BREADTH FIRST SEARCH USING 1 D PARTITION

Course: CSE 633 Parallel Algorithms

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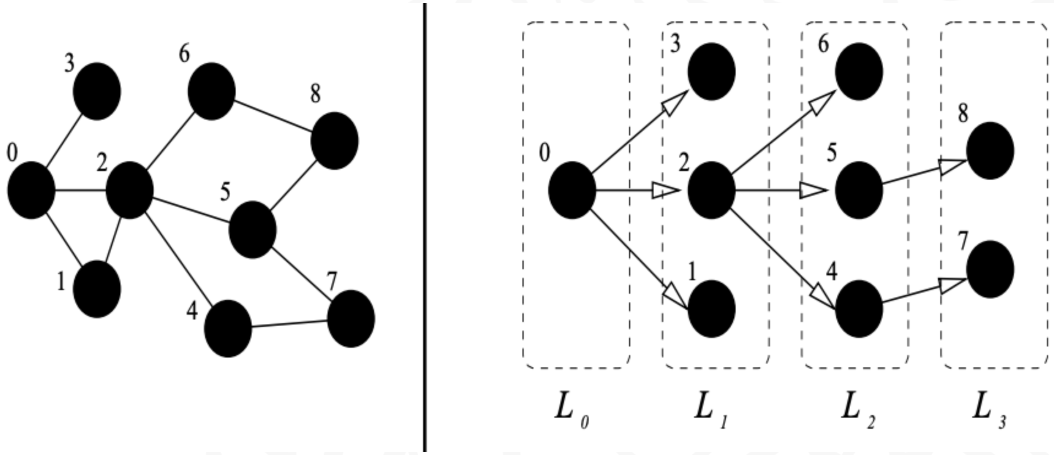
CONTENTS

- About BFS
- Applications of BFS
- Sequential BFS implementation
- Why parallel BFS?
- Parallel BFS implementation
- Future Work Status
- Execution Results
- References

Bread First Search (BFS)

- Algorithm for traversing or searching graph data structures.
- A traversal refers to a systematic method of exploring all the vertices and edges in a graph.
- Explores the vertices at the current level before proceeding to the next level.
- Extra memory is needed to keep track of the child nodes (vertices) encountered but not yet explored.



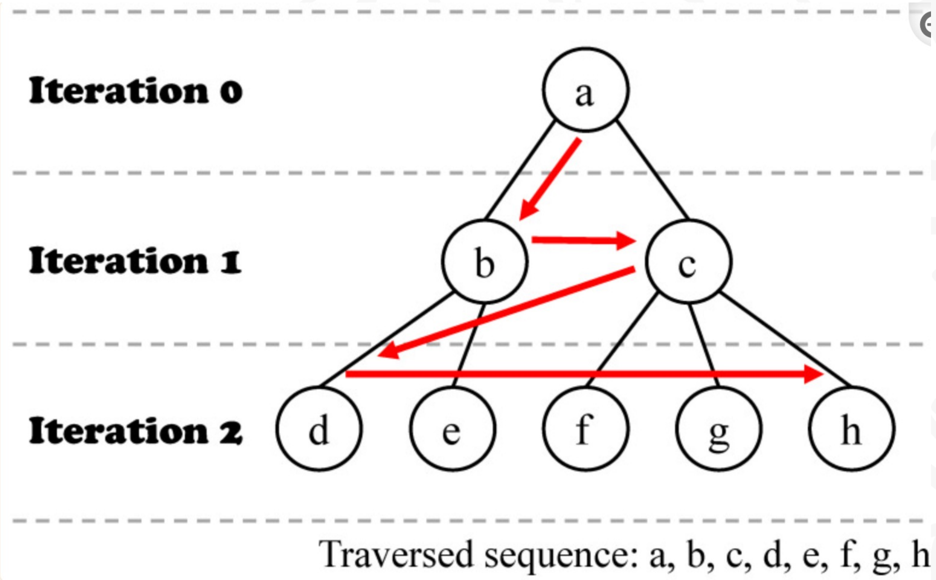
Refer: https://www.researchgate.net/publication/2727226_The_Nature_of_Breadth-First_Search

Applications of BFS

- Shortest Path: Used to find the shortest path between two vertices in an unweighted graph.
- Social Networking: Used to find the shortest path between two users in a social network. Also, can be used to find the connected components in the network.
- Game Theory: Used to find the shortest path to reach the goal state in games such as Chess, Checkers.
- Peer-to-Peer Networks: Used to find the all the neighboring nodes in peer to peer networks like BitTorrent.
- Web Crawlers: Crawlers build search index using BFS. They start from the source page and continue to follow all the links from the source.
- GPS Navigation System: BFS is used to find all the neighboring locations.

Sequential BFS implementation

- Create an empty queue and add the starting vertex to the queue.
- Create a visited set to keep track of the visited vertices.
- Mark the starting vertex as visited and add it to the visited set.



Refer: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9269471/

- While the queue is not empty, do the following:

  a. Dequeue a vertex from the queue.

  b. For each adjacent vertex of the dequeued vertex that is not already visited, do the following:

  i. Mark the adjacent vertex as visited and add it to the visited set.

  ii. Enqueue the adjacent vertex to the queue.

- Repeat the previous step until the queue becomes empty.

```
define bfs_sequential(graph(V,E), source s):
    for all v in V do
        d[v] = -1;
    d[s] = 0; level = 1; FS = {}; NS = {};
    push(s, FS);
    while FS !empty do
        for u in FS do
            for each neighbour v of u do
                if d[v] = -1 then
                    push(v, NS);
                    d[v] = level;
        FS = NS, NS = {}, level = level + 1;
```

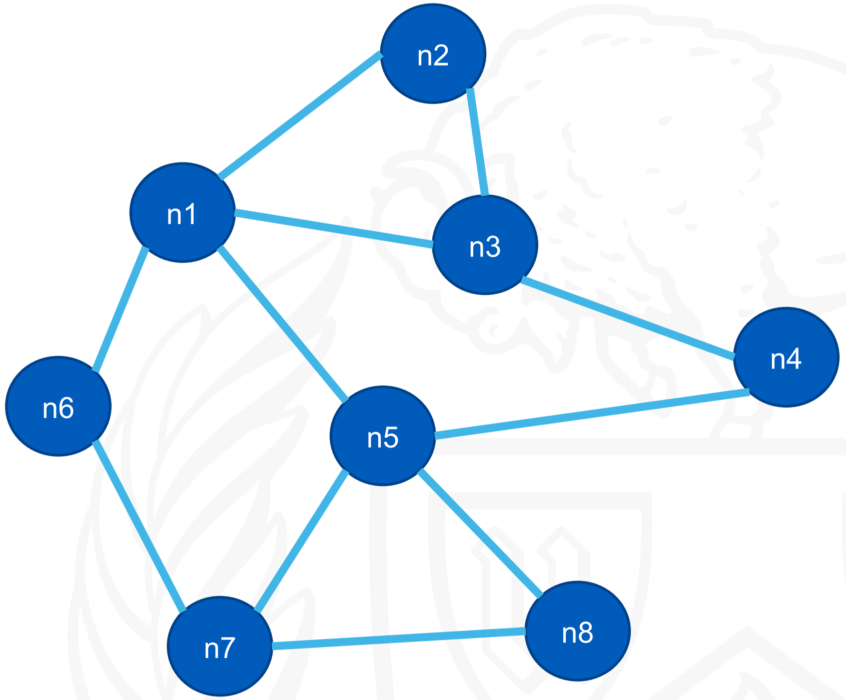
Refer: https://en.wikipedia.org/wiki/Parallel_breadth-first_search

Why parallel BFS?

- Improved performance: Parallel BFS improves performance by processing multiple nodes in parallel.
- Scalability: It is highly scalable and can handle large graphs or trees efficiently.
- Concurrency: Parallel BFS allows for concurrent exploration, minimizing idle time and maximizing resource utilization.
- Load balancing: This ensures efficient utilization of computational resources.
- Flexibility: Parallel BFS can be implemented in various ways, making it flexible to adapt to different hardware configurations.

Parallel BFS implementation

- Similar to sequential BFS implementation, but instead of checking the queue of vertices sequentially, we implement this in parallel across all the vertices at the same level.
- A level-synchronous strategy that relies on a simple vertex-based partitioning of the graph.
- Each processor (p_i) with distributed memory will oversee n/p vertices or graph nodes. (n = number of vertices; p = number of processors)



n = {n1, n2, n3, n4, n5, n6, n7, n8}

p = {p1, p2, p3, p4}

n/p = 8/4 = 2 i.e. 2 vertices for each processor

Parallel BFS implementation

- The processor will store partitioned vertices in a 1 D array structure where each vertex will have a row of outgoing edges represented by destination vertex index.
- Frontier will store the vertices which are at the same distance from the source vertex.
- Next Frontier will contain the unexplored neighbors of the vertices from the Frontier.

		n1	n2	n3	n4	n5	n6	n7	n8
P1	n1	0	1	1	0	1	1	0	0
	n2	1	0	1	0	0	0	0	0
P2	n3	1	1	0	1	0	0	0	0
	n4	0	0	1	0	1	0	0	0
P3	n5	1	0	0	1	0	0	1	1
	n6	1	0	0	0	0	0	1	0
P4	n7	0	0	0	0	1	1	0	1
	n8	0	0	0	0	1	0	1	0

Parallel BFS implementation

- A neighbor vertex from one processor may be stored in another processor; hence each processor needs to communicate to those processors about the traversal status.
- Each processor should also receive communication from all other processors to construct the next frontier.
- This requires an all-to-all communication after every step of analyzing the frontier.
- The algorithm ends when the global size of the frontier is zero.

```
BFS_distributed_1D (local G = (V, E), vertex s)
{
    frontier = {}; next_frontier = {}
    curr_level = 0
    for all v belongs to V:
        level[v] = -1;
    if owner(s) = curr_rank:
        level[s] = 0
        frontier.add(s)
    while True
        {   // contains the local vertices in the current frontier
            for u belongs to frontier:
                for v belongs to neighbor(u):
                    w = owner(v)
                    buffer[w].add(v)

            // send & receive buffers to the respective processors
            All to all v (buffer, receive_buffer)

        for all p = [0 .... numRank - 1]:
            next_frontier.merge(receive_buffer[p])

        frontier = {}
        for v belongs to next_frontier:
            if level[v] == -1:
                level[v] = curr_level + 1
                frontier.add(v)

        next_frontier = {}
        curr_level ++
        size = frontier.size()
        AllReduce(size); //sum
        if (size == 0):
            break out of the while loop;

    }
}
```

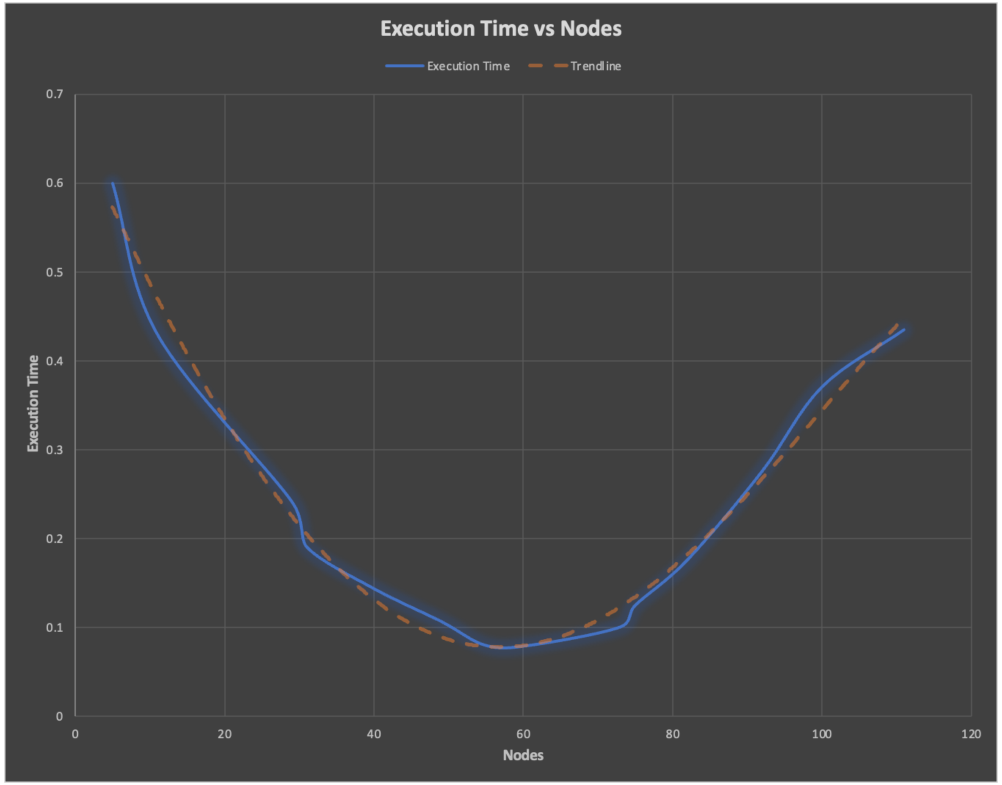
Future Work Status

- **[Completed]** Irregularity in execution time needs investigation for potential code or execution environment errors.
- **[Completed]** Larger graphs with more vertices need to be tested to ensure scalability.
- **[Completed]** Test the algorithm on a higher number of processors for performance evaluation.
- **[Completed]** Calculate the speed up of the parallel BFS algorithm compared to the sequential BFS algorithm.
- **[Completed]** Troubleshoot the Slurm script to make it functional.

Execution Results: Running Time

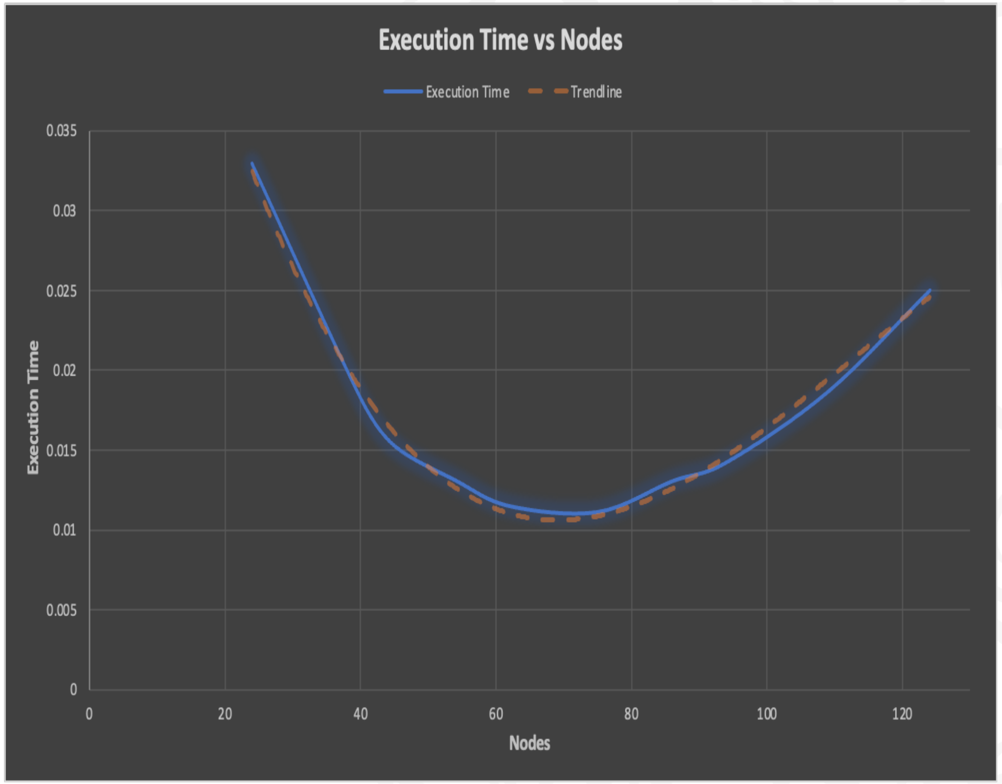
Number of graph vertices: 100

Number of nodes: 125



Number of graph vertices: 500

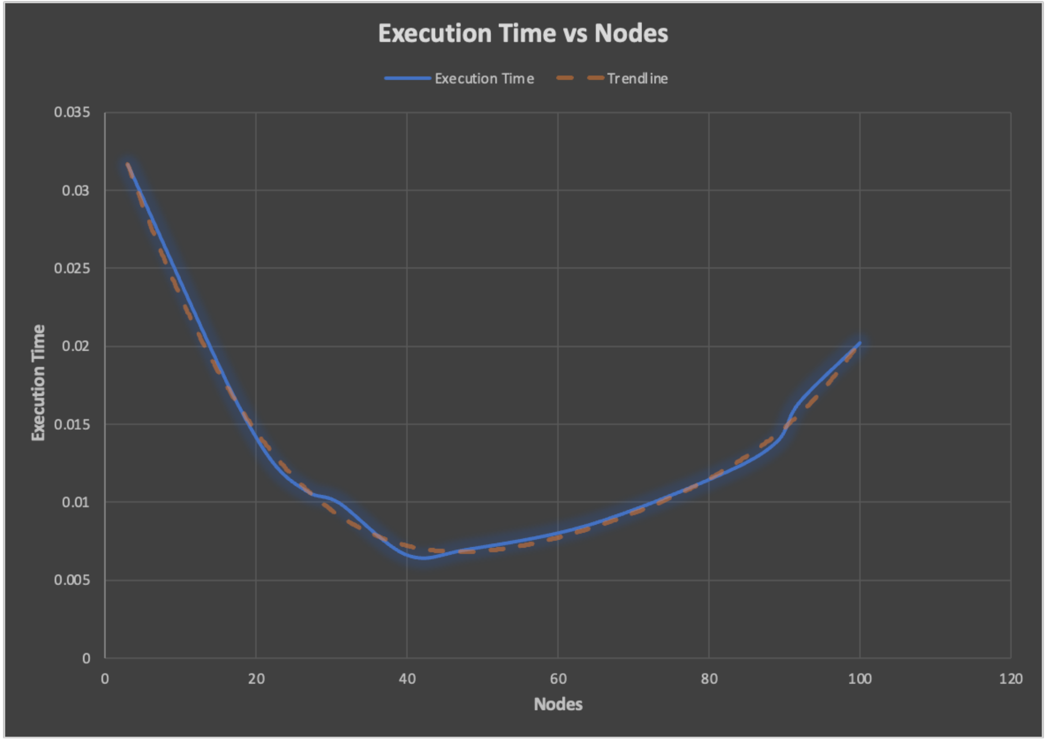
Number of nodes: 125



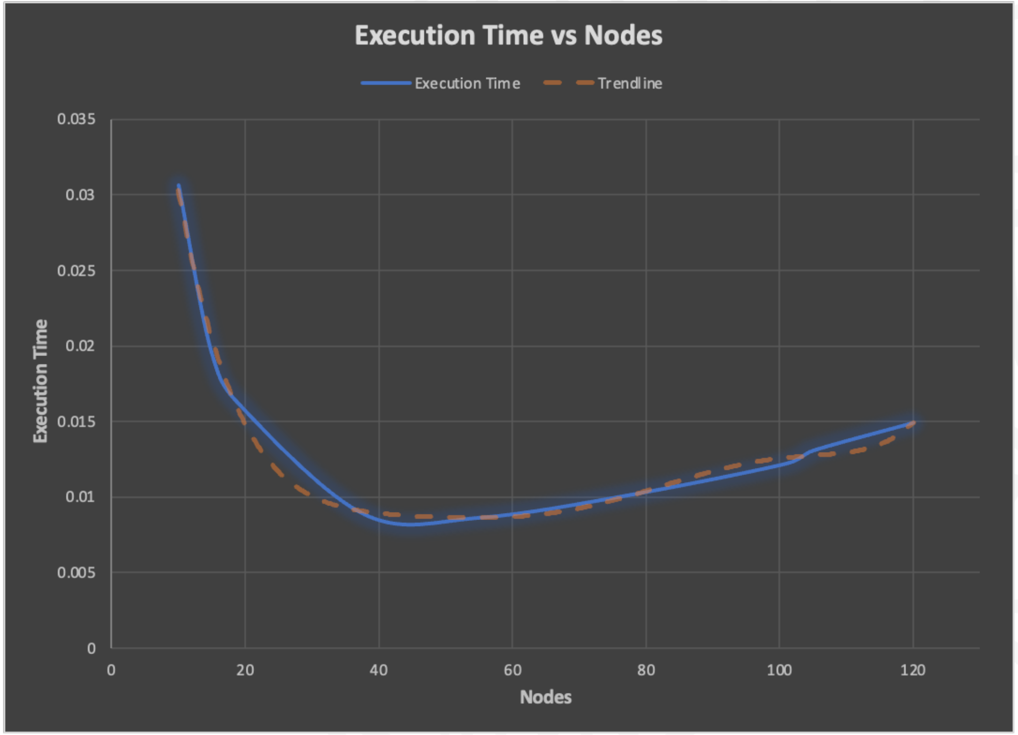
Execution Results: Running Time

Number of graph vertices: 1000

Number of nodes: 125



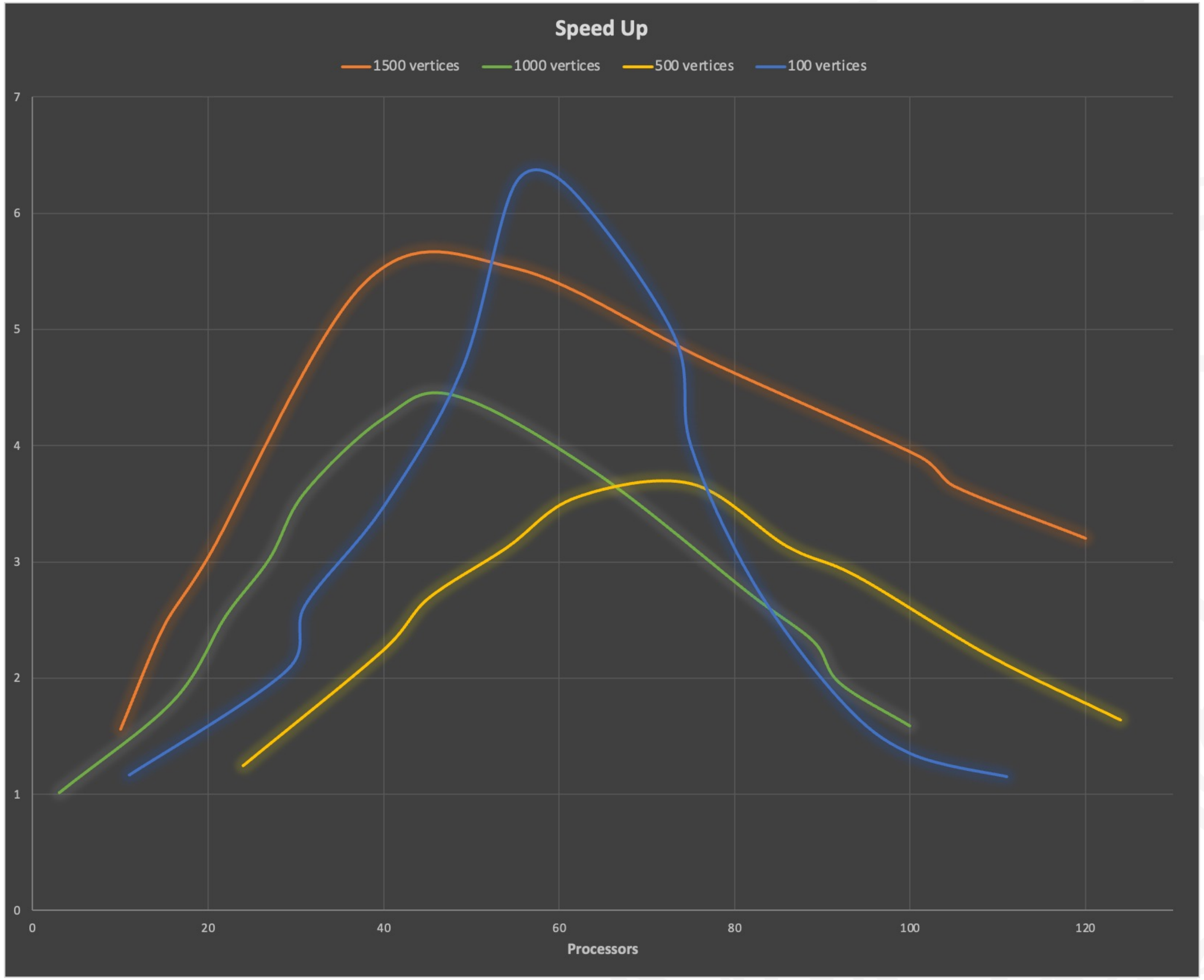
Number of graph vertices: 1500
Number of nodes: 125



Execution Results: Speed Up

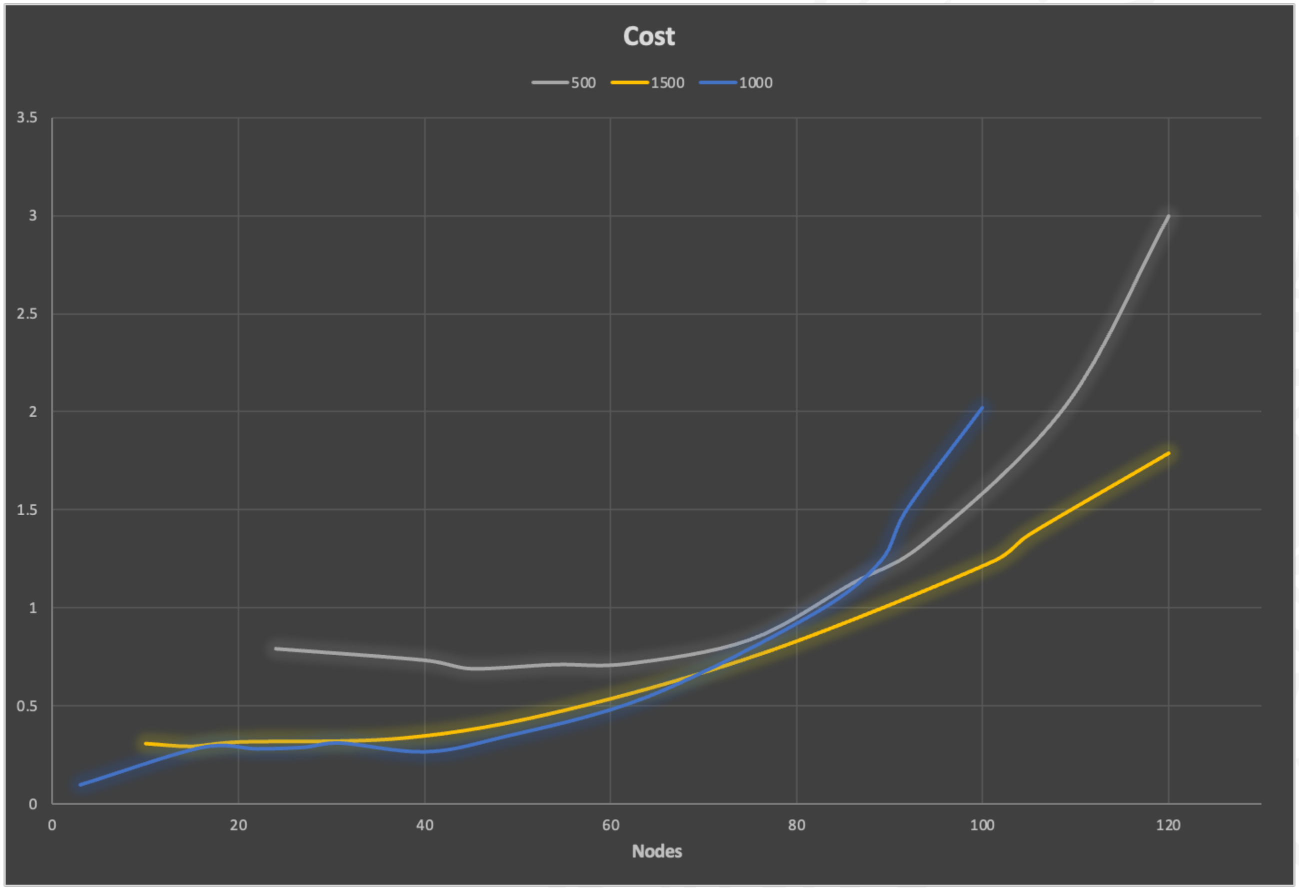
$$Speed\ Up = \frac{Seq.Exec.Time}{Parallel\ Exec.Time}$$

Number of Nodes = 125
Graph Vertices = 100; 500; 1000; 1500



Execution Results: Cost

$$Cost = Execution\,Time\ * No.of\ Processors$$



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