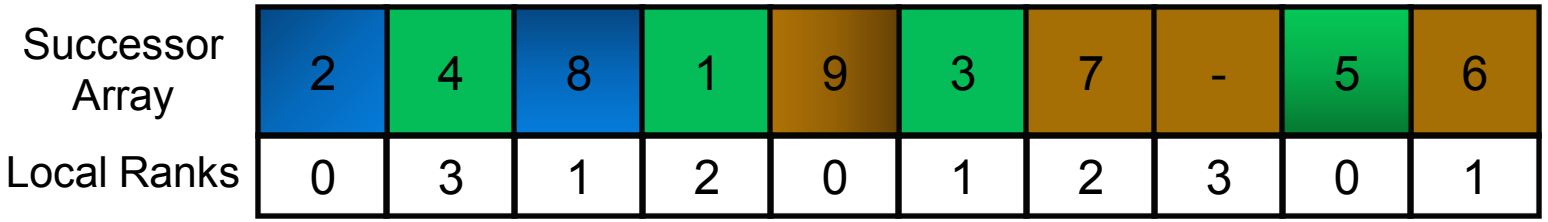


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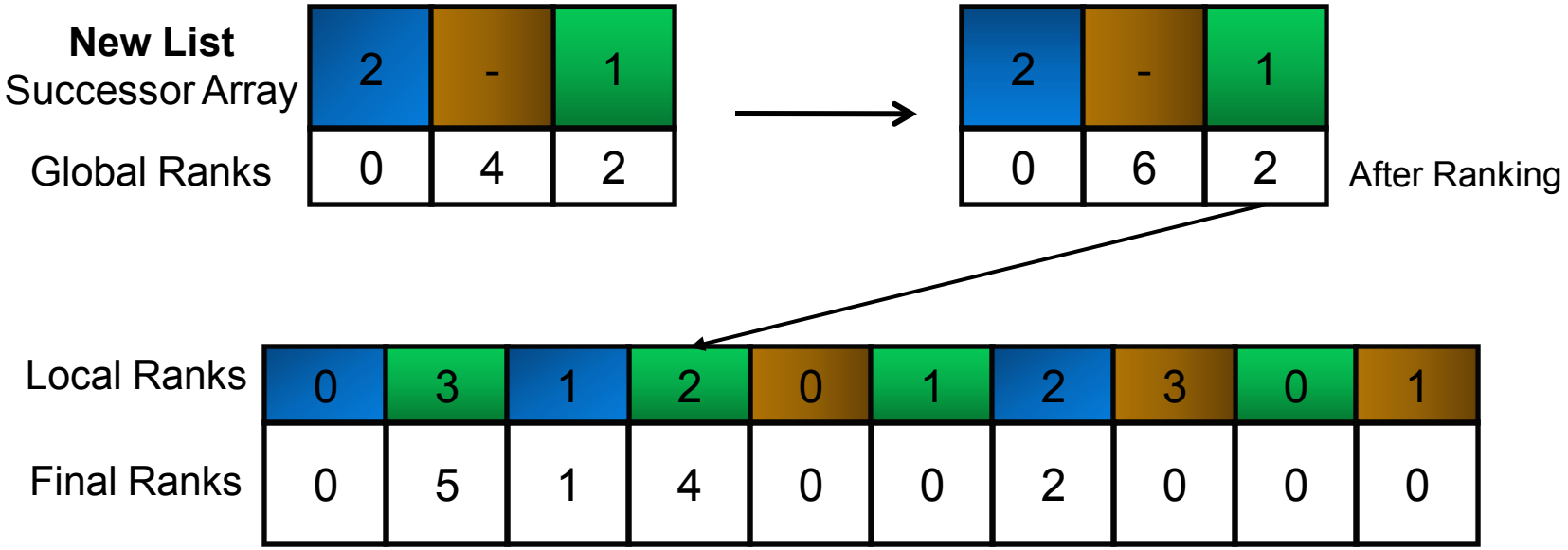

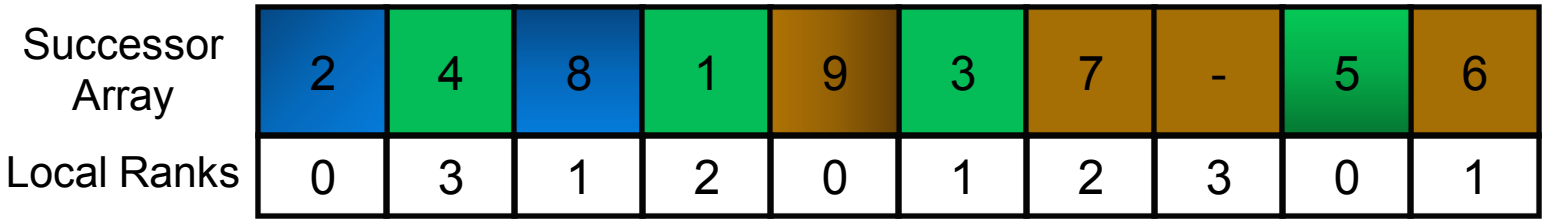


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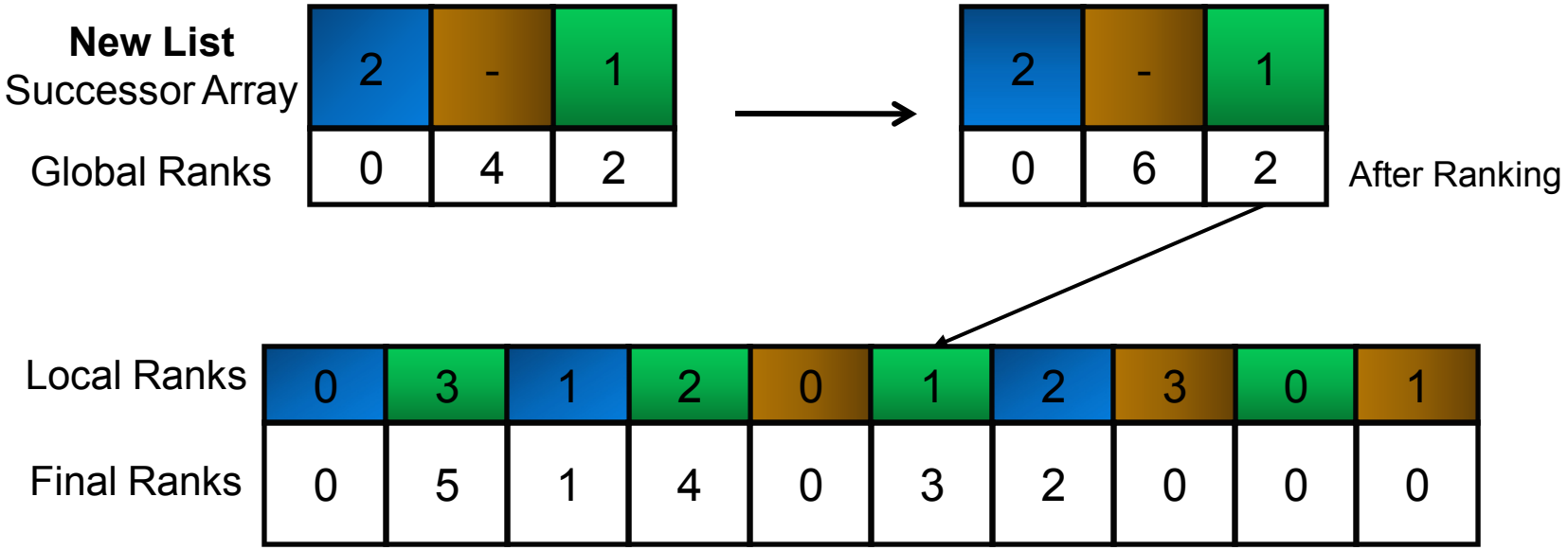

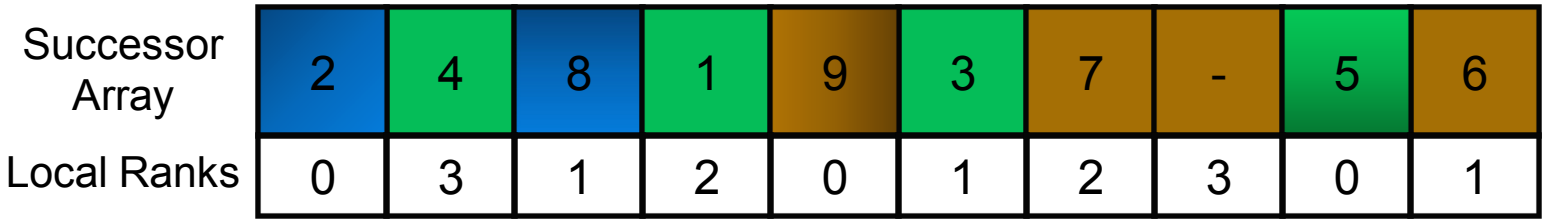


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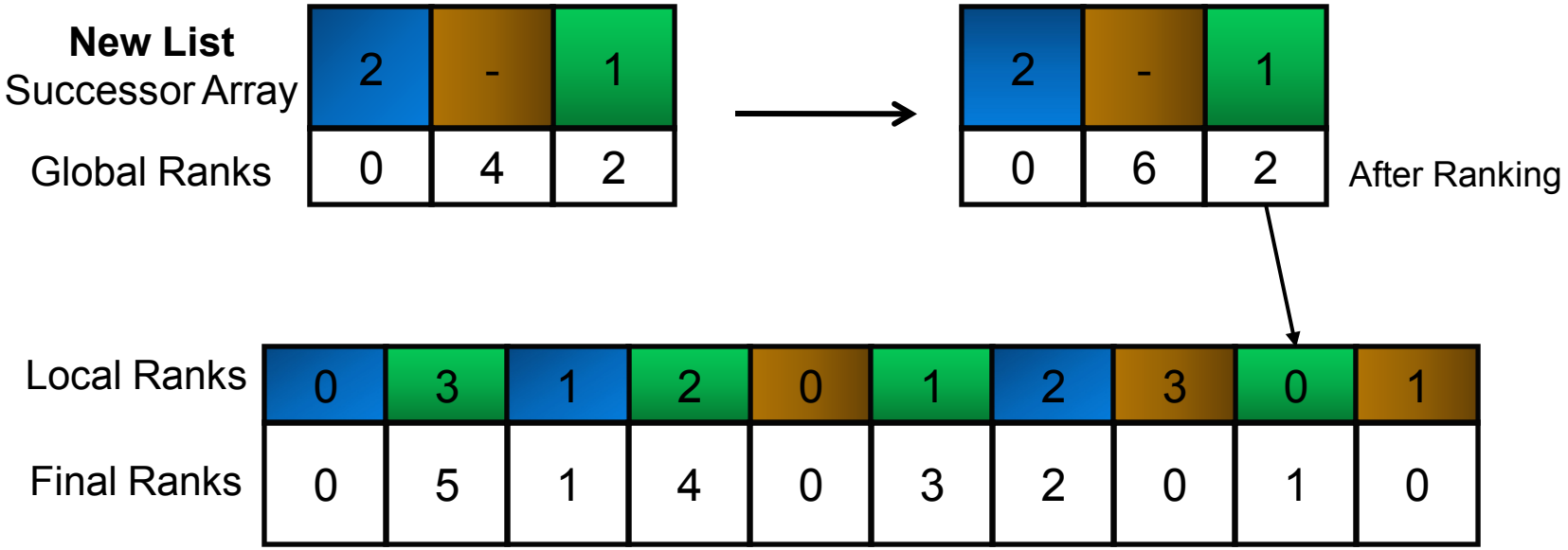


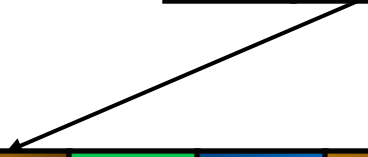
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Successor Array | 2 | 4 | 8 | 1 | 9 | 3 | 7 | - | 5 | 6 |
| Local Ranks | 0 | 3 | 1 | 2 | 0 | 1 | 2 | 3 | 0 | 1 |

Step 6. Add the global ranks to the corresponding local ranks to get the final rank of the list.

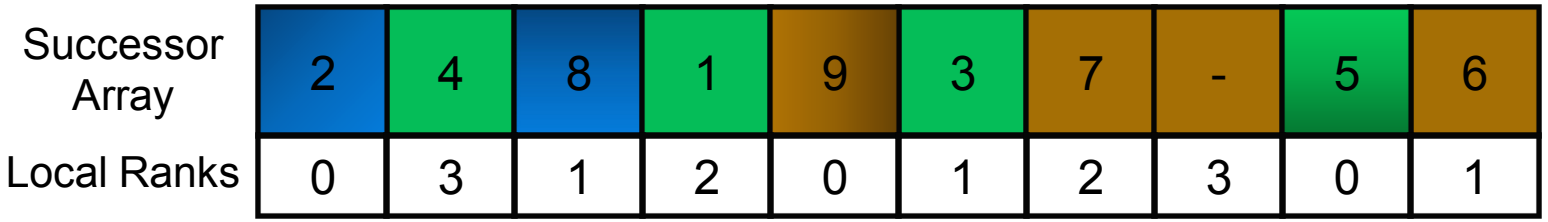
| **New List** Successor Array | 2 | - | 1 |
|---|---|---|---|
| Global Ranks | 0 | 4 | 2 |

| | | | |
|---|---|---|---|
| | 2 | - | 1 |
| | 0 | 6 | 2 |

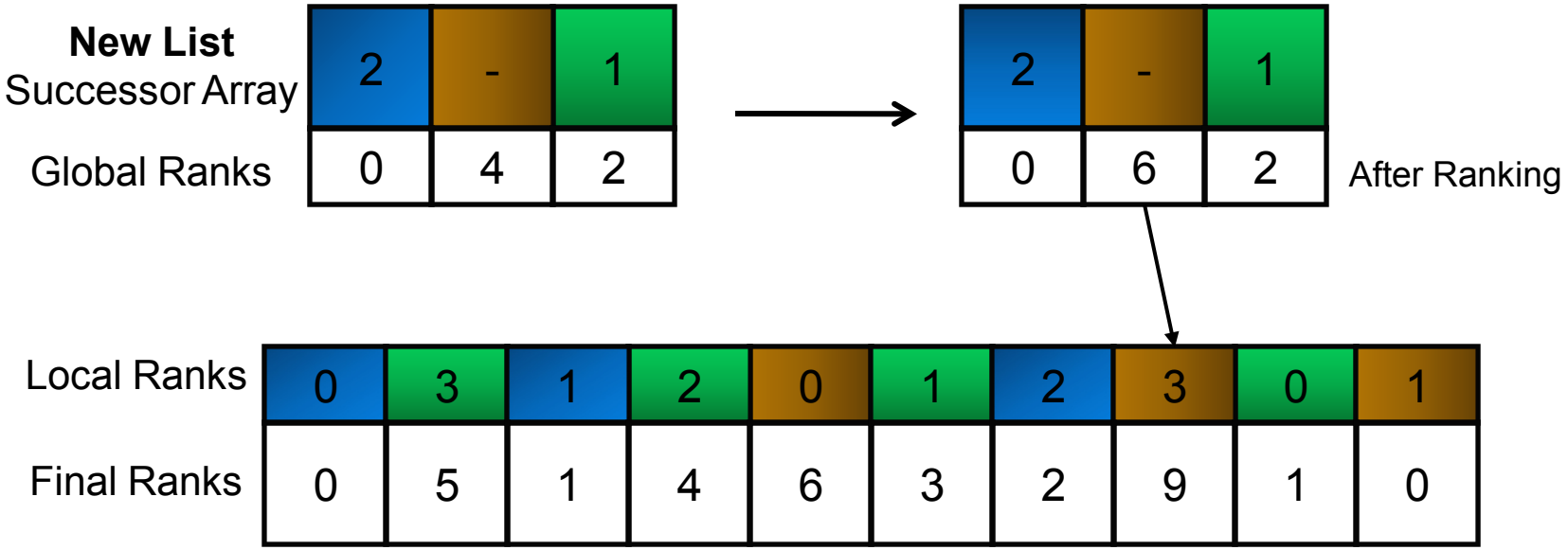
After Ranking

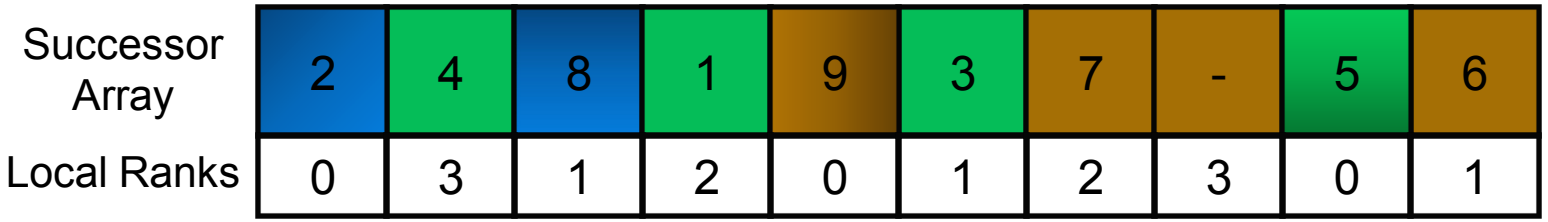


| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Local Ranks | 0 | 3 | 1 | 2 | 0 | 1 | 2 | 3 | 0 | 1 |
| Final Ranks | 0 | 5 | 1 | 4 | 6 | 3 | 2 | 0 | 1 | 0 |




Step 6. Add the global ranks to the corresponding local ranks to get the final rank of the list.



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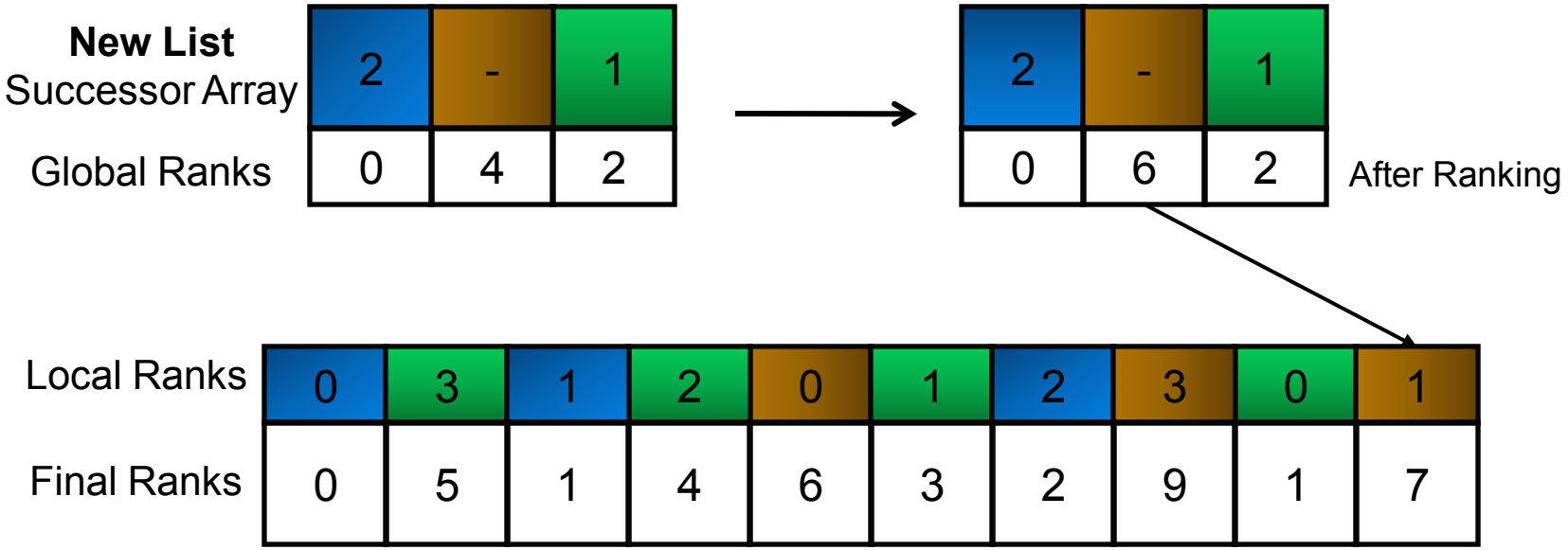

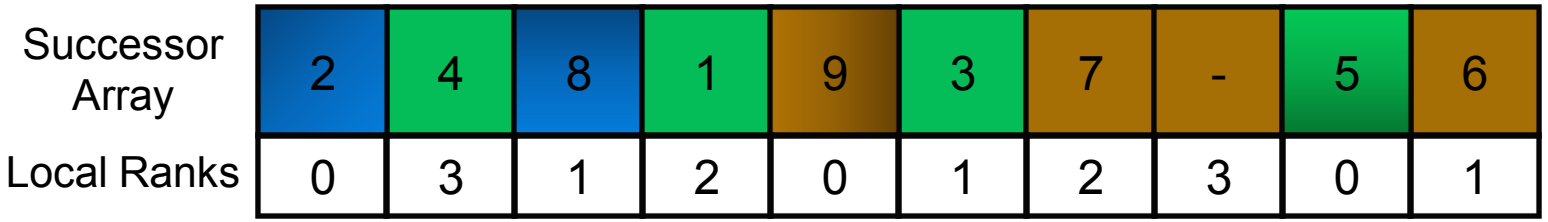


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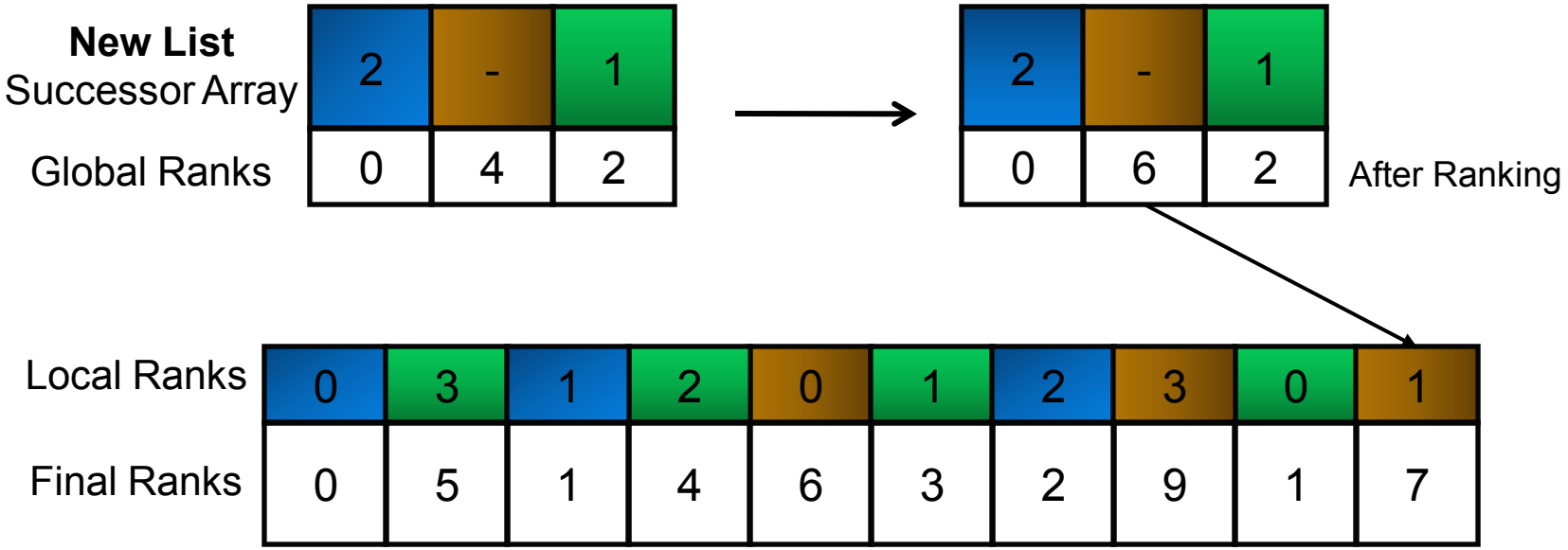
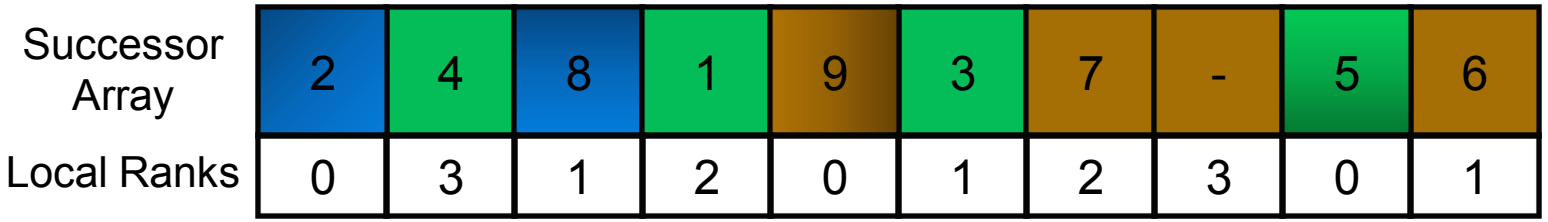


# Is this suitable for the GPU?

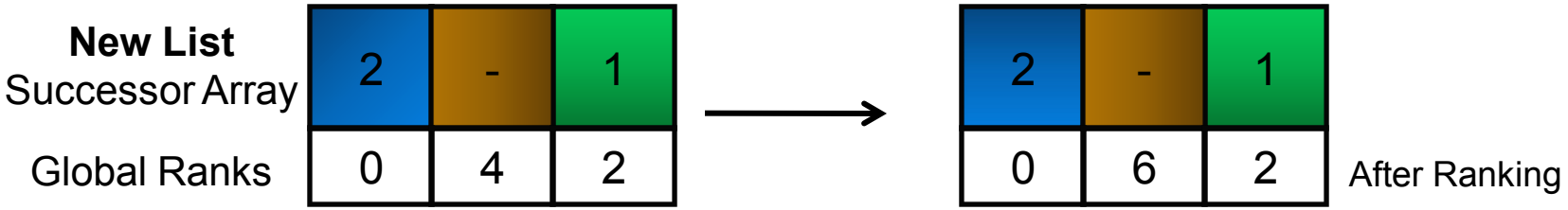
- Assume you select n/log n splitters (for large number of threads)
- The resulting list itself will be very large
- Will slow down the computation as that has to be computed sequentially
- Amdahl's Law comes into effect
  - Large portion of the time is spent in serial section of the Code

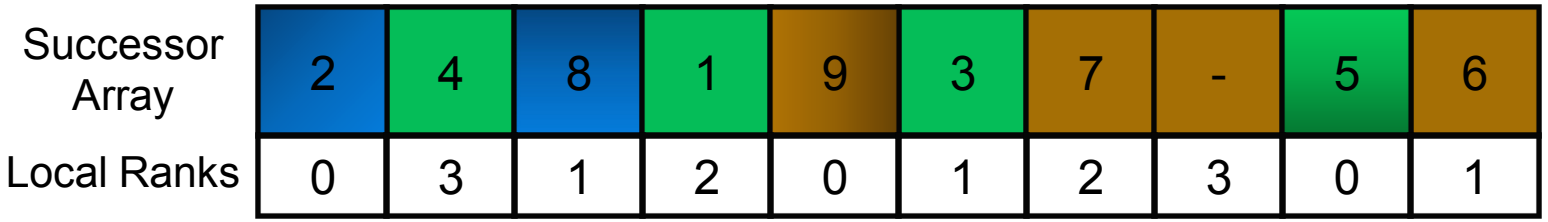
# Solution: Recrusive H-J

- Recursively apply the algorithm in parallel on the newly generated list
  - Stop at a list that's small enough to process very quickly by one thread
- We continue to extract parallelism until the resultant list becomes small




Make step 5 **recursive** to allow the GPU to continue processing the list in parallel



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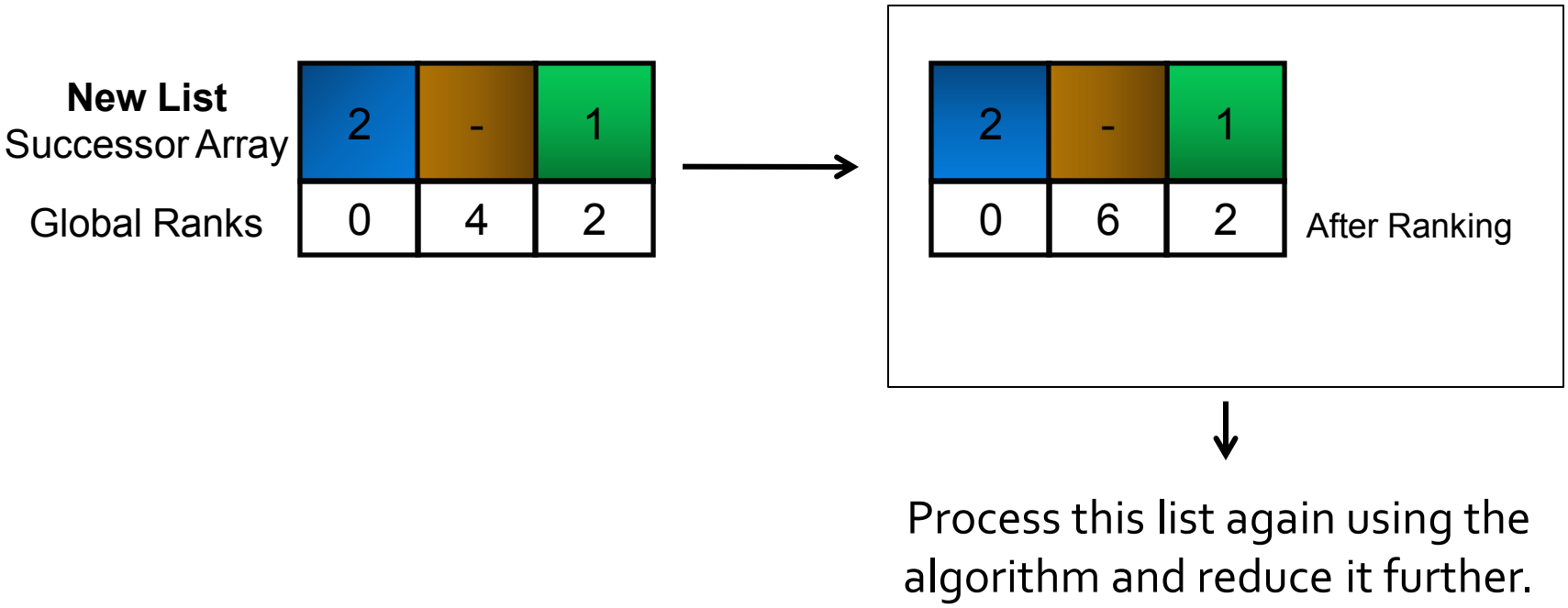



Process this list again using the algorithm and reduce it further.

# GPU Implementation

- Each phase is coded as separate GPU *kernel*
  - Since each step requires global synchronization.
    - Splitter Selection
      - Each thread chooses a splitter
    - Local Ranking
      - Each thread traverses its corresponding sublist and get the global ranks
    - Recursive Step
    - Recombination Step
      - Each thread adds the global and local ranks for each element

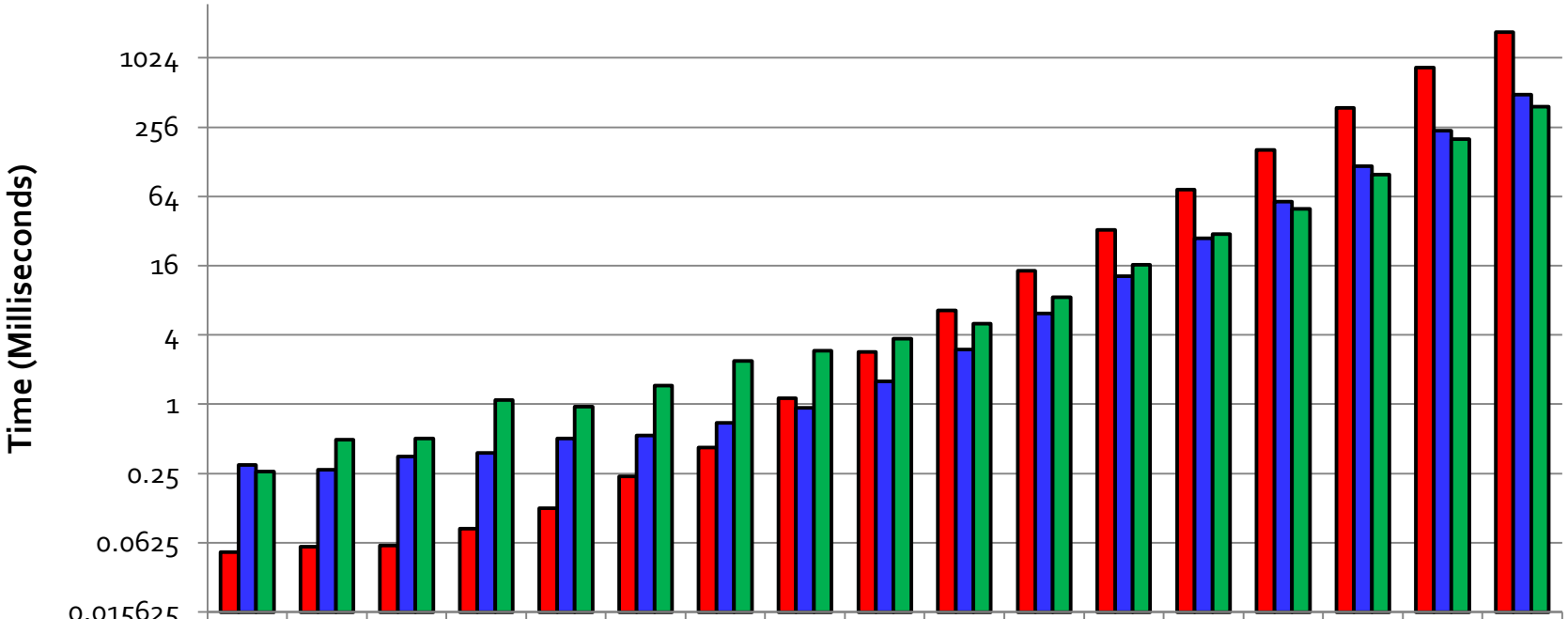
# When do we stop?

- Convergence can be met until list size is 1
- We also have the option to send a small list to CPU or Wyllie's algorithm so that it can be processed faster than on this algorithm.
- May save about 1% time

# Choosing the right amount of splitters

- Notice that choosing splitters in a random list yields uneven sublists
- We can attempt to load balance the algorithm by varying the no. of splitters we choose.
- n/log n works for small lists, n/2 $\log^2$ n works well for lists > 8 M.

# Results – Runtime w.r.t Wyllie's



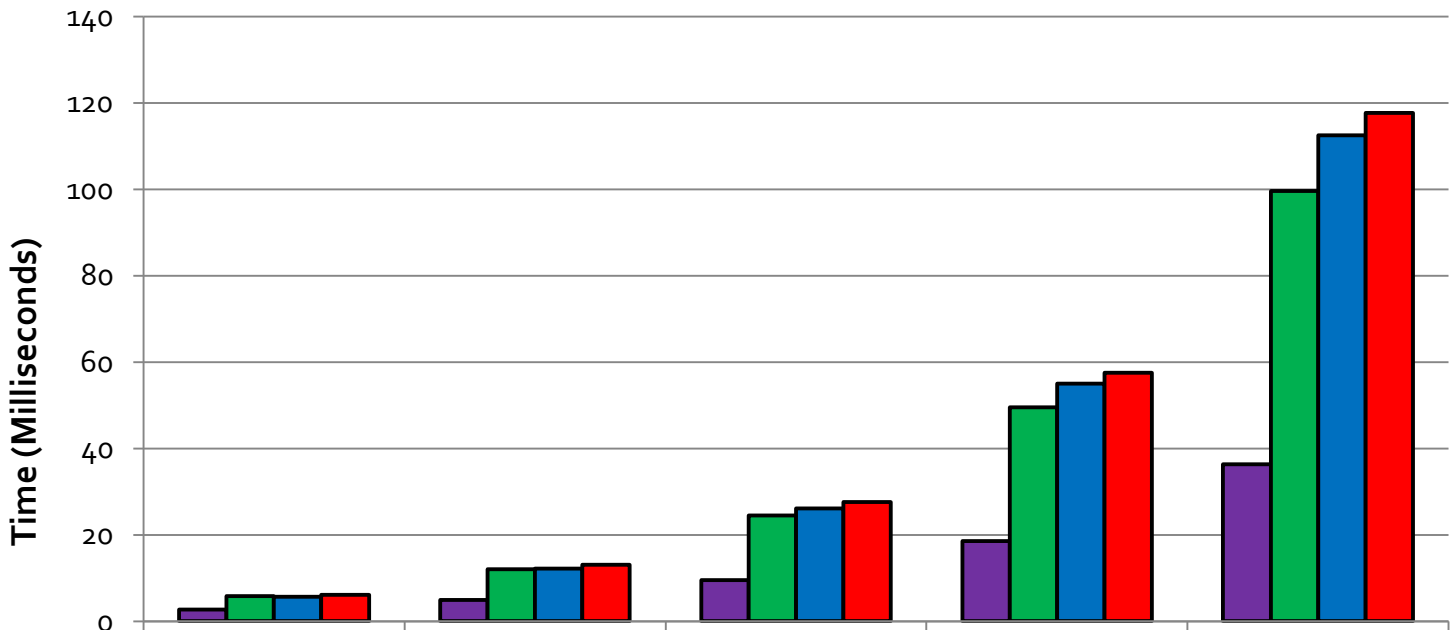

| | 1K | 2K | 4K | 8K | 16K | 32K | 64K | 128K | 256K | 512K | 1M | 2M | 4M | 8M | 16M | 32M | 64M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyllie (RO) | 0.052 | 0.058 | 0.059 | 0.083 | 0.125 | 0.237 | 0.419 | 1.123 | 2.86 | 6.535 | 14.49 | 32.83 | 73.01 | 163.3 | 377.6 | 840.2 | 1718 |
| RHJ (log n) | 0.297 | 0.27 | 0.351 | 0.378 | 0.501 | 0.538 | 0.692 | 0.926 | 1.576 | 3.001 | 6.188 | 13.04 | 27.64 | 57.52 | 117.8 | 239.7 | 488.9 |
| RHJ (2log2n) | 0.259 | 0.493 | 0.501 | 1.089 | 0.954 | 1.444 | 2.369 | 2.914 | 3.731 | 4.992 | 8.557 | 16.32 | 30.09 | 49.75 | 99.08 | 200.7 | 388.2 |

List Size

# Runtime Performance Analysis

- Two factors that contribute to performance
  - Random lists
  - Load Balancing among threads
- Test the effects on four configurations
  - Ordered List
  - Ordered Unbalanced List
  - Random Balanced List
  - Random

# Runtime Performance Analysis

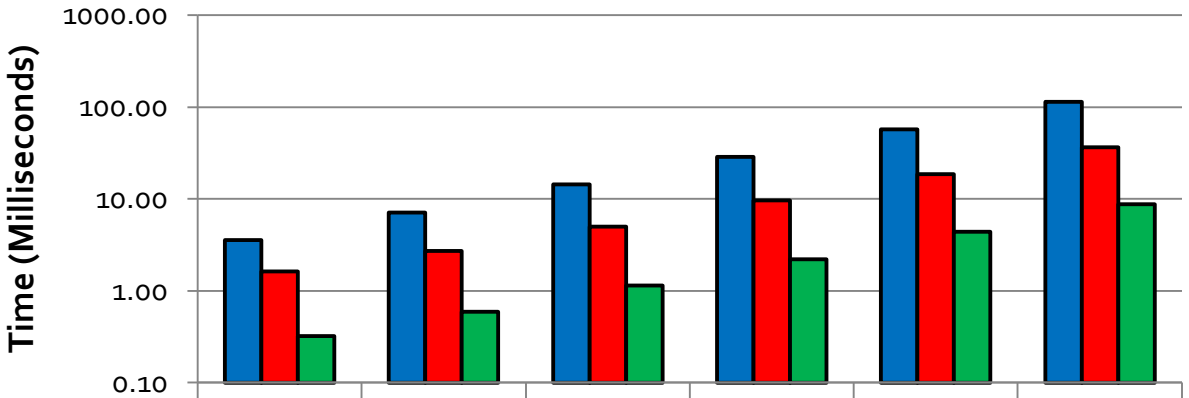



| | 1M | 2M | 4M | 8M | 16M |
|---|---|---|---|---|---|
| Ordered List | 2.719 | 4.956 | 9.56 | 18.615 | 36.432 |
| Ordered/Unbalanced | 5.897 | 12.111 | 24.523 | 49.585 | 99.716 |
| Random/Balanced | 5.649 | 12.211 | 26.164 | 54.992 | 112.59 |
| Random List | 6.188 | 13.038 | 27.638 | 57.516 | 117.771 |

**List Size**

# Results – Ordered Lists

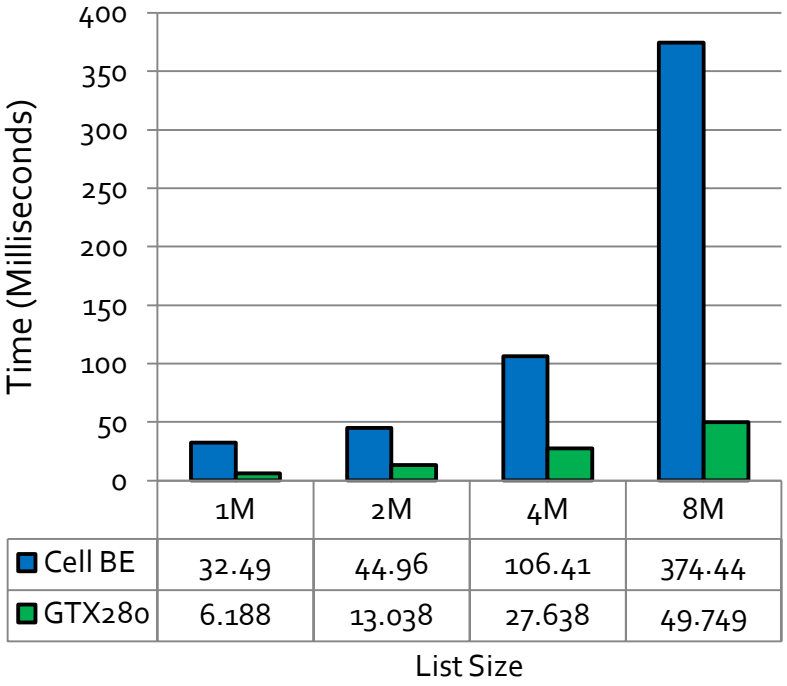
- Ordered Lists are Lists with successor of element $i = i+1$
- List Ranking on Ordered List is equivalent to scan



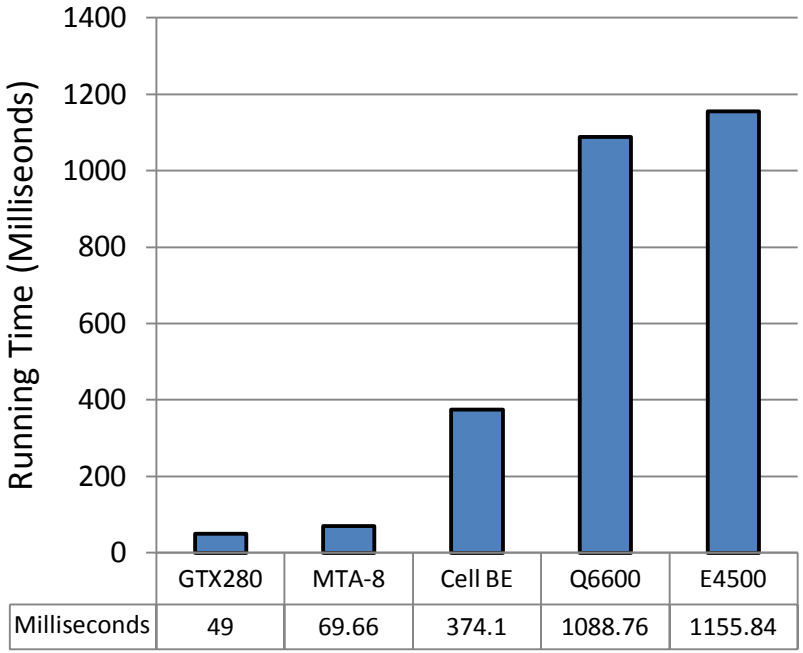

| | 512K | 1M | 2M | 4M | 8M | 16M |
|---|---|---|---|---|---|---|
| CPU | 3.55 | 7.12 | 14.27 | 28.55 | 56.62 | 113.96 |
| GPU RHJ | 1.61 | 2.72 | 4.96 | 9.56 | 18.62 | 36.43 |
| CUDPP | 0.32 | 0.59 | 1.13 | 2.21 | 4.37 | 8.68 |

List Size

# Comparison with recent Results




| | 1M | 2M | 4M | 8M |
|---|---|---|---|---|
| Cell BE | 32.49 | 44.96 | 106.41 | 374.44 |
| GTX280 | 6.188 | 13.038 | 27.638 | 49.749 |




| | GTX280 | MTA-8 | Cell BE | Q6600 | E4500 |
|---|---|---|---|---|---|
| Milliseconds | 49 | 69.66 | 374.1 | 1088.76 | 1155.84 |

**Fastest single-chip List Ranking implementation (at time of publishing)**

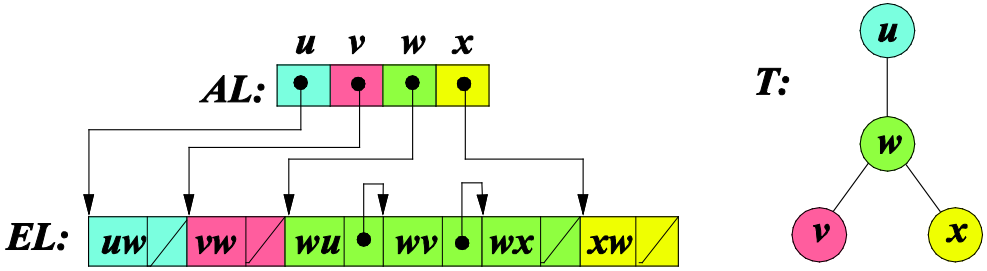
# Applications of List Ranking

# Euler Tour Technique

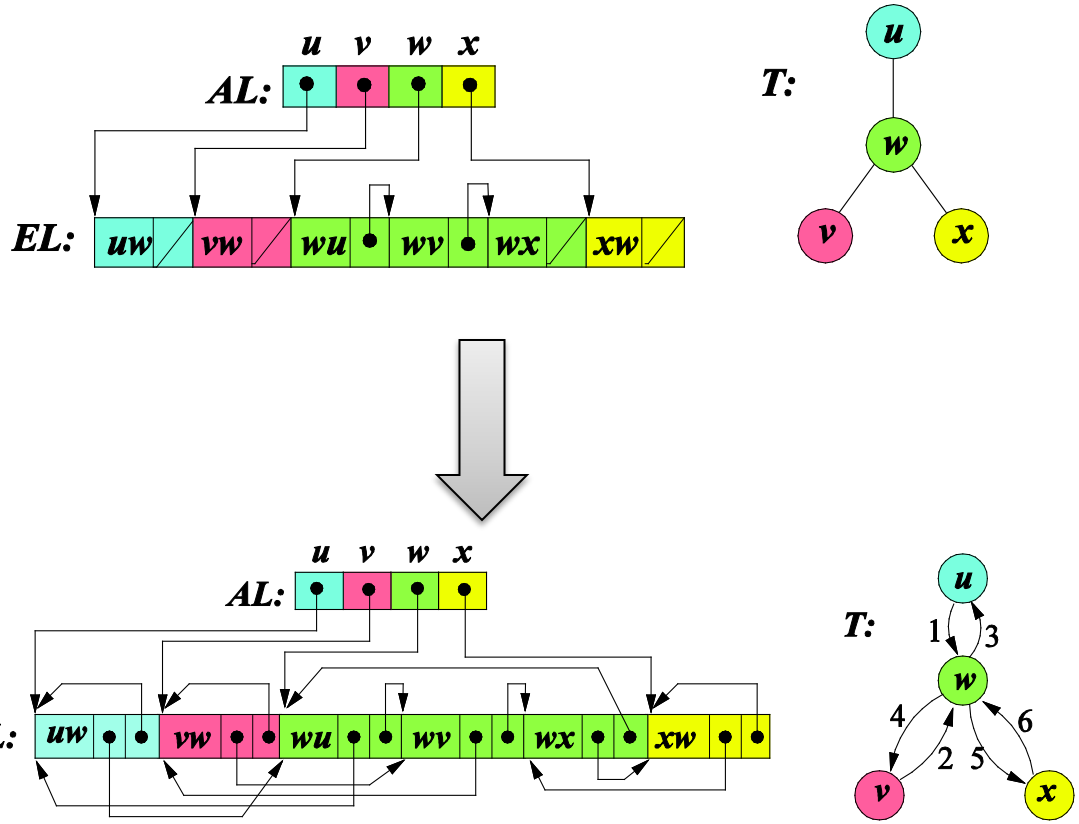
- Parallel Processing of Graphs
  - Utilizes List Ranking
- Can be used for a variety of Tree Computations
  - Parent Finding
  - Traversal
  - Vertex Levels
  - Subtree Size

# Representing a Tree

- Use two linked lists:
  - Adjacency List (Contains pointers from each vertex to the set of edges it's adjacent to)
  - Edge List (List of edges in the tree)



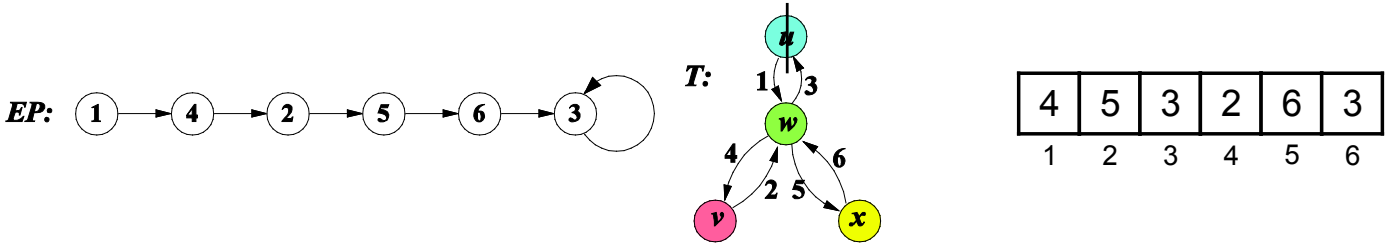
# Creating an Eulerian Graph from T




Each edge is replaced with a set of anti-parallel arcs, and an additional pointer for each edge pointing to their anti-parallel sibling

# Euler Path

- Once the Eulerian graph of Tree T is created, an Euler path can be created
  - Number the edges in some order and create a linked list




- Can be done for all edges in parallel:

$$\mathrm{EP}[e]=(\mathrm{EL}[e].sib).next$$

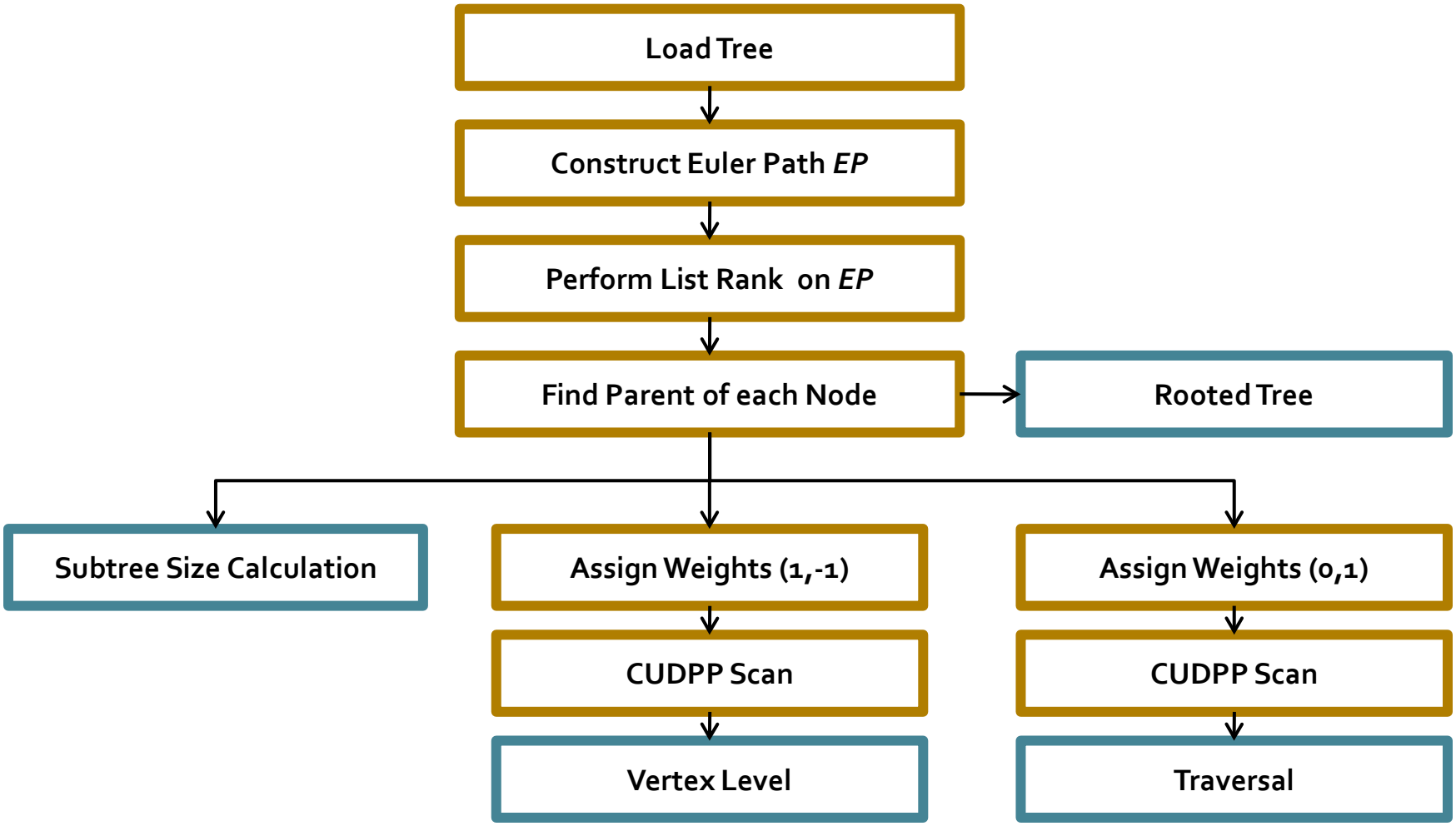
# Tree Computations

- Once an Euler Path is constructed, it is ranked using the List Ranking algorithm
- Tree Computations
  - Parent Finding
    - Mark incoming and outgoing edges according to ranks
    - If R[xy]<R[yx] then Par[y]=x
  - Subtree Size
    - Subtree[i]=(Rank[ij]-Rank[ji]+1)/2 where j= Par[i]

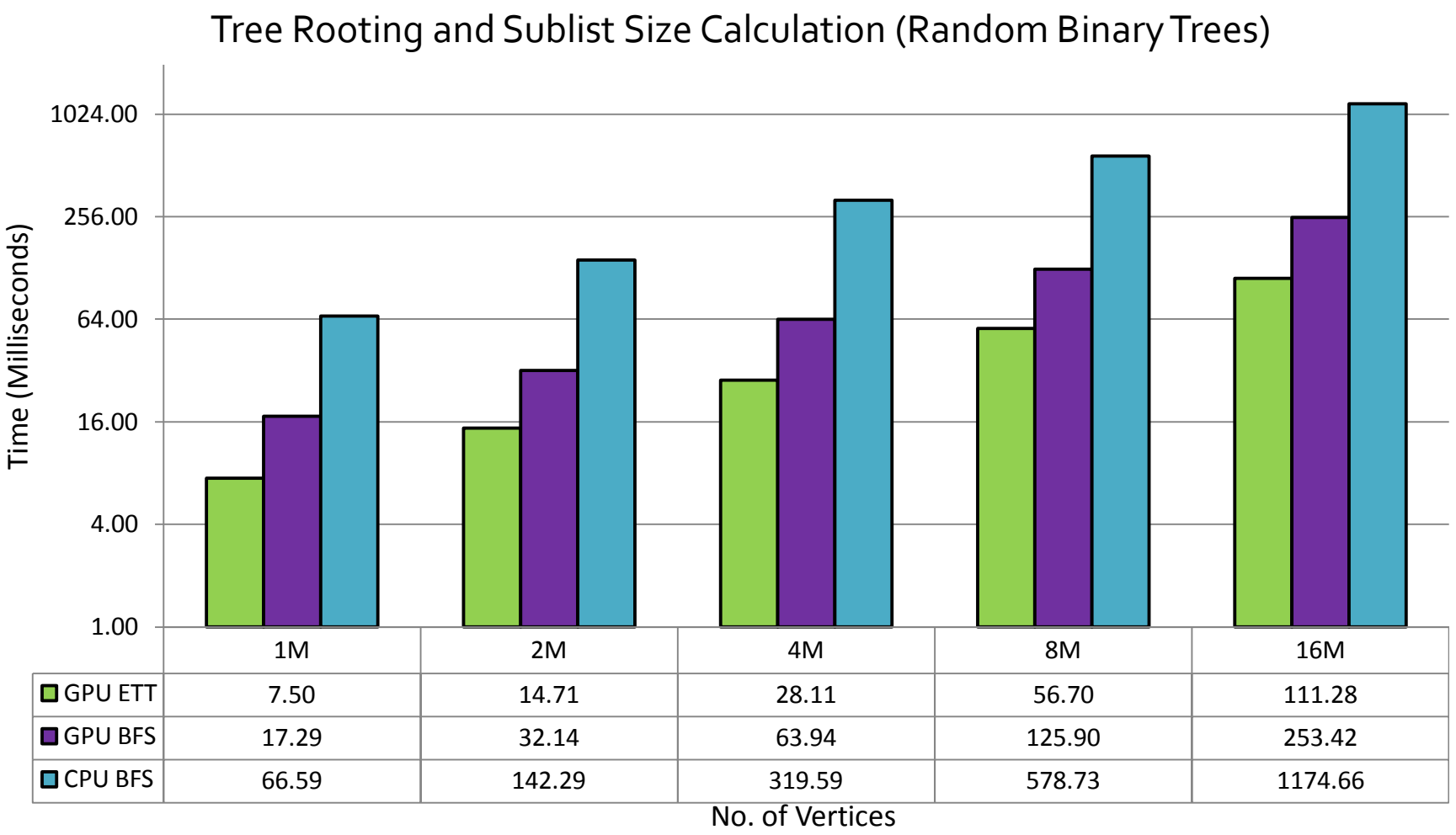
# Tree Computations

- Preorder Traversal
  - Assign 1 to forward edge, 0 to reverse edge
  - Scan Weights, preorder numbering is obtained
- Vertex Levels
  - Assign 1 to forward edge, -1 to reverse edge
  - Scan weights, level of each vertex is obtained.

# On the GPU

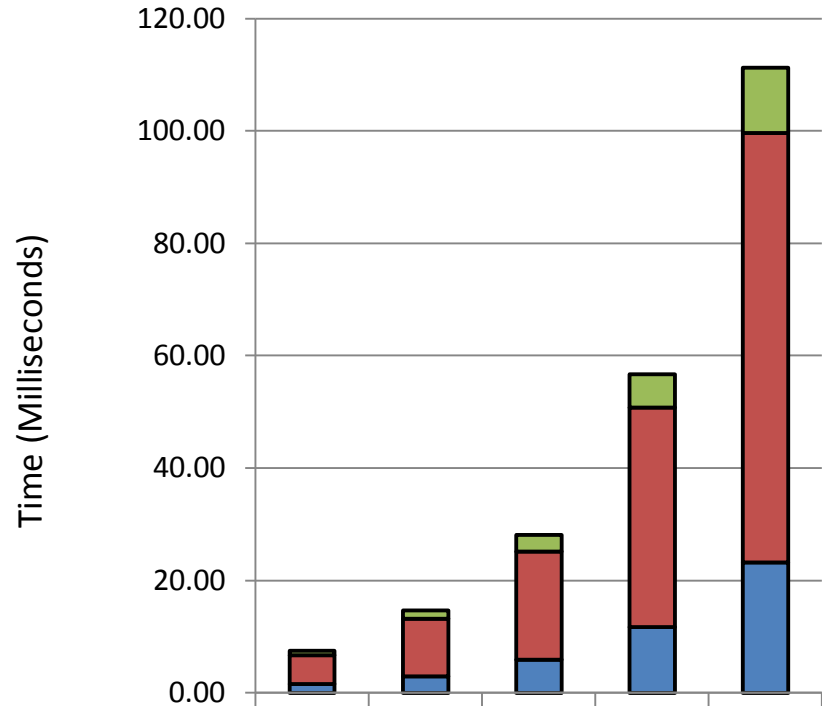

Load Tree
Construct Euler Path *EP*
Perform List Rank on *EP*
Find Parent of each Node
Rooted Tree
Subtree Size Calculation
Assign Weights (1,-1)
CUDPP Scan
Vertex Level
Assign Weights (0,1)
CUDPP Scan
Traversal

# Results for GPU




| | 1M | 2M | 4M | 8M | 16M |
|---|---|---|---|---|---|
| GPU ETT | 7.50 | 14.71 | 28.11 | 56.70 | 111.28 |
| GPU BFS | 17.29 | 32.14 | 63.94 | 125.90 | 253.42 |
| CPU BFS | 66.59 | 142.29 | 319.59 | 578.73 | 1174.66 |

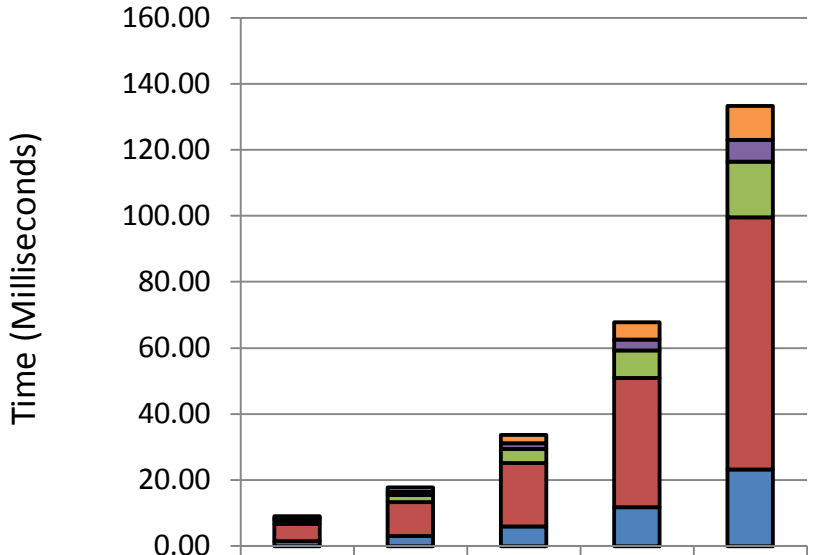
# Timing Breakup




| | 1M | 2M | 4M | 8M | 16M |
|---|---|---|---|---|---|
| FindParent | 0.77 | 1.49 | 2.93 | 5.88 | 11.70 |
| List Ranking | 5.21 | 10.26 | 19.28 | 39.17 | 76.35 |
| EP Construction | 1.52 | 2.96 | 5.90 | 11.65 | 23.23 |

No. of Vertices

Parent Finding




| | 1M | 2M | 4M | 8M | 16M |
|---|---|---|---|---|---|
| Last Kernel | 0.66 | 1.30 | 2.60 | 5.17 | 10.36 |
| CUDPP Scan | 0.55 | 0.98 | 1.72 | 3.31 | 6.50 |
| FindParent | 1.12 | 2.16 | 4.24 | 8.40 | 16.90 |
| List Ranking | 5.21 | 10.26 | 19.28 | 39.17 | 76.35 |
| EP Construction | 1.52 | 2.96 | 5.90 | 11.65 | 23.23 |

No. of Vertices

Preorder Traversal

# Performance Prediction for Irregular Applications on the GPU

# GPU Performance Model

- A Performance prediction model that lets you estimate the runtime of a GPU program
  - Inputs from PRAM, BSP, QRQW models
  - Developed by Kothapalli et. al.
  - Based on Cycle Estimation

$$C(K) = N_B(K) \times N_w(K) \times N_t(K) \times C_T(K) \times \frac{1}{N_C \times D} \text{ cycles}$$

$$T(K) = \frac{C(K)}{R} \text{ seconds}$$

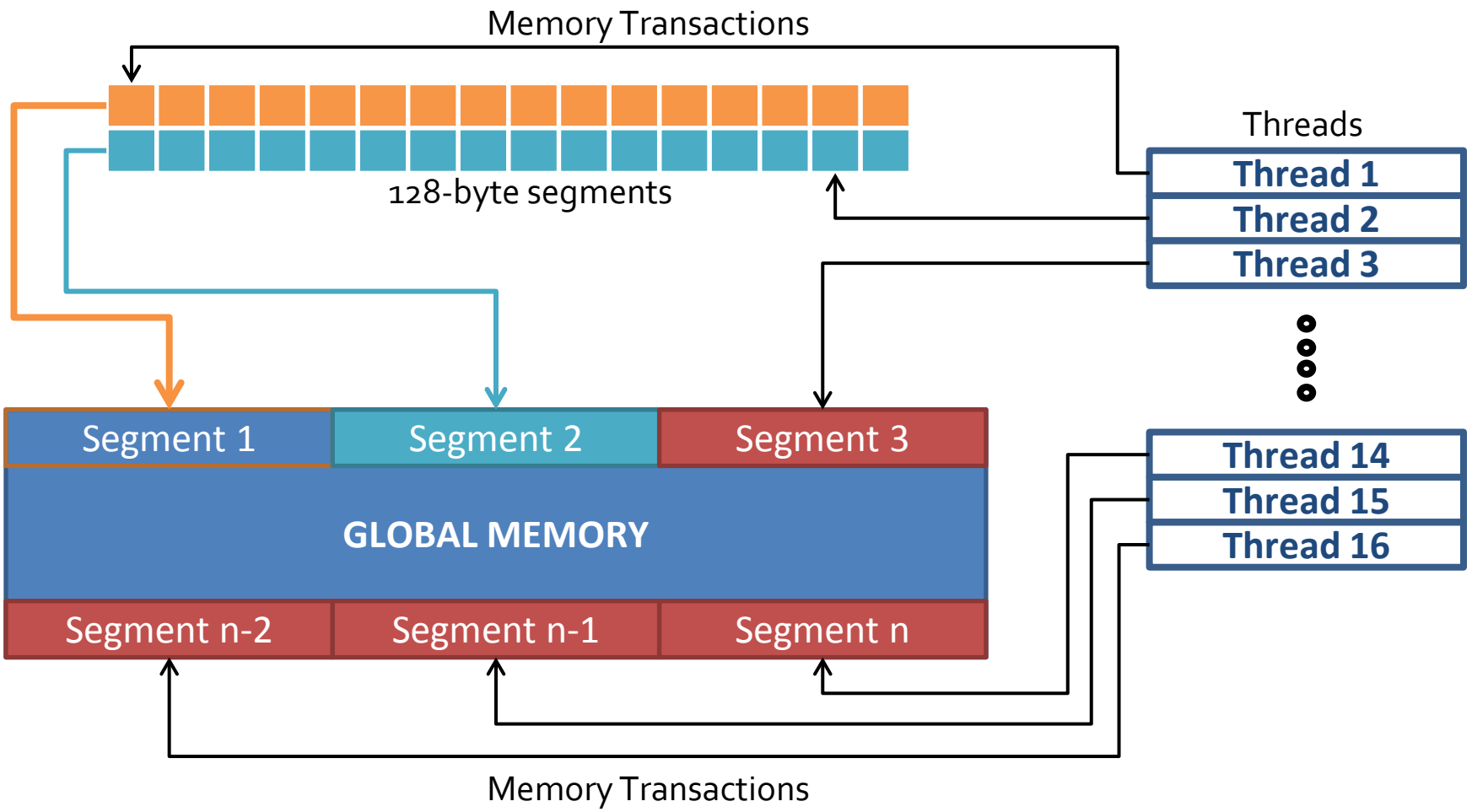
# Estimating Cycles

- Kernel Cycles consists of
  - Data Instructions
  - Compute Instructions
    - Simple to compute
- Difficult to estimate time taken for a data instruction to be serviced
  - Global memory can take around 300 cycles compared to 4 cycles for compute
  - Performance is Memory bound

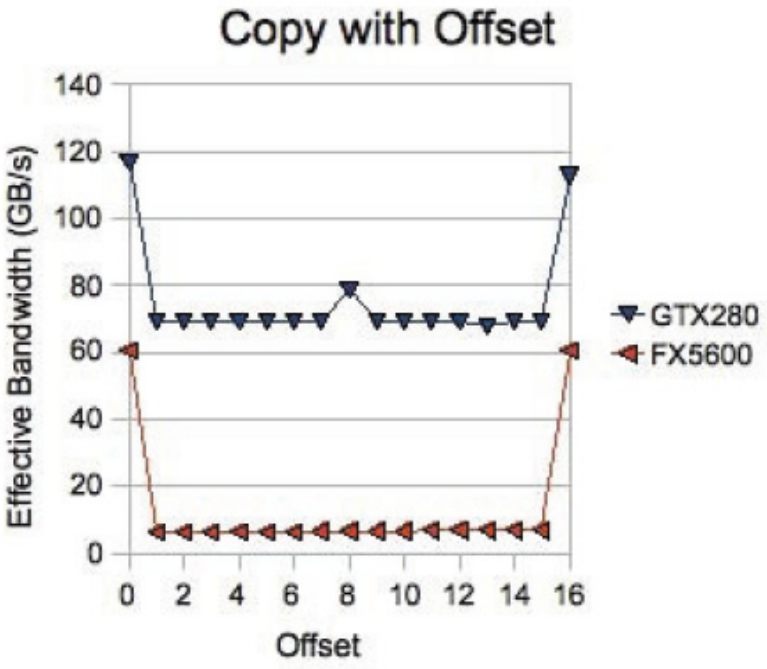
# Global Memory Coalescing

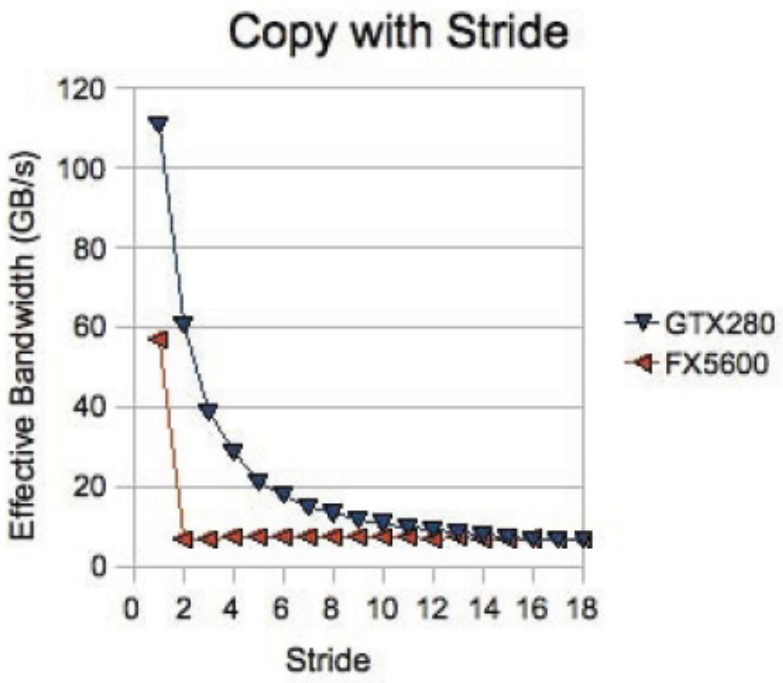
- Global Memory can fetch up to 128 bytes in a single transaction
  - If all threads of a half-warp access elements in 128 byte segment at the same time – then bandwidth improves
- Unlikely to happen with irregular memory applications
- What's the effect of un-coalesced memory accesses?

# Global Memory Coalescing



# Effect on Bandwidth



# How do you model Irregular Applications?

- Estimate how much coalescing is happening
  - "Instantaneous Degree of Locality"
- Estimate cycles per warp
  - Regard all memory transactions are uncoalesced for irregular applications.
  - Memory instructions will overshadow compute in number of cycles

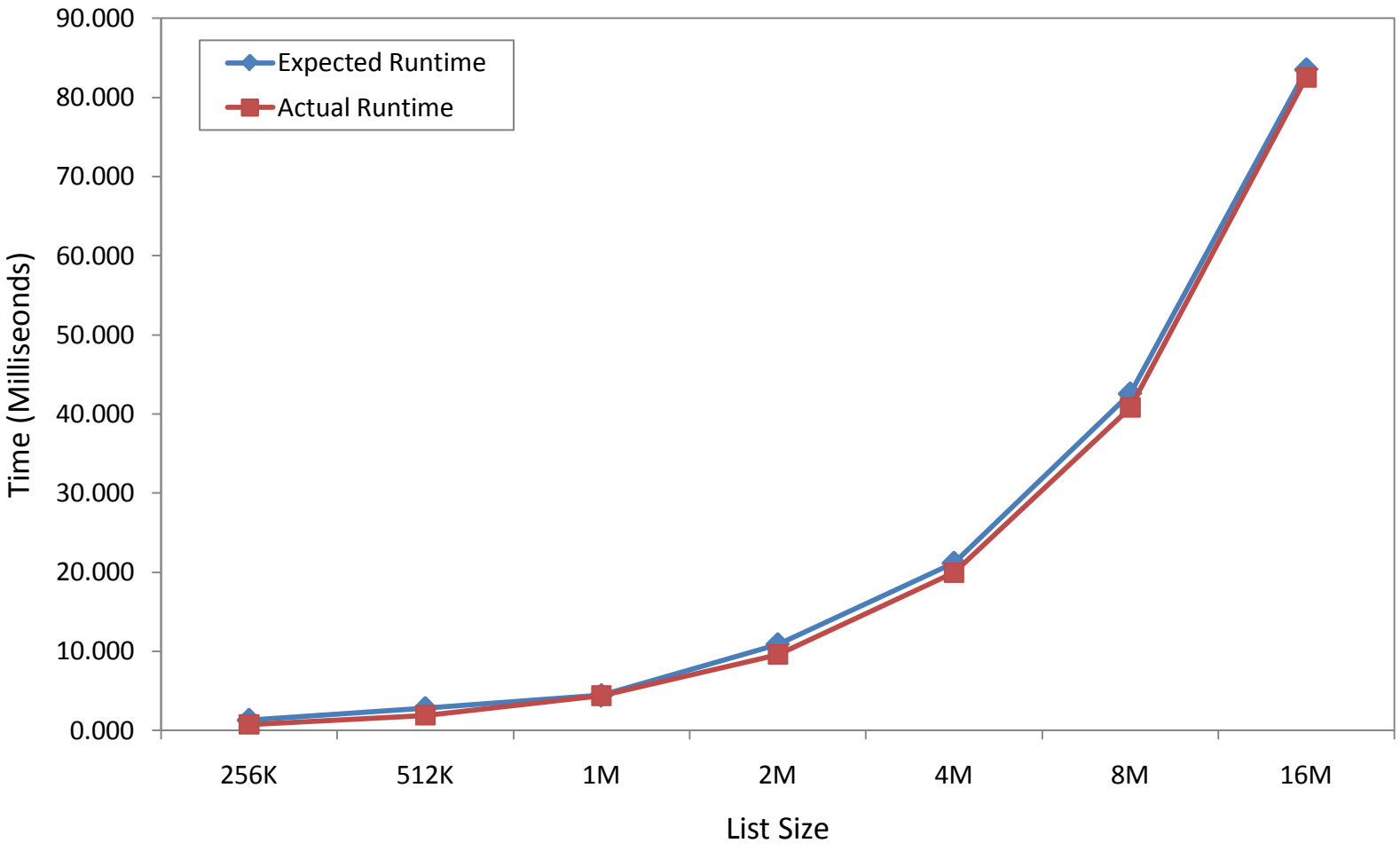
# Modeling List Ranking

- Calculations

$$= \frac{N}{512 \times 30} \times 16 \times \frac{32}{8 \times 4} \times 4 \log N \times 3 \times 500 \times \frac{1}{1.3 \times 10^9} \; sec$$

| List Size | No of Blocks | Blocks per SM | Compute Cycles | Memory Cycles | Expected Runtime | Actual Runtime |
|---|---|---|---|---|---|---|
| 256K | 28 | 1 | 288 | 108000 | 1.333 | 0.773 |
| 512K | 54 | 2 | 304 | 114000 | 2.814 | 1.909 |
| 1M | 102 | 3 | 320 | 120000 | 4.443 | 4.404 |
| 2M | 195 | 7 | 336 | 126000 | 10.884 | 9.588 |
| 4M | 372 | 13 | 352 | 132000 | 21.176 | 19.958 |
| 8M | 712 | 25 | 368 | 138000 | 42.575 | 40.806 |
| 16M | 1365 | 47 | 384 | 144000 | 83.521 | 82.542 |

# Accuracy of the Model



# Strategies for Implementing Irregular Algorithms

- Exploiting massive parallelism of the GPU
  - Enough threads to offset memory access latencies
  - Small input data which fits on CPU cache will be faster on CPU
- Avoid over-reliance on expensive synchronization
- Load Balancing through probabilistic means of dividing work

# Conclusions and Future Work

- Pointer Jumping for GPUs
  - Implemented with some optimization techniques for problems that require it.
- List Ranking for GPUs
  - Our implementation was the fastest single-chip implementation at time of publishing
  - Applied LR for Tree Computations with good results
- Strategies for Irregular Algorithms on the GPU

# Chronology of Work

- 2007 – 2008 Course Work at IIIT-H
  - Parallel Algorithms, Parallel Programming, Multicore Architectures, Graph Theory
- August 2008 – Work on List Ranking Started
- Jan 2009 – Work accepted at ICS 2009
- August 2009 – Started work on Tree Computations
- Current Work – Book Chapter in GPU Computing Gems, Tree Computations on GPU and Larger Applications
- April 2010: Wei and JaJa's paper at IPDPS 2010 improves upon our work, 30% faster timings optimizing thread count and load balancing with appropriate splitter selection.

# Thank You!