

A STUDY ON TRIANGULAR PICTURE LANGUAGES

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Science degree in Mathematics (B.Sc Mathematics)

By

T.K.Kaviya Shree (39060006)

B.Shamily (39060011)



**DEPARTMENT OF MATHEMATICS
SCHOOL OF SCIENCE AND HUMANITIES**

**SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited with Grade "A" by NAAC**

**JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI-600119
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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **T. K . Kaviya Shree (39060006)**, **B. Shamily (39060011)** who carried out the project entitled "**A study on triangular picture languages**" under my supervision from January 2022 to April 2022.

Internal Guide

(Name in Capital letters with Signature)

External Guide

(Name in Capital letters with signature)

Head of the Department
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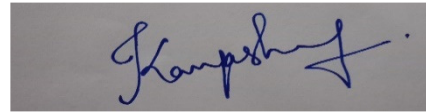
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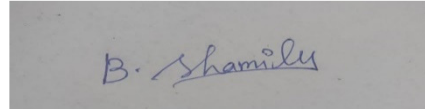
DECLARATION

T. K. Kaviya Shree (39060006), B. Shamily (39060011) hereby declare that the Project Report entitled “**A study on triangular picture languages**” done by us under the guidance of **Dr. K. Bhuvaneswari** (Internal) at Sathyabama Institute of Science and Technology is submitted in partial fulfillment of the requirements for the award of Bachelor of Science degree in Mathematics.



DATE:29.04.22

PLACE: Chennai



SIGNATURE OF THE CANDIDATE

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ABSTRACT

Generating two-dimensional picture languages is a study in formal language theory. To generate a picture language, many computing models are proposed in the literature. The generative grammars and the corresponding classes of automata are well known in the literature to compute the string languages and two-dimensional languages. A string language is defined as a set of strings over some finite alphabets, which are characterized by a grammar, a logical system. Among the models of computing the two-dimensional picture languages, the tile pasting system is a model. Adopting the notion of the tile pasting system, the Triangular tile Pasting system is introduced by Kalyani et al., which pastes edge-to-edge isosceles right-angled triangles in the two-dimensional plane, in which the pasting rules have been defined. Some classes of two-dimensional picture languages are generated and examined for their generative power.

Membrane computing is a new computability model in the theory of computation, P system is a highly distributed and parallel theoretical computing model. Generating two-dimensional picture languages is one of the applications of P systems. It processes multisets of objects and it is a framework for the functioning of living cells called the P system.

By connecting the two areas tile pasting system and P system, a new model, the tile pasting P system is introduced for two-dimensional picture languages. It generates tile patterns by pasting square tiles at the edges. By linking the triangular tile pasting system and P system, a new model, the triangular tile pasting P system for triangular picture languages is proposed in the literature by K. Bhuvaneswari. et.al. Followed by the study of the triangular tile pasting system, the k-order triangular tile pasting system is introduced.

In this project, Generated some classes of two-dimensional picture languages using the k-order triangular tile pasting system, triangular tile pasting system, and triangular tile pasting P system. A comparative study on the generative power of the k-order triangular tile pasting system, triangular tile pasting system, and triangular tile pasting P system is examined.

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LIST OF ABBREVIATIONS

TTPPS - Triangular Tile Pasting P System

TTPS - Triangular Tile Pasting system

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CHAPTER 1

1 INTRODUCTION

This chapter presents extensively the introduction to formal language theory, two-dimensional picture languages, and membrane computing (MC) for both computer and non-computer scientists.

1.1 FORMAL LANGUAGES THEORY

It is a branch in the theory of computation and it deals with strings or words over by finite sets or infinite sets of alphabets processed by the Chomsky hierarchy. With the interest in pattern recognition and image processing in the theory of computer science, several models are proposed (Siromoney et al. 1972, 1973) to recognize and generate two-dimensional objects. Handbook of Formal Languages" (Rozenberg 1997), which gives extensive coverage of the theoretical studies as well as applications of formal language theory. The models made an exclusive development in formal language theory and it gives an enriched handbook of Formal language theory. For the past few decades, this theory enhanced by taking new attention to applications in various filed such as membrane computing. In membrane computing, syntactic techniques constitute one of the main areas of generation and analysis of string languages and digitized images or pictures in two-dimensional planes.

1.2 TWO-DIMENSIONAL PICTURE LANGUAGES

A two-dimensional picture language is a rectangular array of symbols over alphabets. Many computing models have been proposed in the literature to generate two-dimensional picture languages. Triangular patterns and hexagonal patterns are known to occur in picture processing and image analysis (Middleton 2005). This motivated the construction of iso-triangular and hexagonal array grammars. Kalyani et al. (2006) introduced iso-array grammars for triangular pictures. Siromoney et al. (1976) introduced hexagonal array grammars to generate hexagonal patterns. Subramanian et al. (1979) studied the hierarchy of hexagonal array grammars for some of their properties. Dersanambika et al.(2005, 2004) introduced local and recognizable hexagonal picture languages

1.3 MEMBRANE COMPUTING

It is a part of natural computing, deals with an area of computer science, and abstracts computing ideas and models. It originated from the construction and behavior of living cells, where the cells are organized in tissues or higher-order structures. In short, MC is a parallel and distributed computing model. MC processes some sets of objects. Evolution rules and evolving objects are enclosed into the compartments determined means membranes. This new model is the leading research field of molecular computing, introduced by Gh. Păun(2000, 2010, 2010a), and called by his name P system. In the P system membrane structure is the main essential structure. It is a hierarchical arrangement of membranes. The notion of membrane structure is 3D vesicle from biology. The following Figure 1.1 shows the membrane structure of the P system

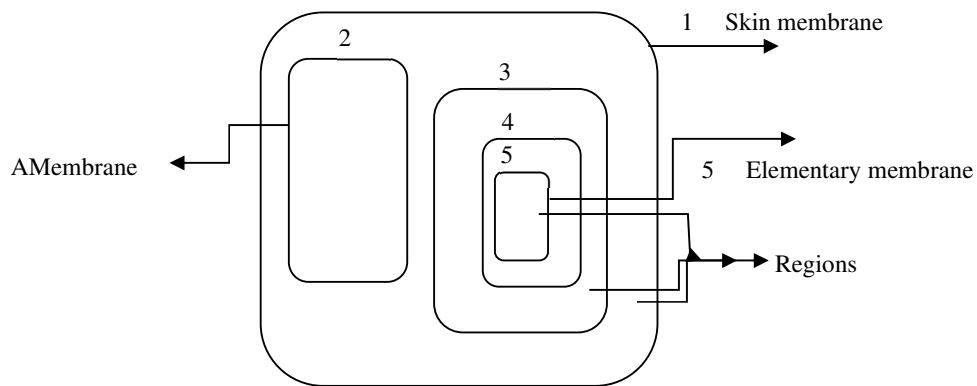


Figure 1.1 Membrane Structure of P system

Tile pasting P system (K.G. Subbbbramanian 2009) for two-dimensional arrays is introduced in formal language theory using square tiles. The parallel rewriting P system is investigated by K.G.Subramanian(2014) for picture languages. Various rewriting P system models are proposed by Ferretti (2003). A variant of the Rewriting P system called iso-array rewriting P system (Annaduralet al. 2008,2008a)is introduced to generate iso-pictures.

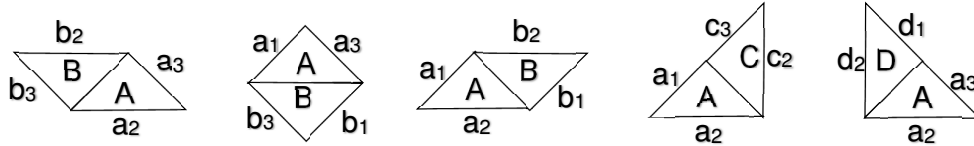
1.4 BASIC DEFINITION

Let $\left\{ \begin{array}{c} a_1 \\ \triangle A \\ a_2 \end{array}, \begin{array}{c} b_2 \\ \triangle B \\ b_1 \end{array}, \begin{array}{c} c_3 \\ \triangle C \\ c_1 \end{array}, \begin{array}{c} d_1 \\ \triangle D \\ d_3 \end{array} \right\}$ be a finite set of labeled isosceles right-angled triangular tiles of dimensions $1/\sqrt{2}$, $1/\sqrt{2}$, and 1 unit are obtained by intersecting a unit square by its diagonals.

1.5 PASTING RULES

The set of all edge labels is called an edge set denoted by E. Tile pasting rules of the tiles A, B, C, D are given below:

- 1 Tile A can be glued with tile B by the pasting rules $\{(a_1, b_1), (a_2, b_2), (a_3, b_3)\}$, with tile C by the rule $\{(a_3, c_1)\}$ and with tile D by the rule $\{(a_1, d_3)\}$
- 2 Tile B can be glued with tile A by the pasting rules $\{(b_1, a_1), (b_2, a_2), (b_3, a_3)\}$, with tile C by the rule $\{(b_1, c_3)\}$ and with tile D by the rule $\{(b_3, d_1)\}$
- 3 Tile C can be glued with tile A by the pasting rule $\{(c_1, a_3)\}$, with tile B by $\{(c_3, b_1)\}$ and with the tile D by the pasting rules $\{(c_1, d_1), (c_2, d_2), (c_3, d_3)\}$
- 4 Tile D can be glued with tile A by the pasting rule $\{(d_3, a_1)\}$, with tile B by $\{(d_1, b_3)\}$ and with the tile C by the pasting rules $\{(d_1, c_1), (d_2, c_2), (d_3, c_3)\}$



CHAPTER 2

2 LITERATURE SURVEY

The membrane system is a new model in the literature which motivates the proposal of new generative models to generate triangular picture languages. The generative grammars and the corresponding classes of automata are well known [3](Hopcroft 1979) in the literature. Array grammars and pasting systems are generating two-dimensional picture languages. An automaton is a machine, which recognizes two-dimensional picture languages. Ceterchi et. al. [1,2](2003) proposed an array of rewriting grammar for two-dimensional array languages and Tissue-like P Systems with Active Membranes for Picture Generation. In general, tiling is a branch concerned with shapes. Two-dimensional languages or array languages also play important roles in character recognition and pictorial information system design. Handbook of Formal Languages” has a chapter on two-dimensional picture languages that provides a comprising discussion of the topic of grammars and automata.

In general, tiling is a branch concerned with shapes. In [12] the square tile pasting system is introduced [12] (K.G. Subramanian et al. 2009) to generate tiling patterns and kolam patterns. Extending the notion of tile pasting further in [10,11](Robinson et al. 2010, 2010a) introduced a tile pasting system to generate certain tiling patterns and tessellations. An extended tile pasting system [9](Robinson et al. 2007) is proposed for kolam patterns. Generating two-dimensional pictures by tile pasting systems motivates the introduction of new tiles and tile pasting systems [5](Kalyani et. al. 2006) to generate triangular pictures. Local and recognizable iso picture language is investigated in [4] (Kalyani et. al. 2004). Many computing models have been proposed in the literature to generate two-dimensional picture languages.

Membrane computing is a part of natural computing, deals with an area of computer science, and abstracts computing ideas and models. It originated from the construction and behavior of living cells, where the cells are organized in tissues or higher-order structures. In short, MC is a parallel and distributed computing model.

MC processes several sets of objects. Evolution rules and evolving objects are enclosed into the compartments determined in the membranes. This new model is the leading research field of molecular computing, introduced by Gh. Păun [6,7,8](2000, 2010,2010a), and called by his name P system. In the P system membrane structure is the main essential structure. It is a hierarchical arrangement of membranes. Tile pasting P system for two-dimensional arrays is introduced in [13](K.G. Subramanian et.al. 2009a), in the theory of formal language. The parallel rewriting P system is investigated by K.G.Subramanian [14](2014) for picture languages.

CHAPTER 3

3 AIM AND SCOPE

- Generating and recognizing triangular picture languages using a new model triangular tile pasting system.
- Computing two-dimensional picture languages using a model, k-order triangular tile pasting system.
- Generating some class of triangular picture languages by triangular tile pasting P systems.
- To examine the computational complexity of the systems.

CHAPTER 4

4 TRIANGULAR TILE PASTING SYSTEM

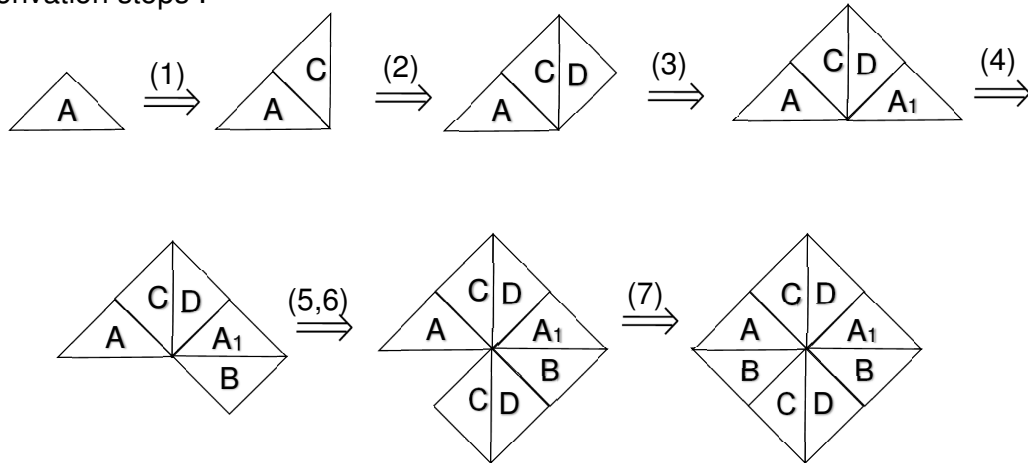
4.1 TRIANGULAR TILE PASTING SYSTEM (TTPS)

Triangular tile pasting system (TTPS) is a three-tuple $S = (\Sigma, P, t_0)$, where Σ is a finite set of labeled triangular tiles, P is a finite set of pasting rules and t_0 is the axiom pattern of tiles. A pattern p_2 is generated from a pattern p_1 by applying the pasting rules in parallel to the boundary edges of p_1 . Note that the labels of pasted edges in a pattern are ignored once the tiles are pasted. The set of all patterns generated from the axiom t_0 constitutes the picture pattern language $T(S)$ of S .

Example 4.1.1

Consider the triangular tile pasting system $G = (\Sigma, P, t_0)$, which computes the picture language L_1 . Here $\Sigma = \{A, A_1, B, C, D\}$, $t_0 = A$ and $P = \{(a_3, c_1), (c_2, d_2), (d_3, a_{11}), (a_{12}, b_2), (b_3, d_1), (d_2, c_2), (a_2, b_2), (d_3, a_1), (a_{13}, c_1)\}$. In this pasting system, the computation starts by applying the rule (a_3, c_1) to the initial axiom tile A . Then the pasting rules $(c_2, d_2), (d_3, a_{11}), (a_{12}, b_2), (b_3, d_1), (d_2, c_2), (a_2, b_2)$ of P are applied non-deterministically, the resultant picture is the first generation of the L_1 . After taking a copy of the pattern, the next generation starts on the resultant picture by applying the pasting rule (a_{13}, c_1) . The 2nd generation is generated by applying the pasting rules of P . Thus, the TTPS generates the language L_1 , shown in fig.4.1.1

Derivation steps :



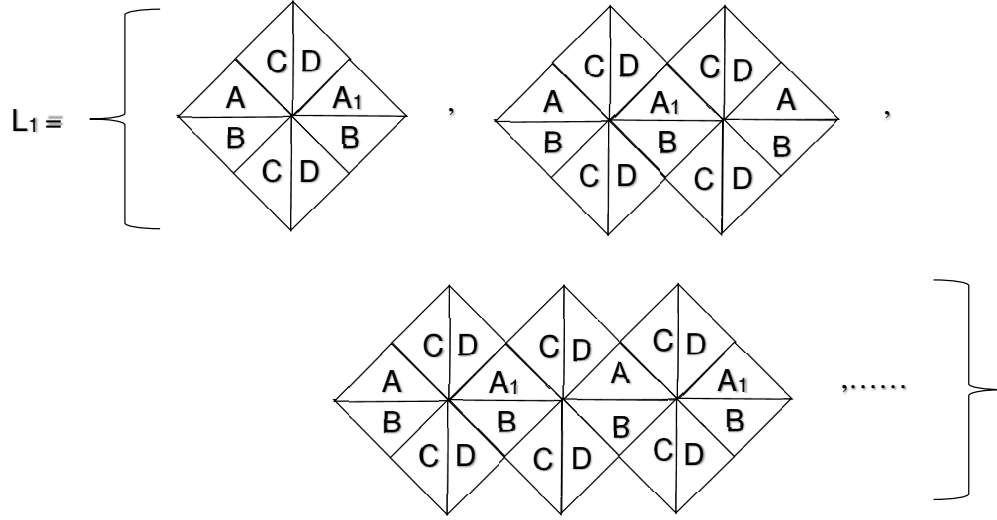


Figure 4.1.1 Languages of adjoint of rhombuses

4.2 A k-ORDER TRIANGULAR TILE PASTING SYSTEM

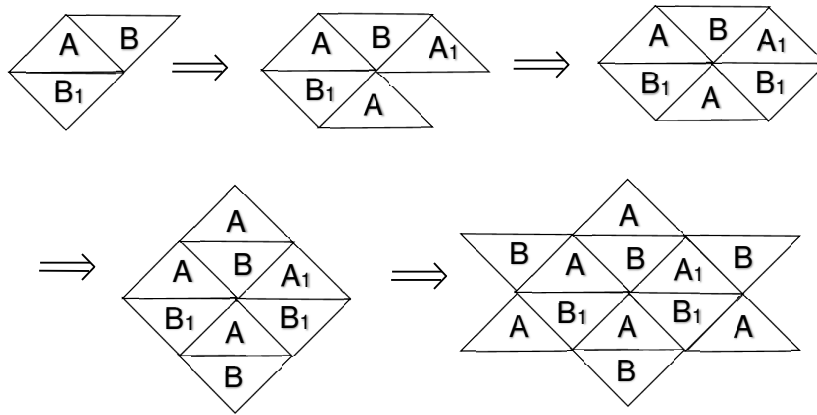
It is defined as a three tuple $k\text{-TTPS} = (\Sigma, P, t_0)$. Σ , a finite set of labeled iso-triangular tiles. P a finite set of pasting subsets ($P = \{P_1, P_2, \dots, P_k\}$, $k \geq 1$). $P_1, P_2, \dots, P_k$ each are the finite set of pasting rules and if the pasting rules of P_1 are applied and if there is no rule can be applied with the resultant pattern, then only the of P_2 is applied with the resultant pattern. Then the rules of other sets can be applied to the resultant pattern. Finally, the pasting rules of P_k of P are applied and if no further rule can be applied to the resultant pattern then the computation stops. The language generated by the k -order TTPS is denoted by $L(k\text{-order TTPS})$ and the family of all languages generated by k -order TTPS is denoted by $F_{k\text{-order}}(L)$.

Example 4.2.1

In the two-dimensional picture patterns, the star picture pattern computed by the k -order TTPS cannot be computed by the triangular tile pasting system.

For, consider the 2-order TTPS $= (\Sigma, P = \{P_1, P_2\}, t_0)$, where $\Sigma = \{A, A_1, B, B_1\}$, $P_1 = \{(a_3, b_3), (a_2, b_{12}), (b_{11}, a_1), (a_{12}, b_{12})\}$, $P_2 = \{(b_2, a_2), (a_1, b_1), (b_{13}, a_3), (a_2, b_2), (a_{13}, b_3), (b_{11}, a_1)\}$ and $t_0 = A$. The iso-triangular tiles A is glued with the tile B and B_1

by the rules $\{(a_3, b_3), (a_2, b_{12})\}$. Then the pasting rules $(b_1, a_{11}), (b_{11}, a_1), (a_{12}, b_{12})$ are applied once and the picture pattern irregular hexagon is generated. Further, no rule of P_1 is applied. The rules of P_2 are applied to each side of the hexagon once. Note that the pasting rules are applied only once, Then the resultant picture pattern is a star, which cannot be generated by the triangular tile pasting system. In the triangular tile pasting system, the pasting rules are taken as a single set and the iso-triangular tiles are passed in a parallel mechanism. This mechanism does not generate the class of star picture patterns. The derivation steps of the star pattern is shown below.



4.3 TRIANGULAR TILE PASTING P SYSTEM

The Triangular tile pasting P system (TTPPS) is defined as a 5 tuple $\Pi = (\Sigma, \mu, F_i, R_i, i_0)$, $1 \leq i \leq m$,

where Σ - A finite set of triangular tiles,

μ - A membrane structure, the membranes are labeled in a 1-1 manner,

F_i - The finite sets of triangular pictures over the tiles of Σ ,

R_i - The finite sets of rules of the type $(t_i, (x_i, y_i), tar)$, $(1 \leq i \leq n)$ associated with m regions of μ ,

i_0 - The output membrane where the picture pattern is collected.

The computation process in TTPPS is defined in such a way that, each picture pattern present in each region should be applied. Then the resultant triangular picture pattern is moved to another region concerning the target indicator in_j (here)

associated with the pasting rule. The resultant triangular picture is sent out immediately from the region of the membrane if the target indicator is out.

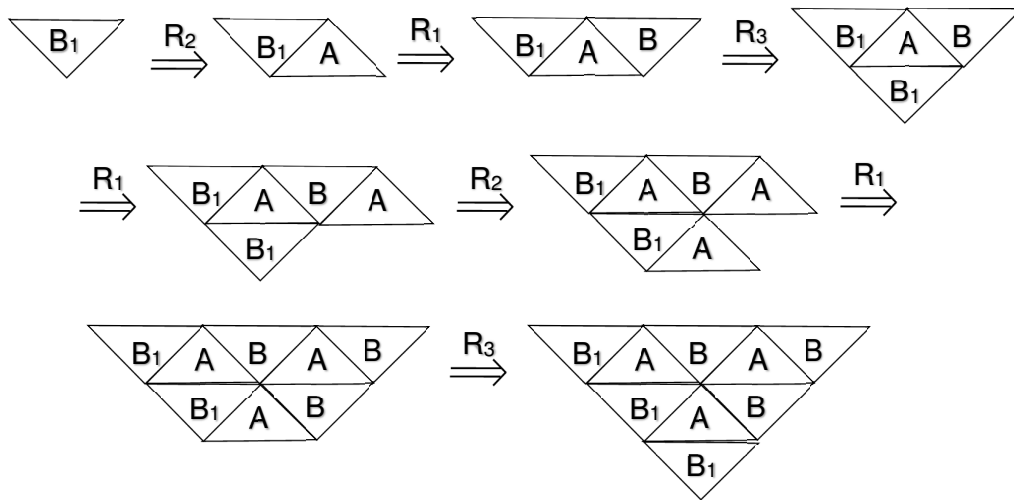
The pasting rules in each region are applied, then the computation is said to be successful, only if no further pasting rules can be applied with the resultant picture pattern. In this model, the result of the halting triangular picture pattern is composed using the iso-triangular tile pasting rules only. The triangular picture is halted in the membrane labeled as i_0 . The set of all triangular pictures generated by the pasting rules of TTPPS is a triangular picture language, denoted by $TTPPL(\Pi)$.

Example 4.3.1

Triangular tile pasting P system $\Pi_1 = (\Sigma, [1[2]2[3]3]1, F_1, F_2, F_3, R_1, R_2, R_3, 1)$ generates the two-dimensional iso-triangular picture language L_1 with at most 3 distinct labeled iso- triangular tiles.

Here $\Sigma = \{A, B, B_1\}$, $F_1 = \phi$, $F_2 = B_1$, $F_3 = \phi$, $R_1 = \{(B, (b_1, a_1), in_2), (A, (a_3, b_3), in_3)\}$, $R_2 = \{(B_1, (b_{11}, a_1), out)\}$, $R_3 = \{(A, (a_2, b_{12}), out)\}$ and 1 is the output region. The rules of R_1 , R_2 and R_3 are applied and $tar \in \{out\} \cup \{in_j\}$, $1 \leq j \leq 3$ and then the resultant iso-triangular picture pattern is collected in the output region one. Here a copy of the resultant picture pattern is considered to generate the next member of the language. Three members of the Picture language L_1 are shown with derivation steps below and the picture language is shown in fig.4.3.1.

Derivation steps :



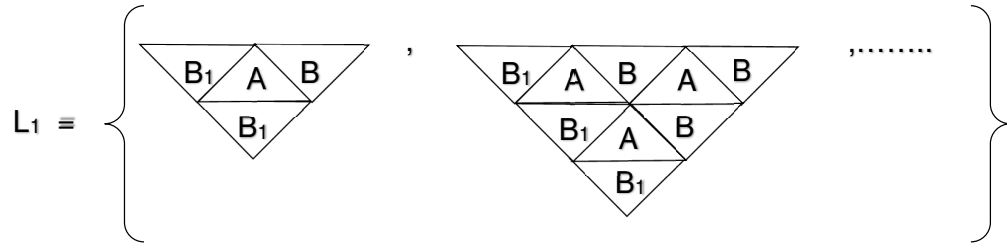


Figure 4.3.1 Language of D-iso arrays

Example 4.3.2

The class of picture language consists of the adjoint of rhombuses computed by the Triangular Tile Pasting P System with 3 membranes.

Consider the triangular tile pasting p system $\Pi_2 = (\Sigma, [1[2]2[3]3]1, F_1, F_2, F_3, R_1, R_2, R_3, 1)$, which generates the two-dimensional iso-triangular picture language L_2 with at most 3 distinct labeled iso- triangular tiles.

Here $\Sigma = \{A, A_1, B, C, D\}$, $F_1 = \phi$, $F_2 = A$, $F_3 = \phi$,

- ◇ $R_1 = \{ (B, (b_3, d_1), in_2), (A, (a_2, b_2), here), (A_1, (a_{13}, c_1), in_3) \}$,
- ◇ $R_2 = \{ (A_1, (a_3, c_1), in_3), (D, (d_3, a_{11}), in_3), (D, (d_2, c_2), out), (D, (d_3, a_1), out) \}$,
- ◇ $R_3 = \{ (C, (c_2, d_2), in_2), (A_1, (a_{12}, b_2), out) \}$ and 1 is the output region.

In region 2 the initial picture (tile) A is pasted with the iso-triangular tile C and the resultant picture is sent to region 3 by the target indicator. In region 3, the iso-triangular tile D is pasted by the pasting rule and the target associated with the pasting rule is sent out, the resultant picture from the region. The resultant picture pattern is glued with A_1 by the pasting rule present in R_2 , then the picture pattern is sent to region 3, and the pasting rules present in R_1, R_2, R_3 are applied and $\tau \in \{here, out\} \cup \{in_j\}$, $1 \leq j \leq 3$ associated with the rules sends the resultant iso-triangular picture pattern to the output region one. Here a copy of the resultant picture pattern is considered to generate the next member of the language. Two members of the Picture language L_2 are shown in the derivation steps. The language consisting of rhombuses is shown in fig,4.3.2.

Derivation steps :

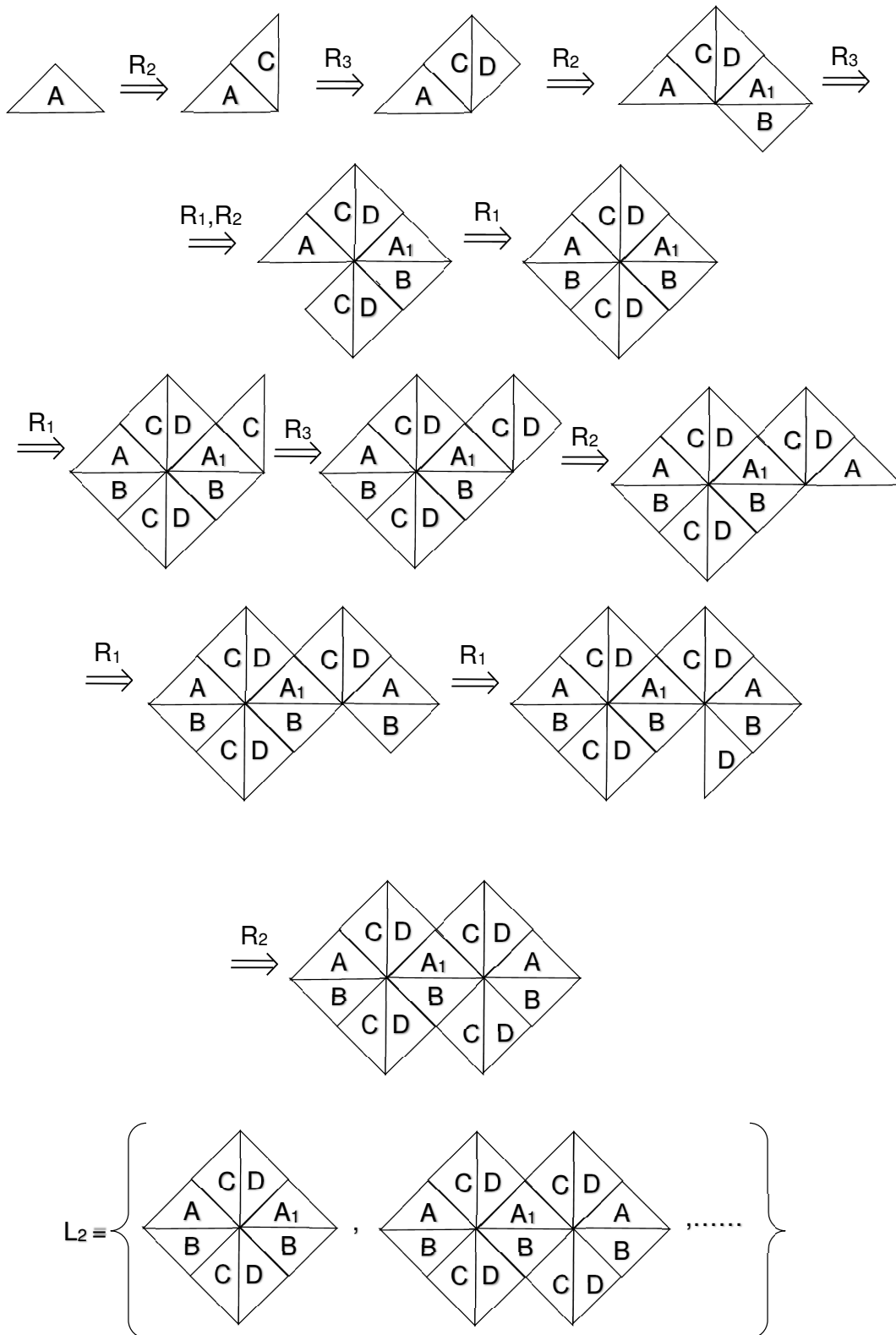


Figure 4.3.2 Language consists of adjoint of rhombuses

CHAPTER 5

5 COMPARISON RESULTS

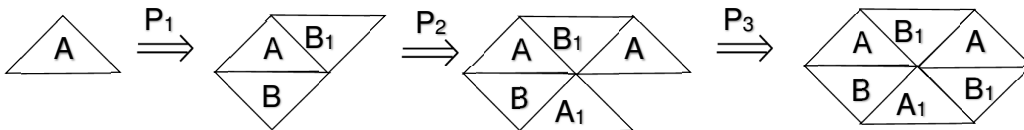
Theorem 5.1

The k-order triangular tile pasting system computes a class of picture language consisting of irregular hexagons that the triangular tile pasting system cannot compute.

Proof:

For, consider the 3-order TTPS = $(\Sigma, P = \{P_1, P_2, P_3\}, t_0)$, where $\Sigma = \{A, A_1, B, B_1\}$, $P_1 = \{(a_3, b_{13}), (a_2, b_2), (a_{12}, b_2)\}$, $P_2 = \{(b_1, a_{11}), (b_{11}, a_1)\}$, $P_3 = \{(a_{13}, b_{13}), (a_2, b_{12})\}$ and $t_0 = A$. The evaluation starts with the initial iso-triangular tile A, which is pasted to the tile B by the pasting rules of P_1 . After that, no rules of P_1 can be applied. Further, the rules of P_2 can be applied, That is with the resultant picture, the iso-triangular tiles A_1 and A are pasted and further no rules of P_2 can be applied. Finally, the resultant picture is glued with the iso-triangular tile B_1 by the pasting rule of P_3 . The picture pattern irregular hexagon is generated in this step. To generate the 2nd member of the language, a copy of the first member is considered. In the next step, on the right-hand side of the hexagon, the iso-triangular tiles B and B_1 are pasted to the resultant pattern with by the set of rules of P_1 . And then to the resultant picture pattern, the pasting rules of P_2 , and P_3 are applied, and we get a second member of a hexagon. The members of the picture language L_3 are shown below with the derivation steps. The language consists of the irregular hexagon that cannot be generated by the triangular tile pasting system since, in this system, the parallel mechanism will not allow generating the patterns. The class of language consists of irregular hexagons as shown in fig.5.1.

Derivation steps :



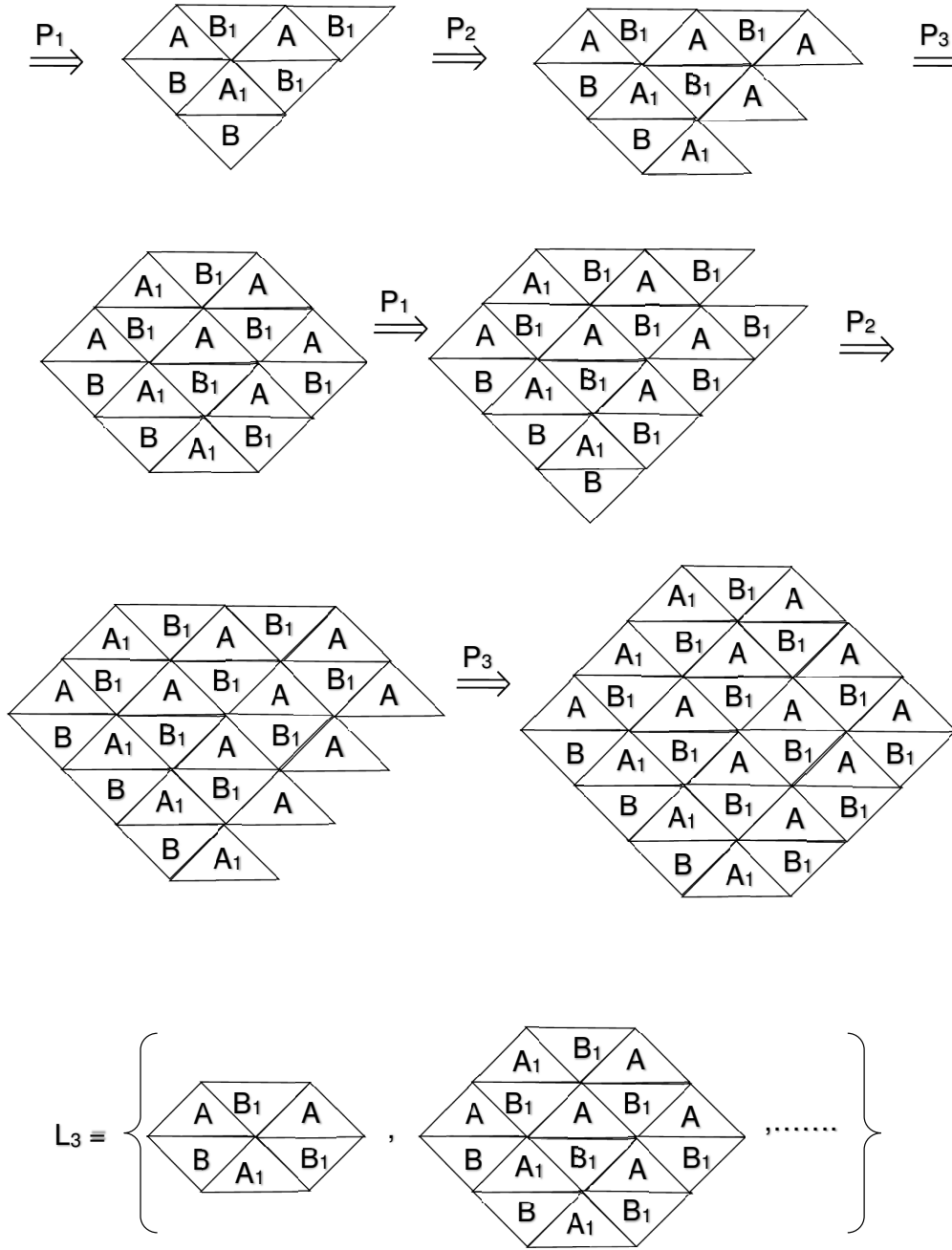


Figure 5.1 Language consists of irregular hexagon

Theorem 5.2

The Triangular tile pasting P system has more generative power than the k-order triangular tile pasting P system.

Proof: Consider the picture language consisting of D-iso arrays generated by the triangular tile pasting P system Π_1 (refer example 4.3.1), which can be generated by the 2-order triangular tile pasting system with the set of pasting rules of P_1, P_2 . The pasting rules of P_1 is $P_1 = \{(b_{11}, a_1), (b_1, a_1)\}$ and the pasting rules of P_2 is $P_2 = \{(a_3, b_3), (a_2, b_{12})\}$. And the picture language consists of adjoint rhombuses L_2 (refer example 4.3.2) can be generated by the 3-order triangular tile pasting system 3-order TTPS = $(\Sigma, P = \{P_1, P_2, P_3\}, t_0)$, where $\Sigma = \{A, A_1, B, B_1\}$, $P_1 = \{(a_3, c_1), (a_{13}, c_1)\}$, $P_2 = \{(c_2, d_2), (d_3, a_{11}), (d_3, a_1)\}$, $P_3 = \{(a_{12}, b_2), \{(b_3, d_1), \{(d_2, c_2), (a_2, b_2)\}$. But the triangular tile pasting P system generates not only the the adjoint rhombuses, it generates some other picture patterns with the help of the target indicators present in the rules. It shows that the result.

Theorem 5.3

The triangular tile pasting P system $\Pi_4 = (\Sigma, [1[2]2[3]3]1, F_1, F_2, F_3, R_1, R_2, R_3, 1)$ generates the adjoint of irregular hexagons L_4 with at most 4 distinct labeled iso-triangular tiles.

Here $\Sigma = \{A, A_1, B, B_1\}$, $F_1 = A$, $F_2 = \phi$, $F_3 = \phi$, $R_1 = \{(A, (a_3, b_3), in_2), (A_1, (a_{13}, b_3), in_2), (A, (a_2, b_2), here)\}$, $R_2 = \{(B, (b_1, a_1), here), (B, (b_1, a_{11}), in_3)\}$, $R_3 = \{(A_1, (a_{12}, b_{12}), out), (B_1, (b_{13}, a_3), here)\}$ and 1 is the output region.

Initially, the picture present in region one is pasted with the iso-triangular tile B by the pasting rule $A, (a_2, b_2), here)$ and then the rule $(A, (a_3, b_3), in_2)$ is applied. The target indicator present in the rule sent the picture pattern into region two of membrane two. With the resultant picture pattern, the rules of R_2 are applied. The resultant picture is sent to region three with the help of the target indicator in_3 . In region three, the rule $(A_1, (a_{12}, b_{12}), out)$ is applied, and then the resultant picture pattern, the irregular hexagon is sent out from the region to region one, where a copy of the pattern is taken. The next evaluation starts in the region, the rule $(A_1, (a_{13}, b_3), in_2)$ is applied, and the target indicator associated with the rule sent the resultant picture to region two. The rule $(B, (b_1, a_{11}), in_3)$ is applied and then the rule present in region three $(A_1, (a_{12}, b_{12}), out)$ is applied and finally, the resultant picture is sent out to region one, the pattern is collected in one. Here a copy of the resultant picture

pattern is considered to generate the next member of the language. Three members of the Picture language L_4 are shown with derivation steps.

Derivation steps :

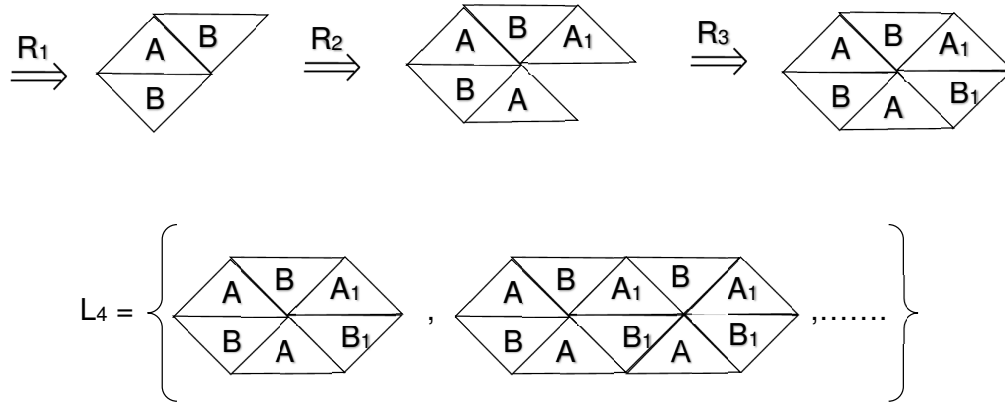


Figure 5.2 Language of adjoint of hexagon

CHAPTER 6

6 CONCLUSION

In this paper, the k-order triangular tile pasting system and triangular tile pasting system are defined with suitable examples. Some classes of iso-triangular picture languages are generated by the triangular tile pasting P system. The generative power of the triangular tile pasting P system and triangular tile pasting system is examined. Also, we examined the generative power of the triangular tile pasting system and the k-order triangular tile pasting system. It is noticed that the triangular tile pasting P system has more generative power than the k-triangular tile pasting system. In this paper, A class of picture language consists of irregular hexagons computed by the 3-order triangular tile pasting system. The computational power of the k-order triangular tile pasting system and the triangular tile pasting system is examined.

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