Semigraph Folding Approach for Generalization of Planar Triangulation

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Abstract
We applied triangulation in the cycle graphs $C_n$, $n \geq 3$ and generalized to $n$ – transformation, also we observed that on splicing and folding introduced by Tom Head and E. El-Kholy & co. respectively in $C_{2m}$, $m \geq 2$ and it’s generalization leads to the resultant graph is $P_2, G_3^0, G_3^1, ..., G_3^{n-1}$ whereas on splicing and semigraph folding introduced by S. Jeyabharathi & Co. in $C_{2m-1}$, $m \geq 2$ and its generalization leads to the resultant semigraph with and an edge and one semi edge.

Keywords: Folding and Semigraph Folding, Planar Trinagulation, Splicing, Semigraph

1. Introduction
The concept of splicing system introduced by Tom Head has become a new interesting area on DNA molecule and the graph splicing scheme of Rudolf Freund with semigraphs introduced by E. Sampath kumar representing the spliced semigraph which is more powerful than graph. This presents communication volume accurately. Semigraph model will eventually replace graph partitioning in scientific computing. Here we apply the theory of splicing system and folding techniques in the planar triangulation where the planar triangulations on the cycle graph is plane graphs in which every face is a triangle. Triangulation today is used for many purposes, including surveying, navigation, metrology, astrometry, binocular vision, model rocketry and gun direction of weapons. In computational geometry, polygon triangulation is the decomposition of a polygonal area (simple polygon) into a set of triangles, i.e., finding a set of triangles with pair wise non-intersecting interiors whose union is polygonal area.

2. Preliminaries

2.1 Splicing System
Splicing is a model of the recombinant behaviour of double stranded molecules of DNA under the action of restriction enzymes and ligases. A single stranded of DNA is an oriented sequence of nucleotides A, C, G & T but since A can bind to T & G to C, two strands of DNA bind together to form a double stranded DNA molecule, if they have matching pairs of nucleotides when reading the second one along the reverse orientation.
2.2 Graph
A graph over \( V \) is a triple \((N, E, L)\) where \( N \) is the set of nodes, \( E \) is the set of edges of the form \((n, m)\) with \( n, m \in N, n \neq m \) and \( L \) is the function from \( N \) to \( V \) assigning a label from \( V \) to each node of \( N \). The set of all graphs over \( V \) is denoted by \( \gamma(V) \).

2.3 SemiGraph
A semigraph \( G \) is a pair \((V, X)\) where \( V \) is a non-empty set whose elements are called vertices of \( G \) and \( X \) is a set of \( n \)-tuples called edges of \( G \) of distinct vertices for various \( n \geq 2 \), satisfying the following conditions:

S.G-1 Any two edges have at most one vertex in common.
S.G-2 Two edges \((u_1, u_2, u_3, ..., u_n)\) and \((v_1, v_2, v_3, ..., v_m)\) are considered to be equal if and only if (i) \( m = n \) and (ii) either \( u_i = v_j \) or \( u_i = v_{n-j+1} \) for \( 1 \leq i \leq n \). Thus the edges \((u_1, u_2, u_3, ..., u_n)\) are the same as the edge \((u_n, u_{n-1}, ..., u_1)\).

2.4 Semi Vertices
Let \( G \) be a graph, when splicing \( G \), we obtain new vertices which are called as semi vertices denoted by \( V' \), where \(|V'|=p'\).

2.5 Semi Edges
Let \( G \) be a graph when splicing \( G \), we obtain new edges by decomposition of edges which are called as semi edges denoted by \( E' \), where \(|E'|=q'\).

2.6 Spliced SemiGraph map
Let \( SSG_1 = (V_1, E_1) \) and \( SSG_2 = (V_2, E_2) \) be two Spliced Semigraphs and a map \( f : SSG_1 \to SSG_2 \) is said to be a spliced semigraph map, if

i. for each vertex \( v \in V_1 \), \( f(v) \) is a vertex in \( V_2 \),
ii. for each semi vertex \( v' \in V_1 \), \( f(v') \) is a vertex in \( V_2 \),
iii. for each edge \( e \in E_1 \), \( \dim(f(e)) \leq \dim(e) \),
iv. for each semi edge \( e' \in E_1 \), \( \dim(f(e')) \leq \dim(e') \).

where \( V_1 \) and \( V_2 \) are the set of vertices and semi vertices of the Spliced Semigraphs \( SSG_1 \) and \( SSG_2 \) respectively. \( E_1 \) and \( E_2 \) are the set of edges and semi edges of the Spliced Semigraphs \( SSG_1 \) and \( SSG_2 \) respectively.

2.7 Semigraph Folding
A Spliced Semigraph map \( f : SSG_1 \to SSG_2 \) a semigraph folding, if and only if \( f \) maps vertices to vertices, semi vertices to semi vertices, edges to edges and semi edges to semi edges.

Example for semigraph folding:
The graph \( G \) [fig 1] represents 1-Cut splicing \((u_1)\) with the semi vertices \(\{1', 2', 3', 4', 5', 6'\}\) and the semi edges \(\{(1, 1'), (2, 2'), (2, 3'), (5, 5'), (5, 4'), (4, 6')\}\). Here \(|V'|=6\) and \(|E'|=6\).

On splicing, the graph \( G \) forms 2 bipartite semigraphs \( G_1 \) & \( H_1 \) [Fig 2]. Further on applying sequence of semigraph folding on either \( G_1 \) or \( H_1 \), the resultant semigraph with one edge and one semiedge. [fig 3]

\[\text{Figure 1. Graph G with 1-Cut splicing (}u_1\text{)}\]

\[\text{Figure 2. Bipartite semigraphs.}\]

\[\text{Figure 3. Semigraph folding on G_1 results in G_3.}\]
2.8 SemiGraph (SG) notation

The semigraph SG is denoted by quadruple \( SG = (V, E, V', E') \).

where 
- \( V \) denotes the set of vertices in the semigraph SG
- \( E \) denotes the set of edges in SG
- \( V' \) denotes the set of semi vertices in SG and
- \( E' \) denotes the set of semi edges in SG.

Example for Semigraph (SG) Notation:
Form Fig. 3, the semigraph \( G_3 \) is denoted by quadruple \( G_3 = ({1, 6}, \{(1, 6)\}, \{1', \}, \{(1,1')\}) \)

2.9 \( \eta(SG) \)

The number of vertices, edges, semi vertices and semi edges in a semigraph SG is denoted by quadruple \( \eta(SG) = (\eta(V), \eta(E), \eta(V'), \eta(E')) \)

where 
- \( \eta(V) \) denotes the number of vertices in SG.
- \( \eta(E) \) denotes the number of edges in SG
- \( \eta(V') \) denotes the number of semi vertices in SG and
- \( \eta(E') \) denotes the number of semi edges in SG.

Example for \( \eta(SG) \):
Form Fig. 3, the number of vertices, edges, semi vertices and semi edges in a semigraph \( G_3 \) is denoted by quadruple \( \eta(G_3) = (2, 1, 1, 1) \).

3. Generating triangulation in \( C_n \)

3.1 Algorithm for generating triangulation in \( C_n \) graph

**Step 1:** Take a cycle graph ‘G’ with ‘n’ vertices \( (v_1, v_2, v_3, …, v_n) \), \( n \geq 3 \). Let it be denoted by \( G_n^0 \).

**Step 2:** Introduce a vertex ‘vn+1’ inside \( G_n^0 \) and connect the vertex ‘vn+1’ to all other vertices by an edge in \( G_n^0 \). The resultant graph is denoted by \( G_n^1 \). And \( T_1 \) is the transformation of generating triangulation from the graph \( G_n^0 \) to \( G_n^1 \).

**Step 3:** Introduce vertices \( v_{n+2}, v_{n+3}, v_{n+4}, …, v_{2n+1} \) in each \( C_n \) embedded in \( G_n^1 \) and connect the corresponding vertices \( v_{n+2}, v_{n+3}, v_{n+4}, …, v_{2n+1} \) to all 3 vertices in the embedded \( C_n \) in which it lies in that region. The resultant graph is denoted by \( G_n^2 \). And \( T_2 \) is the transformation of generating triangulation from the graph \( G_n^1 \) to \( G_n^2 \).

**Step 4:** Repeat Step 3 to required number of times.

**Note:** On repeating step 4 further to infinite and by introducing of new vertex \( (v) \) in each \( C_n \) (a triangle) embedded will lie on the edges at some point.

4. Working model of the proposed algorithm

Let \( G_j^k \), \( j \geq 3 \), \( k \geq 0 \) be the denotation of the Cycle graph (\( C_n \)) and its generalization, \( j \) indicates the number of vertices in the cycle graph and \( k \) indicates the generalization of each stages which takes the value from 0,1, 2, 3, … .

\( C_j \) (Triangle) and its generalization:

\( C_4 \) (Square) and its generalization:

\( C_5 \) (Pentagon) and its generalization:

\( C_6 \) (Hexagon) and its generalization:
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4.1 Cycle graph \((C_n)\), \(n \geq 3\) Versus number of vertices

The number of vertices in each triangulation of \(C_n\), \(n \geq 3\) is given in Table 1.

| Cycle graph \((C_n)\), \(n \geq 3\) Vs number of vertices | \(G_n^0\) | \(G_n^1\) | \(G_n^2\) | \(G_n^3\) | \(G_n^4\) |
|----------------------------------------------------------|--------|--------|--------|--------|--------|
| \(C_3\)                                                  | 3      | 4      | 7      | 16     | 43     |
| \(C_4\)                                                  | 4      | 5      | 9      | 21     | 57     |
| \(C_5\)                                                  | 5      | 6      | 11     | 26     | 71     |
| \(C_6\)                                                  | 6      | 7      | 13     | 31     | 85     |
| \(C_7\)                                                  | 7      | 8      | 15     | 36     | 99     |
| ...                                                      | ...    | ...    | ...    | ...    | ...    |

Note: In Table I, the denotation of \(n, n_1, n_2, n_3, \ldots\) indicates the number of vertices in each cycle graph and its generalization.

On applying triangulation for cycle graph with \(n\) vertices and in its generalization in each triangulation is observed as recurrence relation

\[ n_k = n_{k-1} + (n \times 3^{k-2}), \quad k = 2, 3, \ldots \text{ for } n_1 = n + 1. \]

4.2 Cycle graph \((C_n)\) Versus number of \(C_3\)

The number of \(C_3\) embedded in each triangulation is given in Table 2.

| Cycle graph \((C_n)\) Vs number of \(C_3\) | \(n\) | \(G_n^0\) | \(G_n^1\) | \(G_n^2\) | \(G_n^3\) | \(G_n^4\) |
|------------------------------------------|------|----------|----------|----------|----------|----------|
| \(C_3\)                                  | 3    | 1        | 1        | 9        | 27       | 81       |
| \(C_4\)                                  | 4    | 0        | 4        | 12       | 36       | 108      | 324      |
| \(C_5\)                                  | 5    | 0        | 5        | 15       | 45       | 135      | 405      |
| \(C_6\)                                  | 6    | 0        | 6        | 18       | 54       | 162      | 486      |
| \(C_7\)                                  | 7    | 0        | 7        | 21       | 63       | 189      | 567      |
| \(C_8\)                                  | 8    | 0        | 8        | 24       | 72       | 216      | 648      |
| \(C_9\)                                  | 9    | 0        | 9        | 27       | 81       | 243      | 729      |
| \(C_{10}\)                                | 10   | 0        | 10       | 30       | 90       | 270      | 810      |
| ...                                      | ...  | ...      | ...      | ...      | ...      | ...      | ...      |

From Table 2, \(I_i, i = 0, 1, 2, 3, \ldots\) denotes the number of triangles in each cycle graph and its generalization.

Thus, for any cycle graph with \(n\) vertices \(\forall n \geq 3\), the number of \(C_3\) embedded in each triangulation is separated as Case 1 and Case 2.

Case 1: When \(n = 3\), the number of \(C_3\) embedded in each triangulation is 1, 3, 9, 27, 81,\ldots

Case 2: When \(n \geq 4\), the number of \(C_3\) embedded in each triangulation is 1, 3, 9, 27, 81,\ldots

4.3 Folding on \(C_{2m}\), \(m \geq 2\) and its Generalization

Let \(f_i, i \geq 1\) be the folding on the graphs.

Table III shows the folding on \(C_{2m}\), \(m \geq 2\) and its generalization.

4.3.1 Proposition

For \(C_4\), the number of folding is 2.
Table 3. Folding on $C_{2m}$, $m \geq 2$ and its generalization

| $G_{2m}$ | $m$ | $n$ | Graph | Applying folding techniques on graph | Resultant graph after folding |
|----------|-----|-----|-------|--------------------------------------|-----------------------------|
| $G^n_{2m}$ | 2   | 0   | $G^0_{4}$ | $f_1, f_2$ | $P_2$ (Path of length 1) |
|          | 1   |     | $G^1_{4}$ | $f_1, f_2$ | $C_3$ (which is $G^0_{3}$) |
|          | 2   |     | $G^2_{4}$ | $f_1, f_2$ | $G^1_{3}$ |
|          | 3   |     | $G^3_{4}$ | $f_1, f_2$ | $G^2_{3}$ |
|          | ... |    |          | $f_1, f_2$ | ... |
|          | $n$ |     | $G^n_{4}$ | $f_1, f_2$ | $G^{n-1}_{3}$ |
| 3        | 0   |     | $G^0_{6}$ | $f_1, f_2, f_3$ | $P_2$ (Path of length 1) |
|          | 1   |     | $G^1_{6}$ | $f_1, f_2, f_3$ | $C_3$ (which is $G^0_{3}$) |
|          | 2   |     | $G^2_{6}$ | $f_1, f_2, f_3$ | $G^1_{3}$ |
|          | 3   |     | $G^3_{6}$ | $f_1, f_2, f_3$ | $G^2_{3}$ |
|          | ... |    |          | $f_1, f_2, f_3$ | ... |
|          | $n$ |     | $G^n_{6}$ | $f_1, f_2, f_3$ | $G^{n-1}_{3}$ |
| 4        | 0   |     | $G^0_{8}$ | $f_1, f_2, f_3$ | $P_2$ (Path of length 1) |
|          | 1   |     | $G^1_{8}$ | $f_1, f_2, f_3$ | $C_3$ (which is $G^0_{3}$) |
|          | 2   |     | $G^2_{8}$ | $f_1, f_2, f_3$ | $G^1_{3}$ |
|          | 3   |     | $G^3_{8}$ | $f_1, f_2, f_3$ | $G^2_{3}$ |
|          | ... |    |          | $f_1, f_2, f_3$ | ... |
|          | $n$ |     | $G^n_{8}$ | $f_1, f_2, f_3$ | $G^{n-1}_{3}$ |

...
**Proof:**
From Appendix 5.1, it is evident that the proposition holds true.

### 4.3.2 Proposition

For every $C_{2n}$, $n \geq 3$, the number of folding is 3.

**Proof:**
From Appendix 5.2, it is evident that the proposition holds true.

### 4.4 Folding on $C_{2m-1}$, $m \geq 2$ and its Generalization

Let $f_i, i \geq 1$ be the folding on the graphs and $S_i, i \geq 1$ be the semigraph splicing.

Table 4 shows the folding on $C_{2m+1}$, $m \geq 2$ and its generalization.

**Note:** From Table 4, the resultant semigraph after splicing and folding $\eta(SG)$ is $(2,1,1,1)$ which is equivalent to Fig. i [From Appendix 5.3]

### 4.4.1 Proposition

The number of folding on $C_{2m-1}$, $m \geq 2$ and its generalization is increased by 2.

**Proof:**
From Appendix 5.4, it is evident that the folding $f_1$ is used in Fig.j whereas $f_1, f_2$ and $f_3$ in Fig.k.

Also from Appendix 5.5, the folding $f_1$ and $f_2$ is used in Fig.l and the foldings $f_1, f_2, f_3$ & $f_4$ in Fig.m.

Thus the number of folding is increased by 2 on $C_{2m-1}$, $m \geq 2$ and its generalization.

### 4.4.2 Proposition

The number of folding techniques applied on each $C_{2m-1}$, $m \geq 2$ and its generalization is increased by 1 from one cycle graph to another.

**Proof:**
The folding $f_i$ is used in Fig.j of Appendix 5.4 whereas the folding $f_1$ and $f_2$ in Fig.l of Appendix 5.5.

Also the foldings $f_1$, $f_2$ and $f_3$ is used in Fig.k of Appendix 5.4 whereas the folding $f_1, f_2, f_3$ & $f_4$ in Fig.m of Appendix 5.5. Thus the number of folding is increased by 1 from one cycle graph and it’s generalization to another.

### 5. Appendix

#### 5.1 Folding on $C_4$

On applying folding technique $f_1$ & $f_2$ on each $G_0^0, G_1^1, G_2^2, G_3^3, \ldots$ the corresponding resultant graph is $P_2$ (Path of length 1) $G_0^0, G_1^1, G_2^2, \ldots$ [From Fig. a, Fig. b, Fig. c, Fig. d]
Table 4. Folding on $C_{2m+1}$, $m \geq 2$ and its generalization

| $C_{2m+1}$, $m \geq 2$ and its generalization | $n$ | Graph | Applying splicing | Applying folding | Sequence of applying splicing and folding in graph | Resultant semigraph after splicing $\eta$(SG) |
|-----------------------------------------------|-----|-------|------------------|-----------------|-----------------------------------------------|---------------------------------------------|
| $G_3^n$                                       | 0   | $G_3^0$ | $S_1$             | $f_1$           | $S_1$ $f_1$                                   | (2,1,1,1)                                  |
|                                               | 1   | $G_3^1$ | $S_1, S_2$       | $f_1, f_2, f_3$  | $S_1$ $f_1$, $S_2$ $f_2$, $f_3$               | (2,1,1,1)                                  |
|                                               | 2   | $G_3^2$ | $S_1, S_2, S_3$  | $f_1, f_2, f_3, f_5$ | $S_1$ $f_1$, $S_2$ $f_2$, $S_3$ $f_3$, $f_5$ | (2,1,1,1)                                  |
|                                               | 3   | $G_3^3$ | $S_1, S_2, S_3, S_4$ | $f_1, f_2, f_3, f_4, f_6$ | $S_1$ $f_1$, $S_2$ $f_2$, $S_3$ $f_3$, $S_4$ $f_4$, $f_6$ | (2,1,1,1)                                  |
|                                               | ... | ...     | ...              | ...             | ...                                           | (2,1,1,1)                                  |
|                                               | $n$ | $G_3^n$ | $S_1, S_2, S_3, ..., S_{m+1}$ | $f_1, f_2, f_3, ..., f_{2n+1}$ | $S_1$ $f_1$ $S_2$ $f_2$ $S_3$ $f_3$ $S_{m+1}$ $f_{2n+1}$ | (2,1,1,1)                                  |
| $G_5^n$                                       | 0   | $G_5^0$ | $S_1$             | $f_1, f_2$      | $S_1$ $f_1$, $f_2$                             | (2,1,1,1)                                  |
|                                               | 1   | $G_5^1$ | $S_1, S_2$       | $f_1, f_2, f_3, f_4$ | $S_1$ $f_1$, $f_2$, $S_2$ $f_3$, $f_4$         | (2,1,1,1)                                  |
|                                               | 2   | $G_5^2$ | $S_1, S_2, S_3$  | $f_1, f_2, f_3, f_4, f_5$ | $S_1$ $f_1$, $f_2$, $S_3$ $f_3$, $f_4$, $f_5$ | (2,1,1,1)                                  |
|                                               | 3   | $G_5^3$ | $S_1, S_2, S_3, S_4$ | $f_1, f_2, f_3, f_4, f_5, f_6$ | $S_1$ $f_1$, $S_3$ $f_3$, $S_4$ $f_4$, $f_6$ | (2,1,1,1)                                  |
|                                               | ... | ...     | ...              | ...             | ...                                           | (2,1,1,1)                                  |
|                                               | $n$ | $G_5^n$ | $S_1, S_2, S_3, ..., S_{m+1}$ | $f_1, f_2, f_3, ..., f_{2n+2}$ | $S_1$ $f_1$ $S_2$ $f_2$ $S_{m+1}$ $f_{2n+2}$ | (2,1,1,1)                                  |
| $G_7^n$                                       | 0   | $G_7^0$ | $S_1$             | $f_1, f_2, f_3$  | $S_1$ $f_1$ $f_2$ $f_3$                        | (2,1,1,1)                                  |
|                                               | 1   | $G_7^1$ | $S_1, S_2$       | $f_1, f_2, f_3, f_5$ | $S_1$ $f_1$, $f_2$, $S_2$ $f_3$, $f_5$         | (2,1,1,1)                                  |
|                                               | 2   | $G_7^2$ | $S_1, S_2, S_3$  | $f_1, f_2, f_3, f_4, f_5$ | $S_1$ $f_1$, $f_2$, $S_3$ $f_3$, $f_4$, $f_5$ | (2,1,1,1)                                  |
|                                               | 3   | $G_7^3$ | $S_1, S_2, S_3, S_4$ | $f_1, f_2, f_3, f_4, f_5, f_6$ | $S_1$ $f_1$, $S_3$ $f_3$, $S_4$ $f_4$, $f_6$ | (2,1,1,1)                                  |
|                                               | ... | ...     | ...              | ...             | ...                                           | (2,1,1,1)                                  |
|                                               | $n$ | $G_7^n$ | $S_1, S_2, S_3, ..., S_{m+1}$ | $f_1, f_2, f_3, ..., f_{2n+3}$ | $S_1$ $f_1$ $S_2$ $f_2$ $S_{m+1}$ $f_{2n+3}$ | (2,1,1,1)                                  |
|                                               | ... | ...     | ...              | ...             | ...                                           | (2,1,1,1)                                  |
5.2 Folding on $C_6$:

On applying folding technique $f_1$, $f_2$, & $f_3$ on $G_0^0$, $G_6^1$, $G_6^2$, $G_6^3$, ...., the corresponding resultant graph is $P_2$ (Path of length 1), $G_0^3$, $G_3^1$, $G_3^2$, .... [From Fig. e, Fig. f, Fig. g, Fig. h]

5.3 Folding on $G_n^e$, $n = 0, 1, 2, 3, ...$

In Fig. j & Fig.k, ‘s’ indicates the splicing along the edge and ‘r’ is the semivertices ($r_1$ & $r_2$) after applying splicing along the edge.

5.4 Folding on $G_n^e$, $n = 0, 1, 2, 3, ...$

In Fig.l & Fig.m,’s’ indicates the splicing along the edge and ‘r’ is the semivertices ($r_1$ & $r_2$) after applying splicing along the edge.
On applying splicing rule \( S_1 \) and folding technique \( f_1 \) & \( f_2 \) on \( G_5^0 \) resulting to a semigraph \( \eta(G_5^0) = (2,1,1,1) \). [From Fig. 1]

On applying splicing rule \( S_1, S_2 \) simultaneously and folding technique \( f_1, f_2, f_3 \) & \( f_4 \) on \( G_5^1 \) resulting to a semigraph \( \eta(G_5^1) = (2,1,1,1) \). [From Fig.m]

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