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3D Visual Method of Variant Logic Construction for Random Sequence

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3D VISUAL METHOD OF VARIANT LOGIC CONSTRUCTION FOR RANDOM SEQUENCE

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Abstract
As Internet security threats continue to evolve, in order to ensure information transmission security, various encrypt and decrypt has been used in channel coding and decoding of data communication. While cryptography requires a very high degree of apparent randomness, Random sequences play an important role in cryptography. Both CA (Cellular Automata) and RC4 contain pseudo-random number generators and may have intrinsic properties respectively. In this paper, a 3D visualization model (3DVM) is proposed to display spatial characteristics of the random sequences from CA or RC4 keystream. Key components of this model and core mechanism are described. Every module and their I/O parameters are discussed respectively. A serial of logic function of CA are selected as examples to compare with some RC4 keystreams to show their intrinsic properties in three-dimensional space. Visual results are briefly analyzed to explore their intrinsic properties including similarity and difference. The results provide support to explore the RC4 algorithm by using 3D dimensional visualization tools to organize its interactive properties as visual maps.

Keywords
Pseudo-random sequence, CA, stream cipher, RC4 keystream, 3D maps

INTRODUCTION

Wireless Sensor Networks and Wireless Networks are most popular and widely used types of network of this era. Because of the openness these types of networks are not very much secure. To provide the security over the WSN and WN used algorithm must be fast enough which can encrypt and decrypt data comparatively in less amount of time and must require less resource also. In this concern WPA (Wi-Fi Protected Access) and WEP (Wired Equivalent Privacy) protocols are used as standard. These standards have adopted the RC4 stream cipher algorithm to secure the data over the wireless networks. These standard adopted RC4 algorithms because RC4 algorithm gives speedy encryption and decryption of data, utilize less hardware resource during processing, and easy to implement (Brandon & Patricia 2006; Suhaila & Mansoor 2010). Presently RC4 algorithm is not secure in many aspects. Lots of weaknesses and attacks have been detected by the cryptanalysis. (Fahime, Mohammad, Hamid & Payman 2010; Lamba 2010)

The Weakness of RC4

RC4 algorithm is a stream cipher under the symmetric ciphers algorithms. Typically, in a stream cipher, the keystream is the sequence which is combined, digit-by-digit, to the plaintext sequence for obtaining the ciphertext sequence. However, the data encryption is equivalent to a simple XOR with keystream. The keystream is generated by a finite state automaton called the keystream generator (Robshaw 1995, Bruce 1997). The encryption can be broken if plaintexts are encrypted using the same keystream. RC4 keystream which generated by RC4 keystream generator is completely compromising the security of RC4.

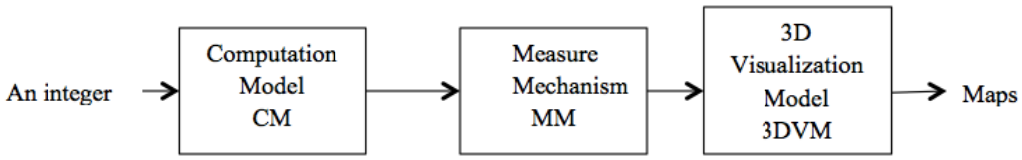
Because it's very hard to trace the characteristics of keystream generators, random characteristics of keystream can be investigated on spatial characteristics of keystream generator to test pseudo-random sequences. This paper is expansion work of (Qingping & Jeffrey 2010) by Qingping Li from 2D to 3D. In this paper, random sequences from given keystreams are collected in comparison with random sequences generated by sample logical function of 1D Cellular Automata to show their intrinsic properties in Three-dimensional space of relationships.

CA

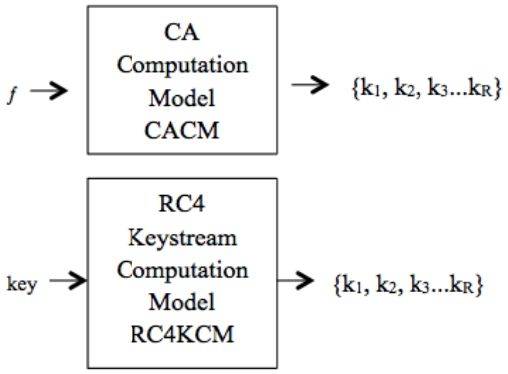
Cellular Automata is a great discovery in the 20th century, it forms a time series according to a given function in an iterations process by introducing logic function and related calculation methods in natural pattern (Wolfram). In 1985, S.Wolfram formed the sequential cipher from pseudo-random sequence generated from logic calculation using cellular automata. Because of the implicated expression of the logic function, the spatial characteristic cannot be directly observed from the function formula (Shiyong).

ARCHITECTURE

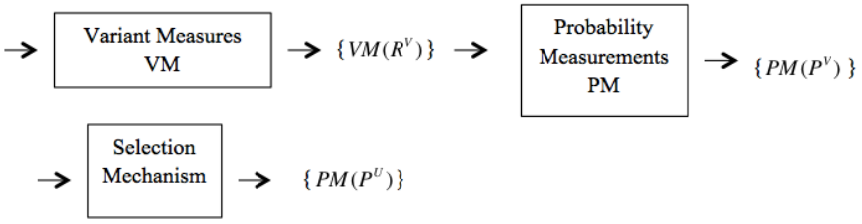
Architecture



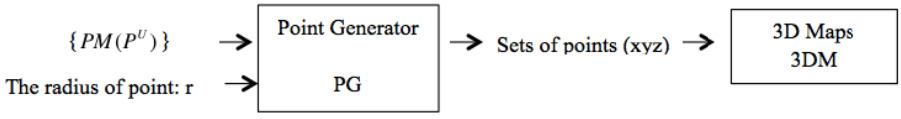
(a) Architecture



(b) CM



(c) MM



(d) 3DVM 3D Visualization Model

Figure 1 Variant 3D Visualization System and key components

The architecture is shown in Figure 1(a). The three main components and their modules are shown in Figure 2(b)-2(d) respectively.

In the first part of this system, two types of data sets are generated by CACM and RC4KCM respectively. The data sets on either CACM or RC4KCM are getting into the MM module as input data. The main function of the VM is to output the four vectors of variant measurements. Using unified or non-unified method, six probability measurements are created by PM module. In order to establish 3D maps, three vectors of probability measurements are selected from the six probability measurements by SM module. Every three vectors set determine its Three-dimensional spatial position. And all vectors sets constructed the 3D map by 3DVM.

With six parameters in an input group, there are three sets of parameters in the intermediate group and one set of parameters in the output group.

Input Group:
An integer indicates the serial number of logic function or the value of key selected
An integer indicates which model selected
An integer indicates the number of elements in binary sequence
An integer indicates the number of elements in a segment
An integer indicates the method of selection mechanism
An integer indicates the control parameter for mapping

Intermediate Group:
A 0-1 vector generated by CA logic function or RC4 keystream generator
A set of four variant measures
A set of six probability vectors

Output Group:
3D maps

Computation Model of CA (CMCA)
CMCA module is used to measure the features of a logic function based on CA (Cellular Automata). Consider a logic function f: $Y = f(X)$ as a function of CA, the output sequence Y can be generated by given initial input sequence X with 2 states. For a N bits initial input sequence, a total of 2^n states are generated under the logic function f: $X \to Y$. A pair of vectors (X, Y) could be collected for their correspondences on the pair of input-output relationships. There are 2^n groups of this corresponding relationship.

Input Group:
X A 0-1 vector with N elements, $X \in B_2^n$
n An integer indicating a 0-1 vector with n elements,
f A function with 2 variables

Intermediate Group:
Y A 0-1 vector with N elements, $Y \in B_2^n$

Output Group:
$\forall Y$ Exhaustive set of all states of N bit vectors with 2^n elements

Computation Model of RC4 Keystream (RC4KCM)

For an *L* bits input keystream *K*, divided into *G* segments and *W* = *L*/*G* bits of each segment with *G*<*L*. The value of parameter *G* determines the amount of points and *W* determines spatial distribution for the output keystream in the phase space.

Input Group:

A 0-1 vector with L elements generated by RC4 keystream generator,

L An integer indicates the number of elements in an input sequence,

G An integer indicates the number of segments divided,

W An integer indicates the number of elements in a segment

Output Group:

G sets of *W* bits 0-1 vectors

The CMRC4 component uses an input vector as input, under different segment strategies to divide into several segments. The output of this component is *G* sets of *W* bits 0-1 vectors.

Measure Mechanism (MM)

The MM component shown in Figure 1(c) is composed of three modules: Variant Measure (VM), Probability Measurement (PM) and Selection Mechanism (SM). Three parameters are listed as input signals; four variant measures are outputted from VM module, six probability measurements are created from variant measures by Probability Measurement (PM), under the Selection Mechanism (SM) module, a set of triples interactive projections selected.

Input Group:

V A symbol is selected from four types of transformations $\{\perp, +, -, \mathrm{T}\}$,

N An integer indicates the number of elements in an input vector,

A 0-1 data vector

Intermediate Group:

$VM(R^V)$ A set of four variant measures,

$PM(P^V)$ A set of four probability vectors

Output Group:

$U \subset V$ A set of three interactive projections under the SM condition, $U \subset V$

$PM(P^U)$ A set of three probability vectors

Variant Measure (VM)

Considering the transformation of every bit between input sequence $\{X_i\}_{i=0}^{N-1}$ and output sequence $\{Y_i\}_{i=0}^{N-1}$, there are a total of 4 types of transformations: 0→0, 0→1, 1→0, and 1→1. (Jeffrey & Christian 2006).

Define the variant representation as follows.

$$V = \begin{cases} \perp, X_i = 0, Y_i = 0; \\ +, X_i = 0, Y_i = 1; \\ -, X_i = 1, Y_i = 0; \\ \mathrm{T}, X_i = 1, Y_i = 1; \end{cases} \quad 0 \le i < N,\ X_i, Y_i \in B_2$$

For any N bit 0-1 vector *X*, $X = X_0 X_1 ... X_i ... X_{N-1} X_N, 0 \le i < N, X_i \in B_2, X \in B_2^N$ under 2-variable function *f*, N bit 0-1 output vector *Y*, $Y = Y_0 Y_1 ... Y_i ... Y_{N-1} Y_N, 0 \le i < N, Y_i \in B_2, Y \in B_2^N$. Let Δ be the variant measure function.

$$\Delta(X \to Y) = \sum_{i=0}^{N-1} \Delta(X_i \to Y_i) = \langle R_\perp, R_+, R_-, R_\top \rangle, N = R_\perp + R_+ + R_- + R_\top, R_0 = R_\perp + R_+, R_1 = R_- + R_\top$$

Example

E.g. N=13, *Y* =*f* (X).

X = 1 0 0 1 0 1 1 1 0 0 1 0 1

Y = 0 0 1 0 1 1 0 1 0 1 1 0 0

$\Delta(X \to Y)$= − ⊥ + − + ⊤ − ⊤ ⊥ + ⊤ −

$\langle R_\perp, R_+, R_-, R_\top \rangle = \langle 3, 3, 4, 3 \rangle, R_0 = 6, R_1 = 7, N = 13$

Input and output pairs are 0-1 variables for only four combinations. For any given function, the quantitative relationship of {□,+,−,⊤} is directly derived from the input/output sequences. Four meta measures are determined (Jeffrey, Christian & Tosiyasu).

Input Group:

V A symbol is selected from four types of transformations {⊥, +, −, T},

N An integer indicates the number of elements in an input vector,
A 0-1 data vector

Output Group:

$VM(R^V)$ A set of four variant measures,

R_0 An integer indicates the number of 0 in an input vector,

R_1 An integer indicates the number of 1 in an input vector

Probability Measurement (PM)

Variant measure parameters and other three parameters are listed as input signals; the output of probability signals is calculated as 8 measurements in two groups by following the given equations.

The first group of probability signal vectors ρ is called non-unified model and defined as follows.

$$\begin{cases} \rho = \frac{R^V}{N} = \langle R_\perp, R_+, R_-, R_\top \rangle \\ \rho_\alpha = \frac{R_\alpha}{N}, \alpha \in \{\perp, +, -, \top\} \end{cases} \quad \& \quad \begin{cases} \rho_0 = \frac{R_0}{N} \\ \rho_1 = \frac{R_1}{N} \end{cases}$$

The second group of probability signal vectors $\tilde{\rho}$ is called unified model and defined as follows.

$$\begin{cases} \tilde{\rho} = \frac{R^V}{R_0 | R_1} = \langle R_\perp, R_+, R_-, R_\top \rangle \\ \rho_\alpha = \frac{R_\alpha}{R_0}, \alpha \in \{\perp, +\} \\ \rho_\beta = \frac{R_\beta}{R_1}, \beta \in \{-, \top\} \end{cases} \quad \& \quad \begin{cases} \rho_0 = \frac{R_0}{N} \\ \rho_1 = \frac{R_1}{N} \end{cases}$$

Under such condition, the output signals of the PM module can be expressed as a pair of probability vectors in quaternion forms $PM(P^V) = \{\rho, \tilde{\rho}\}$.

Input Group:

V A symbol is selected from four types of transformations {⊥, +, −, T},

N An integer indicates the number of elements in an input vector,

$VM(R^V)$ A set of four variant measures,

R_0 An integer indicates the number of 0 in an input vector,
R_1 An integer indicates the number of 1 in an input vector

Output Group:

$PM(P^V)$ A set of four probability vectors

Selection Mechanism Module

The SM Module is proposed two models: Non-unified Model and Unified Model. Under different constructions, two models are established respectively as follows.

Non-unified Model

Selecting two measurements from 4 combinations $\{\rho_{\perp}, \rho_{+}, \rho_{-}, \rho_{\mathrm{T}}\}$, there will be C_4^2 choices. And then selecting one measurement from 2 combinations $\{\rho_0, \rho_1\}$, there will be C_2^1 choices. A 3-tuples S is defined as follows.

$$\begin{cases} S = (\rho_\alpha, \rho_\beta, \rho_\gamma) \\ S = (\rho_\beta, \rho_\alpha, \rho_\gamma) \\ S = S \end{cases}, \quad \alpha, \beta \in V, \gamma \in \{0,1\}, \alpha \neq \beta$$

Unified Model

Selecting two measurements from 4 combinations $\{\tilde{\rho}_{\perp}, \tilde{\rho}_{+}, \tilde{\rho}_{-}, \tilde{\rho}_{\mathrm{T}}\}$, there will be C_4^2 choices. And then selecting one measurement from 2 combinations $\{\tilde{\rho}_0, \tilde{\rho}_1\}$, there will be C_4^2 choices. A 3-tuples $\tilde{S}$ is defined as follows.

$$\begin{cases} \tilde{S} = (\tilde{\rho}_\alpha, \tilde{\rho}_\beta, \tilde{\rho}_\gamma) \\ \widetilde{S} = (\tilde{\rho}_\beta, \tilde{\rho}_\alpha, \tilde{\rho}_\gamma) \\ \tilde{S} = \widetilde{S} \end{cases}, \quad \alpha, \beta \in V, \gamma \in \{0,1\}, \alpha \neq \beta$$

Under such condition, the output signals of the SM module can be expressed as a 3D visual model in 3-tuples forms S or $\tilde{S}$. Specifically ρ_α or $\tilde{\rho}_\alpha$ determines the value of X-axis, ρ_β or $\tilde{\rho}_\beta$ determines the value of Y-axis, and ρ_γ or $\tilde{\rho}_\gamma$ determines the value of Z-axis.

Input Group:

$PM(P^V)$ A set of four probability vectors

Output Group:

$U \subset V$ A set of three interactive projections under the SM condition, $U \subset V$
$PM(P^U)$ A set of three probability vectors

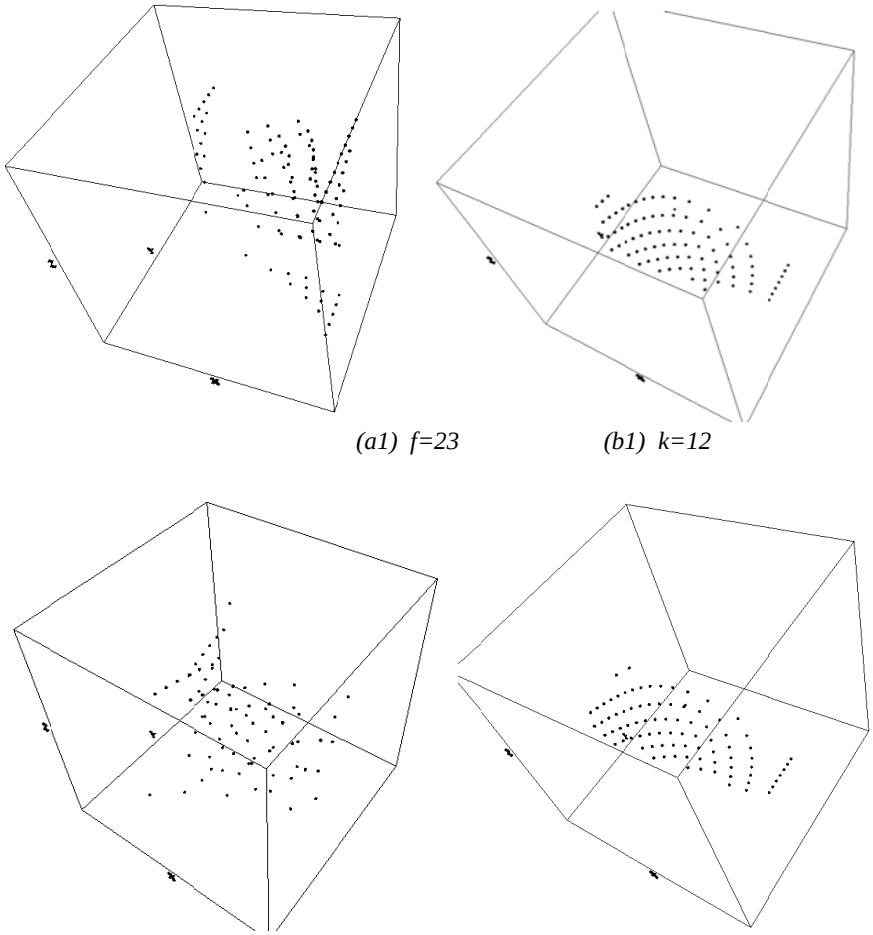
Visualization Model

Using visual model, *all possible measurements are calculated exhaustively on all G-1 vectors. Each 3-tuple* can be drawn as a point in 3-dimensional space (*xyz*-space). All G-1 points are constructed the phase space for the selected keys.

SAMPLE RESULTS ON 3D MAPS

In this section, two types of data sets are selected to illustrate their differences on 3D maps for comparison. The first type of data sets is generated by CA. The second type of data sets is generated by RC4.

Visualization Results of Unified Model



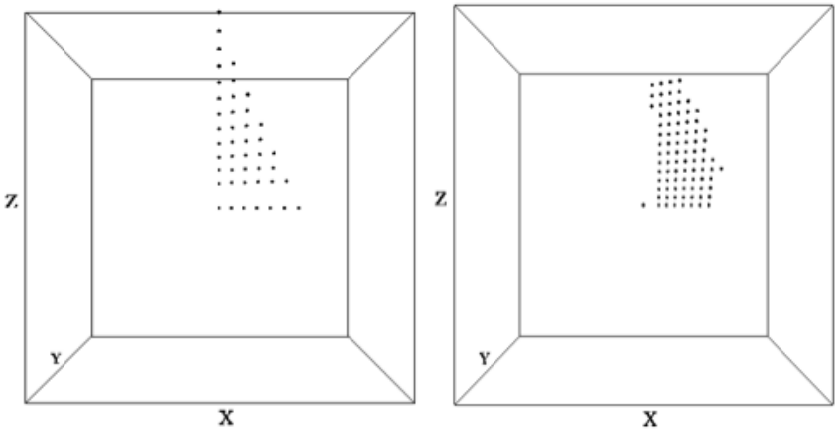
(a1) f=23 *(b1) k=12*

(a2) f=90 *(b2) k=88*

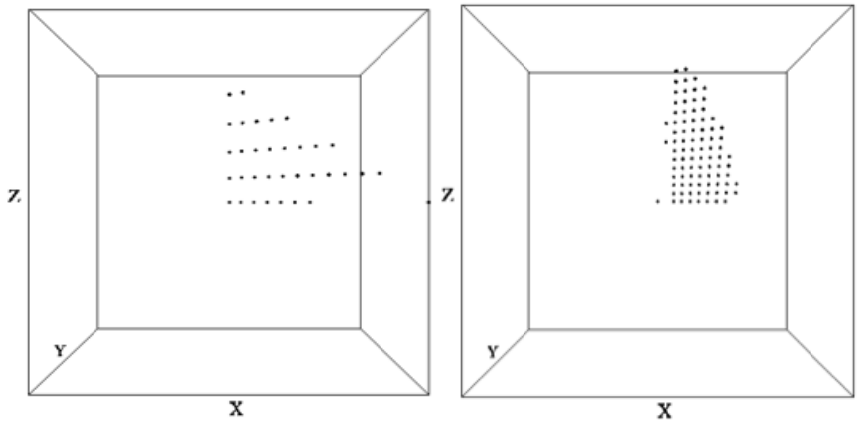
(a3) f=253 *(b3) k=155*

Figure 2. Two sets of six 3D maps based on unified model in different condition; (a1~a3) for the file CA; (b1~b3) for the file RC4

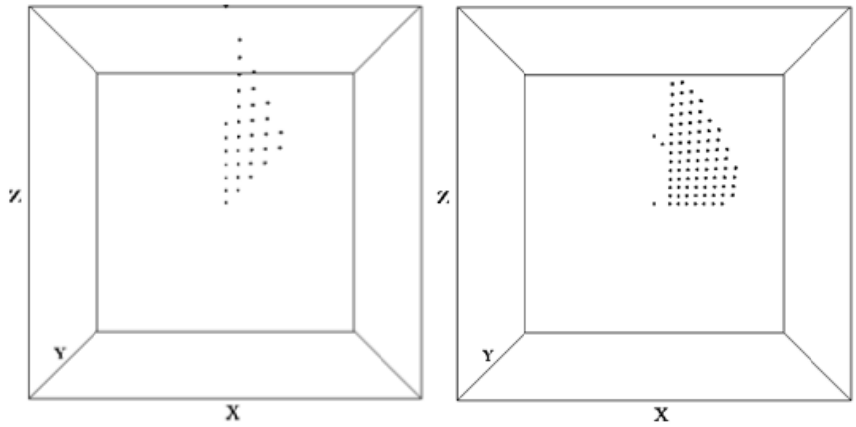
Visualization Results of Non-Unified Model



(a1) f=23 *(b1) k=12*



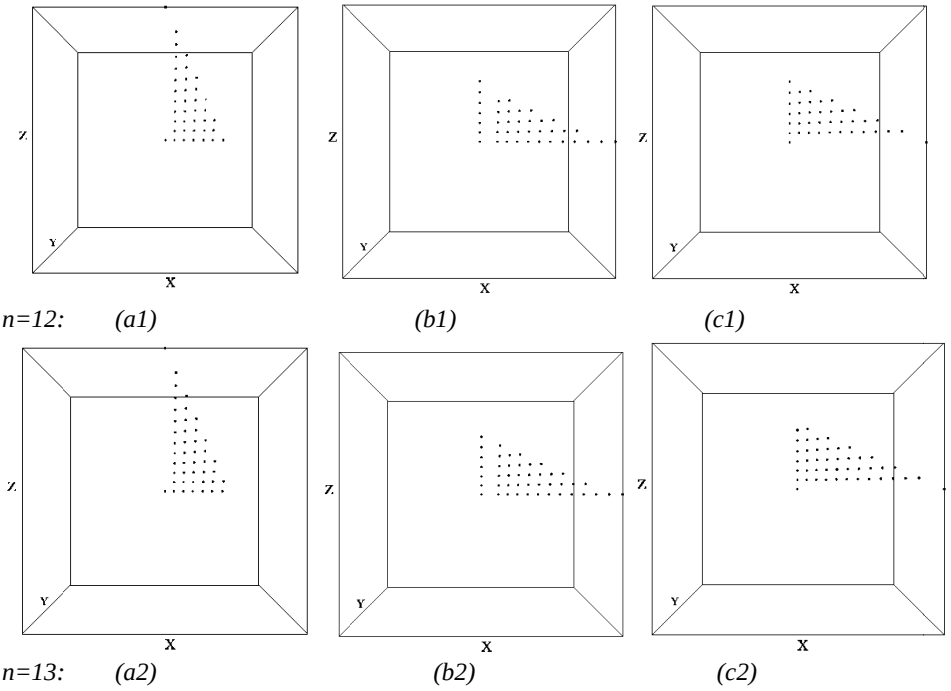
(a2) f=90 *(b2) k=88*



(a3) f=253 *(b3) k=155*

Figure 3. Two sets of six 3D maps based on non-unified model in different condition; (a1~a3) for the file CA; (b1~b3) for the file RC4

Visualization Results of CA With Different Length of Initial Sequence



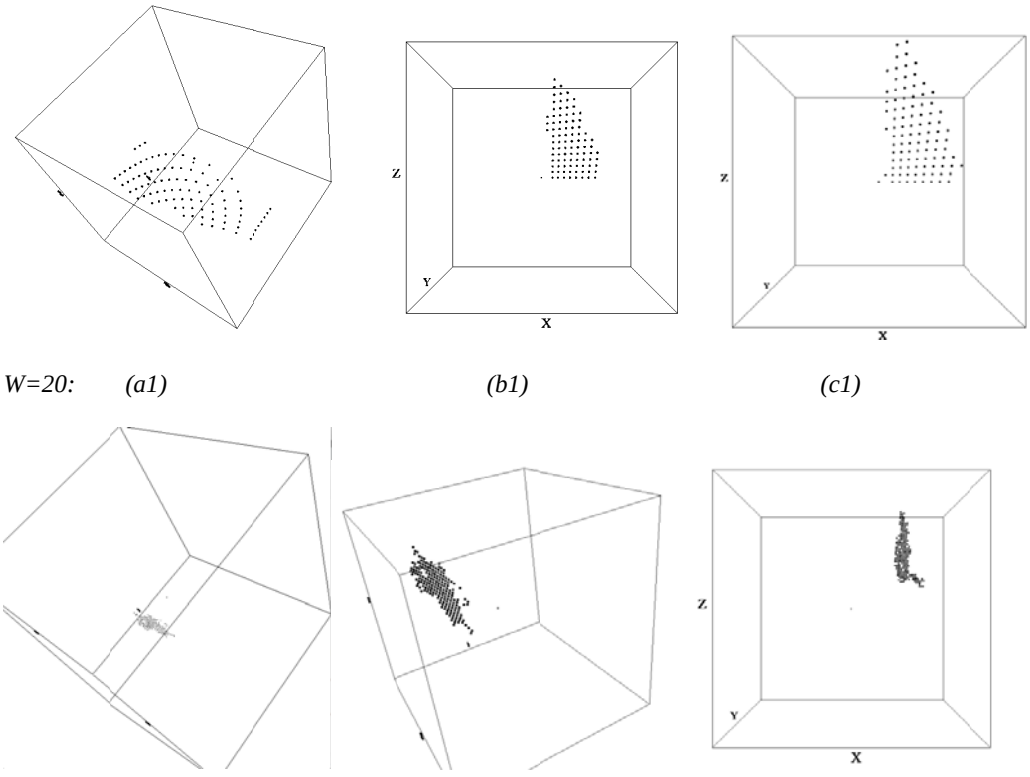
n=12: (a1) (b1) (c1)

n=13: (a2) (b2) (c2)

Figure 4. Three sets of nine 3D maps under different condition;

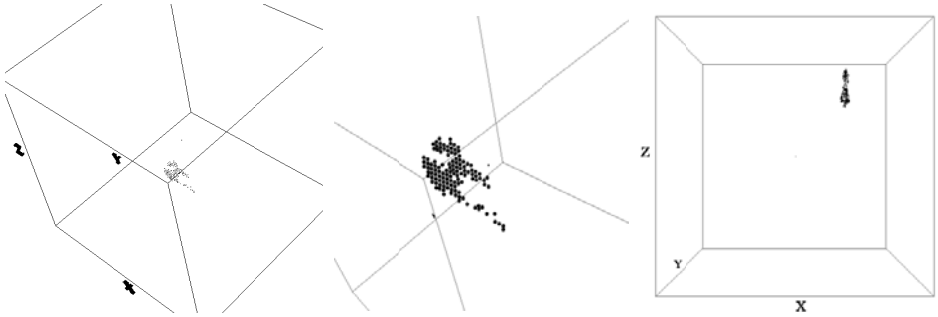
(a1~a2) for the logic function f=15 and non-unified model; (b1~b2) for the logic function f=100 and non-unified model;(c1~c2)for the logic function f=170 and non-unified model

Visualization Results of RC4 Keystream With Different Segment Strategies



W=20: (a1) (b1) (c1)

W=128: *(a2)* *(b2)* *(c2)*



W=256: *(a3)* *(b3)* *(c3)*

Figure 5. Three sets of nine 3D maps under different condition;
(a1~a3) for the key=90 and unified model; (b1~b3) for the key=90 and non-unified model;
(c1~c3)for the key=123 and non-unified model

ANALYSIS OF RESULTS

The above twenty-seven 3D maps contain different information. Some important conclusions will be discussed in detail in this section.

The first group of results shown in Figure 2 presents two sets of six 3D maps constructed by unified model from two data files: CA and RC4 to illustrate their 3D spatial characteristics. Three 3D maps of each group in Figure 2(a1~a3) show 3D spatial characteristics of CA with different logic functions. In this group, No. 23, 90, 253 functions are selected as examples to compare each other. And three 3D maps of each group in Figure 2(b1~b3) show 3D spatial characteristics of RC4 with 20 bits of every segment and different given keys. In this group, keys: 12, 88, 155 are selected as examples to compare each other. From a distribution viewpoint, different logic function can be distinguished by their three-dimensional spatial characteristics from CA files e.g. (a1~a3). Different from CA, for RC4 keystream all spatial distributions are always in a plane e.g. (b1~b3).

The second group of results shown in Figure 3 presents two sets of six 3D maps constructed by non-unified model. It is interesting to observe all maps (no mater CA data files or RC4 keystream data files) are planar distribution e.g. (a1~a3) and (b1~b3).

The third group of results shown in Figure 4 presents three sets of six 3D maps constructed by non-unified model from CA data files with different length of the initial sequence and given logic functions. In Figure 4 (a1~a2) show 3D maps for the No.15 function, (b1~b2) show 3D maps for the No.100 function, and (c1~c2) show 3D maps for the No.170 function. The overall relationship of multiple-variable logic functions for spatial characteristics can be shown clearly. For example, under the non-unified model, No matter what logic functions are, all spatial distributions are always in a plane e.g. (a1~a2), (b1~b2) and (c1~c2). Different length of initial sequence (n=12, 13) has different spatial characteristics distribution with the same given logic function e.g. (a1~a2), (b1~b2) and (c1~c2).

The forth group of results shown in Figure 5 presents three sets of nine 3D maps for the different conditions including segments strategies and keys. In this group, three types of segment strategies

(W=20, 128, 256) are proposed to compare. To observe conveniently, combinations of three set with the same key e.g. (a1~a3), (b1~b3) and (c1~c3). The dispersity of points increased with the reducing of the bit-length of each segment. Obviously, the spatial distribution of points with 256 bits of each segment are more concentrated than the distribution of points with 20 bits, as shown in (a1-a2), (b1-b2) and (c1-c2). 3D map shows the some commonalities of spatial distribution of different keys and different segment strategies. Firstly, under this construction, different keys can be distinguished by their three-dimensional spatial characteristics in the model e.g. (b1-c1), (b2-c2) and (b3-c3).

Secondly, No matter what keys or segment strategies are, all spatial distributions are always in a plane. Thirdly, the distribution features are varying from key to key and segment strategy to segment strategy.

CONCLUSION

Both the similarities and the differences may indicate those maps with comparable mechanism to express keystream with different given key and in their high levels of relationships applying to the Stream Cipher mechanism. Spatial property of random sequence can be detected from the distribution of cluster point in the 3D maps discussed in details. Different spatial distributions are illustrated to show various distributions on each phase space for relevant logic function or keystream. For example no matter what keys or segment strategies are, all spatial distribution is always in a pane. And all maps (no mater CA data files or RC4 keystream data files) are planar distribution under non-unified model. Spatial distribution properties like this provide useful information for further exploring RC4 stream cipher. This construction could provide remarkable insights to spatial information on stream cipher construction via 3D maps. Further explorations are required on this scheme.

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