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Parallel Double Splicing on Iso-Arrays

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Abstract—Image synthesis is an important area in image processing. To synthesize images various systems are proposed in the literature. In this paper, we propose a bio-inspired system to synthesize image and to study the generating power of the system, we define the class of languages generated by our system. We call image as array in this paper. We use a primitive called iso-array to synthesize image/array. The operation is double splicing on iso-arrays. The double splicing operation is used in DNA computing and we use this to synthesize image. A comparison of the family of languages generated by the proposed self restricted double splicing systems on iso-arrays with the existing family of local iso-picture languages is made. Certain closure properties such as union, concatenation and rotation are studied for the family of languages generated by the proposed model.

Keywords—DNA computing, splicing system, iso-picture languages, iso-array double splicing system, iso-array self splicing.

I. Introduction

Bio-inspired computing is a field devoted to tackling complex problems using computational methods modeled after design principles encountered in nature. Many of these Bio-inspired computing techniques have been used successfully to find good solutions to difficult problems in a wide range of areas such as combinatorial optimization, classification and decision making, pattern recognition, machine learning, nonlinear dynamics (modeling), computer security; biometrics, time series prediction, data mining, image processing and many more. Some of the topics covered in bio-inspired computing are evolutionary computing; neural computing, DNA computing and membrane computing.

In DNA computing [9] splicing systems were introduced by Head [2], [3] on biological considerations to model the behaviour of DNA molecules. He also introduced 1-splicing, 2-splicing, iterative splicing and double splicing and showed that double splicing is more powerful than normal splicing on strings. Laterly, Krithivasan et al. [7] extended the concept of splicing to arrays and defined array splicing systems. Parallel splicing on iso-arrays has been introduced by Masilamani et al. [8]. In parallel splicing, we use rules in parallel, to cut an image at a specific site. Fore more details about array languages and iso-picture languages we refer to [1], [5], [6], [10], [11].

In this paper, we define parallel double splicing on iso-arrays based on 1-splicing and we introduce parallel iso-array self double splicing, parallel iso-array self restricted double splicing. As in parallel splicing on images [4] we also do splicing by applying the set of rules parallely. In the second section, we give the basic definitions which are necessary to introduce the new model.

In the third section, we define the double splicing on iso-arrays and compare the family of languages generated by iso-array double splicing systems with the family of languages generated by iso-array self splicing systems. In the fourth section, we introduce a variant of iso-array double splicing called iso-array restricted double splicing. We compare the family of languages generated by iso-array self restricted double splicing systems with existing family of local iso-picture languages and with the family of H-iso-array splicing systems. We give some closure properties of family of languages generated by iso-array self restricted double splicing system.

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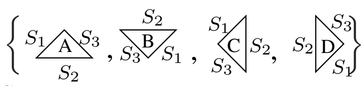
II. Basic Definitions

In this section we recall some of the basic definitions of iso-picture languages and iso-array splicing systems to generate the language L discussed in [8], [6].

Definition 1. *Let* $\Sigma =$ 

The sides S_1, S_2 *and* S_3 *of each tile in* Σ *are of length* $\frac{1}{\sqrt{2}}, 1, \frac{1}{\sqrt{2}}$ *respectively.*

An iso-array is an arrangement of isosceles right angled triangles of tiles from the set Σ.

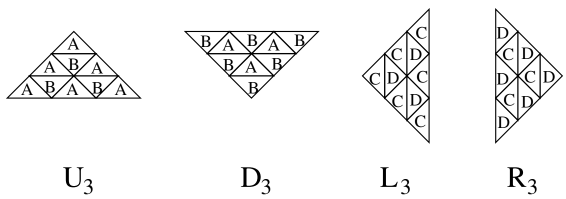


Fig. 1. Iso-arrays of size 3

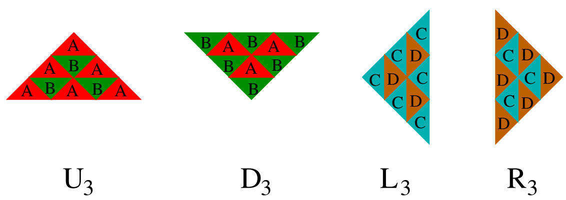


Fig. 2. Corresponding color image

An U*-iso-array of size* m *is formed exclusively by* m  *tiles on side* S_2 *and it is denoted by* U_m*. It will have* m^2 *tiles* *in total (including the m A tiles on S_2). Similarly D-iso-array, L-iso-array and R-iso-array are formed exclusively by B-tile, C-tile and D-tile on side S_2 respectively. The following are the iso-arrays of size 3 (or) size (1,3).*

Iso-arrays of same-size can be catenated using the following catenation operations. There are four types of catenations of iso-arrays.
(i) Horizontal catenation ($\ominus$) : $U \ominus D$
(ii) Vertical catenation ($\obar$) : $L \obar R$
(iii) Right catenation ($\oslash$) : $D \oslash U$, $R \oslash U$, $D \oslash L$, $R \oslash L$
(iv) Left catenation ($\obslash$) : $U \obslash D$, $U \obslash L$, $L \obslash R$, $R \obslash D$.

The iso-array primitives used in Definition 1 uses letters A, B, C, D where each letter denotes a color.

Definition 2. *An iso-picture of size (n, m) over Σ is a picture formed by catenation of n iso-arrays of size m.*

The number of tiles in any iso-picture of size (n, m) is nm^2.

Definition 3. *Two iso-pictures of sizes (n_1, m) and (n_2, m), $n_1, n_2, m \geq 1$ respectively can be catenated using catenation of iso-arrays, if the sides are gluable.*

The set of all iso-pictures over Σ is denoted by Σ_I^{**}. An iso-picture language L over Σ is a subset of Σ_I^{**}.

Definition 4. *Let L be an iso-picture language over $\Sigma = \{$ A , B , C , D $\}$. L is said to be local if there exists a finite set Θ, which is a subset of the set of $(1, 2)$ iso-pictures over $\Sigma \cup \{$ #A, #B , #C , #D $\}$ such that $L = L(\Theta)$ where $L(\Theta) = \{p \in \Sigma_I^{**} / B(\hat{p}) \subseteq \Theta\}$ and $B(\hat{p})$ is the set of all $(1, 2)$ sub-pictures of $\hat{p}$, where $\hat{p}$ is a iso-picture obtained by surrounding p with special symbols* #A, #B , #C , #D $\notin \Sigma$.

The family of local iso-picture languages will be denoted by ILOC.

Definition 5. *Let Σ be an alphabet, # and \$ are two special symbols not in Σ. An iso-array over Σ is an isosceles triangular arrangement of tiles* A , B , C *and* D .

A horizontal splicing rule over Σ is of the form $\alpha_1 \# \alpha_2 \ \$_{\ominus} \ \alpha_3 \# \alpha_4$ where $\alpha_1 = U_m$ or λ, $\alpha_2 = D_m$ or λ, $\alpha_3 = U_m$ or λ and $\alpha_4 = D_m$ or λ. The set of all horizontal splicing rules is denoted by $R_{\ominus}$.

A vertical splicing rule over Σ is of the form $\alpha_1 \# \alpha_2 \ \$_{\obar} \ \alpha_3 \# \alpha_4$ where $\alpha_1 = L_m$ or λ, $\alpha_2 = R_m$ or λ, $\alpha_3 = L_m$ or λ and $\alpha_4 = R_m$ or λ. No other possibility can occur. The set of all vertical splicing rules is denoted by $R_{\obar}$.

A right splicing rule over Σ is of the form $\alpha_1 \# \alpha_2 \ \$_{\oslash} \ \alpha_3 \# \alpha_4$ where
i) $\alpha_1 = D_m$ or λ, $\alpha_2 = U_m$ or λ, $\alpha_3 = D_m$ or λ and $\alpha_4 = U_m$ or λ (or)
ii) $\alpha_1 = R_m$ or λ, $\alpha_2 = U_m$ or λ, $\alpha_3 = R_m$ or λ and $\alpha_4 = U_m$ or λ (or)
iii) $\alpha_1 = D_m$ or λ, $\alpha_2 = L_m$ or λ, $\alpha_3 = D_m$ or λ and $\alpha_4 = L_m$ or λ (or)
iv) $\alpha_1 = R_m$ or λ, $\alpha_2 = L_m$ or λ, $\alpha_3 = R_m$ or λ and $\alpha_4 = L_m$ or λ.
The set of all right splicing rules is denoted by $R_{\oslash}$.

A left splicing rule over Σ is of the form $\alpha_1 \# \alpha_2 \ \$_{\obslash} \ \alpha_3 \# \alpha_4$ where
i) $\alpha_1 = U_m$ or λ, $\alpha_2 = D_m$ or λ, $\alpha_3 = U_m$ or λ and $\alpha_4 = D_m$ or λ (or)
ii) $\alpha_1 = U_m$ or λ, $\alpha_2 = L_m$ or λ, $\alpha_3 = U_m$ or λ and $\alpha_4 = L_m$ or λ (or)
iii) $\alpha_1 = L_m$ or λ, $\alpha_2 = R_m$ or λ, $\alpha_3 = L_m$ or λ and $\alpha_4 = R_m$ or λ (or)
iv) $\alpha_1 = R_m$ or λ, $\alpha_2 = D_m$ or λ, $\alpha_3 = R_m$ or λ and $\alpha_4 = D_m$ or λ.
The set of all left splicing rules is denoted by $R_{\obslash}$.

Definition 6. *An H-iso-array splicing scheme is a 5-tuple $\sigma = (\Sigma, R_{\ominus}, R_{\obar}, R_{\oslash}, R_{\obslash})$ where Σ is an alphabet, $R_{\ominus}$, $R_{\obar}$, $R_{\oslash}$ and $R_{\obslash}$ are the finite set of horizontal, vertical, right and left splicing rules respectively. The iso-array splicing of L with σ is defined as*

$$\sigma(L) = \left\{ p \in \Sigma_I^{**} \Big/ \begin{array}{l} (p_1, p_2) \vdash_{\ominus} p \text{ (or)} \\ (p_1, p_2) \vdash_{\obar} p \text{ (or)} \\ (p_1, p_2) \vdash_{\oslash} p \text{ (or)} \\ (p_1, p_2) \vdash_{\obslash} p \end{array} \right\}$$

for some $p_1, p_2 \in L$. The language generated by H-iso-array splicing system is $\sigma^*(A)$.
$\sigma^*(L)$ is defined iteratively as follows:
$\sigma^0(L) = L$, $\sigma^{i+1}(L) = \sigma^i(L) \cup \sigma(\sigma^i(L))$, for $i \geq 0$, $\sigma^*(L) = \cup_{i=0}^{\infty} \sigma^i(L)$.

The family of iso-picture languages generated by H-iso-array splicing systems is denoted by FHIA.

Definition 7. *The iso-array self splicing of L with $\sigma = (\Sigma, R_{\ominus}, R_{\obar}, R_{\oslash}, R_{\obslash})$ is defined as $\sigma(L) = \{V \in \Sigma^{**} / (u, u) \vdash_{\alpha} v$, for some $u \in \Sigma^{**}$, $\alpha \in \{\obslash, \oslash, \obar, \ominus\}\}$.*

The iso-array self splicing system is defined by $S = (\sigma, A)$ and the family of picture languages generated by the iso-array self splicing systems is denoted by ISHA.

III. Iso-Array Double Splicing

In this section we give the definitions of iso-array double splicing and iso-array restricted double splicing of a picture language and compare the family of picture languages generated by iso-array restricted double splicing system with iso-array self splicing system.

Definition 8.
Let $\sigma = (\Sigma, R_{\ominus}, R_{\obar}, R_{\oslash}, R_{\obslash})$. The iso-array double splicing of a picture language L with σ is defined as $\sigma(L) = \{U \in \Sigma^{**} / (X, Y) \vdash_{\alpha} Z$ and $(Z, Z) \vdash_{\beta} U$ where $X, Y \in L$, for some $Z \in \Sigma^{**}$, $\alpha, \beta \in D$, where $D \in \{\obslash, \oslash, \obar, \ominus\}\}$ and iso-array double splicing system is $S = (\sigma, A)$ where A is a finite subset of images over Σ_I^{**}, called axioms, and the language generated by the system is $\sigma^*(A)$ where σ is the iso-array double splicing scheme.

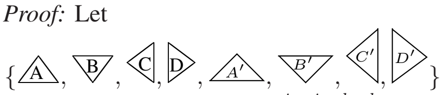
Definition 9. *The iso-array restricted double splicing of a picture language L with σ is defined as $\sigma(L) = \{U \in \Sigma^{**}/(X,Y) \vdash_\alpha Z$, and $(Z,Z) \vdash_\beta U$ for some $X,Y \in L$, $Z \in \Sigma^{**}$, $\alpha,\beta \in D = \{⦸, ⦸, ⦶, ⊖\}$ and $\alpha \neq \beta\}$.*

The iso-array restricted double splicing system is $S = (\sigma, A)$ where $A \subset \Sigma_I^{**}$, called axioms and the language generated by the iso-array restricted double splicing system is given by $\sigma^*(A)$.

The family of picture languages generated by iso-array restricted double splicing systems is denoted by IRDS.

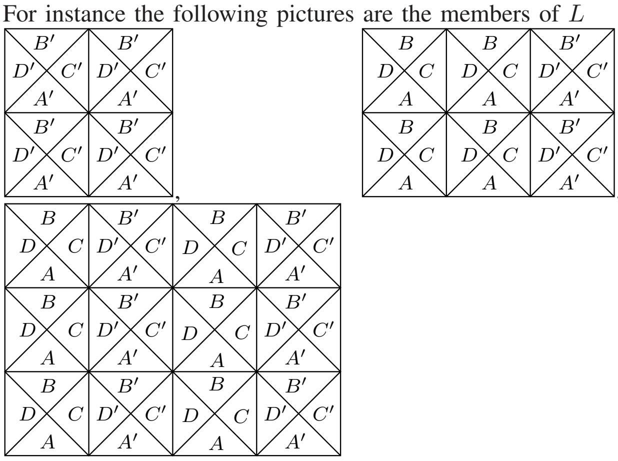
Theorem 1. *IRDS is not a subclass of ISHA.*

Proof: Let

$\Sigma = \{$  $\}$.

Let $L = \{p \in \Sigma^{**}/p = s_m^i t_m^j s_m^k t_m^l$ where $m \geq 2$, $i,j,k,l \geq 0$, s_m^i and t_m^i are $m \times i$ arrays in which each entry (square) carries either of the tile  or  respectively$\}$.

For instance the following pictures are the members of L



Let $S = (\sigma, A)$ where $\sigma = (\Sigma, R_⦶, R_⊖, R_⦸, R_⦸)$ and $A = \{s_2^i t_2^j s_2^k t_2^l / i,j,k,l = 0 \text{ or } 1\}$, $R_⦸ = R_⦸ = \phi$.

The splicing rules to generate the iso-pictures of L are given by

$R_⦶$: (1) $C' \# \lambda \$ C \# D'$; (2) $C \# \lambda \$ \lambda \# D$

$R_⊖$: (1) $A \# \lambda \$ \lambda \# B$ (2) $A' \# \lambda \# \lambda \# B'$

Clearly these iso-array splicing rules will generate the language L. Hence $L \in IRDS$. We now prove that $L \notin ISHA$.

Since the iso-array self splicing involves two copies of the same form, the splicing rule $C \# \lambda \$ \lambda \# D$ attempts to produce an image $I : s_m^i t_m^j s_m^{k+i} t_m^l s_m^k t_m^l$ and $I \notin L$. Hence the proof. ■

IV. Iso-Array Self Restricted Double Splicing

Definition 10. *The iso-array self restricted double splicing of L is defined as $\sigma(L) = \{p \in \Sigma^{**}/(X,X) \vdash_\alpha Y$ and $(Y,Y) \vdash_\beta p$ for some $X \in L$, $\alpha,\beta \in D = \{⦶, ⊖, ⦸, ⦸\}$ and $\alpha \neq \beta\}$.*

An iterative iso-array self restricted double splicing $\sigma^*(L)$ is defined by

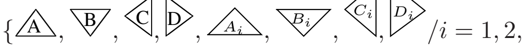
$$\sigma^0(L) = L,$$
$$\sigma^{i+1}(L) = \sigma^i(L) \cup \sigma(\sigma^i(L)) \text{ for } i \geq 0,$$
$$\sigma^*(L) = \bigcup_{i=0}^{\infty} \sigma^i(L).$$

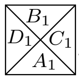
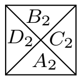
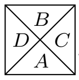
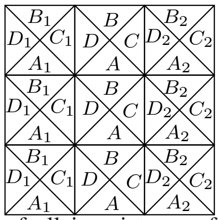
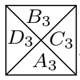
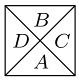
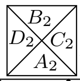
The H-iso-array self restricted double splicing system is defined as a pair $S = (\sigma, A)$ where $\sigma = (\Sigma, R_⦶, R_⊖, R_⦸, R_⦸)$ and A is finite subset of Σ_I^{**}, called axioms.

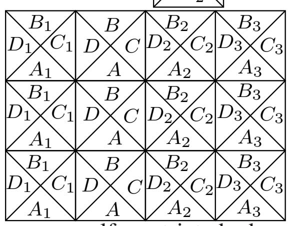
The family of iso-picture languages generated by iso-array self restricted double splicing systems is denoted by FISRD.

Theorem 2. *FISRD is not closed under union and concatenation.*

Proof: Let

$\Sigma = \{$  $/i = 1,2,3\}$.

Let L_1 be the set of all isopictures of rectangles over Σ with 3 rows and at least 3 columns, where all the entries (squares) is in the 1^{st} column should have , the last column should have  and the intermediate column should have . For example the iso-picture $I =$  is a member of L_1. Let L_2 be the set of all iso-pictures of rectangles over Σ with 3 rows and at least 4 columns where all the squares in the 1^{st} column should have , last column should have , the second column should have  and the remaining column should have .

For example the iso-picture $J =$  is a member of L_2. The iso-array self restricted double splicing system that generates L_1 is given by $\sigma = (\Sigma, R_⦶, R_⊖, R_⦸, R_⦸)$ where $R_⦸ = R_⦸ = R_⊖ = \phi$ and $A = \{I\}$.

$R_⦶ = \{C \# D_2 \$ C_1 \# D\}$

It can be easily seen that $\sigma^*(A) = L_1$. The iso-array self restricted double splicing system that generates the language L_2 is given by

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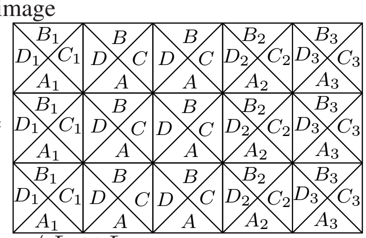
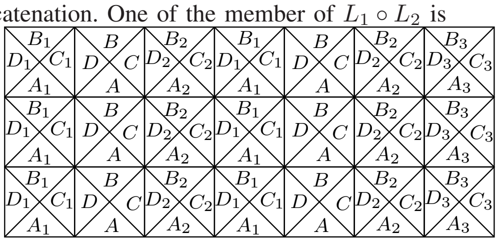
$\sigma = (\Sigma, R_{\oplus}, R_{\ominus}, R_{\oslash}, R_{\otimes})$ where $R_{\oslash} = R_{\otimes} = R_{\ominus} = \phi$ and
$A = \{J\}$.
$R_{\oplus} = \{C_2 \# D_3 \$ C \# D_2\}$
It can be easily seen that $\sigma^*(A) = L_2$.
Now we are going to prove that $L_1 \cup L_2 \notin FISRD$.
Since any splicing rule that attempts to produce members of L_1 and L_2 will also produce an iso-picture p given below, which is not in $L_1 \cup L_2$.
In other words, the splicing rule $C \# D_2 \$ C_1 \# D$ produces an image

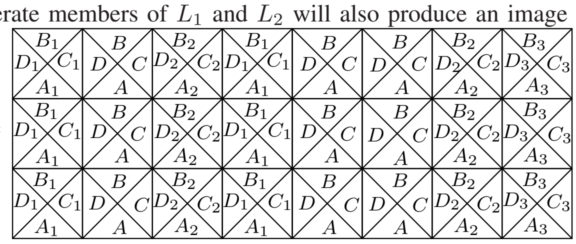
$p =$ 

and $p \notin L_1 \cup L_2$.
Hence FISRD is not closed under union.

$L_1 \circ L_2 \notin FISRD$ where $\circ$ represents vertical concatenation. One of the member of $L_1 \circ L_2$ is

$q =$ 

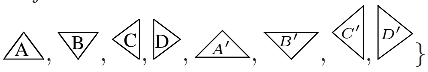
The splicing rule $C \# D_2 \$ C_1 \# D$ that attempts to generate members of L_1 and L_2 will also produce an image

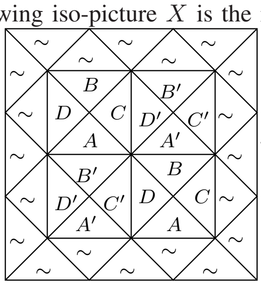
$p' =$ 

which is not a member of $L_1 \circ L_2$. Hence $L_1 \circ L_2 \notin FISRD$ even though L_1 and L_2 are members of $FISRD$. ■

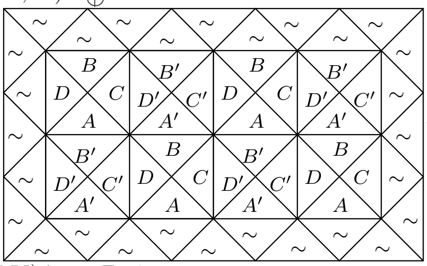
Theorem 3. *FISRD is not a sub class of FHIA.*

Proof: Let

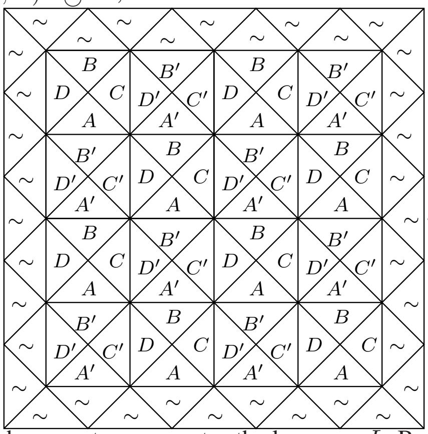
$\Sigma = \{$  $\}$.
Let L be the set of all $m \times m$ iso-pictures over Σ having $\sim$ on the boundary where m is a power of 2. For instance the following iso-picture X is the member of language L.

$X =$  .

Let $S = (\sigma, A)$ be the iso-array self restricted double splicing system, where $\sigma = (\Sigma, R_{\oplus}, R_{\ominus}, R_{\oslash}, R_{\otimes})$, $R_{\oslash} = R_{\otimes} = \phi$, and $A = \{X\}$.
$R_{\oplus}$ consists of
(1) $C' \# \sim \$ \sim \# D$ (2) $C \# \sim \$ \sim \# D'$
$R_{\ominus}$ consists of
(1) $A' \# \sim \$ \sim \# B$ (2) $A \# \sim \$ \sim \# B'$
Let $(X, X) \vdash_{\oplus} Y$. We see that

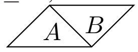
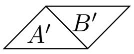
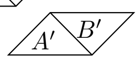
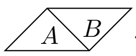
$Y =$  .

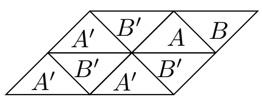
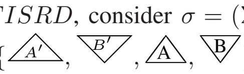
If $(Y, Y) \vdash_{\ominus} Z$, then

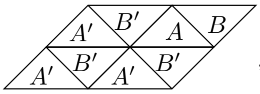
$Z =$  .

The above system generates the language L. But this language L cannot be generated by any H-iso-array splicing system. ■

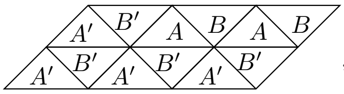
Theorem 4. *The class ILOC of local iso-array languages and the class of FISRD are incomparbale but not disjoint.*

Proof: Let K be a language consisting of iso-pictures of rhombuses of size $m \times n$ with $m, n \geq 2$, where each tile in the rhombus is either of the form  (or)  and all the tiles on the $\angle$ shape should have the tile  and the remaining places in the rhombus should have the tile  .

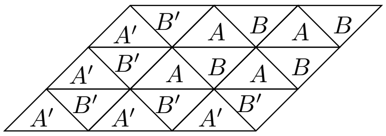
For example the iso-picture  is a member of K.
The language K can be proved to be in $ILOC$. To prove that $K \in FISRD$, consider $\sigma = (\Sigma, R_{\oplus}, R_{\ominus}, R_{\oslash}, R_{\otimes})$ where $\Sigma = \{$  $\}$ and $R_{\oplus} = R_{\otimes} = \phi$ and $A = \{X\}$.
$R_{\oslash}$ consists of the following rules:
(1) $B \# \lambda \$ B' \# A$ (2) $B' \# \lambda \$ B' \# A'$
$R_{\ominus} = \{A' \# B' \$ \lambda \# B'; A \# B' \$ \lambda \# B\}$.

Let $X =$ 

,

$Y =$ 

,

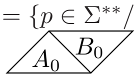
$Z =$ 

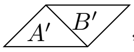
Clearly $(X, X) \vdash_{\oslash} Y$ and $(Y, Y) \vdash_{\ominus} Z$. In a similar way we can generate all iso-pictures of rhombuses of K.

Hence the iso-array self restricted double splicing system $S = (\sigma, A)$, which is defined above generates the language K.

Hence $FISRD \cap ILOC \neq \phi$.

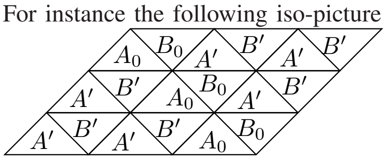
Now we exhibit that there exists a language in $ILOC$ but not in $FISRD$.

Let $\Sigma = \{A_0, B_0, B', A'\}$. Let $L = \{p \in \Sigma^{**}/$ The diagonal positions of p should have the tile 

and other positions should have the tile 

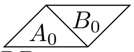
, and the size of p is $m \times m$, $m \geq 2\}$.

For instance the following iso-picture is a member of L.



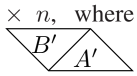
It can be clearly seen that the language L is proved to be in ILOC.

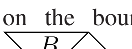
But the language $L \notin FISRD$.

If $L \in FISRD$, then there exists a FISRD system $S = (\sigma, A)$ to generte L. Any splicing rules that attempts to generate the required language L will produce an image which is not in L. i.e., it will produce an image having a tile 

in non-diagonal positions also. Hence $L \notin FISRD$.

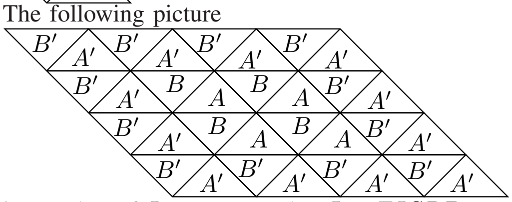
We finally show that there exists a language in FISRD which is not in ILOC.

Let $\Sigma = \{A, B, B', A'\}$ and L be the language of iso-pictures of parallelogram of size $m \times n$, where $m = 2 + 2^i$ for $i \geq 0$ and $n = 4$ having a tile 

on the boundary and other positions are having a tile 

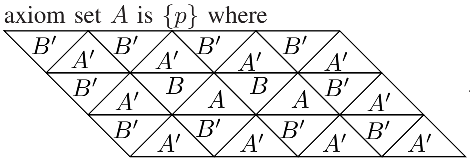
.

The following picture



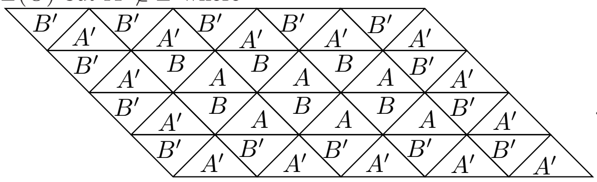
is member of L. We prove that $L \in FISRD$.

The axiom set A is $\{p\}$ where

$p =$ 

.

Let $R_{\ominus} = \{A' \# B' \$ A' \# B'; A \# B' \$ A' \# B\}$.
and $R_{\oslash} = \{A' \# B' \$ A' \# B'; A \# B' \$ A \# B'\}$.
Now it can be easily verified that the system $S = (\sigma, A)$ generates the language L.
But $L \notin ILOC$.
Suppose $L \in ILOC$. Then there exists a set Θ of $(1, 2)$ tiles over $\Sigma \cup \{\ \#\ \}$, which generates $L = L(\Theta)$.
By using the same Θ set we can generate the following iso-picture of size $m \times 5$ which does not belongs to L. i.e., $X \in L(\Theta)$ but $X \notin L$ where

$X =$ 

.

■

Theorem 5. *FISRD is closed under rotation by* 90°, 180° *and* 270°.

Proof: It is known that the class of FHIA is closed under rotations by 90°, 180° and 270° [8]. Similar proof can be given to FISRD also. ■

V. Conclusion

In this paper, we have introduced a new model called double splicing on iso-arrays and its variants to generate iso-pictures. We compared the family of languages generated by self restricted double splicing systems on iso-arrays with the family of local iso-picture languages. Closure properties such as union, concatenation and rotation of iso-array self restricted double splicing are studied.

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