PARALLEL MATRIX MULTIPLICATION ALGORITHMS ACQUIRE CONNECTED NETWORK SUBGRAPHS

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***Abstract*--The network of interactions between biomolecules is essential to biological processes. Many studies have shown that molecular networks can be analyzed by breaking them down into smaller modules known as network subgraphs. We hypothesize that identifying the set of possible 5-node subgraphs and 6-node subgraphs embedded in a network is a necessary step to elucidate the complex topology of a network. Accomplishing this goal requires determining the complete set of subgraphs that are composed of five and six connected nodes.**

We developed a parallel algorithm to reduce time consumption that tackles the exponential problem. It is implemented in matrix multiplication insert in the process of identifying isomorphic patterns and removing the isolated and disconnected patterns. The experiment showed that the parallelization matrix multiplication algorithm is approximately 1.4 times faster than serial programming for identifying 5-node subgraphs and approximately 1.3 times faster than serial programming for identifying 6-node subgraphs with all the nodes connected.

***Keywords*: Digraphs; Matrix Multiplication; Molecular Networks; Network Subgraph; Parallel Algorithm.**

I. INTRODUCTION

Molecular networks consist of genetic elements that can be activated or suppressed. It is more productive to investigate how bio-molecules organize or cooperate at the system level in the post-genome era. Decomposing complex networks into small modules is a useful concept for understanding the topological structure of the underlying network. These modules are known as network subgraph. Auto-regulation (either catalytic or repression), coherent feed-forward loops, single-input modules, and bi-fans are examples of such subgraph [1-5]. Network subgraph play an important role in various types of networks, including molecular networks, ecological networks, electrical networks, etc. [6-12]. In this paper, subgraph consisting of *N* nodes are referred to as '*N*-node subgraphs'. It is well known that identifying N-node subgraphs in large networks is an NP-complete problem in terms of time complexity [13]. We note that there was a work claiming that network subgraphs do not necessarily determine biological functions, there is no characteristic behavior for network subgraphs [14], while other works [15-17] reported opposite results. Multilayer network description is also an important area in multi-omics study, the concept of (i) tensorial framework has been introduced to study this problem [18], and (ii) graph isomorphism has been generalized to determine whether two multilayer networks are equivalent structurally or not [19].

In our previous work, we used 3- and 4-nodes to dissect and analyze cancerous tissue. Thus, we know the constructive type of cancer-causing network through the driver and essential genes that mutually affect the cancer disease condition [20-22]. We continued our IMECS2019 conference paper [23] and IJCS volume 46 [24] by developing a parallel matrix multiplication algorithm to solve huge computation and mix adding parallelization with input five-millions as maximum input all possible subgraphs that compose six connected nodes be approached of 1,530,843. Moreover, network subgraphs such as 3-, 4-, and 5-nodes are done to define of subgraph, in total 13, 199, and 9364, respectively [25, 26]. To approach 6-nodes, we implement a new parallelization inside of matrix multiplication to reduce time consumption that causes effect computation. Our experiment demonstrated that the matrix multiplication parallelized algorithm speeds up for 5-nodes around 1.4 times and for 6-nodes around 1.3 times faster than serial programming.

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II. METHOD

In this study, we concentrate on generating the '34,089,189,246' id-decimal numbers for *6*-node, which requires the generation of integer numbers. It is unable to do so since a hardware device's RAM capacity is restricted. Therefore, we build a more efficient algorithm and include parallel matrix multiplication, where the input decimal number is given in the form of a range, with a maximum of 5 million possible with limited RAM.

Suppose $\boldsymbol{G}$ is a graph or motif, and $\boldsymbol{G} = (\boldsymbol{V}, \boldsymbol{E})$, where $\boldsymbol{V}$ and $\boldsymbol{E}$ represent vertices and edges, respectively. To represent the connectivity of each node embedded in the subgraphs, an adjacency matrix, $\boldsymbol{A}$, can be constructed. The matrix $\boldsymbol{A}$ is made up of matrix elements with values of '0' or '1' that represent unconnected or connected nodes, respectively. We do not consider self-interacting nodes in this work. As a result, the diagonal elements of $\boldsymbol{A}$ are all zero.

Subgraphs or called motifs, which distiguish how to obtain from method it used [22], can be represented by integers given an adjacency matrix. A *6*-node motif named 'Multiple Input Motif (MIM),' for example can be represented by the binary string 000000100000010000001000000000000, which is equivalent to '545392672' in decimal representation. The adjacency matrix 2^X can represent the entire set of N-node motifs, where $X = 2*C(N, n)$, and $C(N, n)$ is the combinatorial factor for selecting $\boldsymbol{n}$ nodes from $\boldsymbol{N}$ nodes. We have a factor of two because we are looking at a digraph.

Previously study solved network motifs of 3-, 4-, and 5-nodes digraphs [23], exponential numbers in 6-nodes make consequently to search and find id-decimal numbers in huge numbers. Therefore, we put matrix multiplication in a single function of parallel because this function was used many times. We found that used three times in prior algorithms, to reach impact in five-millions numbers in one time to collect and make it faster than the last algorithm.

We noted that two algorithms use matrix multiplication such as permutation matrix multiplication to identify isomorphic patterns, and to remove disconnected patterns using the 4th Power of Matrix A[24]; therefore, we create a function of matrix multiplication to accommodate all multiplication matrices in this algorithm.

The matrix $\boldsymbol{A}$ multiplies to another matrix and or matrices multiply the process in parallel. In the process of parallelism, it conducts a function that calls *NumPy* and *n-jit* at the same time, multiplying each line on each processor unit. The core unit of the processor accelerates the calculation, line by line, till of process finish as comes a result.

Determining by the result of the algorithm, it changed the process, i.e., Eq. (1) permutation matrix multiplication [23] and Eq. (2) 4th Power of Matrix A [24].

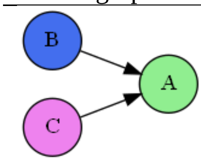
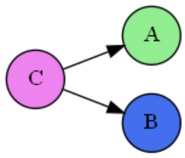
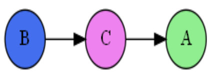
$$[A = A \times P_n],\ [P_0, P_1, P_2, \dots] \quad (1)$$

$$[A = A \times A^T],\ [B^2, B^3, \dots] \quad (2)$$

where matrix $\boldsymbol{A}$ multiplied respectively. For each process of multiplication tackled in a parallel process, which performance of computation raises.

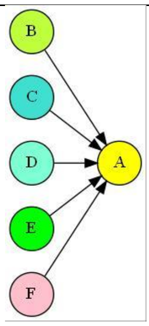
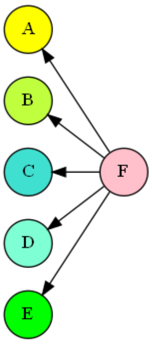
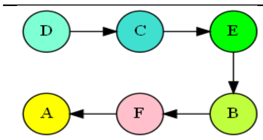
Table I and Table II illustrate the structure of MIM, SIM, and Cascade as a group of 2-edges at 3-nodes and 5-edges at 6-nodes. Its motifs are associated with decimal numbers 36, 6, and 12, 545392672, 62, and 17335328. Further analysis shows that the number of decimal variations in one edge group exceeds millions, and it required a longer time to discover all motifs on 6-nodes.

TABLE I
Motifs of Three Nodes Mim, Sim, and Cascade in Members of Two Edges

Network Subgraphs	Adjacency Matrix	Decimal Number
	$\begin{bmatrix}0&0&0\\1&0&0\\1&0&0\end{bmatrix}$	36
	$\begin{bmatrix}0&0&0\\0&0&0\\1&1&0\end{bmatrix}$	6
	$\begin{bmatrix}0&0&0\\0&0&1\\1&0&0\end{bmatrix}$	12

Suppose $\boldsymbol{A_1}$ is the matrix result of multiplying the matrix, $\boldsymbol{A_0}$, by the permutation matrix, $\boldsymbol{P_1}$, to collect isomorphism. In our [VMS] machine to perform parallelism, we split the process into two running on core-1 and core-2 at the same time, i.e., yellow highlights are to be processed on core-1 and green highlights are to be processed on core-2. The $\boldsymbol{A_1}$ isomorphism result shows the decimal number 17335328, the matrix is identical to $\boldsymbol{A_0}$.

TABLE II
Motifs of Six Nodes Mim, Sim, And Cascade In Members of Five Edges

Network Motif	Adjacency Matrix	Decimal Number
	$\begin{bmatrix}0&0&0&0&0&0\\1&0&0&0&0&0\\1&0&0&0&0&0\\1&0&0&0&0&0\\1&0&0&0&0&0\\1&0&0&0&0&0\end{bmatrix}$	545392672
	$\begin{bmatrix}0&0&0&0&0&0\\0&0&0&0&0&0\\0&0&0&0&0&0\\0&0&0&0&0&0\\0&0&0&0&0&0\\1&1&1&1&1&0\end{bmatrix}$	62
	$\begin{bmatrix}0&0&0&0&0&0\\0&0&0&0&0&1\\0&0&0&0&1&0\\0&0&1&0&0&0\\0&1&0&0&0&0\\1&0&0&0&0&0\end{bmatrix}$	17335328

$A_1 = [A_0 \times P_1]$

$$= \begin{bmatrix}0&0&0&0&0&0\\0&0&0&0&0&1\\0&0&0&0&1&0\\0&0&1&0&0&0\\0&1&0&0&0&0\\1&0&0&0&0&0\end{bmatrix} \times \begin{bmatrix}1&0&0&0&0&0\\0&1&0&0&0&0\\0&0&1&0&0&0\\0&0&0&1&0&0\\0&0&0&0&0&1\\0&0&0&0&1&0\end{bmatrix}$$

$$= \left[\begin{matrix} C1 \\ 0\times1+0\times0+0\times0+0\times0+0\times0+0\times0 \\ 0\times1+0\times0+0\times0+0\times0+0\times0+1\times0 \\ 0\times1+0\times0+0\times0+0\times0+1\times0+0\times0 \\ 0\times1+0\times0+1\times0+0\times0+0\times0+0\times0 \\ 0\times1+1\times0+0\times0+0\times0+0\times0+0\times0 \\ 1\times1+0\times0+0\times0+0\times0+0\times0+0\times0 \end{matrix}\right.$$

$$\begin{matrix} C2 \\ 0\times0+0\times1+0\times0+0\times0+0\times0+0\times0 \\ 0\times0+0\times1+0\times0+0\times0+0\times0+1\times0 \\ 0\times0+0\times1+0\times0+0\times0+1\times0+0\times0 \\ 0\times0+0\times1+1\times0+0\times0+0\times0+0\times0 \\ 0\times0+1\times1+0\times0+0\times0+0\times0+0\times0 \\ 1\times0+0\times1+0\times0+0\times0+0\times0+0\times0 \end{matrix}$$

$$\begin{matrix} C3 \\ 0\times0+0\times0+0\times1+0\times0+0\times0+0\times0 \\ 0\times0+0\times0+0\times1+0\times0+0\times0+1\times0 \\ 0\times0+0\times0+0\times1+0\times0+1\times0+0\times0 \\ 0\times0+0\times0+1\times1+0\times0+0\times0+0\times0 \\ 0\times0+1\times0+0\times1+0\times0+0\times0+0\times0 \\ 1\times0+0\times0+0\times1+0\times0+0\times0+0\times0 \end{matrix}$$

$$\begin{matrix} C4 \\ 0\times0+0\times0+0\times0+0\times1+0\times0+0\times0 \\ 0\times0+0\times0+0\times0+0\times1+0\times0+1\times0 \\ 0\times0+0\times0+0\times0+0\times1+1\times0+0\times0 \\ 0\times0+0\times0+1\times0+0\times1+0\times0+0\times0 \\ 0\times0+1\times0+0\times0+0\times1+0\times0+0\times0 \\ 1\times0+0\times0+0\times0+0\times1+0\times0+0\times0 \end{matrix}$$

$$\begin{matrix} C5 \\ 0\times0+0\times0+0\times0+0\times0+0\times0+0\times1 \\ 0\times0+0\times0+0\times0+0\times0+0\times0+1\times1 \\ 0\times0+0\times0+0\times0+0\times0+1\times0+0\times1 \\ 0\times0+0\times0+1\times0+0\times0+0\times0+0\times1 \\ 0\times0+1\times0+0\times0+0\times0+0\times0+0\times1 \\ 1\times0+0\times0+0\times0+0\times0+0\times0+0\times1 \end{matrix}$$

$$\left.\begin{matrix} C6 \\ 0\times0+0\times0+0\times0+0\times0+0\times1+0\times0 \\ 0\times0+0\times0+0\times0+0\times0+0\times1+1\times0 \\ 0\times0+0\times0+0\times0+0\times0+1\times1+0\times0 \\ 0\times0+0\times0+1\times0+0\times0+0\times1+0\times0 \\ 0\times0+1\times0+0\times0+0\times0+0\times1+0\times0 \\ 1\times0+0\times0+0\times0+0\times0+0\times1+0\times0 \end{matrix}\right]$$

$$= \begin{bmatrix}0&0&0&0&0&0\\0&0&0&0&0&1\\0&0&0&0&1&0\\0&0&1&0&0&0\\0&1&0&0&0&0\\1&0&0&0&0&0\end{bmatrix} = 17335328 \quad (4)$$

Fig. 1 is the workflow of our algorithm to identify 6-node motifs composed of six connected nodes. Table III is the description of the workflow shown in Figure 1. Below we provide the pseudo-codes of the workflow steps.

TABLE III
The Seven Steps of The Workflow

Step 1–Range of five-millions decimal numbers
Step 2–Check possible decimal numbers using Permutation Matrices.
Step 3–According Possible, which is selected from five-millions decimal numbers, Adjacency Matrices and denotes each Matrix by a Decimal Number.
Step 4–Classify the Decimal Number Representation According to the Number of Edges.
Step 5–Isomorphic Patterns are Identified by Permutation Matrices Multiplication. **(Parallelization Adding process and Matrix Multiplication process)**
Step 6– Remove All Disconnected Patterns Using The 4th Power of Matrix A **(Parallelization Matrix Multiplication process)**.
Step 7– Isomorphic Patterns are Removed Except the One Associates with The Minimal Decimal

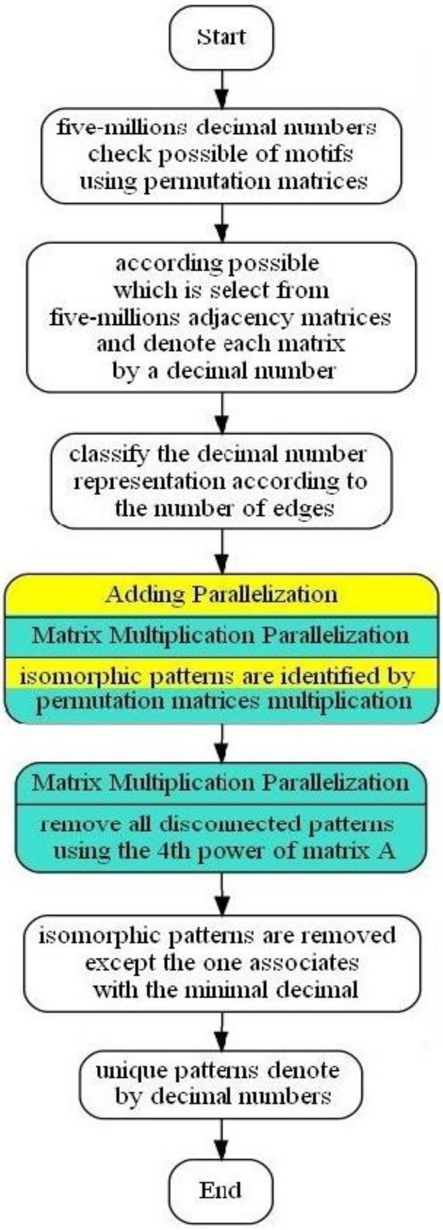


Fig. 1. Workflow of the present study

Step 1 input decimal numbers in total five-millions of decimal numbers. Step 2 generates the set of all possible permutation matrices, i.e. $N!$ for N-node motifs. This is done by calling the library ‘multiset_permutation’ (available in Python 3.7). As step 3 shown, one defines a maximum decimal number for a given number of edges. We generate an adjacency matrix consisting of the number of occurrences of ‘1’ which is equal to the number of edges. Then, we denote each matrix by a decimal number and save the decimal numbers in a list.

```
Step 1: Input five-millions decimal numbers
  Input: integerN
  Output: [62, ..., 5000000]
maximum-numbers=500000
minimum-numbers=62
```

Fig. 2. The pseudocodes of step 1

```
Step 2: Check possible decimal numbers using Permu-
tation Matrices.
  Input: identity_matrix_permutation
  Output: permutation_matrix
temp_matrix=identity_matrix_permutation
Call multiset_permutation
Function save_numberof_permutation=
multiset_permutation.sum()
for save_numberof_permutation in
  multiset_permutation(list_permutation) do
    save_list_permutation(save_numberof_permutation
```

Fig. 3. The pseudocodes of step 2

```
Step 3: According Possible, which is selected from
five-millions decimal numbers, Adjacency Matrices
and denotes each Matrix by a Decimal Number
  Input: integerN
  Output: A set of decimal numbers represent motifs
          with at least one edge
matrix_adjccy=numpy.ones// change diagonal to
  zero
for i in reversed(matrix_adjccy(element)) do
    max_decimal_number=2^counterxint(i)
    counter+=1
for i in range(2, max_decimal_number) do
    save_number_of_decimal=i
    i+=1
while i<length(save_numberof_decimal) do
    graph_inmatrix =numpy.binary_repr(
     save_number_of_decimal[i], width=NxN)
     graph_inmatrix_adj=numpy.array(graph_inmatrix)
    while j<length(diagonal_matrix_NxN) do
        if
         diagonal_matrix_NxN(graph_inmatrix_adj)=0
         then
            number_of_decimal[i]=
            save_number_of_decimal[i]
        j+=1
    i+=1
```

Fig. 4. The pseudocodes of step 3

```
Step 4: Classify the decimal number representation
according to the number of edges
  Input: A set of decimal numbers represent motifs with
         at least one edge
  Output: Groups of decimals associate motifs with
          motifs compose of different number of edges,
          i.e. 4 to 20 edges for 5-node motifs
while i<length(number_of_decimal) do
    graph_inmatrix=numpy.binary_repr
    (number_of_decimal[i],width=NxN)
    sum_of_element[i]=numpy.sum
    (graph_inmatrix[element])
    i+=1
while j<length(edge-index) do
    while k<length(number_of_decimal) do
        if sum_of_element[k]=edge-index[j] then
            class_of_decnum.extend([number_of_decimal])
        k+=1
    j+=1
```

Fig. 5. The pseudocodes of step 4

In step 4, we grouped motifs with the same number of edges (without considering edge direction) together into the same list. Step 5 is to group all the isomorphic motifs that are related by permutation matrix multiplication. For instance, in three-node, the group [6, 40, 192] means that 'motif_6', 'motif_40', and 'motif_192' are isomorphic. These three motifs are related by permutation matrix multiplication that the parallel process within this step. Group, [12, 34, 66, 96, 132, 136], represents another group of isomorphic motifs, it has the same number of edges as a group, [6, 40, 192]. Output from step 5 serves as the input for steps 6 and 7.

Step 5: Isomorphic patterns are identified by permutation matrices multiplication

```
Input: Groups of decimals associate motifs with motifs
       compose of different number of edges
Output: Groups of decimals correspond to isomorphic
        patterns
while i<length(class_of_decnum) do
    decnum_classes =class_of_decnum[i]
    while j<length(decnum_classes) do
        adj_matrix_trf =numpy.binary_repr
        (decnum_classes[j],width=NxN)
        adj_matrix=numpy.array(adj_matrix_trf)
        while k<length(save_list_permutation* do
            permutation=save_list_permutation[k]
            permutation_transpose=permutation.transpose()
            // Parallelization Matrix
               Multiplication
            matrix_isomorphm=((permutation.adj_matrix)
            .permutation_transpose)
            // Parallelization Adding
            [decnum_isomorphm=convert
            (matrix_isomorphm)]
            k+=1
        collect_of_decnum_isomorphm.extend
        (decnum_isomorphm)
        j+=1
    class_of_decnum[i]=collect_of
    _decnum_isomorphm
    sorted(class_of_decnum[i])
    i+=1
```

Fig. 6. The pseudocodes of step 5
*save_list_permutation is call permutation in step 3

Step 6: Remove all disconnected patterns using power matrices

```
Input: The minimal decimals, including motifs
       compose of disconnected components
Output: The minimal decimals that represent motifs
        compose of connected nodes, i.e. connected
        motif patterns
while i<length(class_of_decnum) do
    decnum_classes =class_of_decnum[i]
    while j<length(decnum_classes) do
        adj_matrix_trf =numpy.binary_repr
        (decnum_classes[j],width=NxN)
        adj_matrix=numpy.array(adj_matrix_trf)
        B=adj_matrix+(adj_matrix.transpose)
        variable_to_sum = 0
        while h<N do
            // Parallelization Matrix
               Multiplication
            B2=matriXirtam(B2,B)
            B_listed(B2[0])
            h+=1
        while k<N do
            while l<N do
                variable_to_sum=variable_to_sum+
                B_listed[l][k]
                if l=minimum-edge AND
                 variable_to_sum=0 then
                    del_of_decnum=decnum
                l+=1
            k+=1
        j+=1
    class_of_decnum=class_of_decnum[i]-
     del_of_decnum
    i+=1
sorted(class_of_decnum)
```

Fig. 7. The pseudocodes of step 6

Step 7: Isomorphic patterns are removed except the one associate with the minimal decimal

```
Input: Groups of decimals correspond to isomorphic
       patterns
Output: The minimal decimals, including motifs
        compose of disconnected components
while i<length(class_of_decnum) do
    decnum_classes =classof_decnum[i]
    while j<length(decnum_classes) do
        decnum_minimal=decnum_classes[0]
         collect_of_decnum_minimal=decnum_minimal
         j+=1
    class_of_decnum=collect_of_decnum_minimal
    sorted(class_of_decnum)
    i+=1
```

Fig. 8. The pseudocodes of step 7

After that, we removed all the disconnected patterns using the power of matrix *B*, which implements a parallel process within. A motif pattern was removed if the sum of the matrix element b_{ij} obtained from the 1st to the 4th power of *B* is equal to zero.

Finally, for each group of isomorphic motifs, from step 5 and 6 selected the minimal decimal number to represent that group, it is collected at once and divided by edges.

III. Result and discussion

In this section, we measure and compare the matrix multiplication algorithm using parallelization to determine the speed-up ratio.

A. Virtual machine environment

This algorithm is implemented in Python 3.7.15. Experiments are performed on Virtual Machine Server (VMS) using Linux x86_64, 2-core Xeon 2.2GHz 13GB memory.

B. Speed up time result

The result of 2-core on VMS time compares of running 5-node and 6-node motifs that given of all network motifs except 6-nodes only of 18344 numbers id-motifs base range between 62 and five-millions decimal numbers in total.

The results of the VMS execution time and speed-up ratios for finding 6-node motifs are given in Table 4. As shown in Table 4, compare the algorithm serial algorithm utilized less VMS time than the parallel matrix multiplication algorithm, i.e. about 1.3 times faster.

In order to satisfy the utilization requirements of our network identification technique, as shown in Table 5, we have identified sets of 1520873 ids, which were approximately 11 days 5 hours 16 minutes, out of 1530843; as reported in Refs.[20, 21]. Therefore, 9970 additional ids for the 6-node motif are required to complete our algorithm of subgraph finder.

TABLE IV
Speed Up Serial and Parallel on The Virtual Machine Server

Nodes	(hh:mm: ss)		Speed
	Serial	Parallel-MX	Up
5	0:52:42.664	0:37:17.05	1.4
6	1:36:14.47	1:15:26.74	1.3

**Parallel-MX (Matrix Multiplication Parallelization)*

TABLE V
Number of Motifs Identified by The Presented Algorithm

Node	5	6
The number of motifs found	9364	1520873

In the Appendix section, Table A1 listed the set of decimals associated with 6-node motifs. The total number of 6-node motifs is 1520873, because of space limitation, only a partial list of the decimals is shown.

IV. Conclusions

We devised a systematic and rigorous method for generating entire sets of 3-, 4-, 5- and 6-node network motifs that are free of unconnected and isomorphic patterns. Furthermore, a parallelized version of our approach was developed to reduce the time required to identify 5-node motifs by approximately 1.4 times and identify 6-node motifs by approximately 1.3 times. With 5- and 6-node motif patterns that were tackled in prior works, we plan to identify 5- and 6-node motifs embedded in the molecular networks in the following stage, allowing us to analyze the network's underlying topological structures as input for the subgraph finder.

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VI. APPENDIX

Table A1. The Set of Decimals is Associated with the 6-Node Motifs

Number of Edges	Motif ID [Decimal representation]
5	[62, 124, 314, 316, 376, 818, 820, 4216, 4408, 4658, 4664, 4720, 4912, 5666, 5672, 5728, 5920, 7688, 12848, 33330, 33336, 33392, 33830, 33834, 33848, 33892, 33896, 34084, 34088, 34096, 34344, 34352, 266352, 266544, 267298, 267312, 267360, 267552, 269314, 269328, 270896, 271394, 271396, 271408, 275488, 295970, 295984, 296032, 296224, 296480, 298000, 304160, 328738, 328752, 328800, 329248, 329734, 329746, 329776, 329808, 330000, 330016, 330256, 330768, 330784, 853024, 4260898, 4260912, 4260960, 4261924, 4261936, 17043552, 17043744, 17045506, 17045536, 17048096, 17049602, 17049604, 17049632, 17073184, 17074178, 17074208, 17172482, 17172512, 17335328, 17336352, 17433632, 17434656, 21104672, 25298976, 545392672] The total Number is 91
6	[126, 318, 378, 380, 822, 828, 882, 884, 1836, 4218, 4410, 4412, 4472, 4662, 4666, 4668, 4722, 4724, 4728, 4914, 4916, 4920, 4976, 5670, 5674, 5676, 5688, 5730, 5732, 5736, 5922, 5924, 5928, 5984, 7686, 7690, 7692, 7704, 7748, 7752, 7944, 12850, 12852, 12856, 12912, 13104, 13864, 33334, 33338, 33394, 33396, 33400, 33586, 33588, 33592, 33648, 33838, 33850, 33894, 33898, 33900, 33908, 33912, 34086, 34090, 34092, 34098, 34100, 34104, 34152, 34160, 34346, 34348, 34354, 34356, 34360, 34416, 34608, 35892, 35896, 37488, 37680, 37986, 37992, 38178, 38184, 38192, 38436, 38440, 38448, 39960, 39984, 99880, 100912, 266354, …, 17433122, 17433184, 17433352, 17433376, 17433612, 17433634, 17433636, 17433640, 17433648, 17433696, 17433888, 17434144, 17434658, 17434660, 17434664, 17434672, 17437704, 17437728, 17438728, 17438736, 17438752, 17466400, 17467400, 17467424, 17631236, 17631264, 17695776, 17696770, 17696772, 17696776, 17696784, 17696800, 18417696, 18483208, 18483232, 21071904, 21104650, 21104674, 21104680, 21104688, 21104712, 21104736, 21104928, 21105184, 21105696, 21366816, 21628960, 25298950, 25298962, 25298978, 25298992, 25299024, 25299040, 25299232, 25300000, 58853408, 545392674] The total Number is 551

Number of Edges	Motif ID [Decimal representation]
7	[894, 1854, 1902, 1916, 3900, 4478, 4734, 4926, 4982, 4986, 4988, 5694, 5742, 5754, 5756, 5934, 5946, 5948, 5990, 5994, 5996, 6008, 7710, 7738, 7740, 7758, 7770, 7772, 7800, 7950, 7962, 7964, 7992, 8006, 8010, 8012, 8024, 12666, 12862, 12918, 12922, 12924, 13110, 13114, 13116, 13170, 13172, 13176, 13870, 13882, 13884, 13930, 13932, 13944, 14124, 14136, 15928, 33406, 33598, 33654, 33658, 33660, 33918, 34110, 34158, 34166, 34170, 34172, 34366, 34414, 34422, 34426, 34428, 34606, 34614, 34618, 34620, 34674, 34676, 34680, 35902, 35958, 35962, 35964, 36150, 36154, 36156, 36216, 36410, 36412, 37494, 37498, 37686, 37690, 37692, 37746, 37748, 37752, 37998, 38010, 38190, 38198, 38202, 38204, 38246, 38250, 38252, 38258, 38260, 38264, 38446, 38454, 38458, 38460, 38502, 38506, 38508, 38514, 38516, 38520, 38694, 38698, 38700, 38706, 38708, 38712, 38756, 38760, 38768, 39966, 39990, 39994, 39996, 40014, 40022, 40026, 40028, 40050, 40052, 40056, 40206, 40214, 40218, 40220, 40242, 40244, 40248, 40268, 40280, 40304, 40462, 40470, 40474, 40476, 40498, 40500, 40504, 40524, 40532, 40536, 40560, 40728, 40752, 45936, 46440, 46634, 46636, 46642, 46644, 46648, 46704, 46896, 48178, 48180, 48184, 99886, 99898, 99946, 99948, 99960, 100138, 100140, 100152, 100200, 100918, 100922, 100970, 100972, 100978, 100980, 100984, 101164, 101172, 101176, 101944, 266366, 266558, 266614, 266618, 266620, 267062, 267068, 267122, 267124,, …, 21366802, 21366818, 21366824, 21366832, 21366864, 21366880, 21367072, 21367312, 21367328, 21367840, 21571616, 21596192, 21628448, 21628934, 21628938, 21628940, 21628946, 21628948, 21628952, 21628962, 21628964, 21628968, 21628976, 21629024, 21629216, 21629472, 21629984, 21633056, 21637152, 21661728, 21694496, 21891088, 21891104, 22677536, 25298958, 25298966, 25298982, 25298994, 25299014, 25299020, 25299026, 25299028, 25299042, 25299044, 25299056, 25299206, 25299210, 25299212, 25299218, 25299220, 25299224, 25299234, 25299236, 25299240, 25299248, 25299280, 25299296, 25299744, 25299974, 25299980, 25299986, 25299988, 25300002, 25300004, 25300016, 25300048, 25300064, 25300256, 25303120, 25303136, 25303312, 25303328, 25303568, 25303584, 25304080, 25304096, 25307424, 25307680, 25308192, 25332256, 25332768, 25365536, 51251232, 51775520, 54921248, 55707680, 58852448, 58852640, 58853410, 58853412, 58853424, 58857504, 58886176, 58918944, 125962272, 545392678, 545392738] The total Number is 2134
8	[894, 1854, 1902, 1916, 3900, 4478, 4734, 4926, 4982, 4986, 4988, 5694, 5742, 5754, … , 1091112456, 1091112480, 1091113478, 1091113990, 1091113996, 1091114004, 1091115014, 1091115020, 1091115028, 1091117378, 1091117380, 1091117384, 1091117392, 1091117408, 1091117826, 1091117828, 1091118338, 1091118340, 1091118344, 1091118352, 1091118368, 1091119362, 1091119364, 1091119368, 1091119376, 1091119392, 1091121666, 1091121668, 1091121672, 1091121680, 1091121696, 1091122178, 1091122180, 1091122184, 1091122192, 1091122208, 1091123202, 1091123204, 1091123208, 1091123216, 1091123232, 1091146754, 1091146756, 1091146760, 1091146768, 1091146784, 1091147778, 1091147780, 1091147784, 1091147792, 1091147808, 1091150338, 1091150340, 1091150352, 1091150368, 1091150850, 1091150852, 1091150856, 1091150864, 1091150880, 1091151874, 1091151876, 1091151880, 1091151888, 1091151904, 1091244546, 1091245058, 1091245060, 1091245064, 1091245072, 1091245088, 1091248642, 1091248644, 1091248648, 1091248656, 1091249154, 1091249156, 1091249160, 1091249168, 1091249184, 1091273730, 1091273732, 1091273736, 1091273744, 1091273760, 1091371586, 1091371588, 1091371600, 1091371616, 1091373066, 1091373068, 1091373080, 1091373096, 1092133890, 1092133892, 1092133904, 1092133920, 1092158978, 1092158984, 1092160002, 1092160008, 1092421634, 1092421640, 1094785030, 1094785036, 1094785044, 1094788354, 1094788360, 1094788384, 1094789378, 1094789380, 1094793218, 1094793220, 1094793224, 1094817794, 1094817796, 1094817800, 1094821890, 1094821892, 1094821896, 1094847554, 1094847556, 1094847746, 1094847748, 1094847752, 1094854914, 1094854920, 1094854944, 1108115722, 1108115724, 1108115736, 1108115752, 1108116064, 1108116240, 1108116256, 1108116504, 1108116520, 1108117008, 1108117528, 1108148490, 1108148492, 1108148504, 1108148746,

Number of Edges	Motif ID [Decimal representation]
	1108148748, 1108148804, 1108148808, 1108148832, 1108148996, 1108149000, 1108149024, 1108150282, 1108150284, 1108150296, 1108150788, 1108150792, 1108150816, 1108378448, 1108378464, 1108378662, 1108378960, 1108379408, 1108379670, 1108379676, 1108379700, 1108383756, 1108383764, 1108390416, 1108391952, 1108410894, 1108410922, 1108410954, 1108410962, 1108411208, 1108411976, 1108412168, 1108412430, 1108412442, 1108412444, 1108412458, 1108412460, 1108412472, 1108412490, 1108645892, 1108645904, 1108674570, 1108674572, 1108674584, 1108705796, 1108705824, 1108738572, 1108738584, 1108771332, 1109197064, 1109197088, 1109198852, 1111595016, 1111597572, 1111622158, 1111622182, 1111622214, 1111634464] The total Number is 6446
9	[1918, 3902, 4990, 5758, 5950, 5998, 6010, 6012, 7742, 7774, 7802, 7804, 7966, 7994, ..., 1112638560, 1112638736, 1112639494, 1112639500, 1112639506, 1112639508, 1112639522, 1112639524, 1112639536, 1112639568, 1112639584, 1112639760, 1112640528, 1112703312, 1112703568, 1112703760, 1112704272, 1112704528, 1112705044, 1112705048, 1124991556, 1124991748, 1124993540, 1125423106, 1125689346, 1125777988, 1125778180, 1125778500, 1125778692, 1125779972, 1125780484, 1128924228, 1128924420, 1128924676, 1129416706, 1132627016] The total Number is 17274
10	[3966, 6014, 7806, 7998, 8030, 8058, 8060, 13182, 13950, 14142, 14190, 14202, 14204, 15934, 15994, 15996, 16188, 34686, 36222, 46, 278348, 278354, 278356, 278360, 278384, ..., 1179256076, 1179256100, 1179256326, 1179256330, 1179256332, 1179256340, 1179256356, 1179260168, 1179260192, 1179260448, 1179261960, 1179322440, 1182840072, 1182868746, 1182868808, 1182870026, 1182870028, 1182870056, 1182870088, 1182894604, 1182894616, 1183131744, 1183197456, 1183393798, 1183393802, 1183393804, 1183393826] The total Number is 40182
11	[8062, 14206, 15998, 16190, 36734, 38782, 40318, 40574, 40766, 40798, 40822, 40826, 40828, 45950, 46462, 46718, 46910, 46958, 46966, 46970, 46972, 48254, 48446, 48502, …,1653221644, 1653221656, 1653221666, 1653221668, 1653221672, 1653246470, 1653246474, 1653246476, 1653246484, 1653246498, 1653246500, 1653246982, 1653246986, 1653246988, 1653246994, 1653246996, 1653247000, 1653247010, 1653247012, 1653247016, 1653247024, 1653771270, 1653771276, 1653771298] The total Number is 76496
12	[16254, 40830, 46974, 48510, 48766, 48958, 102270, 104318, 105342, 106110, 106302, 106334, 106350, 106362, 106364, 112494, 112506, 113526, 113530, 114238, 114298, 114300, 114492, 233086, 233278, 237178, ..., 3310430308, 3310430312, 3310453836, 3310453858, 3310454858, 3310454860, 3310454866, 3310454882, 3310455302, 3310455330, 3310491142, 3310491148, 3310491154, 3310491170, 3310491172, 3310491176, 3310492166, 3310492170, 3310492178, 3310494794, 3310494824, 3310495818, 3310495820, 3310495832, 3310496262, 3310496266, 3310496268, 3310496280, 3310496778, 3310519370, 3427931682] The total Number is 121941
13	[49022, 106366, 112510, 113534, 114302, 114494, 233342, 237182, 237374, 237436, 278398, 302974, 307070, 309118, 310654, …,3348300362, 3348300364, 3351347526, 3351347532, 3351413062, 3351413068, 3427895074, 3427895398, 3427899480, 3427931674, 3427931686, 3427931690, 3427931736, 3427931746, 3427931938, 3427932504, 3428193810, 3431367958, 3431367962, 3431367986, 3431368020, 3431368276] The total Number is 168964
14	[114558, 237438, 311166, 343934, 368510, 372606, 374654, 375678, 376190, 376446, 376638, 376670, 376686, 376694, 376698, …, 3448407340, 3448407372, 3448408334, 3448408342, 3448408346, 3448408396, 3448409164, 3448409356, 3448411402, 3448415308, 3448416332, 3448416344, 3448444170, 3448669446, 3448931148, 3448963916, 3481699078, 3787687500, 3788186700] The total Number is 206281
15	[245630, 376702, 475006, 499582, 503678, 507742, 507766, 507770, 835454, 868222, 892798, 898942, 899966, 900478, 900734, 900926, 991102, 997246, 998782, 999038, …, 3818324774, 3818324812, 3818325324, 3818326348, 3818328866, 3821241102, 3821474594, 3838219608, 3838221400, 3838223894, 3838254168] The total Number is 220668
16	[507774, 900990, 999294, 1023870, 1030014, 1031550, 1031806, 1031998, 1884030, 1916798, 1941374, 1947518, 1948542, …, 3851851376, 3851851554, 3851852130, 3851852144, 3851852386, 3851852400, 3851852898, 3852119054,

Number of Edges	Motif ID [Decimal representation]
	3852119062, 3852119066, 3854996322, 3854997282, 3854997858, 3855816040] The total Number is 207292
17	[1032062, 1949566, 2047870, 2072446, 4702078, 5095294, 5160830, 5193598, 5218174, 5224318, 5225342, 5225854, 5226110, 5226302, 6141822, 6142846, …, 3973284686, 3973284694, 3973284700, 3973284710, 3973284716, 3973284722, 3973284724, 3973285660, 3973285670, 3973285676, 3973286246, 3973286250, 3973286252, 3973286264, 3973286700, 3973286708] The total Number is 171002
18	[2080638, 5226366, 6143870, 6209406, 6242174, 6266750, 13090686, 13582206, 13606782, 13614718, 13614910, 17809278, …, 8116348508, 8116348518, 8116348524, 8116348710, 8116349532, 8116349542, 8116349548, 8116471566, 8117131050, 8117132058, 8217012006] The total Number is 124105
19	[6274942, 13614974, 18857854, 22003582, 22790014, 22921086, 22986622, 23019390, 23043966, 23048062, 23052126, 23052142, …, 8117258092, 8117368614, 8117368626, 8117394198, 8117394226, 8117397286, 8117495382, 8183457574, 8217012014] The total Number is 78810
20	[14663550, 23052158, 27246462, 30392190, 31178622, 31440734, 31440750, 31440758, 52412286, 55558014, 56082302, 56475518, …,8183979306, 8184043302, 8184044826, 8217012030, 8217012078, 8217012092, 8217014062, 8217014076, 8217016166, 8217016184, 8217018150, 8217278254, 8217640218] Total Number is 43851
21	[31440766, 56606590, 60800894, 63946622, 64470910, 64993150, 64994174, 64994686, 64995134, 119521150, 122666878, …, 8217667444, 8217668894, 8217672986, 8218324348, 8218326904, 8218328440, 8218426744, 8251095398, 8251160934, 8251714334] Total Number is 21207
22	[64995198, 123715454, 127909758, 131055486, 131972990, 132038526, 132071294, 132095870, 257802110, …, 8251718520, 8251719270, 8251743846, 8252143974, 8252143986, 8252144754, 8252209510, 8252209522, 8252233574, 8252242278, 8319285606] Total Number is 8950
23	[132104062, 257933182, 262127486, 265273214, 601866110, 664780670, 667926398, 668942206, 668966782, 1138737022, 1189068670, 1197457278, 1201651582, 1204797310, 1205583742, 1205714814, 1205780350, 1205813118, 1205837694, 1205841790, 1205845854, 1205845870, 1205845878, 1205845882, 1314897790, 1319092094, 1322237822, 1323024254, 1323286366, 1323286382, 1323286390, 1331543934, 1331609470, 1331666814, 1331670910, 1331674974, 1331674990, 1331675002, 1334820734, 1335607166, 1335803774, 1335836542, 1335861118, 1335865214, 1335869278, 1335869294, 1335869302, 1335869306, 1338490750, 1338752894, 1338982270, 1339006846, 1339010942, 1339014782, 1339014974, 1339015006, 1339015022, 1339015030, 1339015034, 1339015036, 1339797374, 1339801438, 1339801454, 1339801462, 1339801466, 1340063566, 1340063574, 1340063590, 1340063602, 1642053502, 1658830718, 1671413630, 1674559358, 1675083646, 1675345790, 1675606910, 1675607422, 1675607870, 1675607902, 1675607918, 1675607926, 1675607932, 1721745278, 1724891006, 1725677438, 1725874046, 1725906814, 1725931390, 1725935486, 1725939550, 1725939566, 1725939574, 1725939578, 1738456958, 1738514302, 1738518398, 1738522462, 1738522478, 1738522490, 1741602686, 1741660030, 1741664126, 1741667710, 1741667966, 1741668158, 1741668190, 1741668206, 1741668214, 1741668218, 1741668220, 1742421886, 1742446462, 1742450558, 1742454622, 1742454638, 1742454646, 1742454650, 1742683518, 1742683966, 1742683998, 1742684014, 1742684022, 1742684028, 1742708574, 1742708590, 1742708598, 1742712638, 1742712670, 1742712686, 1742712694, 1742712698, 1742712700, 1742716750, 1742716758, 1742716762, 1742716774, 1742716778, 1742716786, 1742716792, 1859891070, 1859895134, 1859895150, 1859895162, 1860157262, 1860157270, 1860157286, 1860157298, 1876934470, 1876934498, 3277832062, 3285172094, 3285696382, 3286218622, 3286220158, 3286220606, 3311386494, 3318726526, 3319512958, 3319644030, 3319709566, 3319742334, 3319766910, 3319771006, 3319775070, 3319775094, 3319775098, 3340746622, 3343892350, 3344416638, 3344809854, 3344875390, 3344908158, 3344932734, 3344938878, 3344939902, 3344940414, 3344940670, 3344940862, 3348086654, 3348610942, 3349004158, 3349069694, 3349102462, 3349127038, 3349133182, 3349134206, 3349134718, 3349134974, 3349135166, 3351756670, 3352149886, 3352215422, 3352248190, 3352272766, 3352278910, 3352279934, 3352280446, 3352280702,

Number of Edges	Motif ID [Decimal representation]
	3352280894, 3352543102, 3352674174,
	3352739710, 3352772478, 3352797054,
	3352801150, 3352803198, 3352804222,
	3352804734, 3352804990, 3352805182,
	3352805214, 3352805230, 3352805238,
	3352805242, 3352805244, 3353165694,
	3353190270, 3353196414, 3353197438,
	3353197950, 3353198206, 3353198398,
	3353231230, 3353255806, 3353261950,
	3353262974, 3353263486, 3353263742,
	3353263934, 3353288574, 3353294718,
	3353295742, 3353296254, 3353296510,
	3353296702, 3353317246, 3353319294,
	3353320318, 3353320830, 3353321086,
	3353321278, 3353321310, 3353321326,
	3353321334, 3353321338, 3353321340,
	3353326462, 3353326974, 3353327230,
	3353327422, 3353327454, 3353327470,
	3353327478, 3353327482, 3353327484,
	3353327998, 3353328254, 3353328446,
	3353328494, 3353328502, 3353328506,
	3353328508, 3353328766, 3353328958,
	3353329014, 3353329018, 3353329020,
	3353329214, 3353329274, 3353329276,
	3353329468, 3428827006, 3433021310,
	3436167038, 3436691326, 3445079934,
	3445342078, 3445473150, 3445538686,
	3445571454, 3445596030, 3445600126,
	3445602174, 3445603198, 3445603710,
	3445603966, 3445604158, 3445604190,
	3445604206, 3445604214, 3445604218,
	3445604220, 3448749950, 3449274238,
	3449536382, 3449732990, 3449765758,
	3449790334, 3449794430, 3449796478,
	3449797502, 3449798014, 3449798270,
	3449798462, 3449798494, 3449798510,
	3449798518, 3449798522, 3449798524,
	3452419966, 3452682110, 3452911486,
	3452936062, 3452940158, 3452942206,
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29	[16909320062] The total Number is 1
30	[34089189246] The total Number is 1

The partial of total decimal numbers, which is found, associated with the 6-node motifs is 1520873.