Parallel Computing Lab - Assignment 2

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Under the Guidance of
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Computer Science and Engineering

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My Approach:

The input to the program is number of vertices and number of edges and then the edges given in separate lines as

```
source destination weight
```

And I am using the adjacency matrix representation of the graph. In the graph, weight(i, j) = INF if there is no edge from i to j. This graph (adjacency matrix) is passed to the shortest path algorithm.

My Parallel Implementation:

We know that the following formula is the heart of the Shortest Path Algorithm:

$$\text{shortestPath}(i, j, k) =$$

$$\min\Big(\text{shortestPath}(i, j, k-1), \text{shortestPath}(i, k, k-1) + \text{shortestPath}(k, j, k-1)\Big)$$

The algorithm works by first computing *shortestPath(i, j, k)* for all *(i,j)* pairs for *k=0*, then *k=1*, and so on. This process continues until *k=N - 1*, and we have found the shortest path for all *(i,j)* pairs using any intermediate vertices.

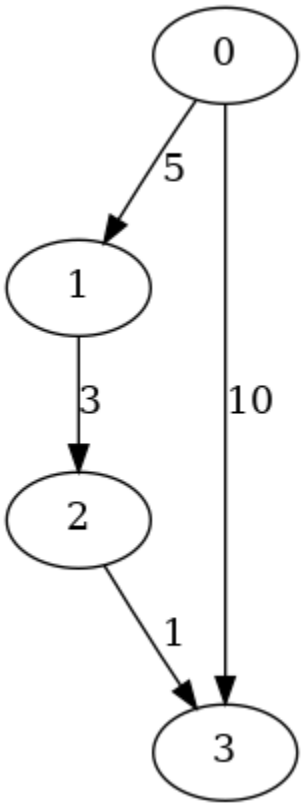
In this formula, we see that newer values of *shortestPath(i, j, k)* are dependent on the previous values of *shortestPath* computed for values of *k* less than current *k*. But, in each iteration of *k*, the values of *i, j* are independent from *i, j* of other iterations. Therefore, I have parallelized the iterations of *i, j* in the above formula using the following openmp directive

```
#pragma omp parallel for collapse(2) num_threads(NUM_THREADS)
```

Here, *collapse* is for parallelizing both the loops (*i* and *j*)

Inputs and Outputs:

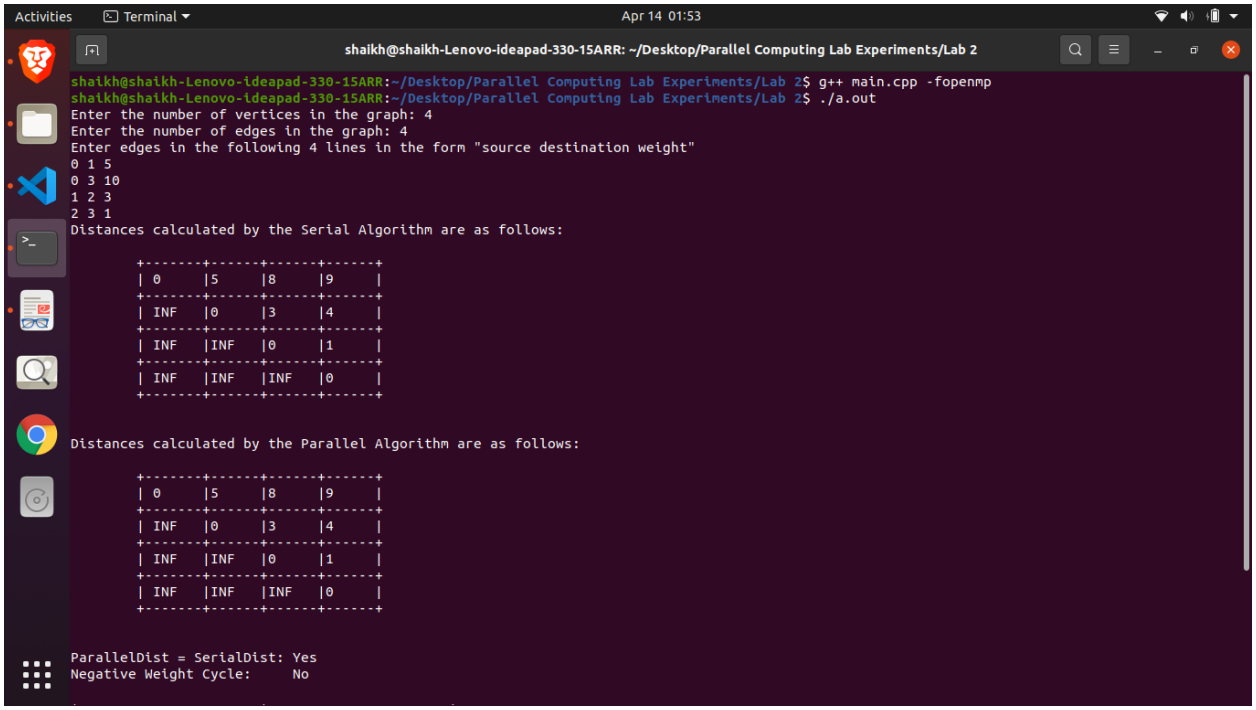
Graph1:

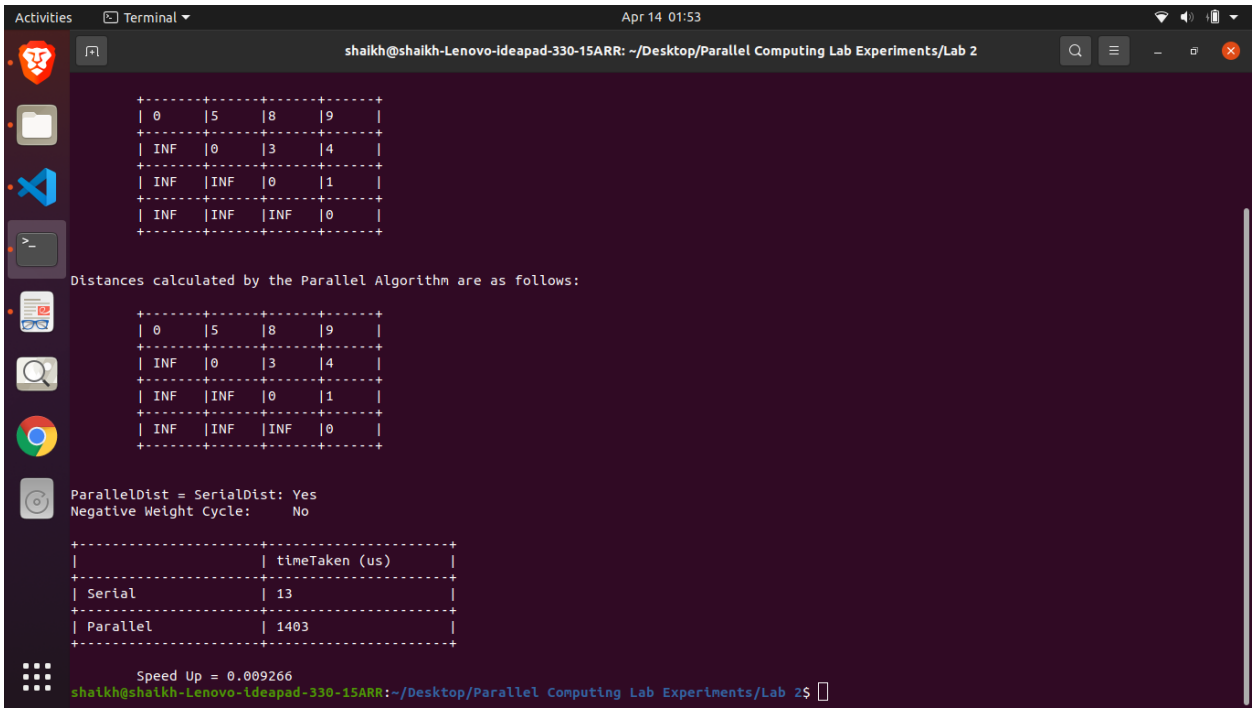


Input:

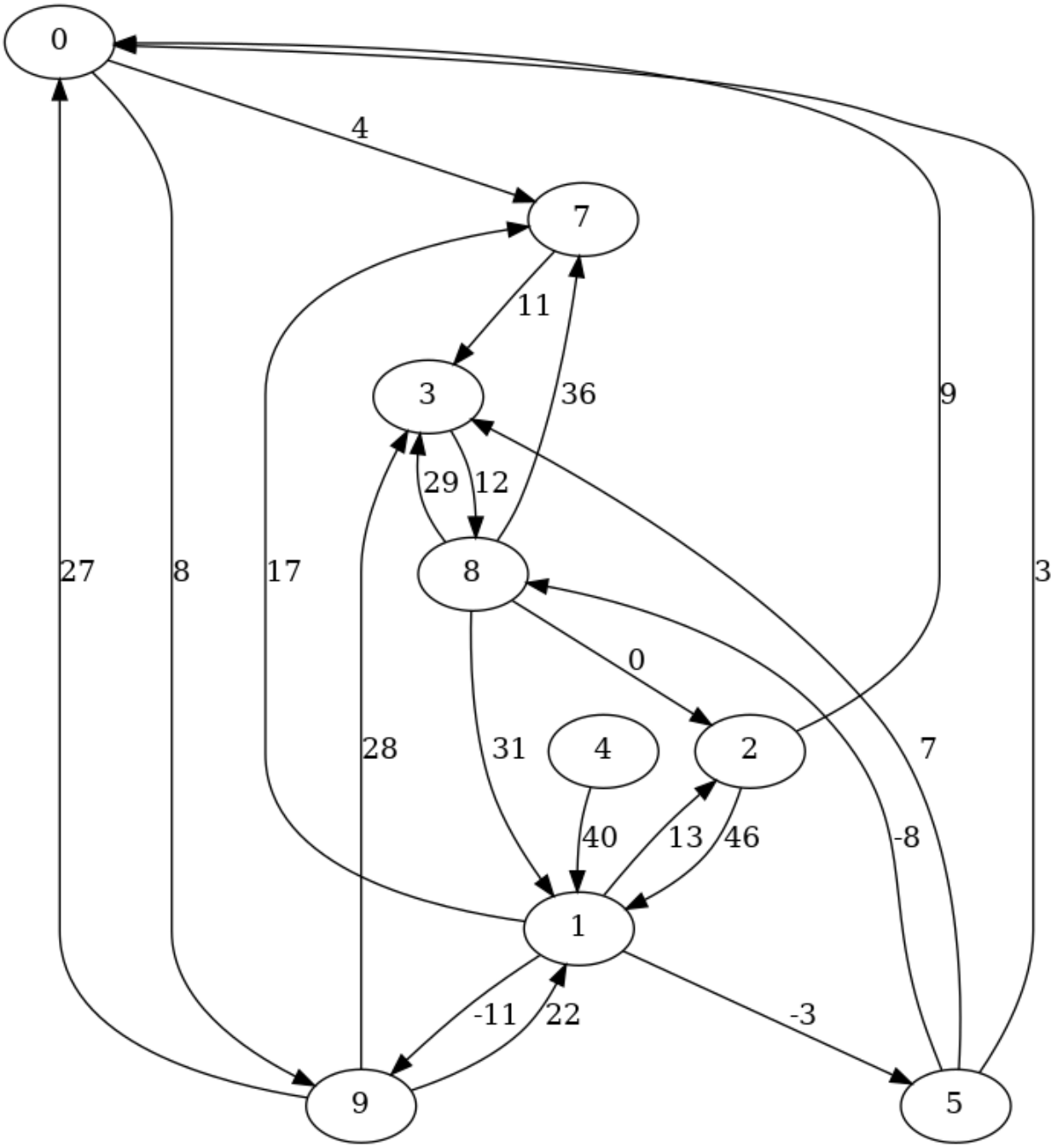
```
4 4
0 1 5
0 3 10
1 2 3
2 3 1
```

Output:


Activities
Terminal
Apr 14 01:53
shaikh@shaikh-Lenovo-ideapad-330-15ARR: ~/Desktop/Parallel Computing Lab Experiments/Lab 2
shaikh@shaikh-Lenovo-ideapad-330-15ARR:~/Desktop/Parallel Computing Lab Experiments/Lab 2$ g++ main.cpp -fopenmp
shaikh@shaikh-Lenovo-ideapad-330-15ARR:~/Desktop/Parallel Computing Lab Experiments/Lab 2$ ./a.out
Enter the number of vertices in the graph: 4
Enter the number of edges in the graph: 4
Enter edges in the following 4 lines in the form "source destination weight"
0 1 5
0 3 10
1 2 3
2 3 1
Distances calculated by the Serial Algorithm are as follows:
+-------+------+------+------+
| 0 |5 |8 |9 |
+-------+------+------+------+
| INF |0 |3 |4 |
+-------+------+------+------+
| INF |INF |0 |1 |
+-------+------+------+------+
| INF |INF |INF |0 |
+-------+------+------+------+
Distances calculated by the Parallel Algorithm are as follows:
+-------+------+------+------+
| 0 |5 |8 |9 |
+-------+------+------+------+
| INF |0 |3 |4 |
+-------+------+------+------+
| INF |INF |0 |1 |
+-------+------+------+------+
| INF |INF |INF |0 |
+-------+------+------+------+
ParallelDist = SerialDist: Yes
Negative Weight Cycle: No


Activities
Terminal
Apr 14 01:53
shaikh@shaikh-Lenovo-ideapad-330-15ARR: ~/Desktop/Parallel Computing Lab Experiments/Lab 2
+-------+------+------+------+
| 0 |5 |8 |9 |
+-------+------+------+------+
| INF |0 |3 |4 |
+-------+------+------+------+
| INF |INF |0 |1 |
+-------+------+------+------+
| INF |INF |INF |0 |
+-------+------+------+------+
Distances calculated by the Parallel Algorithm are as follows:
+-------+------+------+------+
| 0 |5 |8 |9 |
+-------+------+------+------+
| INF |0 |3 |4 |
+-------+------+------+------+
| INF |INF |0 |1 |
+-------+------+------+------+
| INF |INF |INF |0 |
+-------+------+------+------+
ParallelDist = SerialDist: Yes
Negative Weight Cycle: No
+----------------------+----------------------+
| | timeTaken (us) |
+----------------------+----------------------+
| Serial | 13 |
+----------------------+----------------------+
| Parallel | 1403 |
+----------------------+----------------------+
Speed Up = 0.009266
shaikh@shaikh-Lenovo-ideapad-330-15ARR:~/Desktop/Parallel Computing Lab Experiments/Lab 2$

Graph2:

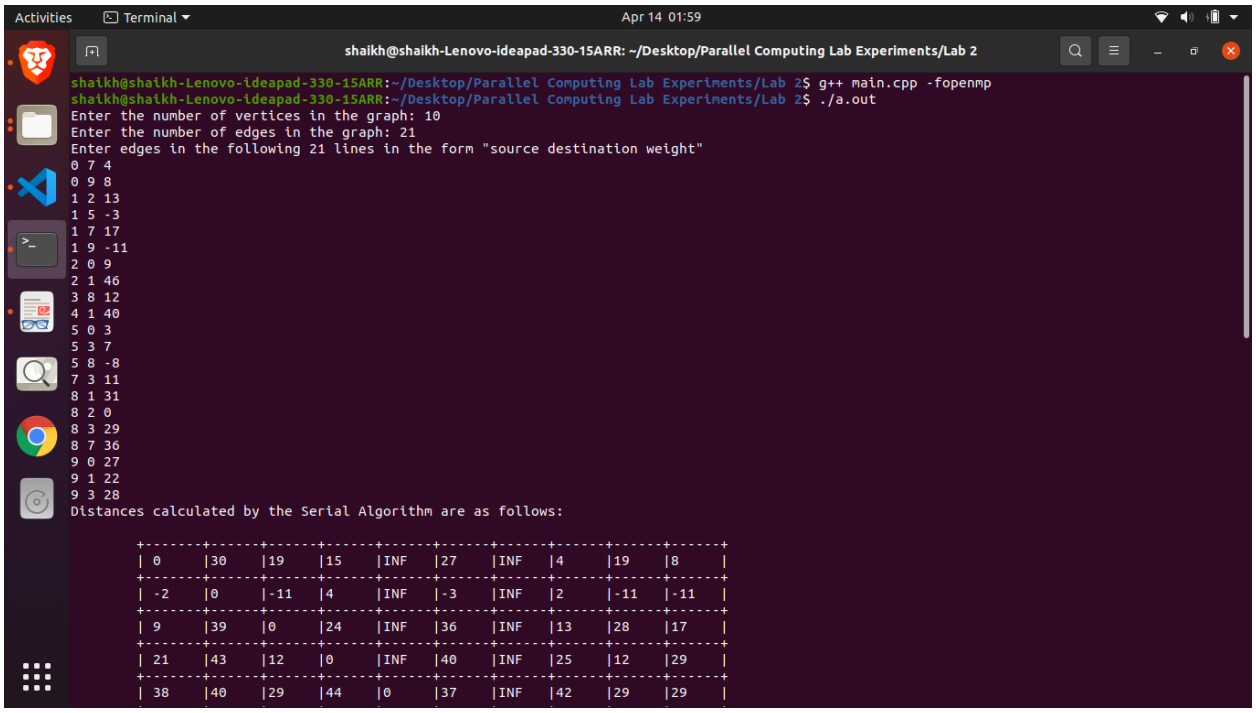


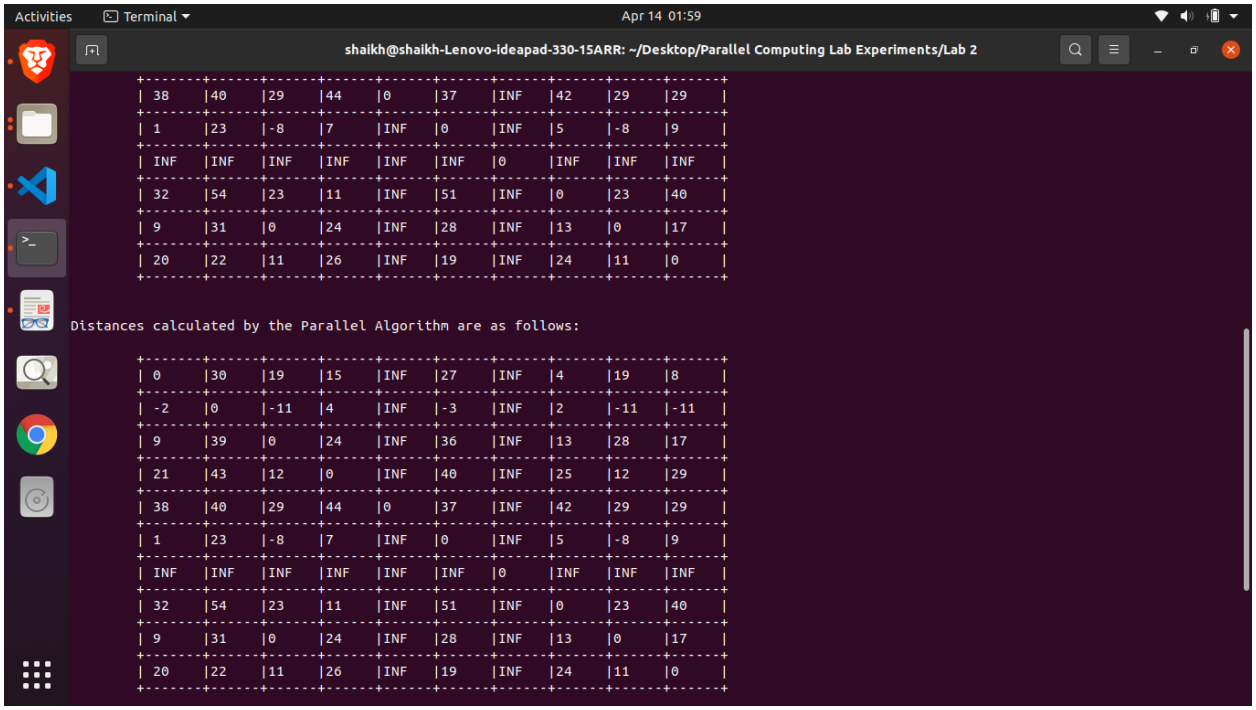
Input:

```
10 21
0 7 4
0 9 8
```

```
1 2 13
1 5 -3
1 7 17
1 9 -11
2 0 9
2 1 46
3 8 12
4 1 40
5 0 3
5 3 7
5 8 -8
7 3 11
8 1 31
8 2 0
8 3 29
8 7 36
9 0 27
9 1 22
9 3 28
```

Output:

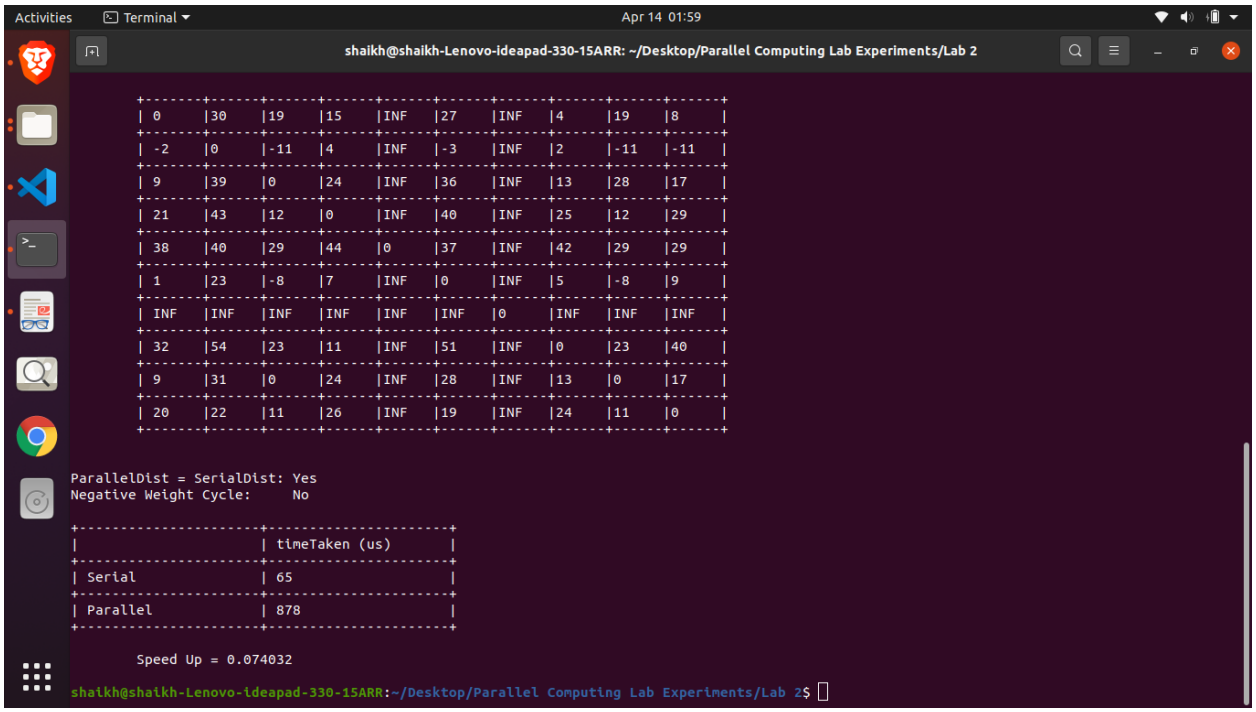





```
+-------+------+------+------+------+------+------+------+------+------+
| 38    |40    |29    |44    |0     |37    |INF   |42    |29    |29    |
+-------+------+------+------+------+------+------+------+------+------+
| 1     |23    |-8    |7     |INF   |0     |INF   |5     |-8    |9     |
+-------+------+------+------+------+------+------+------+------+------+
| INF   |INF   |INF   |INF   |INF   |INF   |0     |INF   |INF   |INF   |
+-------+------+------+------+------+------+------+------+------+------+
| 32    |54    |23    |11    |INF   |51    |INF   |0     |23    |40    |
+-------+------+------+------+------+------+------+------+------+------+
| 9     |31    |0     |24    |INF   |28    |INF   |13    |0     |17    |
+-------+------+------+------+------+------+------+------+------+------+
| 20    |22    |11    |26    |INF   |19    |INF   |24    |11    |0     |
+-------+------+------+------+------+------+------+------+------+------+


Distances calculated by the Parallel Algorithm are as follows:

+-------+------+------+------+------+------+------+------+------+------+
| 0     |30    |19    |15    |INF   |27    |INF   |4     |19    |8     |
+-------+------+------+------+------+------+------+------+------+------+
| -2    |0     |-11   |4     |INF   |-3    |INF   |2     |-11   |-11   |
+-------+------+------+------+------+------+------+------+------+------+
| 9     |39    |0     |24    |INF   |36    |INF   |13    |28    |17    |
+-------+------+------+------+------+------+------+------+------+------+
| 21    |43    |12    |0     |INF   |40    |INF   |25    |12    |29    |
+-------+------+------+------+------+------+------+------+------+------+
| 38    |40    |29    |44    |0     |37    |INF   |42    |29    |29    |
+-------+------+------+------+------+------+------+------+------+------+
| 1     |23    |-8    |7     |INF   |0     |INF   |5     |-8    |9     |
+-------+------+------+------+------+------+------+------+------+------+
| INF   |INF   |INF   |INF   |INF   |INF   |0     |INF   |INF   |INF   |
+-------+------+------+------+------+------+------+------+------+------+
| 32    |54    |23    |11    |INF   |51    |INF   |0     |23    |40    |
+-------+------+------+------+------+------+------+------+------+------+
| 9     |31    |0     |24    |INF   |28    |INF   |13    |0     |17    |
+-------+------+------+------+------+------+------+------+------+------+
| 20    |22    |11    |26    |INF   |19    |INF   |24    |11    |0     |
+-------+------+------+------+------+------+------+------+------+------+
```




```
+-------+------+------+------+------+------+------+------+------+------+
| 0     |30    |19    |15    |INF   |27    |INF   |4     |19    |8     |
+-------+------+------+------+------+------+------+------+------+------+
| -2    |0     |-11   |4     |INF   |-3    |INF   |2     |-11   |-11   |
+-------+------+------+------+------+------+------+------+------+------+
| 9     |39    |0     |24    |INF   |36    |INF   |13    |28    |17    |
+-------+------+------+------+------+------+------+------+------+------+
| 21    |43    |12    |0     |INF   |40    |INF   |25    |12    |29    |
+-------+------+------+------+------+------+------+------+------+------+
| 38    |40    |29    |44    |0     |37    |INF   |42    |29    |29    |
+-------+------+------+------+------+------+------+------+------+------+
| 1     |23    |-8    |7     |INF   |0     |INF   |5     |-8    |9     |
+-------+------+------+------+------+------+------+------+------+------+
| INF   |INF   |INF   |INF   |INF   |INF   |0     |INF   |INF   |INF   |
+-------+------+------+------+------+------+------+------+------+------+
| 32    |54    |23    |11    |INF   |51    |INF   |0     |23    |40    |
+-------+------+------+------+------+------+------+------+------+------+
| 9     |31    |0     |24    |INF   |28    |INF   |13    |0     |17    |
+-------+------+------+------+------+------+------+------+------+------+
| 20    |22    |11    |26    |INF   |19    |INF   |24    |11    |0     |
+-------+------+------+------+------+------+------+------+------+------+


ParallelDist = SerialDist: Yes
Negative Weight Cycle:     No

+---------------------+---------------------+
|                     | timeTaken (us)      |
+---------------------+---------------------+
| Serial              | 65                  |
+---------------------+---------------------+
| Parallel            | 878                 |
+---------------------+---------------------+

       Speed Up = 0.074032

shaikh@shaikh-Lenovo-ideapad-330-15ARR:~/Desktop/Parallel Computing Lab Experiments/Lab 2$
```

Graph3:


12
33
16
1
4
20
11
44
47
45
10
3
31
25
9
29
26
41
42
28
30
22
39
27
5
15
48
34
6
18
8
40
21
32
43
0
24
13
7
2
37
38
36
46
23
35
49
17
19
14

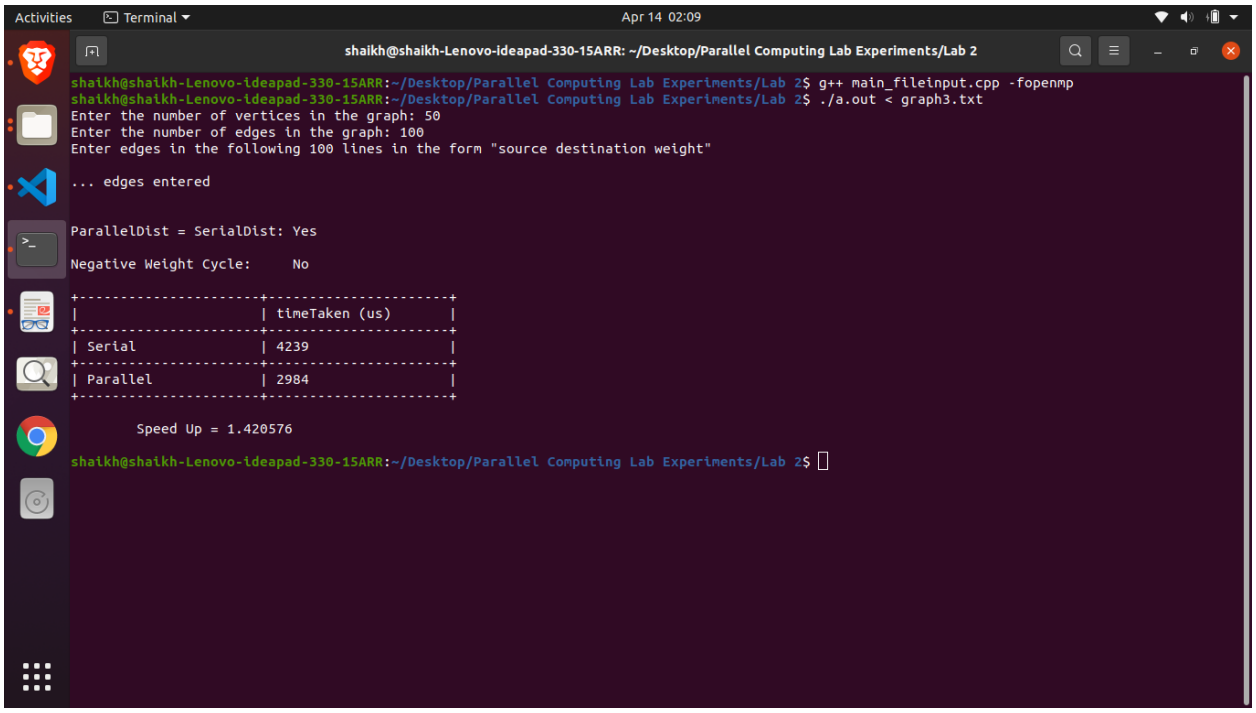
Input:

```
50 100
0 24 56
1 4 31
1 22 115
1 26 71
2 36 42
2 38 130
2 43 144
3 4 124
3 38 -15
3 42 3
4 11 165
4 44 113
5 0 162
5 15 -19
5 32 88
6 0 98
7 37 -6
7 38 117
7 49 49
8 21 12
9 42 17
9 46 190
10 5 75
10 14 126
10 42 129
11 41 92
12 24 -2
12 33 -24
13 2 92
13 7 140
13 19 13
15 48 92
16 4 87
17 14 5
18 12 181
19 15 175
20 13 85
20 44 93
20 47 78
21 32 33
```

```
21 43 172
21 47 23
22 39 19
22 41 116
23 19 35
25 41 -37
25 43 108
26 2 0
26 7 84
26 42 149
27 5 48
27 42 -30
28 13 164
28 22 41
28 30 84
29 13 133
29 19 89
29 32 -19
29 42 80
30 3 128
30 27 182
32 0 160
32 15 84
32 47 53
32 48 -25
33 16 -6
33 24 19
34 3 -47
34 8 98
34 18 200
35 17 150
36 23 -30
37 23 48
37 46 -45
38 16 103
40 7 150
40 32 109
41 18 114
41 22 189
42 22 -8
42 30 104
42 38 -25
43 13 157
```

```
43 33 -26
44 0 84
44 47 156
45 15 66
45 29 78
45 35 48
46 17 161
46 49 88
47 3 25
47 15 14
47 31 53
47 49 145
48 6 134
48 8 196
48 34 91
48 37 160
48 49 193
```

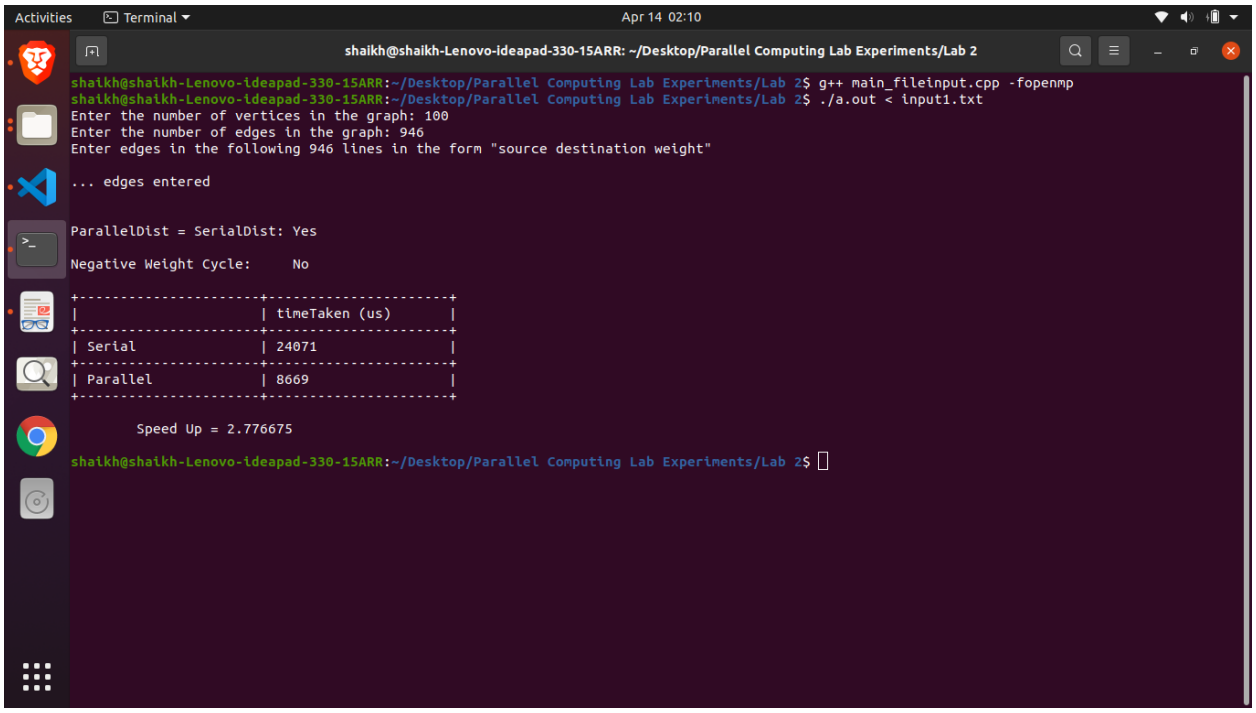
Output:

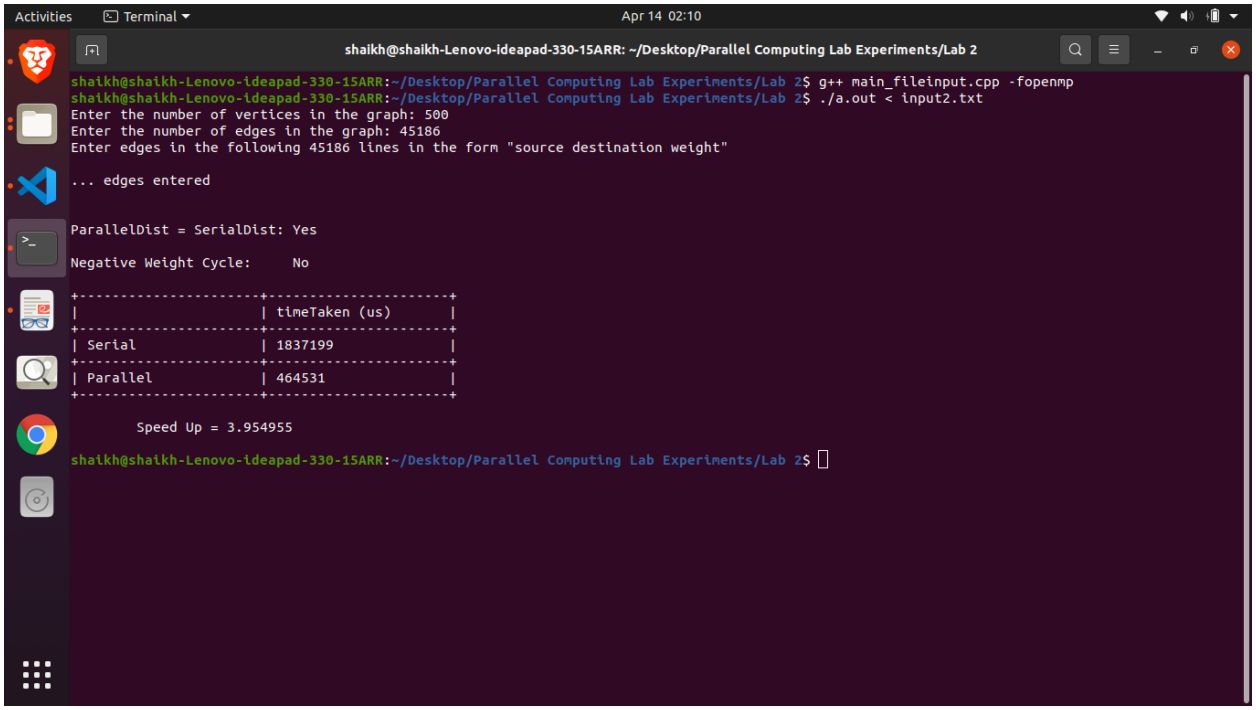


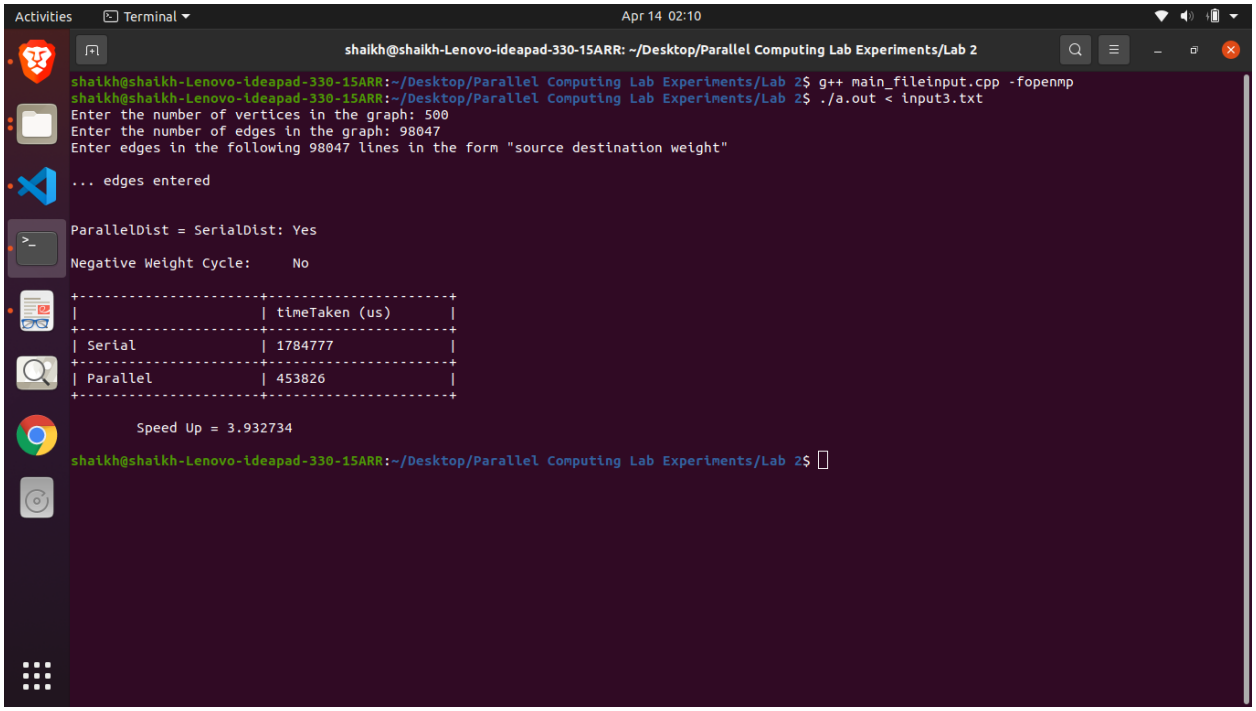
Big Inputs:

(These inputs are too big for pasting here, I request you to check in uploaded files)

Outputs for Input1.txt, input2.txt and input3.txt:



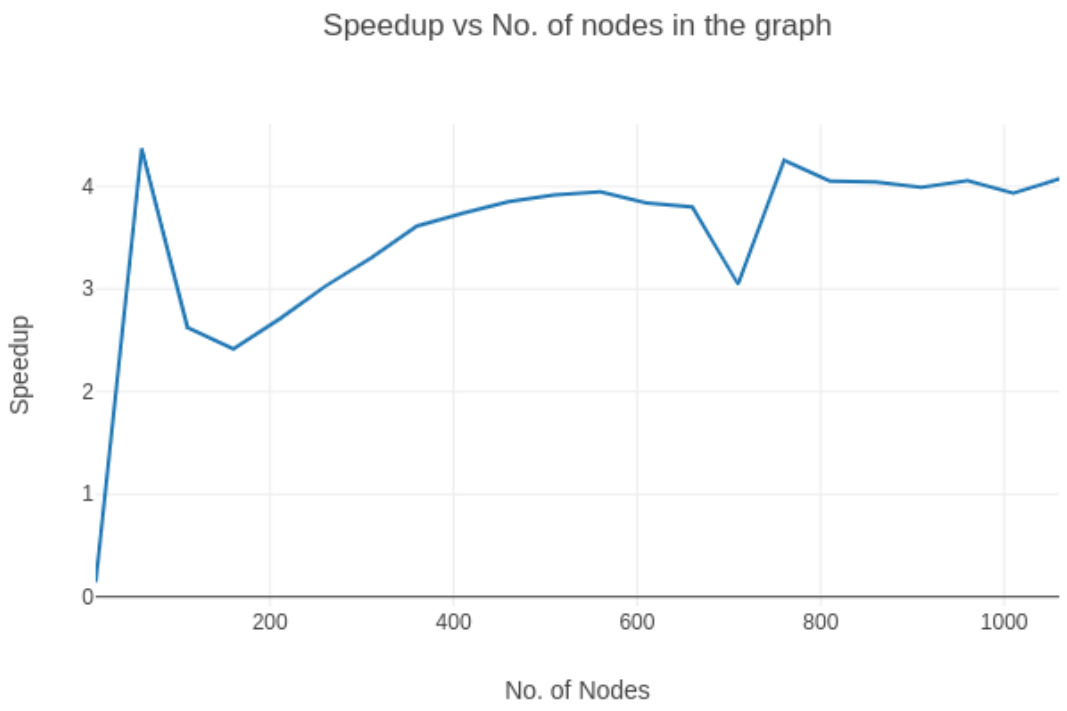

Activities
Terminal
Apr 14 02:10
shaikh@shaikh-Lenovo-ideapad-330-15ARR: ~/Desktop/Parallel Computing Lab Experiments/Lab 2
shaikh@shaikh-Lenovo-ideapad-330-15ARR:~/Desktop/Parallel Computing Lab Experiments/Lab 2$ g++ main_fileinput.cpp -fopenmp
shaikh@shaikh-Lenovo-ideapad-330-15ARR:~/Desktop/Parallel Computing Lab Experiments/Lab 2$ ./a.out < input2.txt
Enter the number of vertices in the graph: 500
Enter the number of edges in the graph: 45186
Enter edges in the following 45186 lines in the form "source destination weight"
... edges entered
ParallelDist = SerialDist: Yes
Negative Weight Cycle: No
	timeTaken (us)
Serial	1837199
Parallel	464531
Speed Up = 3.954955
shaikh@shaikh-Lenovo-ideapad-330-15ARR:~/Desktop/Parallel Computing Lab Experiments/Lab 2$

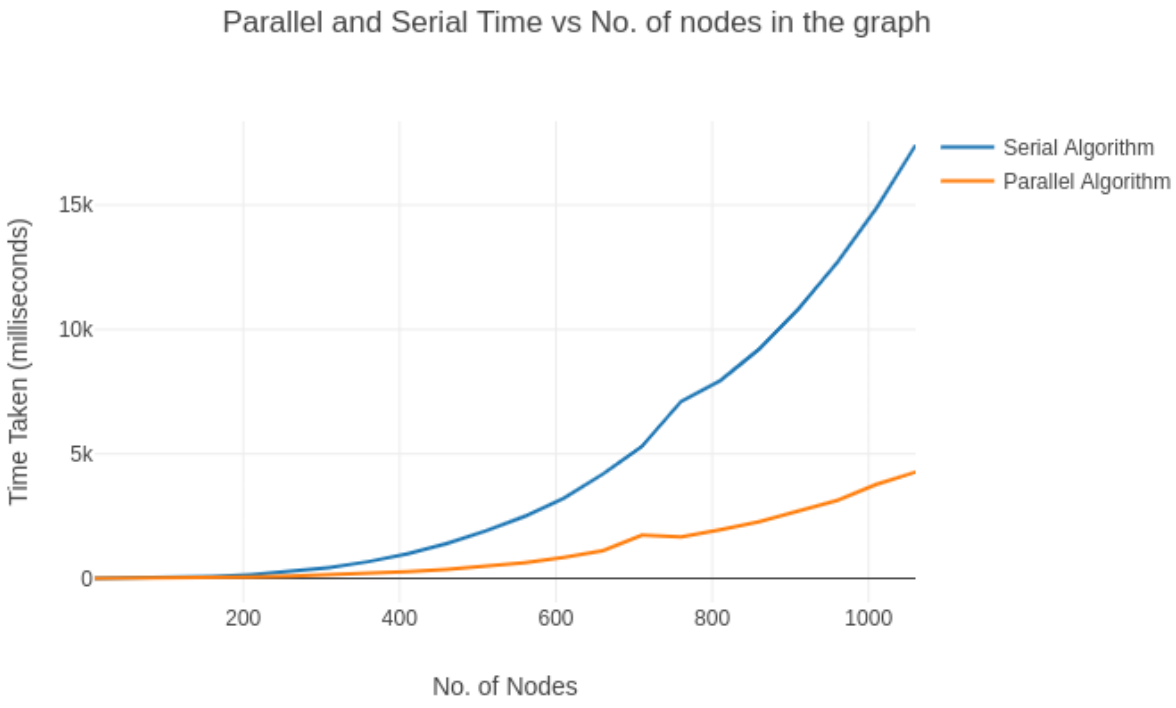

Activities
Terminal
Apr 14 02:10
shaikh@shaikh-Lenovo-ideapad-330-15ARR: ~/Desktop/Parallel Computing Lab Experiments/Lab 2
shaikh@shaikh-Lenovo-ideapad-330-15ARR:~/Desktop/Parallel Computing Lab Experiments/Lab 2$ g++ main_fileinput.cpp -fopenmp
shaikh@shaikh-Lenovo-ideapad-330-15ARR:~/Desktop/Parallel Computing Lab Experiments/Lab 2$ ./a.out < input3.txt
Enter the number of vertices in the graph: 500
Enter the number of edges in the graph: 98047
Enter edges in the following 98047 lines in the form "source destination weight"
... edges entered
ParallelDist = SerialDist: Yes
Negative Weight Cycle: No
	timeTaken (us)
Serial	1784777
Parallel	453826
Speed Up = 3.932734
shaikh@shaikh-Lenovo-ideapad-330-15ARR:~/Desktop/Parallel Computing Lab Experiments/Lab 2$

Observing the Variation in Speedup, Parallel and Serial Time with respect to no. of Nodes and no. of Threads:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	no_of_nodes	10	60	110	160	210	260	310	360	410	460	510	560	610	660	710	760	810
2	speedup	0.142442	4.370819	2.627474	2.417334	2.706504	3.027305	3.301822	3.614327	3.73897	3.85143	3.919881	3.950192	3.841923	3.800508	3.048716	4.256671	4.053152
3	serial_time	0	9	26	65	137	259	430	672	989	1398	1904	2485	3208	4191	5296	7098	7937
4	parallel_time	0	2	10	26	50	85	130	186	264	363	485	629	835	1102	1737	1667	1958
5																		
6	no_of_threads	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
7	speedup	1.024423	1.804452	2.562682	4.28177	3.044055	3.721787	4.161798	4.858617	2.639906	2.200895	2.309802	2.251599	2.827546	2.656876	3.397534	2.489104	2.632571
8																		

Speedup Vs No. of nodes (threads cnt = 8)





No. of threads vs speedup (n = 500)