Language study on Spliced Semigraph using Folding techniques

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Abstract. In this paper, we proposed algorithm to identify cut vertices and cut edges for n-Cut Spliced Semigraph and splicing the n-Cut Spliced Semigraph using cut vertices else cut edges or combination of cut vertex and cut edge and applying sequence of folding to the spliced semigraph to obtain the semigraph quadruple $\eta(S)=(2, 1, 1, 1)$. We observed that the splicing and folding using both cut vertices and cut edges is applicable only for n-Cut Spliced Semigraph where $n > 2$. Also, we transformed the spliced semigraph into tree structure and studied the language for the semigraph with $n+2$ vertices and $n+1$ semivertices using Depth First Edge Sequence algorithm and obtain the language structure with sequence of alphabet ‘$a$’ and ‘$b$’.

1. Introduction

Everyone aware of the importance of application of graph theory to various aspects of theoretical and practical fields of activities. Initially generalization of graph was concentrated upon the fact that a graph $G$ consists of a set $V$ of elements called vertices together with a prescribed set $X$ of unordered 2-tuple $\{u, v\}$ called an edge which can be pictorially denoted by joining $u$ and $v$ by a line where $u, v \in V$. Sampathkumarachar [9] who proposed an edge with more than two vertices viz., $(u_1, u_2, u_3, ..., u_i)$ where the edges $(u_1, u_2, u_3, ..., u_i)$ and $(v_1, v_2, v_3, ..., v_j)$ are considered to represent the same edge if and only if $i = j$ and either $u_k = v_k$ or $u_k = v_{k+n+1}$ for $1 \leq n \leq i$. However, in order to retain the original structure of graph, where two distinct edges intersect in at most at one vertex only, it became necessary for the new edges to satisfy the same condition that two distinct edges in the new structure intersect in at most at one vertex. This new generalization of graph called semigraph its originator E. Sampathkumar. And D. Acharya in 1994 generalized graph originally named as graphoid was renamed later on as semigraph and it was structurally designed so as to apply to problems as demanded by situations in real life that involve relations more than binary ones.

S. Jeyabharathi et al. [4] and [5], found that semigraph is more effective tool than graphs for describing DNA splicing, thereby establishing the requirement for creation of such a generalization. Semigraph model will eventually replace graph partitioning in scientific computing. Here, the theory of splicing system using cut vertices and cut edges applied to DNA semigraphs and folding [1] techniques are applied to the spliced semigraph and obtained resultant semigraph. Also studied the language of semigraph using Depth First Edge Sequence algorithm
2. Preliminaries

2.1. Splicing System: [4]
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 $G = (V, E)$ consist of non-empty set of objects $V$, called Vertices and set $E$ of two element subsets of $V$, whose elements are called Edges.

2.3. Semigraph: [9]
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 $u_i = v_i$ or $u_i = v_{n-i+1}$ 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. Semivertices: [4]
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. Semiedges: [4]
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. 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.

2.7. Semigraph folding :[4]
A Spliced Semigraph map $f : SSG_1 \rightarrow SSG_2$ a semigraph folding, if and only if $f$ maps vertices to vertices, semivertices to semivertices, edges to edges and semiedges to semiedges.

2.8. Cut Vertex
Let ‘$G$’ be a connected semigraph. A vertex $V \in G$ is called a cut vertex of ‘$G$’, if ‘$G-V$’ (Delete ‘$V$’ from ‘$G$’) results in a disconnected semigraph. Removing a cut vertex from a semigraph breaks it in to two or more semigraphs.
2.9. Cut Edge:
Let ‘G’ be a connected semigraph. An edge ‘e’ ∈ G is called a cut edge if ‘G-e’ results in a disconnected semigraph. If removing an edge in a semigraph results in two or more semigraphs, then that edge is called a Cut Edge.

n-Cut Splicing:

Case 1: n = 1

1-Cut splicing:

\[ (1, 2, 3) \]

Figure 1. 1-Cut Splicing (1-SSG1 & 1-SSG2)

Case 2: n = 2

2-Cut splicing:

\[ (1, 2, 3, 4) \]

Figure 2. 2-Cut Splicing (2-SSG1 & 2-SSG2)

Case 3: n = 3

3-Cut splicing:

\[ (1, 2, 3, 4, 5) \]

Figure 3. 3-Cut Splicing (3-SSG1 & 3-SSG2)

3. Proposed algorithm to identify cut vertices and cut edges of n-Cut Spliced Semigraph

Step 1: Consider n-Cut Spliced Semigraph n-SSG1 or n-SSG2 where n = 1, 2,..., m where m is the number of bonds [4] used for splicing.

Step 2: Let the vertices be \{v_i\}_{i=1}^{n+2}, Semivertices be \{v'_i\}_{i=1}^{n+2}, Edges be \{(v_i, v_j)\}_{i,j=1}^{n+2} and Semiedges be \{(v'_i, v'_j)\}_{i,j=1}^{n+2}.

Step 3: Let the start vertex be ‘v_i’, i=1, 2,..., (n+2).

Step 4: (a) Find the adjacent vertices (and semivertices) set and adjacent edges (and semiedges) set of vertex ‘v_i’, i =1, 2, .., (n+2) in semigraph n-SSG1 (or n-SSG2).
Say the adjacent vertex and semivertex set, $A_i = \{v_i, v_{(i+1)}\}$ where $i = 1, 2, ..., (n+2)$ and adjacent edge and semiedge set, $B_i = \{(v_i, v'_i), (v_i, v_{(i+1)})\}$ where $i = 1, 2, ..., (n+2)$.

(b) Calculate degree of vertices in $A_i$, i.e., $\deg(v_{(i+1)})$ where $i = 1, 2, ..., (n+2)$ (Consider vertices $v_j$, where $j \geq (i+1)$.)

(c) If $\deg(v_{(i+1)}) = 2$ Then GOTO Step 5.

Else If $\deg(v_{(i+1)}) = 3$ Then $v_{(i+1)} \in V, \{(v_i, v_{(i+1)})\} \in E$ and GOTO Step 6.

Else proceed Step 8.

Step 5: (a) Find the adjacent vertices (and semivertices) set and adjacent edges (and semiedges) set of Vertex $v_{(i+1)}$, $i = 1, 2, ..., (n+2)$ in semigraph $n\text{-}SSG_1$ (or $n\text{-}SSG_2$).

Say the adjacent vertex and semivertex set, $A_i = \{v_i, v_{(i+2)}, v_{(i+1)}\}$ where $i = 1, 2, ..., (n+2)$ and adjacent edge and semiedge, $B_i = \{(v_i, v_{(i+1)}), (v_{(i+1)}, v_{(i+2)})\}$ where $i = 1, 2, ..., (n+2)$

(b) Calculate degree of vertices in $A_i$, i.e., $\deg(v_{(j+1)})$ where $i = 1, 2, ..., (n+2)$ (Consider vertices $v_j$, where $j \geq (i+2)$.)

(c) If $\deg(v_{(j+2)}) = 2$ Then repeat Step 5.

Else If $\deg(v_{(j+2)}) = 3$ Then $v_{(j+2)} \in V, \{(v_j, v_{(j+2)})\} \in E$ and then GOTO Step 6.

Else GOTO Step 8.

Step 6: (a) Find the adjacent vertices (and semivertices) set and adjacent edges (and semiedges) set of Vertex $v_j$, $j = 1, 2, ..., (n+2)$ in semigraph $n\text{-}SSG_1$ (or $n\text{-}SSG_2$).

Say the adjacent vertex and semivertex set, $A_i = \{v_{(j+1)}, v_{(j+2)}, v_{(j+1)}\}$ where $j = 1, 2, ..., i$ and adjacent edge and semiedge, $B_i = \{(v_j, v_{(j+1)}), (v_j, v_{(j+2)}), (v_{(j+1)}, v_{(j+2)})\}$ where $j = 1, 2, ..., i$

(b) Calculate degree of vertices in $A_i$, i.e., $\deg(v_{(j+1)})$ where $i = 1, 2, ..., (n+2)$ (Consider vertices $v_k$, where $k \geq j+1$.)

(c) If $\deg(v_{(j+1)}) = 2$ Then GOTO 5.

Else If $\deg(v_{(j+1)}) = 3$ Then $v_{(j+1)} \in V, \{(v_j, v_{(j+1)})\} \in E$ and then repeat Step 6.

Else GOTO Step 8.

Step 7: The set of vertices belong to $V$ are cut vertices and set of edges belong to $E$ are cut edges.

Step 8: End the process.

4. Splicing and Folding $n\text{-}SSG$ using cut vertices and cut edges

By above algorithm, we are able to find the cut vertices and cut edges of $n$-Cut Spliced Semigraph. Hence splice the $n$-Cut Spliced Semigraph using corresponding Cut Vertices (CV) and Cut Edges (CE) and apply folding techniques to obtain the resultant semigraph $\eta(S) = (2, 1, 1, 1)$.

Case 4.1: Let $n = 1$ [1- Cut Spliced Semigraph]

4.1.1 Splicing 1-Cut Spliced Semigraph using Cut Vertex

Here Cut Vertex (CV) = \{3\}. On splicing the 1-SSG$_1$ with Cut Vertex, we obtain semigraph $\eta(S) = (2, 1, 1, 1)$

![Figure 4. Spliciing 1-SSG$_1$ using Cut Vertices](image)
4.1.2 Splicing and Folding 1-Cut Spliced Semigraph using Cut Edge

Here Cut Edge (CE) = \{(2, 3)\}. On splicing the 1-SSG with Cut Edge and folding using \(f_1, f_2\), we obtain semigraph \(\eta(S) = (2, 1, 1, 1)\)

Case 4.2: Let \(n = 2\) [2- Cut Spliced Semigraph]

4.2.1 Splicing 2-Cut Spliced Semigraph using Cut Vertices

Here Cut Vertices (CV) = \{3, 4\}. On splicing the 2-SSG with Cut Vertices, we obtain semigraph \(\eta(S) = (2, 1, 1, 1)\)

4.2.2 Splicing and Folding 2-Cut Spliced Semigraph using Cut Edges:

Here Cut Edges (CE) = \{(2, 3), (3, 4)\}. On splicing the 2-SSG with Cut Edges and folding using \(f_1, f_2\), we obtain semigraph \(\eta(S) = (2, 1, 1, 1)\)

Case 4.3: Let \(n = 3\) [3- Cut Spliced Semigraph]

4.3.1 Splicing 3-Cut Spliced Semigraph using Cut Vertices:

Here Cut Vertices (CV) = \{3, 4, 5\}. On splicing the 3-SSG with Cut Vertices, we obtain semigraph \(\eta(S) = (2, 1, 1, 1)\)
4.3.2 Splicing and Folding 3-Cut Spliced Semigraph using Cut Edges:

Here Cut Edges (CE) = {(2, 3), (3, 4), (4, 5)}. On splicing the 3-SSG1 with Cut Edges and folding using \( f_1, f_2 \), we obtain semigraph \( \eta(S) = (2, 1, 1, 1) \).

4.3.3 Splicing and Folding 3-Cut Spliced Semigraph using both Cut Vertex & Cut Edge:

Here Cut Vertex (CV) = {3} and Cut Edges (CE) = {(4, 5)}. On splicing the 3-SSG1 with Cut Vertex and Cut Edge and folding using \( f_1, f_2 \), we obtain semigraph \( \eta(S) = (2, 1, 1, 1) \).

Case 4.4: Let \( n = 4 \) [4 - Cut Spliced Semigraph]

4.4.1 Splicing 4-Cut Spliced Semigraph using Cut Vertices:

Here Cut Vertices (CV) = {3, 4, 5, 6}. On splicing the 4-SSG1 with Cut Vertices, we obtain semigraph \( \eta(S) = (2, 1, 1, 1) \).
4.4.2 Splicing and Folding 4-Cut Spliced Semigraph using Cut Edges:

Here Cut Edges (CE) = \{(2, 3), (3, 4), (4, 5), (5, 6)\}. On splicing the 2-SSG\(_1\) with Cut Edges and folding using \(f_1, f_2\), we obtain semigraph \(\eta(S) = (2, 1, 1, 1)\)

![Figure 12. Splicing 4-SSG\(_1\) using Cut Edges and folding](image)

4.4.3 Splicing and Folding 4-Cut Spliced Semigraph using both Cut Vertex & Cut Edge:

Here Cut Vertex (CV) = \{3\} and Cut Edges (CE) = \{(4, 5), (5, 6)\}. On splicing the 4-SSG\(_1\) with Cut Vertex and Cut Edge and folding using \(f_1, f_2\), we obtain semigraph \(\eta(S) = (2, 1, 1, 1)\)

![Figure 13. Splicing 4-SSG\(_1\) using Cut Vertices & Cut Edges and folding](image)

The below table indicates possible number of Cut Vertices for n-Cut Spliced Semigraph and on applying splicing using cut vertices on n-Cut Spliced Semigraph which results to the semigraph \(\eta(S) = (2, 1, 1, 1)\)

| Number of Spliced Semigraph | Number of Cut Vertex(CV) | Resultant semigraph |
|-----------------------------|--------------------------|---------------------|
| 1- Cut Spliced Semigraph    | 1 CV                     | (2, 1, 1, 1)        |
| 2- Cut Spliced Semigraph    | 2 CV                     | (2, 1, 1, 1)        |
| 3- Cut Spliced Semigraph    | 3 CV                     | (2, 1, 1, 1)        |
| 4- Cut Spliced Semigraph    | 4 CV                     | (2, 1, 1, 1)        |
| 5- Cut Spliced Semigraph    | 5 CV                     | (2, 1, 1, 1)        |
| 6- Cut Spliced Semigraph    | 6 CV                     | (2, 1, 1, 1)        |
| ...                         | ...                      | ...                 |
| n- Cut Spliced Semigraph    | n CV                     | (2, 1, 1, 1)        |

The below table indicates possible number of Cut Edges and on applying splicing using cut edges on n-Cut Spliced Semigraph and applying folding \(\{f_i\}, i = 1, 2\) onto semigraph \(\eta(S) = (2, 1, 1, 1)\)

| Number of Spliced Semigraph | Number of Cut Edge(CE) | Folding | Resultant semigraph |
|-----------------------------|------------------------|---------|---------------------|
| 1- Cut Spliced Semigraph    | 1 CE                   | \(f_1, f_2\) | (2, 1, 1, 1)        |
| 2- Cut Spliced Semigraph    | 2 CE                   | \(f_1, f_2\) | (2, 1, 1, 1)        |
| 3- Cut Spliced Semigraph    | 3 CE                   | \(f_1, f_2\) | (2, 1, 1, 1)        |
| 4- Cut Spliced Semigraph    | 4 CE                   | \(f_1, f_2\) | (2, 1, 1, 1)        |
| 5- Cut Spliced Semigraph    | 5 CE                   | \(f_1, f_2\) | (2, 1, 1, 1)        |
| 6- Cut Spliced Semigraph    | 6 CE                   | \(f_1, f_2\) | (2, 1, 1, 1)        |
| ...                         | ...                    | ...     | ...                 |
| n- Cut Spliced Semigraph    | n CE                   | \(f_1, f_2\) | (2, 1, 1, 1)        |
The below table indicates possible number of both Cut Vertices and Cut Edges and on applying splicing using cut edges on n-Cut Spliced Semigraph and applying folding \{f_i\}, i=1, 2 onto semigraph $\eta(S)= (2, 1, 1, 1)$

### Table 3. Possible number of Cut Vertices and Cut Edges applied to n-Spliced Semigraph to obtain $\eta(S)$

| Number of Spliced Semigraph | Number of Cut Vertex and Cut Edge | Folding | Resultant semigraph |
|-----------------------------|----------------------------------|---------|---------------------|
| 1- Cut Spliced Semigraph    | -                                | -       | -                   |
| 2- Cut Spliced Semigraph    | -                                | -       | -                   |
| 3- Cut Spliced Semigraph    | 1 CV & 1 CE                      | $f_1, f_2$ | (2, 1, 1, 1)       |
| 4- Cut Spliced Semigraph    | 1 CV & 2 CE                      | $f_1, f_2$ | (2, 1, 1, 1)       |
| 5- Cut Spliced Semigraph    | 1 CV & 3 CE                      | $f_1, f_2$ | (2, 1, 1, 1)       |
| 6- Cut Spliced Semigraph    | 1 CV & 4 CE                      | $f_1, f_2$ | (2, 1, 1, 1)       |
| ...                         | ...                              | ...     | ...                |
| n- Cut Spliced Semigraph    | 1 CV & (n-2) CE                  | $f_1, f_2$ | (2, 1, 1, 1)       |

**Observation 1:** Any n-Cut Spliced Semigraph which use Cut Edges or both Cut Vertices and Cut Edges for splicing and would requires 2 folding $\{f_i\}$, i=1, 2 to obtain semigraph $\eta(S)= (2, 1, 1, 1)$

**Result 1:**
The splicing and Folding using both Cut Vertices and Cut Edges are applicable only for $n$-SSG where $n > 2$

**Result 2:**
A $n$-SSG (for $n \geq 1$) may have at most ‘$n$’ number of cut vertices or cut edges.

**Proposition 1:**
For any n-Cut Spliced Semigraph $n$-SSG ($n > 2$), ‘$n$’ number of vertices have degree ‘3’.
We prove this by three different case.

**Case 1:** Let $n = 1$ [1-Cut Spliced Semigraph(1-SSG)]
From 1-SSG$_1$ of Figure 1, there are only one vertex have degree 3.
The vertex whose degree 3 in 1-SSG$_1$ are $\{3\}$.

**Case 2:** Let $n = 2$ [2-Cut Spliced Semigraph(2-SSG)]
From 2-SSG$_1$ of Figure 2, there are two vertices have degree 3.
The vertices whose degree 3 in 2-SSG$_1$ are $\{3, 4\}$.

**Case 3:** Let $n = 3$ [3-Cut Spliced Semigraph(3-SSG)]
From 3-SSG$_1$ of Figure 3, there are three vertices have degree 3.
The vertices whose degree 3 in 3-SSG$_1$ are $\{3, 4, 5\}$.
Hence for n-Cut Spliced Semigraph ($n$-SSG), there are ‘$n$’ vertices whose degree 3 in n-SSG$_1$.

**Result 3:** The number of vertices of degree three in a n-Cut Spliced Semigraph having k number of pendent vertices are $n$-k-2.

**Observation 2:**
On applying splicing to n-Cut Spliced semigraph using Cut Vertex and Cut Edge and folding techniques will lead to the resultant semigraph with quadruple $\eta(S) = (2, 1, 1, 1)$. 
**Theorem 1:**
The total number of vertices and semi vertices in \( n \)-Cut Spliced Semigraph is always even.

**Proof:** Consider a \( n \)-Cut Spliced Semigraph. For \( n \)-Cut Spliced Semigraph, there are \( 2n+4 \) vertices and semi vertices. Since it contains exactly ‘\( n \)’ number of vertices of degree 3, ‘2’ vertices of degree 2 and ‘\( n+2 \)’ semi vertices of degree 1, it follows that there are \( 2n+2 \) odd degree vertices and semi vertices in the semigraph. But the number of odd degree vertices and semi vertices in a semigraph is even. It follows \( 2n+2 \) is even and hence \( n \) is even.

**Theorem 2:**
The number of pendent semi vertices or number of pendent semiedges of any \( n \)-Cut Spliced Semigraph \((n>1)\) is \( n+2 \).

**Proof:** Consider a \( n \)-Cut Spliced Semigraph with \( 2n+4 \) vertices and semi vertices. Let the number of pendent semi vertices or number of pendent semiedges in a \( n \)-Cut Spliced Semigraph be \( k \). Then there are \( k \) semi vertices(or semiedges) of degree 1, ‘2’ vertices of degree 2 and \( 2n+2-k \) number of vertices of degree 3. By Observation 1, there are ‘\( n \)’ number of vertices of degree 3. Therefore, \( 2n+2-k = n \)

\[ \Rightarrow k = n+2. \]
Hence the number of pendent semi vertices (semiedges) of any \( n \)-Cut Spliced Semigraph is \( n+2 \).

5. **Depth First Edge (DFE) sequence of Spliced Semigraph:** [6] & [7]
Consider Edge as ‘a’ and Semiedge as ‘b’

**For 1-SSG, the language indication as below,**

![Figure 14. Language of the 1-SSG1 (or 1-SSG2)](image)

On applying DFE of 1-cut spliced semigraph – abbaabbbba which is \( ab^2a^2b^4a \) (Reading the vertices and semi vertices in the way as \( A_1A_0B_0A_0A_1A_2B_1A_2B_2A_2A_1 \) where as start vertex as \( A_1 \))

**For 2-SSG, the language indication as below,**

![Figure 15. Language of the 2-SSG1 (or 2-SSG2)](image)

On applying DFE of 2-cut spliced semigraph – abbaabbbbba which is \( ab^2a^2b^2ab^4a^2 \) (Reading the vertices and semi vertices in the way as \( A_1A_0B_0A_0A_1A_2B_1A_2B_2A_2B_3A_3A_2A_1 \) where as start vertex as \( A_1 \)
For 3-SSG₁, the language indication as below,

![Diagram](image)

Figure 16. Language of the 3-SSG₁(or 3-SSG₂)

On applying DFE of 3-cut spliced semigraph – abbaabbabbbbaaa which is (ab²a²)(b²a)(b⁴a³)
(Reading the vertices and semivertices in the way as A₁A₀B₀A₀A₁A₀A₂A₁A₂A₂A₁A₂A₃B₁A₃A₄A₃A₄A₅A₄A₁
where as start vertex as A₁)

Observation 3:
Therefore, on applying DFE of n-cut spliced semigraph –ab²a²(b²a)...(n-1)times(b⁴aⁿ)
(Reading the vertices and semivertices in the way as A₁A₀B₀A₀A₁A₂B₁A₂A₃B₂A₃A₄B₃A₄A₅B₄A₅A₆A₆A₇...An-2An-1AnB₁n-1AnAn+1BₙAn+1Bₙ+1An+1An+1...A₁ whereas start vertex as A₁)

Observation 4:
On applying DFE for any resultant semigraph η(S)=(2, 1, 1, 1), the language is a²b²

6. Conclusion:
The algorithmic approach is used to identify and obtain Cut Vertex set and Cut Edge set and splicing is done for n-Cut Spliced Semigraph is with the help of Cut Vertices and Cut Edges and folding techniques are applied to n-SSG₁ (n-SSG₂) to get resultant semigraph η(S)=(2, 1, 1, 1). Also language is studied for any spliced semigraph using Depth First Edge Sequence algorithm and obtained the language for semigraph η(S)=(2, 1, 1, 1). Further we extend the language study on spliced semigraph using Breadth First Vertex and Edge sequence algorithm comparing with the Depth First Vertex and Edge sequence algorithm to find efficiency to obtain fast generation of language of spliced semigraph.

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