International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-2, July 2019

Chain Code P System using Cycle Grammar

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Abstract**:** ***P system is a bio-inspired distributed computing model to generate string languages [4], arrays [7] and tessellation patterns [2]. Chain Code P System is a string rewriting computing model to generate chain code picture languages in the frame work of P system. A variant of chain code P system is introduced in this paper, namely Cycle Rewriting Chain Code P system, where the string rewriting rules uses cycle grammar to construct cycle picture languages. We consider the problem of constructing chain code picture languages with even number of chains, kites, Von Koch quadric 8 segment like curves and Von Koch-like curves.***

Index Terms**:** ***Cycle grammar, Chain Code languages, Chain Code P System, Picture languages***

I. INTRODUCTION

Picture languages are generalization of string languages. In the literature we find various methods to generate picture languages using grammars [8]. A string over the alphabet $\Sigma = \{n, e, w, s\}$ denotes a picture if the alphabets describes a unit line move in the two dimensional plane by walking in the direction of north, east, west and south respectively. Such a word is called a chain code, introduced by Freeman [9]. A set of pictures described using a chain code is called a chain code picture language. The theoretical properties of chain code picture languages had been studied intensively by many researchers [9]. Motivated by kolam patterns, Gift Siromoney introduced cycle picture languages [1] using cycle grammar. Membrane Computing (or P System), a bio-inspired computing model, was introduced based on the structure and functioning of cells. The Oxford Handbook of Membrane Computing, edited by Gh. Paun, G. Rozenberg, A. Salomaa, [4] presents the motivation and the mechanism of membrane computing. A P System consists of a membrane structure, multi sets of objects placed inside the membranes, development rules governing the modification of these objects in time and convey the objects from one membrane to another membrane (inter-cellular communication). In [7] P system working with string objects is extended to P system with array objects linking membrane computing and array grammars. The region of membranes in such a system contains sets of array, which evolve by means of array rewriting rules.Recently context-free rewriting chain Code P System was introduced in [6] to construct chain code pictures using context free rewriting rules in the membrane region sequentially. In [5] context free parallel chain code system was introduced to reduce the number of membranes required for the construction of chain code pictures. The model was found to generate Hilbert curves, Peano curves and space filling curves [5]. In this paper we study the construction of cycle languages using chain code p system with cycle grammar. In section 2, we define cycle rewriting chain code P system and study the construction of picture languages of chains, kites and Von Koch quadric 8 segment -like curves on a square grid. We also study the construction of Von Koch-like curves on a triangular grid.

Revised Manuscript Received on 30 July 2019.
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II. CYCLE REWRITING CHAIN CODE P SYSTEM

Let v = (m, n) be a point in the two dimensional plane Z x Z. The north, east, west and south neighbours of the point (m, n) are given by (m, n+1), (m+1, n), (m-1, n) and (m, n-1). A picture p is a finite, connected sub graph of the two dimensional plane Z x Z.

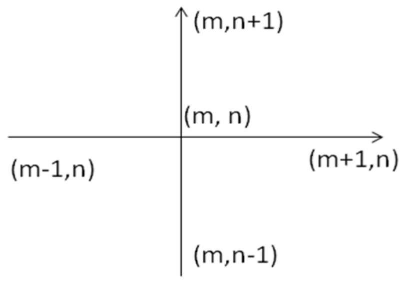

Fig. 1: Directions on a square grid

Let Σ be a finite set of alphabet and Σ^* denote the set of words over Σ. Let $\Sigma = \{n, e, w, s\}$ denote the picture description alphabets corresponding to the directions north, east, west and south respectively. A word $w \in \Sigma^*$ is called a picture word. A picture is regarded as a walk on the grid following the direction of the alphabets Σ. A picture word describes a cycle if it is a closed curve. A picture word w denotes elementary cycle if it is a cycle and no proper sub word of w forms a cycle. A set of pictures p(w) is called a picture language p(L) and a set L of picture words is called a picture description language. $p(L) = \{p(w) / w \in L\}$.

In the following we define Cycle Rewriting Chain Code P System. A Cycle Rewriting Chain Code P system of degree m, $m \geq 1$, is a construct

$\prod = (N, \Sigma, \mu, L_1, L_2, ..., L_n, R_1, ..., R_n, i_0)$ where:

(i) N is the non terminal alphabets;

(ii) Σ is the terminal alphabet

(iii) μ is a membrane structure consisting of m membranes labelled in a one-to-one manner;

(iv) $L_i, 1 \leq i \leq n$, are finite set of strings over $V = N \cup \Sigma$ initially present in the regions 1, 2, ... , m of μ, such that dpict (L_i) represent a cycle or a elementary cycle;

(vi) $R_i, 1 \leq i \leq n$ are the finite sets of context free *cycle rewriting rules* over V associated with the regions 1,2,... , m of μ. The rules are of the form $C \rightarrow x_1 x_2 ... x_n (tar)$, $C \rightarrow \lambda(tar)$, where $\lambda \notin V$ is the empty word, $C \in N$, $x_1 x_2 ... x_n \in V$, tar $\in$ {*here, out, in*}.

(vii) i_0 is the label of an elementary membrane of μ.

The computation of cycle rewriting chain code P system is similar to the parallel chain code P system but with some important differences. The initial set of strings present in the membrane regions should represent a cycle or elementary cycle and the final output of the system should represent a cycle. The initial string (cycle) $L_i, 1 \leq i \leq n$ present in a membrane region is rewritten using the rule $C \rightarrow x_1 x_2 ... x_n (tar)$ and the resultant string is communicated to another membrane or retained in the same membrane according to the target tar $\in$ {*here, out, in*}. While rewriting a string in a membrane region, all the rewriting rules with same target tar $\in$ {*here, out, in*} which can be applied, should be applied. The system will non-deterministically select the rules with same target when there are rules having more than one target indication.

The system is said to have completed a computation successfully only if the computation halts in the output membrane and the string collected in the output membrane represents a cycle. The cycle picture language generated by a cycle rewriting chain code P system is denoted by $CL(\Pi) = \{dpict(w) / w\}$.

Example 1:

Consider the cycle rewriting CCPS $\prod$ to construct a sequence of even number of chains in a square grid.

Let $\prod = (N, \Sigma, \mu, L_1, L_2, R_1, R_2, m_2)$ where N = {C}, $\Sigma = \{n, e, w, s\}$, $\mu = [_1[_2\,]_2\,]_1$, $L_1 = e^2 Cnws^2 wn$, $L_2 = \phi$, $R_1 = \{C \rightarrow \lambda(in), C \rightarrow e^2 Cnws^2 wn(here)\}$, $R_2 = \{C \rightarrow \lambda(here)\}$.

The system has two membrane regions m_1 and m_2. Initially the system has the string $e^2 Cnws^2 wn$ in the membrane region m_1 and the other region contains no strings. In the region m_1 the system can either apply the rule $C \rightarrow \lambda(in)$ or $C \rightarrow e^2 Cnws^2 wn(here)$ non-deterministically. If the rule $C \rightarrow e^2 Cnws^2 wn(here)$ is used $(k-1)$ times then it generates a string in the form $e^{2k} C(nws^2 wn)^k$. When the rule $C \rightarrow \lambda(in)$ is used, the string $e^{2k}(nws^2 wn)^k$ is communicated to the region m_2 and the computation stops. The picture language generated by the system is the sequence of even number of chains given by the set $CL(\Pi) = \{dpict(w) / w = e^{2k}(nws^2 wn)^k, k \geq 1\}$.

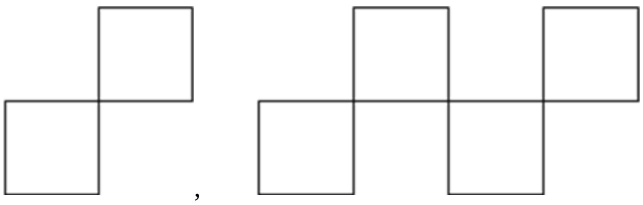

Fig. 2: A sequence of even number of chains

Example 2:

Consider the following cycle rewriting CCPS to construct a sequence of kites on a square grid. Let *u, d, r* and *l* represent unit length in the directions up, down, right, and left on a square grid.

Let $\prod = (N', \Sigma, \mu, L_1, L_2, R_1, R_2, m_2)$ where N' = {N, E, S, W},

$\Sigma = \{n, s, e, w\}$, $\mu = [_1[_2\,]_2\,]_1$, $L_1 = XN^2 E^2 S^2 W^2 Y$

$L_2 = \phi$,

$R_1 = \{X \rightarrow NEX(here), Y \rightarrow SWY(here), X \rightarrow \lambda(in), Y \rightarrow \lambda(in), N \rightarrow n(in), S \rightarrow s(in), E \rightarrow e(in), W \rightarrow w(in)\}$, $R_2 = \phi$.

The construction of the kites is similar to the Von Koch curve discussed in the previous example. The system has two membrane regions m_1 and m_2. Initially the system has the string $XN^2 E^2 S^2 W^2 Y$ in the membrane region m_1 and the other region contains no strings. The system should apply all the rewriting rules either with the direction here or in. Therefore in the region m_1 the system can either apply the rule

$X \rightarrow NEX(here), Y \rightarrow SWY(here)$ or $X \rightarrow \lambda(in), Y \rightarrow \lambda(in), N \rightarrow n(in), S \rightarrow s(in), E \rightarrow e(in), W \rightarrow w(in)$ non-deterministically.

If the rule $X \rightarrow NEX(here), Y \rightarrow SWY(here)$ is used k times then it generates a string in the form

$(NE)^k XN^2E^2S^2W^2(SW)^kY$. Finally when the rule $X \to \lambda(in), Y \to \lambda(in), N \to n(in), S \to s(in), E \to e(in), W \to w(in)$ is used, the string $(ne)^k(n^2e^2s^2w^2)(sw)^k$ is communicated to the region m_2 and the computation stops. The cycle generated by the system is the sequence of kites given by the set

$$L(\Pi) = \{dpict(w) / w = (ne)^k n^2e^2s^2w^2(sw)^k, k \geq 0\}$$

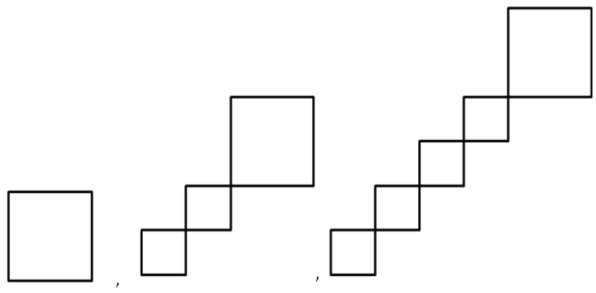

Fig. 3: A sequence of kites

Example 3: Consider the following cycle rewriting CCPS to construct a sequence of Von Koch-like curve on a hexagonal grid. Let x, y, z represent unit length in the directions of the hexagonal grid and $\bar{x}$, $\bar{y}$, $\bar{z}$ represent the reverse directions.

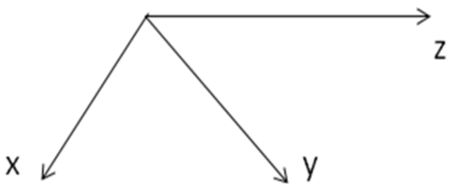

Fig. 4: Directions on a hexagonal grid

Let $\prod = (N, \Sigma, \mu, L_1, L_2, R_1, R_2, m_2)$ where N = {A, B, C, X, Y, Z}, $\Sigma = \{x, y, z, \bar{x}, \bar{y}, \bar{z}\}$,

$\mu = [_1[_2]_2]_1$, $L_1 = ABC$, $L_2 = \phi$,

$R_1 = \{A \to AYZA(here), B \to BZXB(here),$
$C \to CXYC(here), X \to XBCX(here),$
$Y \to YCAY(here), Z \to ZABZ(here), A \to x(in), ,$
$B \to y(in), C \to z(in),$
$X \to \bar{x}(in), Y \to \bar{y}(in), Z \to \bar{z}(in)\}$

$R_2 = \{\phi\}$.

The computation starts from the membrane m_1 containing the string ABC. The rule set R_1 contains rewriting rules with two different target indications *here* and *in*. The system non-deterministically chooses to apply the rewriting rules with one particular target indication. If the system selects rewriting rules with the target indication *in* then the rules $A \to x(in)$, $B \to y(in)$ and $C \to z(in)$ are applied to the string ABC and the resultant string of terminals xyz is communicated to the membrane m_2. The computation stops in m_2 as the rule set R_2 is empty. If the rewriting rules with the target indication *here* is used then the string ABC is rewritten as AYZABZXBCXYC and it is retained in the membrane m_1. Again the system may choose to apply the rules with the target indication *here* or *in* and the process continues. The Von Koch–like curves generated by the system are shown in figure 5.

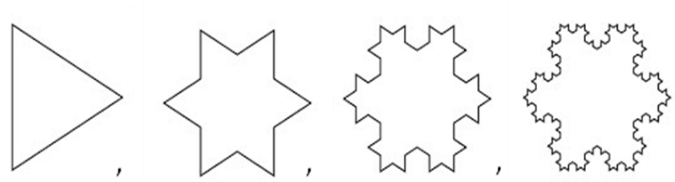

Fig. 5: A sequence of Von Koch –like curves

Example 4:

Consider the following CCPS to construct a sequence of Von Koch quadric 8 segment curve on a squrare grid. Let *u*, *d*, *r* and *l* represent unit length in the directions up, down, right, and left on a square grid.

Let $\prod = (N, \Sigma, \mu, L_1, L_2, R_1, R_2, m_2)$ where N = {N, E, S, W}, $\Sigma = \{n, s, e, w\}$,

$\mu = [_1[_2]_2]_1$, $L_1 = NESW$, $L_2 = \phi$,

$R_1 = \{N \to NWNE^2NEN(here), S \to SESW^2SES(here),$
$E \to ENES^2ENE(here), W \to ESEN^2ESE(here),$
$N \to u(in), S \to d(in), E \to r(in), W \to l(in)\}$

, $R_2 = \{\phi\}$. The construction of the Von Koch quadric 8 segment curve is similar to the Von Koch curve discussed in the previous example.

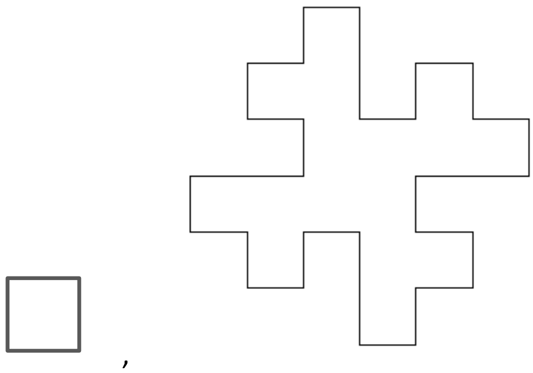

Figure 6: A sequence of Von Koch Quadric curves

III. CONCLUSION

In this paper, cycle picture languages are studied using cycle rewriting chain code P system. We have presented a P system with two membranes to generate the cycle languages namely, even number of chains, kites, Von Koch quadric 8 segment-like curves on a square grid.

We also presented a P system with two membranes to generate the Von Koch-like cuves on a triangular grid. The model was found to generate interesting geometric and fractal patterns using context free cycle rewriting rules in a distributed and parallel computing system.

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