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A New Approach to Generate Line Graphs of Undirected and Directed Graphs

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Abstract: In this paper we have introduced a new matrix and developed two algorithms to generate line graphs of undirected and directed graphs (digraph). The algorithms are tested for a large number of random graphs and the outputs are appended at the end of the paper. It has been found that the actual computing time is nearly 1% of the theoretical bound $O(n^4)$ of the algorithms.

Keywords: adjacency matrix; incidence matrix; line graph; time complexity of algorithm

Mathematics Subject Classification: 05C85

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1. Introduction

Let G(V,E) be a simple undirected graph where V = {v_i | i= 1,2,…,n } is the set of vertices and E ={ e_i | i= 1,2,…,m } the set of edges in G[West, 2000]. The line graph of G, denoted by L(G), is defined by a simple undirected graph with m vertices and $q = -m + (\sum d_i{}^2)/2$ edges where d_i denotes the degree of the vertex v_i . The vertices in L(G) correspond to the edges in G, and two vertices in L(G) are adjacent if the corresponding edges in G have a vertex in common. If B is the incidence matrix of G, it is known that the adjacency matrix of L(G) is B^TB (modulo 2) and the time complexity of computing L(G) by this result is $O(n^5)$ [Harary, 1994].

Line graph of a graph was independently discovered by many authors. Whitney was the first, but he did not assign any name to it. But others gave it different names. Hoffman: line graphs; Beineke: derived ; Kasteleyn : covering; Menon : adjoint. Ore: interchange graphs; Sabidussi: derivative; Seshu and Reed: edge-to-vertex. Line graphs have lots of applications in electrical engineering [Harary, 1994], in communication networks [Krawczyk M et al, 2011], in 'characterization of DNA sequences' [Kumar. V, 2010], in 'Codes and designs' [Fish.W et al, 2011] in VLSI design [Tatsuo.O et al, 1979], to mention a few.

In this paper a new matrix called degree edge matrix of an undirected graph G has been used as a data structure to develop an efficient algorithm to generate L(G) from G. An analogous development for generating line graph of a digraph has also been done. The computing time of the algorithms for generating line graphs of undirected graphs as well as directed graphs is $O(n^4)$ [Chartrand. and Oellermann, 1993]. Both the algorithms have been coded to C programming [ ] and tested for a large number of random graphs with varying densities. When the programs are run for undirected as well as directed graphs, it has been found that the actual computing time in both the cases is nearly 1% of the theoretical bound $O(n^4)$.

In section 2, we have given relevant definitions with illustrations. In section 3, a new method is developed with a new matrix to generate line graphs undirected graphs. In section 4, we have suggested how we can minimize actual computing time. An algorithm for generating line graph of an undirected graph is developed in this section. In section 5, an analogous development for generating line graph of a digraph is given. Programmers in C corresponding to these two algorithms are written and tested for random graphs with varying densities. Finally, the outputs are appended at the end of the paper.

2. Definitions:

Definition1. The edge matrix of G (n,m), denoted by E (G), is a (2 x m) matrix defined by

$$E(G) = \begin{pmatrix} v_{11} \; v_{12} \cdots\cdots v_{1m} \\ \\ v_{21} \; v_{22} \cdots\cdots v_{2m} \end{pmatrix}$$

where a column represents two end vertices of an edge of G.

The vertices of G are renamed as v_{ij} and the edges as (v_{1j}, v_{2j}) for (i= 1,2; j= 1,2,...,m).

Obviously, for a graph without self loops v_{1j} v_{2j}, j= 1,2 ... , m

and without parallel edges $\begin{pmatrix} v_{1j} \\ v_{2j} \end{pmatrix} \neq \begin{pmatrix} v_{1j} \\ v_{2j} \end{pmatrix}$, i$\leq j \neq k \leq m$

Since G is undirected, without any loss of generality we can choose the end vertices of the edges e_j as $v_{1j} < v_{2j}$ for 1≤ j≤ m.

Thus if we compare any two columns (say j the and k th) of E(G), then two possible cases may arise:

(a) $e_j = \begin{pmatrix} v_{1j} \\ v_{2j} \end{pmatrix}$ and $e_k = \begin{pmatrix} v_{1k} \\ v_{2k} \end{pmatrix}$ have one vertex in common

(b) $e_j = \begin{pmatrix} v_{1j} \\ v_{2j} \end{pmatrix}$ and $e_k = \begin{pmatrix} v_{1k} \\ v_{2k} \end{pmatrix}$ have no vertex in common

Thus the adjacency between the edges of G can be studied with the help of the edge matrix of the graph.

Definition 2. The degree of an edge e = (u,v), denoted by d(e), is defined by

$$d(e) = d(u) + d(v) - 2.$$

Definition 3. The degree edge matrix of G (n,m), denoted by DE(G), is a (3 x m) matrix defined by

$$DE(G) = \begin{pmatrix} v_{11} \; v_{12} \cdots\cdots v_{1m} \\ v_{21} \; v_{22} \cdots\cdots v_{2m} \\ v_{31} \; v_{32} \cdots\cdots v_{3m} \end{pmatrix}$$

where the submatrix formed by the first two rows of DE(G) is the matrix E(G) and v_{3j} is the degree of the edge e_j for j = 1,2,..,m . The third row of DE(G) will be called the degree edge vector of G. In an analogous way we can define the matrices EL(G) and DEL(G) as the Edge Matrix and Degree Edge Matrix respectively of L(G).

3. A New Method to Generate Line Graph of an Undirected Graph

We now present a new method based on the edge matrix of a graph G as data structure to generate line graph of an undirected graph. To explain the method we consider the following examples.

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Here the number of edges is 5 and the degrees of the vertices are 2, 3, 2, and 3.
So the number of columns of EL(G) is q= -5 + (4+9+4+9)/2 = 8.
From the 1st and 2nd columns of E(G), we see e_1 and e_2 are adjacent, hence they will be the vertices of L(G). So the 1st column of EL(G) is $\begin{bmatrix}1\\2\end{bmatrix}$ (for convenience writing i for e_i etc.)
Again, the lst and the 3rd columns of E(G) have an element (viz.2) in common, the 2nd column of EL(G) will be $\begin{bmatrix}1\\3\end{bmatrix}$
Following this way we get the edge matrix of the line graph of G as

$$EL(G) = \begin{pmatrix} 1 & 1 & 1 & 2 & 2 & 3 & 3 & 4 \\ 2 & 3 & 4 & 4 & 5 & 4 & 5 & 5 \end{pmatrix}$$

Since E(G) completely characterizes G, EL(G) does the same for L(G). The method of constructing EL(G) from E(G) as mentioned above is better than the existing method because the time complexity for computing EL(G) from E(G) is $O(n^4)$. This is due to the fact that the number of times the inner loop executed in the worst case is

$$(m-1)+(m-2)+\cdots+2+1= m(m-1)/2= O(m^2) = O(n^4).$$

4. Improvement of Actual Computing Time of Our Method

We can still make some improvement of the method mentioned in section 3 by slightly changing the input data structure. In the above method we have compared the 1st column with (m-1) columns (and the 2nd column with (m-2) columns and so on) without having any prior knowledge about the adjacency of the 1st edge (respectively the 2nd edge and so on) with others. So if, for example, the 1st edge is adjacent to p number of edges in G, we need not continue searching as soon as the comparison between the first edge and the adjacent p edges are over. So the effective computing time in most of the cases will decrease, although the theoretical bound of computing time remains the same. Therefore, from practical point of view it is better to use DE(G) for generating EL(G) or DEL(G). An algorithm for generating DEL(G) from DE(G) is given below.

Algorithm 1

Step 1 j=1

Step 2 If $v_{3j} = 0$ then go to Step 10

Step 3 k=j +l

Step 4 If $v_{3k} = 0$ then go to Step7.

Step 5 If the j th and the k th columns of DE(G) have one element in common, then $\begin{bmatrix}j\\k\end{bmatrix}$ will be an edge in DEL(G) with degree
$v_{3j} + v_{3k} - 2$ /* original degrees are taken */
$v_{3j} = v_{3j} -1$, $v_{3k} = v_{3k} -1$. /* degree edge vector updated formulae */

Step 6 If deg(e_j) = 0 then go to Step10

Step 7 k=k+l

Step 8 If k > m then print" Error ": goto Step 14

Step 9 Go to Step 4

Step 10 j= j+l

Step 11 If j = m then print" Error ": goto Step 14

Step 12 Go to Step 2

Step 13 Print DEL(G).

Step 14. Stop**.**

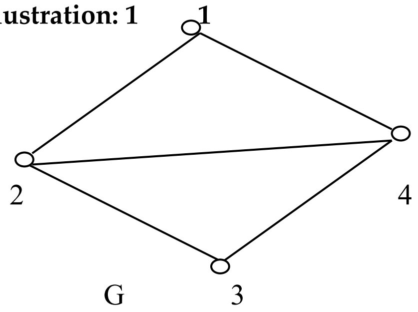
Following the algorithm given above we demonstrate below how the actual computing time reduces for generating line graph from a given undirected graph.

Illustration: 2 DE(G) of the graph as shown in shown in Figure 1 is given by

$$DE(G) = \begin{pmatrix} 1\ 1\ 2\ 2\ 3 \\ 2\ 4\ 3\ 4\ 4 \\ 3\ 3\ 3\ 4\ 3 \end{pmatrix}$$

Since v_{31} 0, v_{32} 0 and the corresponding columns have an element (here '1') in common, thus $\begin{bmatrix} 1 \\ 2 \end{bmatrix}$ will be an edge of L(G) with degree d(1)+ d(2) - 2= 4. (original values of v_{3j} are stored in a linear array).

Illustration: 1 **The edge matrix of G is**



$$E(G) = \begin{pmatrix} 1 & 1 & 2 & 2 & 3 \\ 2 & 4 & 3 & 4 & 4 \end{pmatrix}$$

Figure 1.

To update the degrees of the corresponding edges of G [i.e., the elements of the third row of DE(G)] we replace v_{31} by v_{31}-1 and v_{32} by v_{32} -1. We next compare the first column (provided v_{31}-1 0) and the third column (since v_{33} 0) of DE(G). The moment the updated value of v_{31} becomes zero, we move to the next column v_{3j} , 2 j m , provided its updated value is non-zero.

The degree of $\begin{bmatrix} 1 \\ 2 \end{bmatrix}$ in ELG = (deg of e_1+deg of e_2 in DE(G)) -2 = 3+3-2 = 4.

In this way we get the degree edge matrix [DEL(G)] of the line graph of the above graph as

$$DEL(G) = \begin{pmatrix} 1\ 1\ 1\ 2\ 2\ 3\ 3\ 4 \\ 2\ 3\ 4\ 4\ 5\ 4\ 5\ 5 \\ 4\ 4\ 5\ 5\ 4\ 5\ 4\ 5 \end{pmatrix}$$

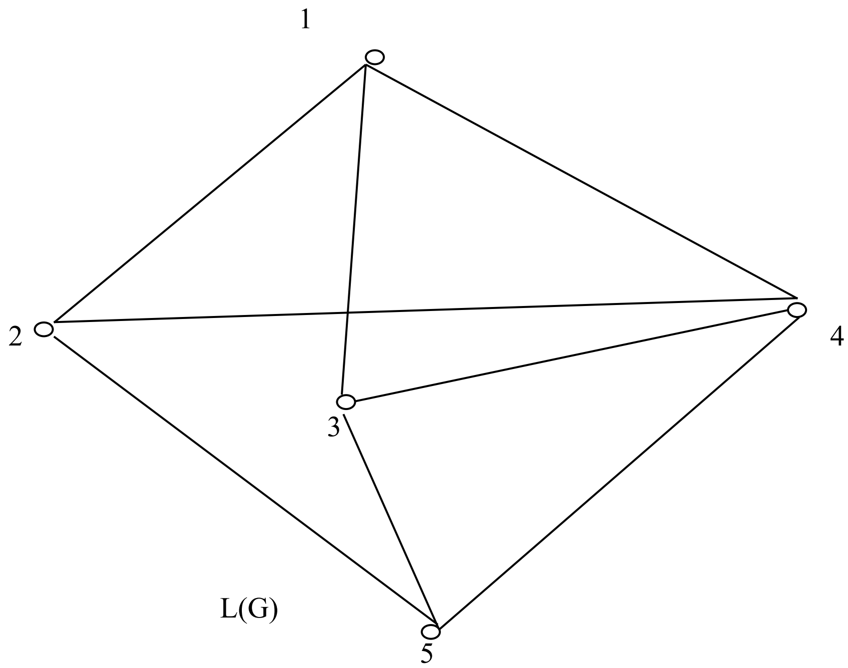


Figure 2.

The degree edge vector of the graph G is (3,3,3,4,3). We depict below how the degrees of the edges are changing when we implement Algorithm 1.

Degree edge vector	**Degree sum**
(3 3 3 4 3)	16
(2 2 3 4 3)	14
(1 2 2 4 3)	12
(0 2 2 3 3)	10
(0 1 2 2 3)	8
(0 0 2 2 2)	6
(0 0 1 1 2)	4
(0 0 0 1 1)	2
(0 0 0 0 0)	0

The algorithm stops when the Degree sum becomes 0.

5. Line Graph of Directed Graph:

The concept of line graph of a graph can be extended to that of a digraph in an analogous way. But a difficulty arises in assigning a unique line digraph corresponding to a digraph, for there are three possible ways of defining the adjacency between any two arcs of a digraph. In fact, each of the following three types of adjacency (i) head-to-head, (ii) head-to-tail or tail-to-head and (iii) tail-to-tail corresponds to a line digraph and consequently they differ significantly. The convention is to accept "head-to-tail" adjacency for defining line graph of a digraph and we will stick to that. However, head-to-head and tail-to-tail adjacency relations are used in digraphs corresponding to food webs. Head-to head adjacency relation identifies species having common predators and thus the preys form Common enemy or Resource graphs; while tail-to tail adjacency relation identifies species having common preys and thus the predators form Competition or Consumer graphs [Mukherjee, 2010].

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Definition 4. The degree of an arc $e_j=(v_{ij}, v_{2j})$, denoted by deg(e_j), is defined by the out degree of the vertex v_{2j} (i.e.,deg (e_j)=d^+ (v_{2j})).

Definition 5. The degree arc matrix of a digraph, denoted by DA(G), is defined by

$$DA(G) = \begin{pmatrix} v_{11} & v_{12} \cdots\cdots v_{1m} \\ v_{21} & v_{22} \cdots\cdots v_{2m} \\ v_{31} & v_{32} \cdots\cdots v_{3m} \end{pmatrix}$$

where the j th column ,1 j m, denote the j th arc emanating from the vertex v_{1j} and converging to the vertex v_{2j}, and v_{3j}=deg(e_j). The third row of DA(G) will be called the degree arc vector of a digraph G.

Thus to compare whether e_j and e_k are adjacent, we are to check whether v_{2j} is identical with v_{1k}. If e_j and e_k are adjacent, we shall update the degree of the arcs just by reducing the degree of e_j by unity only (i.e,v_{3j} is updated by v_{3j}-1, but v_{3k} remains same).

In DAL(G), the degree of the arc $\begin{bmatrix} j \\ k \end{bmatrix}$ will be calculated from DAG as:

degree of the arc e_k = out degree of v_{2k}.

The degree arc matrix is

$$DAG = \begin{pmatrix} 1 & 1 & 2 & 3 & 4 & 4 \\ 2 & 3 & 4 & 2 & 3 & 5 \\ 1 & 1 & 2 & 1 & 1 & 0 \end{pmatrix}$$

Here v_{31} 0, so we compare between e_1 and e_2. Since v_{21} v_{12}, we next compare and see that $v_{21} = v_{13}$, hence $\begin{bmatrix} 1 \\ 3 \end{bmatrix}$ is an arc of the line digraph with degree2 (since $v_{33} = 2$).

Since v_{31}= 0 (updated value), we move to the second column and see that v_{32} 0. We now compare e_2 with e_1 [although deg(e_1) = 0].

Since v_{22} v_{11}, we compare v_{22} with v_{13} and find v_{22} v_{13}.

Next we see $v_{22} = v_{14}$. So $\begin{Bmatrix} 2 \\ 4 \end{Bmatrix}$ is an arc of the line digraph with degree1.

In this way we construct DAL(G) of the given DA(G) as

$$DAL(G) = \begin{pmatrix} 1 & 2 & 3 & 3 & 4 & 5 \\ 3 & 4 & 5 & 6 & 3 & 4 \\ 2 & 1 & 1 & 0 & 2 & 1 \end{pmatrix}$$

Algorithm for DAL(G) will differ from that of DEL(G) in the following points.

(i) If e_j is adjacent to e_k then only deg(e_j) is updated.

(ii) To check whether e_j is adjacent to e_k, the columns of DAG are to be considered from the first column to the last column until (updated) v_{3j} = 0. So k assumes the values 1,2,......j-1, j+1,.....,m

Algorithm 2

Step 1 j=1

Step 2 If v_{3j} = 0 then go to Step 10

Step 3 k= 1

Step 4 If k = j then go to Step7.

Step 5 If the j th and the k th columns of DA(G) have one element in common

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Then $\begin{bmatrix} j \\ k \end{bmatrix}$ will be an arc in DAL(G) with degree deg(e_k).

deg(e_j) = deg(e_j) – 1 /* Degree arc vector updated formulae*/

Step 6 If deg(e_j) = 0 then go to Step10

Step 7 k = k+l

Step 8 If k > m then print" Error ": goto Step 14

Step 9 Go to Step 3

Step 10 j= j+l

Step 11 If j = m then print" Error ": go to Step 14

Step 12 Go to Step 2

Step 13 Print DAL(G).

Step 14. Stop.

Illustration: 4 Let us consider the digraph as shown in Figure 3:

The degree arc matrix of the above digraph is

$$DA(G) = \begin{pmatrix} 1 & 1 & 2 & 3 & 4 & 4 \\ 2 & 3 & 4 & 2 & 3 & 5 \\ 1 & 1 & 2 & 1 & 1 & 0 \end{pmatrix}$$

Here $v_{31} \neq 0$, so we compare between e_1 and e_2. Since $v_{21} \neq v_{12}$, we next compare and see that $v_{21} = v_{13}$, hence $\begin{bmatrix} 1 \\ 3 \end{bmatrix}$ is an arc of the line digraph with degree 2 (since v_{33}=2).

We update the degree of the arc following Step 5. Since v_{31}= 0 (updated value), we move to the second column and see that $v_{32} \neq 0$. We next compare e_2 with e_1 (although deg(e_1) = 0). Since $v_{22} \neq v_{11}$, we now compare v_{22} with v_{13} and see that $v_{22} \neq v_{13}$ and then find $v_{22} = v_{14}$.

So $\begin{bmatrix} 1 \\ 4 \end{bmatrix}$ will be an arc of the line digraph with degree 1.

In this way we construct DAL(G) from DA(G).

Illustration: 3: Let us consider the digraph:

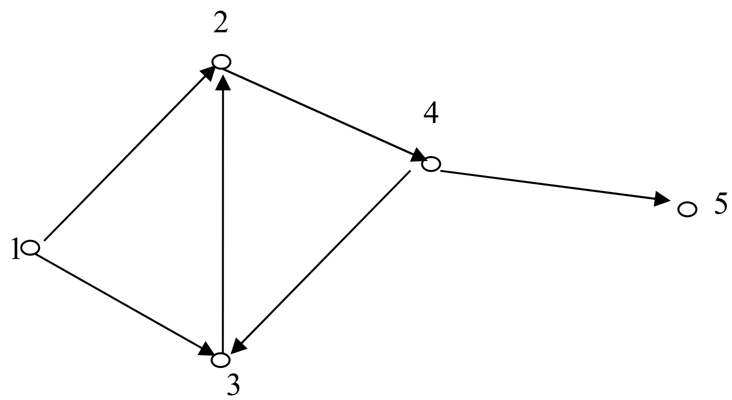

Figure 3.

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$$\text{So} \quad DAL(G) = \begin{pmatrix} 1 & 2 & 3 & 3 & 4 & 5 \\ 3 & 4 & 5 & 6 & 3 & 4 \\ 2 & 1 & 1 & 0 & 2 & 1 \end{pmatrix}$$

The degree arc vector of the digraph is (2,1,1,0,2,1). We demonstrate below how the degrees of the arcs are changing when we implement Algorithm 2.

Degree arc vector	**Degree sum**
(1 1 2 1 1 0)	6
(0 1 2 1 1 0)	5
(0 0 2 1 1 0)	4
(0 0 1 1 1 0)	3
(0 0 0 1 1 0)	2
(0 0 0 0 1 0)	1
(0 0 0 0 0 0)	0

The algorithm stops when the Degree sum becomes 0.

Conclusion

The time complexity of computing the line graph of an undirected graph with n vertices and m edges by Algorithm 1 is $O(n^4)$. This is due to the fact that the number of times the inner loop executed in the worst case is

$$= (m-1)+(m-2)+ \ldots+2+1=m(m-1)/2=O(m^2) = O(n^4), \text{ [since } m= O(n^2).]$$

We have run programs in C corresponding to Algorithm 1 and Algorithm 2 where the inputs are the random graphs with varying threshold values. We have calculated the actual number of comparisons taking place in our method and then compared it with the method given in [3]. Apart from theoretical point of view, the outputs of the program show that our method is efficient from computational aspects as well. It has been found that the actual computing time is nearly 1% of the bound $O(n^4)$.

Appendix A

OUTPUT OF THE PROGRAM

SL. NO.	N	THRESHOILD	DENSITY	OPERATIONS (EXISTING)	OPERATIONS (ACTUAL)	(%) TIME SAVING
1	6	0.67	0.2667	7776	39	99.4985
2	7	0.56	0.2143	16807	56	99.6668
3	8	0.34	0.2321	32768	80	99.7559
4	12	0.78	0.4167	248832	1221	99.5093
5	20	0.34	0.1684	3200000	1001	99.9687
6	24	0.45	0.2391	7962624	3787	99.9524
7	12	0.9	0.4773	248832	1591	99.3606
8	15	0.45	0.2476	759375	903	99.8811
9	18	0.88	0.4444	1889568	5157	99.7271

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10	8	0.99	0.4821	32768	414	98.7366
11	20	0.9	0.4474	3200000	7347	99.7704
12	15	0.88	0.4238	759375	2589	99.6591
13	12	0.87	0.4394	248832	1350	99.4575
14	18	0.34	0.1863	1889568	858	99.9546
15	22	0.45	0.2186	5153632	2284	99.9557
16	24	0.67	0.3514	7962624	7883	99.9010
17	16	0.9	0.4542	1048576	3694	99.6477
18	17	0.77	0.375	1419857	3098	99.7818
19	8	0.99	0.4821	32768	422	98.7122
20	6	0.44	0.2333	7776	25	99.6785
21	14	0.88	0.4231	537824	2066	99.6159
22	7	0.45	0.2143	16807	44	99.7382
23	3	0.98	0.5	243	8	96.7078
24	4	0.89	0.5	1024	32	96.8750
25	5	0.33	0.1	3125	3	99.9040
26	10	0.78	0.4333	100000	722	99.2780
27	13	0.88	0.4423	371293	1795	99.5166
28	19	0.33	0.1433	2476099	635	99.9744
29	19	0.99	0.4971	2476099	7655	99.6908
30	25	0.33	0.1367	9765625	1378	99.9859
31	25	0.68	0.35	9765625	8950	99.9084
32	21	0.5	0.231	4084101	2289	99.9440
33	22	0.86	0.4264	5153632	8980	99.8258
34	23	0.568	0.2747	6436343	4222	99.9344
35	25	0.22	0.1117	9765625	888	99.9909
36	6	0.67	0.1667	7776	14	99.8200
37	6	0.99	0.5	7776	160	97.9424
38	10	0.23	0.1	100000	24	99.9760
SL. NO.	**N**	**THRESHOILD**	**DENSITY**	**OPERATIONS (EXISTING)**	**OPERATIONS (ACTUAL)**	**(%) TIME SAVING**
39	10	0.61	0.3	100000	325	99.6750
40	10	0.89	0.4444	100000	750	99.2500
41	15	0.23	0.1	759375	153	99.9799
42	15	0.61	0.3238	759375	1557	99.7950
43	15	0.89	0.4667	759375	3137	99.5869
44	25	0.19	0.0933	9765625	698	99.9929
45	25	0.56	0.275	9765625	5496	99.9437
46	25	0.92 .	0.4417	9765625	4255	99.8540
47	7	0.23	0.0714	16807	7	99.9584
48	7	0.56 .	0.3333	16807	120	99.2860

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49	7	0.95	0.5	16807	280	98.3340
50	14	0.23	0.1319	537824	189	99.9649
51	14	0.56	0.2582	537824	773	99.8563
52	14	0.96	0.489	537824	2776	99.4838
53	21	0.23	0.1119	4084101	549	99.9866
54	21	0.67	0.3381	4084101	4817	99.8821
55	21	0.89	0.4262	4084101	7656	99.8125
56	8	0.23	0.125	32768	19	99.9420
57	8	0.61	0.3393	32768	202	99.3835
58	8	0.91	0.4821	32768	423	98.7091
59	16	0.23	0.1625	1048576	495	99.9528
60	16	0.67	0.3417	1048576	2070	99.8026
61	16	0.89	0.4083	1048576	2927	99.7209
62	26	0.36	0.1631	11881376	2109	99.9822
63	26	0.96	0.4785	11881376	19002	99.8401
64	9	0.23	0.1806	59049	87	99.8527
65	9	0.61	0.2639	59049	174	99.7053
66	9	0.92	0.4444	59049	520	99.1194
67	11	0.23	0.1364	161051	87	99.9460
68	11	0.65	0.3364	161051	587	99.6355
69	11	0.92	0.4455	161051	1050	99.3480
70	22	0.64	0.3203	5153632	5053	99.9020
71	22	0.96	0.4784	5153632	11281	99.7811
72	12	0.23	0.0909	248832	56	99.9775
73	12	0.36	0.1591	248832	159	99.9361
74	12	0.96	0.4924	248832	1714	99.3112
75	24	0.23	0.1359	7962624	1122	99.9859
76	24	0.61	0.3243	7962624	6743	99.9153
77	24	0.98	0.4837	7962624	15163	99.8096
78	13	0.23	0.0833	371293	53	99.9857

SL. NO.	N	THRESHOILD	DENSITY	OPERATIONS (EXISTING)	OPERATIONS (ACTUAL)	(%) TIME SAVING
79	13	0.64	0.3205	371293	975	99.7374
81	26	0.23	0.1138	11881376	1029	99.9913
82	26	0.64	0.32	11881376	8609	99.9275
83	26	0.98	0.4862	11881376	19634	99.8347
84	14	0.23	0.115454	537824	175	99.9675
85	14	0.56	0.2308	537824	606	99.8873
86	14	0.92	0.4725	537824	2596	99.5173

87	28	0.23	1164	17210368	1342	99.9922
88	28	0.63	0.3122	17210368	10216	99.9406
89	28	0.91	0.4563	17210368	21896	99.8728
90	16	0.23	0.15	1048576	375	99.9642
91	16	0.65	0.3	1048576	1638	99.8438
92	16	0.96	0.4792	1048576	4110	99.6080
93	28	0.36	1799	17210368	3454	99.9799
94	28	0.96	0.4894	17210368	25118	99.8541
95	17	0.23	0.1287	1419857	393	99.9723
96	17	0.61	0.3309	1419857	2326	99.8362
97	17	0.92	0.4522	1419857	4467	99.6854
98	29	0.23	0.1182	20511149	1661	99.9919
99	29	0.63	0.3005	20511149	10349	99.9495
100	29	0.96	0.4766	20511149	26541	99.8706
101	18	0.23	0.1307	1889568	477	99.9748
102	18	0.61	0.317	1889568	2654	99.8595
103	18	0.92	0.4739	1889568	5852	99.6903
104	19	0.23	0.0848	2476099	214	99.9914
105	19	0.62	0.3216	2476099	3284	99.8674
106	19	0.95	0.4561	2476099	6442	99.7398
107	25	0.22	0.1117	9765625	888	99.9909
108	6	0.67	0.1667	7776	14	99.8200
109	6	0.99	0.5	7776	160	97.9424
110	6	0.19	0	7776	0	100.0000
111	10	0.23	0.1	100000	24	99.9760
112	10	0.61	0.3	100000	325	99.6750
113	10	0.89	0.4444	100000	750	99.2500
114	15	0.23	0.1	759375	153	99.9799
115	15	0.61	0.3238	759375	1557	99.7950
116	15	0.89	0.4667	759375	3137	99.5869
117	25	0.19	0.0933	9765625	698	99.9929
118	25	0.56	0.275	9765625	5496	99.9437
119	25	0.92 .	0.4417	9765625	4255	99.8540
120	7	0.23	0.0714	16807	7	99.9584
123	14	0.23	0.1319	537824	189	99.9649
124	14	0.56	0.2582	537824	773	99.8563

SL. NO.	N	THRESHOILD	DENSITY	OPERATIONS (EXISTING)	OPERATIONS (ACTUAL)	(%) TIME SAVING
125	14	0.96	0.489	537824	2776	99.4838
126	21	0.23	0.1119	4084101	549	99.9866

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127	21	0.67	0.3381	4084101	4817	99.8821
128	21	0.89	0.4262	4084101	7656	99.8125
129	8	0.23	0.125	32768	19	99.9420
130	8	0.61	0.3393	32768	202	99.3835
131	8	0.91	0.4821	32768	423	98.7091
132	16	0.23	0.1625	1048576	495	99.9528
133	16	0.67	0.3417	1048576	2070	99.8026
134	16	0.89	0.4083	1048576	2927	99.7209
135	26	0.36	0.1631	11881376	2109	99.9822
136	26	0.96	0.4785	11881376	19002	99.8401
137	9	0.23	0.1806	59049	87	99.8527
138	9	0.61	0.2639	59049	174	99.7053
139	9	0.92	0.4444	59049	520	99.1194
140	11	0.23	0.1364	161051	87	99.9460
141	11	0.65	0.3364	161051	587	99.6355
142	11	0.92	0.4455	161051	1050	99.3480
143	22	0.64	0.3203	5153632	5053	99.9020
144	22	0.96	0.4784	5153632	11281	99.7811
145	12	0.23	0.0909	248832	56	99.9775
146	12	0.36	0.1591	248832	159	99.9361
147	12	0.96	0.4924	248832	1714	99.3112
148	24	0.23	0.1359	7962624	1122	99.9859
149	24	0.61	0.3243	7962624	6743	99.9153
150	24	0.98	0.4837	7962624	15163	99.8096
151	13	0.23	0.0833	371293	53	99.9857
152	13	0.64	0.3205	371293	975	99.7374
153	13	0.89	0.4615	371293	1918	99.4834
154	26	0.23	0.1138	11881376	1029	99.9913
155	26	0.64	0.32	11881376	8609	99.9275
156	26	0.98	0.4862	11881376	19634	99.8347
157	14	0.23	0.115454	537824	175	99.9675
158	14	0.56	0.2308	537824	606	99.8873

SL. NO.	N	THRESHOILD	DENSITY	OPERATIONS (EXISTING)	OPERATIONS (ACTUAL)	(%) TIME SAVING
159	14	0.92	0.4725	537824	2596	99.5173
160	28	0.23	1164	17210368	1342	99.9922
161	28	0.63	0.3122	17210368	10216	99.9406
165	16	0.96	0.4792	1048576	4110	99.6080
166	28	0.36	1799	17210368	3454	99.9799
167	28	0.96	0.4894	17210368	25118	99.8541
168	17	0.23	0.1287	1419857	393	99.9723
169	17	0.61	0.3309	1419857	2326	99.8362
170	17	0.92	0.4522	1419857	4467	99.6854
171	29	0.23	0.1182	20511149	1661	99.9919
172	29	0.63	0.3005	20511149	10349	99.9495
173	29	0.96	0.4766	20511149	26541	99.8706
174	18	0.23	0.1307	1889568	477	99.9748
175	18	0.61	0.317	1889568	2654	99.8595
176	18	0.92	0.4739	1889568	5852	99.6903
177	19	0.23	0.0848	2476099	214	99.9914
178	19	0.62	0.3216	2476099	3284	99.8674
179	19	0.95	0.4561	2476099	6442	99.7398
180	3	0.66	0.3333	243	1	99.5885
181	8	0.1234	0.0714	32768	8	99.9756
182	10	0.2513	1333	100000	56	99.9440
183	9	0.236	0.0972	59049	27	99.9543
184	16	0.369	2083	1048576	712	99.9321
185	18	0.1234	0.0621	1889568	74	99.9961

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