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Some Properties of Probabilistic One-Sided Sticker Systems

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ABSTRACT

Sticker systems have been introduced by Kari in 1998as an abstract computational model which uses the Watson-Crick complementary principle of DNA molecules: starting from the incomplete double stranded sequences and iteratively using sticking operations, complete double stranded sequences are obtained. It is known that sticker systems with finite sets of axioms and sticker rules generate only regular languages. Hence, different types of restrictions have been considered to increase the computational power of sticker systems. Recently, probabilistic sticker systems have been introduced where the probabilities are initially associated with the axioms, and the probability of a generated string is computed by multiplying the probabilities of all occurrences of the initial strings in the computation of the string. In this paper, some properties of probabilistic one-sided sticker systems, which are special types of probabilistic sticker systems, are investigated. We prove that probability restriction on one-sided sticker systems can increase the computational power of the languages generated.

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INTRODUCTION

One of the early theoretical proposals for DNA based computation was given by Head in 1987, known as the *splicing systems*. There is in fact another method of DNA computing, known as the *sticker systems*. A sticker system is a model of the techniques used by Adleman in his experiment of computing a Hamiltonian path in a graph by using DNA molecules [1]. The structure of DNA is a double helix (helicoidal) which is composed of four nucleotides: A (adenine), C (cytosine), G (guanine), and T (thymine), which is paired as A-T, C-G according to *Watson-Crick complementary*[2].

The concept of sticker systems as a language generating model based on sticker operations was first proposed by Kari [2].The axioms and strings generated by a sticker system are considered as encoded models of single and double stranded DNA molecules. Moreover, the sticker operations have the advantages over splicing operations used in splicing systems because the sticker operations require no strands extension and use no enzymes [3].In sticker systems, the initial sequences of DNA are prolonged to the left and right, producing computations of possible arbitrary length and the process stop when a complete double stranded sequence is obtained and no sticky ends exist [2].

One-sided sticker systems were first considered in [2]. When forming new complete double stranded sequences, the initial strands called axioms and well started sequences are utilized and prolonged either to the left or to the right direction by the process of the sticker operation μ [4]. Starting from the axiom and iteratively using the operation of sticking, strands are prolonged in order to obtain a complete double stranded sequence.In probabilistic sticker systems, the probabilities are initially associated with the axioms, and the probability of a generated string is computed by multiplying the probabilities of all occurrences of the initial strings in the computation of the string.

Sincesticker systems with finite sets of axioms and sticker rules generate only regular languageswithout restrictions [5], monoids[6] and permutation groups [7] had been associated to generate more powerful languages than regular languages. However, the languages produced only up to context free**CF** languages. Hence, probability has been introduced to increase the computational power of the sticker language generated up to recursively enumerable **RE** languages. In probabilistic sticker systems, the probabilities are initially

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associated with the axioms, and the probability of a generated string is computed by multiplying the probabilities of all occurrences of the initial strings in the computation of the string. Probabilistic sticker systems are suitable models for stochastic processes, and on the other hand, the use of different cut-points with the languages generated by probabilistic sticker systems allows the producing of non-regular languages [8].

In this paper, we consider probabilistic sticker systems to introduce a new variant of sticker system, called probabilistic one-sided sticker systems. In such system, the probability $p(z)$ of the string z generated from two strings x and y is calculated from the probability $p(x)$ and $p(y)$ according to the operation * defined on the probabilities, i.e. $p(z) = p(x) * p(y)$. Then the language generated by a probabilistic one-sided sticker system consists of all strings generated by the one-sided sticker systems whose probabilities are greater than (or smaller than, or equal to) some previously chosen cut-points.

In this paper, some necessary definitions ofsticker system and probabilistic sticker system are stated. Next, the definitionsand some examples of probabilistic one-sided sticker systems are presented and some basic results concerning the generative power of probabilistic one-sided sticker systemsare established. The conclusion of this research is then discussed at the end of the paper.

Preliminaries:

In this section, we recall some definitions of sticker system and probabilistic sticker system.

Definition 1[2]:

A sticker system is a construct of 4-tuple

$\gamma = (V, \rho, A, D),$

where V is an alphabet, $\rho \subseteq V \times V$ is the symmetric relation in V, A is a finite subset of axioms $(W_\rho(V))$ and D is a finite set of pairs B_d, B_u where B_d and B_u are finite subsets of lower and upper stickers of the forms $\begin{pmatrix} \# \\ V \end{pmatrix}^+$ and $\begin{pmatrix} V \\ \# \end{pmatrix}^+$, respectively. A language resulting from a sticker system is called a *one-sided sticker language* (*OSSL*) if for each pair $(u, v) \in D$, we have either $u = \lambda$ or $v = \lambda$.

Definition 2[4]:

A sticker language (SL) is the language generated by a sticker system which consists of all strings formed by the set of upper strands of all complete strings derived from the axioms for which an exactly matching sequence of lower stickers can be found.

Definition 3[8]:

A *probabilistic sticker system* (*pSS*) is a 5-tuple

$$\gamma = (V, \rho, A_p, D_p, p),$$

where V is an alphabet, $\rho \subseteq V \times V$ is the symmetric relation in V, A_p is a finite subset of axioms $(W_\rho(V) \times p), D_p$ is a finite set of pairs $[(B_d \times B_u) \times p]$ where B_d and B_u are finite subsets of lower and upper stickers of the forms $\binom{\#}{V}^+$ and $\binom{V}{\#}^+$ respectively and $p : V^* \to [0, 1]$ is a probability function such that $\sum_{(x, p(x)) \in A_p, D_p} p(x) = 1$.

Definition 4[8]:

The probabilistic sticker language is defined as

$pSL(\gamma) = \{y \in WK_p(V) | (x, p(x)) \overset{*}{\Rightarrow} (y, p(y)) \text{for} (x, p(x)) \in A_p\}$.

In order to increase the generative power of probabilistic sticker systems, we consider a threshold (cut-point) sub-segments and discrete subset of [0, 1] as well as real numbers in [0, 1].

Results:

In this section, some preliminary results regarding probabilistic one-sided sticker systems are discussed and proved. Here, *OSSL*and*pOSSL*denote the families of languages generated by one-sided sticker system and probabilistic one-sided sticker systemrespectively.

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Definition 5: Probabilistic One-Sided Sticker System (*pOSSS*)

A probabilistic one-sided sticker system is a construct of 5-tuple
$\gamma_p = (V, \rho, A_p, D_p, p),$
where V is an alphabet, $\rho \subseteq V \times V$ is the symmetric relation in V, A_p is a finite subset of axioms $(W_\rho(V) \times p)$ and D_p is a finite set of pairs $\left[\left(B_d, B_u\right) \times p\right]$ where B_d and B_u are finite subsets of lower and upper stickers of the forms $\begin{pmatrix} \# \\ V \end{pmatrix}^+$ or $\begin{pmatrix} V \\ \# \end{pmatrix}^+$ respectively and $p : V^* \to [0,1]$ is a probability function such that

$$\sum_{(x, p(x)) \in A_p, D_p} p(x) = 1.$$

Definition 6: Probabilistic One-Sided Sticker Operation (*pOSSO*)

For the axioms $(x, p(x)) \in A_p$ and $[(u, p(u)), (v, p(v))] \in D_p$,

$$\left[x, p(x)\right] \overset{*}{\Rightarrow} \left[y, p(y)\right]$$

if and only if

1) $(y, p(y)) = \mu[(u, p(u)), \mu\{(x, p(x)), (v, p(v))\}]$ and $p(y) = p(u) \cdot p(x \cdot v)$.
2) $(y, p(y)) = \mu[\mu\{(x, p(x)), (u, p(u))\}, (v, p(v))]$ and $p(y) = p(x \cdot u) \cdot p(v)$.

Definition 7: Probabilistic One-Sided Sticker Language (*pOSSL*)

The language generated by the probabilistic one-sided sticker system is defined as

$$pOSSL(\gamma) = \{y \in WK_p(V) \mid (x, p(x) \overset{*}{\Rightarrow} (y, p(y)) \text{ for } (x, p(x)) \in A_p\}.$$

The families of recursively enumerable and context-free languages are denoted by **RE** and **CF** respectively. Further we cite the results of our paper.

The next theorem shows that probabilistic one-sided sticker systems are more powerful than the usual one-sided sticker systems:

Theorem 1: $OSSL \subset pOSSL$.

Proof:

Consider a one-sided sticker system $\gamma = (V, \rho, A, D)$. Then the language generated by the sticker system γ is

$$OSSL(\gamma) = \left\{ z \in WK(V) \mid x \overset{*}{\Rightarrow} z, x \in A \right\}.$$

Let $\gamma_1 = \left(V, \rho, A_p, D_p, p\right)$ be a probabilistic one-sided sticker system where $A_p = \left\{\left(x_i, p\left(x_i\right) \mid x_i \in A, 1 \le i \le n\right)\right\}$, $D_p = \left\{\left(u_i, p\left(u_i\right)\right), \left(v_i, p\left(v_i\right)\right) \mid u_i, v_i \in D, 1 \le i \le n\right\}$ and $p\left(\theta_i\right) = 1/m$ for all $1 \le i \le n, \theta \in \left\{x, u, v\right\}$, then

$$\sum_{i=1}^{n} p\left(\theta_i\right) = 1.$$

The language generated by the probabilistic one-sided sticker system γ_1:

$$pSL(\gamma_1, *\alpha) = \{z \in WK_p\left(V\right) \mid \left[x, p\left(x\right)\right] \overset{*}{\Rightarrow} \left[z, p\left(z\right)\right] \text{for} \left[x, p\left(x\right)\right] \in A_p \} \quad \text{where}$$

$p\left(z\right) = p\left(x\right) \cdot p\left(\tau_1\right) \cdot p\left(\tau_2\right) \cdots p\left(\tau_n\right)$ for $\tau_1, \tau_2, \ldots, \tau_n \in D_p$.

We define the threshold language generated by γ_1 as $pOSSL(\gamma_1, > 0)$, then it is not difficult to see that

$$OSSL(\gamma) = pOSSL(\gamma_1, > 0).$$

Next, some examples of probabilistic one-sided sticker languages are illustrated in the following.

Example 1:

Given a probabilistic one-sided sticker system $\gamma_1 = \{V, \rho, A_p, D_p, p\}$ where

$V = \{a, b\}$,

$\rho = \{(a,a),(b,b)\}$,

$A = \left\{\begin{pmatrix} a \\ \lambda \end{pmatrix}\begin{pmatrix} b \\ \lambda \end{pmatrix}, \left(\frac{2}{28}\right)\right\}$,

$D = \left\{\left(\begin{pmatrix} \lambda \\ a \end{pmatrix}\begin{pmatrix} \lambda \\ a \end{pmatrix}, \frac{3}{28}\right), \left(\begin{pmatrix} \lambda \\ b \end{pmatrix}\begin{pmatrix} \lambda \\ b \end{pmatrix}, \frac{5}{28}\right), \left(\begin{pmatrix} a \\ \lambda \end{pmatrix}, \frac{7}{28}\right), \left(\begin{pmatrix} b \\ \lambda \end{pmatrix}, \frac{11}{28}\right)\right\}$.

For the given sticker system, we start the computation with the axiom in *A* being attached to its complementary axiom from *D*. The first step of computation starts with prolongation to the right side and it is shown below:

$$\left[\left\{\begin{pmatrix} a \\ \lambda \end{pmatrix}\begin{pmatrix} b \\ \lambda \end{pmatrix}, \frac{2}{28}\right\}, \left\{\begin{pmatrix} \lambda \\ b \end{pmatrix}\begin{pmatrix} \lambda \\ b \end{pmatrix}, \frac{5}{28}\right\}\right] \Rightarrow \left\{\begin{pmatrix} a \\ \lambda \end{pmatrix}\begin{pmatrix} b \\ b \end{pmatrix}\begin{pmatrix} \lambda \\ b \end{pmatrix}, \left(\frac{2}{28}\right)\cdot\left(\frac{5}{28}\right)\right\}.$$

The computation is complete when a complete double strand sequence is obtained, that is when no sticky end exists in the string. Here, sticky end still exists from the first step. Therefore, the computation has to be continued until the double strand sequence is obtained.

For this example, the second step of the computation is shown in the following:

$$\left[\left\{\begin{pmatrix} a \\ \lambda \end{pmatrix}\begin{pmatrix} b \\ b \end{pmatrix}\begin{pmatrix} \lambda \\ b \end{pmatrix}, \left(\frac{2}{28}\right)\cdot\left(\frac{5}{28}\right)\right\}, \left\{\begin{pmatrix} b \\ \lambda \end{pmatrix}, \frac{11}{28}\right\}\right] \Rightarrow \left\{\begin{pmatrix} a \\ \lambda \end{pmatrix}\begin{pmatrix} b \\ b \end{pmatrix}\begin{pmatrix} b \\ b \end{pmatrix}, \left(\frac{2}{28}\right)\cdot\left(\frac{5}{28}\right)\cdot\left(\frac{11}{28}\right)\right\}.$$

To obtain a complete computation on the right side, the sticking operations have to follow the above steps. Now, to obtain a complete computation on the left side, the computation follows the steps below:

$$\left[\left\{\begin{pmatrix} a \\ \lambda \end{pmatrix}\begin{pmatrix} b \\ \lambda \end{pmatrix}, \frac{2}{28}\right\}, \left\{\begin{pmatrix} \lambda \\ a \end{pmatrix}\begin{pmatrix} \lambda \\ a \end{pmatrix}, \frac{3}{28}\right\}\right] \Rightarrow \left\{\begin{pmatrix} \lambda \\ a \end{pmatrix}\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} b \\ \lambda \end{pmatrix}, \left(\frac{2}{28}\right)\cdot\left(\frac{3}{28}\right)\right\},$$

$$\left[\left\{\begin{pmatrix} \lambda \\ a \end{pmatrix}\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} b \\ \lambda \end{pmatrix}, \left(\frac{2}{28}\right)\cdot\left(\frac{3}{28}\right)\right\}, \left\{\begin{pmatrix} a \\ \lambda \end{pmatrix}, \left(\frac{7}{28}\right)\right\}\right] \Rightarrow \left\{\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} b \\ \lambda \end{pmatrix}, \left(\frac{2}{28}\right)\cdot\left(\frac{3}{28}\right)\cdot\left(\frac{7}{28}\right)\right\}.$$

By joining both stickers, the complete double strand string with the probability $\left\{\left(\frac{2}{28}\right)\cdot\left(\frac{3\cdot7\cdot5\cdot11}{28}\right)^n\right\}$ is obtained. Then the language produced is

$$L(\gamma, p) = \{(a^{2k}b^{2m}, \left(\frac{2}{28}\right)\cdot\left(\frac{3\cdot7}{28^2}\right)^k\left(\frac{5.11}{28^2}\right)^m) \mid k, m \geq 1\}, \text{ where } p = \left(\frac{2}{28}\right)\cdot\left(\frac{3\cdot7}{28^2}\right)^k\left(\frac{5.11}{28^2}\right)^m \tag{1}$$

We can iteratively prolong a complete double strand DNA sequences to generate the general form of the language produced using the same sequences as done earlier.

We can produce a language of sticker system as $L(\gamma, p) = \{a^{2n}b^{2n} \mid n \geq 1\}$ when the probability p is equal to $\left\{\left(\frac{2}{28}\right)\cdot\left(\frac{3\cdot7\cdot5\cdot11}{28}\right)^n\right\}$.

From (1) and using the threshold properties, we can conclude the following:

i : $\eta = 0, \Rightarrow L(\gamma, = 0) = \varnothing \in \mathbf{REG}$,

ii : $\eta > 0, \Rightarrow L(\gamma, > 0) = L(\gamma) \in \mathbf{REG}$, iii : $\bar{\eta} = \{\left(\frac{2}{28}\right)\left(\frac{3.7.5.11}{28^4}\right)^n \mid n \geq 1\}, \Rightarrow L(\gamma, \bar{\eta}) = \left\{a^{2n}b^{2n} \mid n \geq 1\right\} \in \mathbf{CF - REG},$

iv : $\dot{\eta} \neq \{\left(\frac{2}{28}\right)\left(\frac{3.7.5.11}{28^4}\right)^n \mid n \geq 1\}, \Rightarrow L(\gamma, \dot{\eta}) = \left\{a^k b^m \mid k > m \geq 1\right\} \cup \left\{a^k b^m \mid m > k \geq 1\right\} \in \mathbf{CF - REG}.$

Example 2:
Given a probabilistic one-sided sticker system $\gamma_2 = \{V, \rho, A_p, D_p, p\}$ where

$V = \{a, b, c\}$,
$\rho = \{(a,a),(b,b),(c,c)\}$,
$A = \left\{\left[\begin{pmatrix} a \\ \lambda \end{pmatrix}, \left(\frac{2}{77}\right)\right], \left[\begin{pmatrix} c \\ \lambda \end{pmatrix}, \left(\frac{3}{77}\right)\right]\right\}$,
$D = \left\{\left(\begin{pmatrix} \lambda \\ a \end{pmatrix}\begin{pmatrix} \lambda \\ a \end{pmatrix}, \frac{5}{77}\right), \left(\begin{pmatrix} \lambda \\ c \end{pmatrix}\begin{pmatrix} \lambda \\ c \end{pmatrix}, \frac{7}{77}\right), \left(\begin{pmatrix} b \\ \lambda \end{pmatrix}, \frac{11}{77}\right), \left(\begin{pmatrix} a \\ \lambda \end{pmatrix}, \frac{13}{77}\right), \left(\begin{pmatrix} c \\ \lambda \end{pmatrix}, \frac{17}{77}\right), \left(\begin{pmatrix} \lambda \\ b \end{pmatrix}, \frac{19}{77}\right)\right\}.$

For the given sticker system, we start the computation with the axiom in *A* being attached to its complementary axiom from *D*. In this example, there are two cases. The first step of each case of computation starts with prolongation to the right side and it is shown below.

Case 1: For string $\left\{\left[\begin{pmatrix} a \\ \lambda \end{pmatrix}, \left(\frac{2}{77}\right)\right]\right\}$,

$$\left[\left\{\begin{pmatrix} a \\ \lambda \end{pmatrix}, \frac{2}{77}\right\}, \left\{\begin{pmatrix} \lambda \\ a \end{pmatrix}\begin{pmatrix} \lambda \\ a \end{pmatrix}, \frac{5}{77}\right\}\right] \Rightarrow \left\{\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} \lambda \\ a \end{pmatrix}, \left(\frac{2}{77}\right)\cdot\left(\frac{5}{77}\right)\right\}.$$

The computation is complete when a complete double strand sequence is obtained, that is when no sticky end exists in the string. Here, sticky end still exists from the first step. Therefore, the computation has to be continued until the double strand sequence is obtained.
For this example, the second step of the computation is shown in the following:

$$\left[\left\{\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} \lambda \\ a \end{pmatrix}, \left(\frac{2}{77}\right)\cdot\left(\frac{5}{77}\right)\right\}, \left\{\begin{pmatrix} a \\ \lambda \end{pmatrix}, \frac{13}{77}\right\}\right] \Rightarrow \left\{\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} a \\ a \end{pmatrix}, \left(\frac{2}{77}\right)\cdot\left(\frac{5}{77}\right)\cdot\left(\frac{13}{77}\right)\right\}.$$

To obtain a complete computation on the right side, the sticking operations have to follow the above steps. To obtain string $a^{2k}b^m$ we continue the computation as below:

$$\left[\left\{\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} a \\ a \end{pmatrix}, \left(\frac{2}{77}\right)\cdot\left(\frac{5}{77}\right)\cdot\left(\frac{13}{77}\right)\right\}, \left\{\begin{pmatrix} b \\ \lambda \end{pmatrix}, \left(\frac{11}{77}\right)\right\}\right] \Rightarrow \left\{\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} b \\ \lambda \end{pmatrix}, \left(\frac{2}{77}\right)\cdot\left(\frac{5}{77}\right)\cdot\left(\frac{13}{77}\right)\cdot\left(\frac{11}{77}\right)\right\},$$

$$\left[\left\{\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} b \\ \lambda \end{pmatrix}, \left(\frac{2}{77}\right)\cdot\left(\frac{5}{77}\right)\cdot\left(\frac{13}{77}\right)\cdot\left(\frac{11}{77}\right)\right\}, \left\{\begin{pmatrix} \lambda \\ b \end{pmatrix}, \left(\frac{19}{77}\right)\right\}\right] \Rightarrow$$

$$\left\{\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} a \\ a \end{pmatrix}\begin{pmatrix} b \\ b \end{pmatrix}, \left(\frac{2}{77}\right)\cdot\left(\frac{5}{77}\right)\cdot\left(\frac{13}{77}\right)\cdot\left(\frac{11}{77}\right)\cdot\left(\frac{19}{77}\right)\right\}.$$

Hence, the complete double strand string with the probability $\left\{\left(\frac{2}{77}\right)\cdot\left(\frac{5\cdot 11\cdot 19}{77^3}\right)^n\left(\frac{13}{77}\right)^{2n-1}\right\}$ is obtained.

Then the language produced is $\left\{L(\gamma_2, p) = a^{2k}b^m \middle| k, m \geq 1\right\}$ where

$$p = \left\{\left(\frac{2}{77}\right)\cdot\left(\frac{5}{77}\right)^k\cdot\left(\frac{13}{77}\right)^{2k-1}\cdot\left(\frac{11\cdot 19}{77^2}\right)^m\right\}.$$

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Case 2: For string $\left\{\left[\binom{c}{\lambda},\left(\frac{3}{77}\right)\right]\right\}$,

$$\left[\left\{\binom{c}{\lambda},\frac{3}{77}\right\},\left\{\binom{\lambda}{c}\binom{\lambda}{c},\frac{7}{77}\right\}\right]\Rightarrow\left\{\binom{c}{c}\binom{\lambda}{c},\left(\frac{3}{77}\right)\cdot\left(\frac{7}{77}\right)\right\}.$$

The computation is complete when a complete double strand sequence is obtained, that is when no sticky end exists in the string. Here, sticky end still exists from the first step. Therefore, the computation has to be continued until the double strand sequence is obtained.

For this example, the second step of the computation is shown in the following:

$$\left[\left\{\binom{c}{c}\binom{\lambda}{c},\left(\frac{3}{77}\right)\cdot\left(\frac{7}{77}\right)\right\},\left\{\binom{c}{\lambda},\frac{17}{77}\right\}\right]\Rightarrow\left\{\binom{c}{c}\binom{c}{c},\left(\frac{3}{77}\right)\cdot\left(\frac{7}{77}\right)\cdot\left(\frac{17}{77}\right)\right\}.$$

To obtain a complete computation on the right side, the sticking operations have to follow the above steps. To obtain string $b^m c^{2r}$ we continue the computation as below:

$$\left[\left\{\binom{b}{\lambda},\left(\frac{11}{77}\right)\right\},\left\{\binom{c}{c}\binom{c}{c},\left(\frac{3}{77}\right)\cdot\left(\frac{7}{77}\right)\cdot\left(\frac{17}{77}\right)\right\}\right]\Rightarrow\left\{\binom{b}{\lambda}\binom{c}{c}\binom{c}{c},\left(\frac{3}{77}\right)\cdot\left(\frac{7}{77}\right)\cdot\left(\frac{17}{77}\right)\cdot\left(\frac{11}{77}\right)\right\},$$

$$\left[\left\{\binom{\lambda}{b},\left(\frac{19}{77}\right)\right\},\left\{\binom{b}{\lambda}\binom{c}{c}\binom{c}{c},\left(\frac{3}{77}\right)\cdot\left(\frac{7}{77}\right)\cdot\left(\frac{17}{77}\right)\cdot\left(\frac{11}{77}\right)\right\}\right]\Rightarrow\left\{\binom{b}{b}\binom{c}{c}\binom{c}{c},\left(\frac{2}{77}\right)\cdot\left(\frac{5}{77}\right)\cdot\left(\frac{13}{77}\right)\cdot\left(\frac{11}{77}\right)\cdot\left(\frac{19}{77}\right)\right\}.$$

Hence, the complete double strand string with the probability $\left\{\left(\frac{3}{77}\right)\cdot\left(\frac{7\cdot 11\cdot 19}{77^3}\right)^n\left(\frac{17}{77}\right)^{2n-1}\right\}$ is obtained.

Then the language produced is $\left\{L(\gamma_2,p)=b^m c^{2r}\,\middle|\,m,r\geq 1\right\}$ where

$$p=\left\{\left(\frac{3}{77}\right)\cdot\left(\frac{7}{77}\right)^r\cdot\left(\frac{17}{77}\right)^{2r-1}\cdot\left(\frac{11\cdot 19}{77^2}\right)^m\right\}.$$

Then, by joining both complete string from

Case 1 $\left[a^{2k}b^m,\left(\frac{2}{77}\right)\cdot\left(\frac{5}{77}\right)^k\cdot\left(\frac{13}{77}\right)^{2k-1}\cdot\left(\frac{11\cdot 19}{77^2}\right)^m\right]$ and Case 2 $\left[b^m c^{2r},\left(\frac{3}{77}\right)\cdot\left(\frac{7}{77}\right)^r\cdot\left(\frac{17}{77}\right)^{2r-1}\cdot\left(\frac{11\cdot 19}{77^2}\right)^m\right]$,

the language produced is

$L(\gamma_2,p)=\left\{a^{2k}b^{2m}c^{2r}\,\middle|\,k,m,r\geq 1\right\}$, where $p=\left\{\left(\frac{2.3}{77^2}\right)\cdot\left(\frac{5}{77}\right)^k\cdot\left(\frac{13}{77}\right)^{2k-1}\cdot\left(\frac{11.19}{77^2}\right)^{2m}\cdot\left(\frac{7}{77}\right)^r\cdot\left(\frac{17}{77}\right)^{2r-1}\right\}$.

Using the threshold properties, we can conclude the following:

i : $\eta>0,\Rightarrow L(\gamma_2,>0)=L(\gamma_2)\in$ **REG**,

ii : $\eta>0,\Rightarrow L(\gamma_2,>0)=L(\gamma_2)\in$ **REG**,

iii :

$$\overline{\eta} = \left\{ \left(\frac{2\cdot 3}{77^2}\right)\left(\frac{5.7}{77^2}\right)^n \left(\frac{11.19}{77^2}\right)^{2n} \left(\frac{13.17}{77^2}\right)^{2n-1} \middle| n \geq 1 \right\} \Rightarrow L\left(\gamma_2, \overline{\eta}\right) = \left\{ a^{2n}b^{2n}c^{2n} \,|n \geq 1 \right\} \in \mathbf{CS} - \mathbf{REG},$$

iv : $$\dot{\eta} \neq \left\{ \left(\frac{2\cdot 3}{77^2}\right)\left(\frac{5.7}{77^2}\right)^n \left(\frac{11.19}{77^2}\right)^{2n} \left(\frac{13.17}{77^2}\right)^{2n-1} \middle| n \geq 1 \right\} \Rightarrow L\left(\gamma_2, \dot{\eta}\right) = \left\{ a^{2k}b^{2m}c^{2r} \,|\text{k>m>r} \geq 1 \right\} \cup$$

$$\left\{ a^{2k}b^{2m}c^{2r} \,|\text{k>r>m} \geq 1 \right\} \cup \left\{ a^{2k}b^{2m}c^{2r} \,|\text{m>k>r} \geq 1 \right\} \cup \left\{ a^{2k}b^{2m}c^{2r} \,|\text{m>r>k} \geq 1 \right\} \cup$$

$$\left\{ a^{2k}b^{2m}c^{2r} \,|\text{r>k>m} \geq 1 \right\} \cup \left\{ a^{2k}b^{2m}c^{2r} \,|\text{r>m>k} \geq 1 \right\} \cup \in \mathbf{CS} - \mathbf{REG}.$$

From the examples, we obtain some propositions as stated below:

Proposition 1:

For any probabilistic one-sided sticker system γ the threshold language $L\left(\gamma, = 0\right)$ is the empty set, i.e. $L\left(\gamma, = 0\right) = \varnothing$

Proposition 2:

If for each prolongation in a probabilistic one-sided sticker system γ, $p\left(r\right) < 1$, then every threshold language $L\left(\gamma, > \eta\right)$ with $\eta > 0$ is finite.

The language generated by probabilistic one-sided sticker system is up to the families of context-sensitive languages according to the Chomsky hierarchy, sincethe sticker operation does not contain the erasing rule which is needed to generate the recursively enumerable languages. Hence,

Conjecture 1*:* $pOSSL \subseteq \mathbf{CS}$.

From Conjecture 1 and example 2, the following conjecture shows that probabilistic one-sided sticker systems can generate some non-context-free languages:

Conjecture 2: $pOSSL - \mathbf{CF} \neq \varnothing$.

Conclusion:

In this paper, the definition of a new restriction of one-sided sticker systems, namely probabilistic one-sided sticker systems, has been introduced. Here, some preliminary results on the generative power of one-sided sticker systems have also been established. It has been shown by the examples that the probabilistic extension of sticker systems can increase the computational power of sticker systems up to the context-sensitive languages. By increasing the computational power of the sticker system, the capability of generating DNA based computer is brighter. DNA based computers are important as it can run with high speed and the capability of memory information are enormous. Even though the probabilistic variants that have been proposed in this paper are not so much powerful (inferior) as compared to the other extended or restricted variants in the literature review, the probabilistic modification in one-sided sticker system is very useful in the study of stochastic and uncertainty processes.

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