Hindawi Publishing Corporation
Mathematical Problems in Engineering
Volume 2013, Article ID 685725, 7 pages
http://dx.doi.org/10.1155/2013/685725

Research Article

Synchronization Analysis of Four Symbolic Complex Dynamical Systems for Future Biology Research

Yagang Zhang,[1,2] Zheng Zhao,[2] and Yi Sun[3]

[1] *Department of Mathematics and Physics, North China Electric Power University, Baoding, Hebei 071003, China*
[2] *State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, NCEPU, Beijing 102206, China*
[3] *Hebei Electric Power Research Institute, Shijiazhuang 050022, China*

Correspondence should be addressed to Yagang Zhang; yagangzhang@gmail.com

Received 22 June 2013; Accepted 2 July 2013

Academic Editor: Dumitru Baleanu

The synchronization analysis of four symbolic complex dynamical systems will be discussed carefully in this paper. Grey system theory is mainly being used to study data sequences that are generated by 4-letter chaotic dynamical system, and the usual prediction accuracy has exceeded 90%. In this place we have found a generating rule that may at least realize chaotic synchronization in short and medium terms. Considering the current study of DNA base sequences A-G-C-T and the symbolic characteristic of four symbolic dynamical systems, which are formally in good corresponding relation. In this paper we have offered an effective research means to approach problems of this kind.

1. Introduction

The problems on uncertainty exist commonly in nature: the ones in myriad sample can be resolved by probability and statistics ways, the ones in recognizing uncertainty can be dealt with by fuzzy mathematics. However, there also exists another kind of uncertainty in less data, little samples, incomplete information, and devoid of experience, which is just suitable to be dealt with by grey system theory [1]. A system with both partially known information and certain unknown information can be defined as a grey system. That is to say, grey system is the system that lacks information, such as architecture, parameters, operation mechanism, and system behavior. Therefore, the key problem is how to make use of the finite available information to approximate the system dynamical behaviors [2].

Grey system theory mainly includes the theoretical system based on grey algebra system, grey equation, and grey matrix; the methodology system based on grey sequence generation; the analysis system based on grey correlation space; the grey-model-centered modeling system; and the technical system based on system analysis, evaluation, modeling, prediction and decision, and control and optimization. Since there is not any certain physical model in many social and economic issues, it is quite difficult to specify all the factors, not to mention establishing definite mapping relations, though some influence factors are known. For instance, those factors that affect prices, such as psychological expectation and government orientation, are immeasurable. While some data are measurable yet short of detailed information. If the available data alone are taken into consideration, the analysis outcome will surely be inaccurate. Grey system theory can generate new data sequences which indicate the variation trend of the original data and eliminate the fluctuation as well. Grey system theory can also solve some complex system issues with unknown parameters. The applications of grey system theory lie in many scientific fields, such as agriculture, industry, energy, traffic, petroleum, geology, meteorology, hydrology, ecology, environment, medicine, military affairs, economy, and society, which succeeds in solving good many practical problems in production and daily life.

As early as in 1947, Ulam and Neumann studied the densities distribution [3] of surjective parabolic maps' orbital point $\{x_i\}_{i=0}^{\infty}$ and got famous Chebyshev distribution. The study of chaotic symbolic sequences is gradually developing in theory. However, the applied research of stochastic chaotic sequences has not been fully carried out, for most of studies focus on controlling or avoiding chaos. Chaos, nevertheless, affords inherent stochastic properties that can be calculated, which is an important applied domain. The stochastic symbolic sequences bear the following three features. First, computer can generate them iteratively. Secondly, like false stochastic numbers, they can set up a stochastic sequence simulation (in contradiction, they are based on corresponding symbolic spaces). Thirdly, they can produce numerous symbolic spaces, which is not a characteristic of common stochastic numbers. Therefore, the symbolic dynamics [4–8] developed by this means are supposed to be very useful. We are familiar with two symbolic sequences and have clarified the inherent randomicity in 4 symbolic dynamics [9], the knot theory based on the minimal braid in Lorenz system [10]. In this paper, we are mainly using grey system theory to study the chaotic synchronization of four symbolic complex dynamical systems.

This paper is organized as follows. In Section 2, grey system theory is introduced. In Section 3, the symbolic dynamics of 4-letter surjective map are exhibited. In Section 4, synchronization analysis of 4-letter chaotic dynamical system based on grey system theory is clarified in detail.

2. Grey System Theory

Grey system theory provides an approach to investigate the relationships of input-output process with unclear inner relationships, uncertain mechanisms, and insufficient information. It deals directly with the original data and searches the intrinsic regularity of the data rather than using statistical method. In the grey system theory, grey relational analysis and grey prediction model account for the essential parts [11, 12]. The grey prediction model uses grey differential models to generate data series from the original data series of a dynamical system. And the data series generated by the grey prediction model are converted back to the original data series by a reverse procedure to predict the performance of the dynamical system. Grey prediction can reveal underlying rules within a random time sequence via a special data processing. Now it has been successfully used to model the dynamical systems in different fields, such as agriculture, ecology, economy, statistics, meteorology, and industry [13, 14].

The grey models have many different forms [15] that mainly include

$$
\begin{gathered}
x^{(0)}(k)+ax^{(1)}(k)=b,\\
x^{(0)}(k)+az^{(1)}(k)=b,\\
\frac{dx^{(1)}}{dt}+ax^{(1)}=b,\\
\widehat{x}^{(1)}(k+1)=\left(x^{(0)}(1)-\frac{b}{a}\right)e^{-ak}+\frac{b}{a},\\
\widehat{x}^{(0)}(k+1)=\widehat{x}^{(1)}(k+1)-\widehat{x}^{(1)}(k),\\
\widehat{x}^{(0)}(k)=\beta-\alpha x^{(1)}(k-1),\\
\left(k=2,3,\ldots,n,\ \beta=\frac{b}{1+0.5a},\ \alpha=\frac{a}{1+0.5a}\right),\\
\widehat{x}^{(0)}(2)=\beta-\alpha x^{(0)}(1),\\
\widehat{x}^{(0)}(k)=(1-\alpha)x^{(0)}(k-1),\quad (k=3,4,\ldots,n),\\
\widehat{x}^{(0)}(2)=\beta-\alpha x^{(0)}(1),\\
\widehat{x}^{(0)}(k)=\frac{1-0.5a}{1+0.5a}x^{(0)}(k-1),\quad (k=3,4,\ldots,n),\\
\widehat{x}^{(0)}(2)=\beta-\alpha x^{(0)}(1),\\
\widehat{x}^{(0)}(k)=\frac{x^{(1)}(k-1)-0.5b}{x^{(1)}(k-2)+0.5b}x^{(0)}(k-1),\quad (k=3,4,\ldots,n),\\
\widehat{x}^{(0)}(k)=\left(\frac{1-0.5a}{1+0.5a}\right)^{k-2}\left(\frac{b-ax^{(0)}(1)}{1+0.5a}\right),\\
(k=2,3,\ldots,n),\\
\widehat{x}^{(0)}(k)=\frac{1}{(1-a)^{3}}x^{(0)}(3)e^{k\ln(1-a)},\quad (k=4,5,\ldots,n),\\
\widehat{x}^{(0)}(k)=\left(\beta-\alpha x^{(0)}(1)\right)e^{-a(k-2)},\quad (k=3,4,\ldots,n),\\
\widehat{x}^{(0)}(k)=\left(1-e^{a}\right)\left(x^{(0)}(1)-\frac{b}{a}\right)e^{-a(k-1)},\\
(k=2,3,\ldots,n),\\
\widehat{x}^{(0)}(k)=(-a)\left(x^{(0)}(1)-\frac{b}{a}\right)e^{-a(k-1)},\quad (k=2,3,\ldots,n).
\end{gathered}
\tag{1}
$$

One of the most important properties of chaotic system is *sensitivity to initial conditions*. Sensitivity to initial conditions means that an arbitrarily small perturbation of current trajectory may lead to significantly different future behavior. As a result of sensitivity, two different trajectories tend to depart exponentially with time. The behavior of chaotic systems appears to be random.

One of the primary motivations of our research is designed to discuss the corresponding relationships between the exponential separate characteristic in chaotic system and the exponential increasing law of grey prediction. For example, let us choose logistic equation as a model, which has been studied extensively in nonlinear system. One of its equivalent forms can be expressed as

$$
x_{n+1}=F(\mu,x_n)=1-\mu x_n^2, \tag{2}
$$

hereinto, x_n is defined on interval $[-1,1]$ and $\mu\in(0,2]$. Its bifurcation diagram is well known: see Figure 1.

Let us adopt unimodal surjective map as $\mu=2$ to get chaotic iterative sequences, namely,

$$
x_{n+1}=f(x_n)=1-2x_n^2. \tag{3}
$$

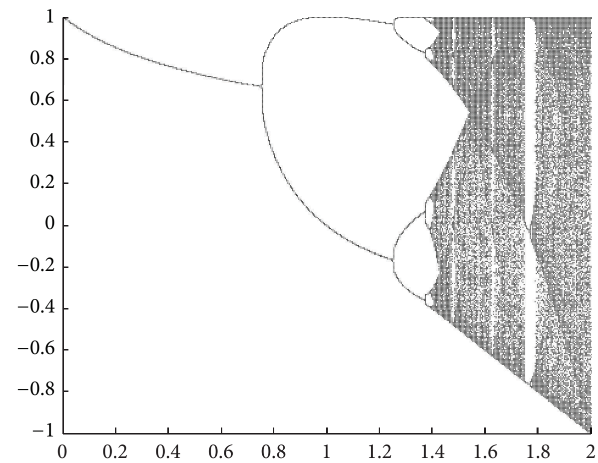

Figure 1: The bifurcation diagram of logistic map.

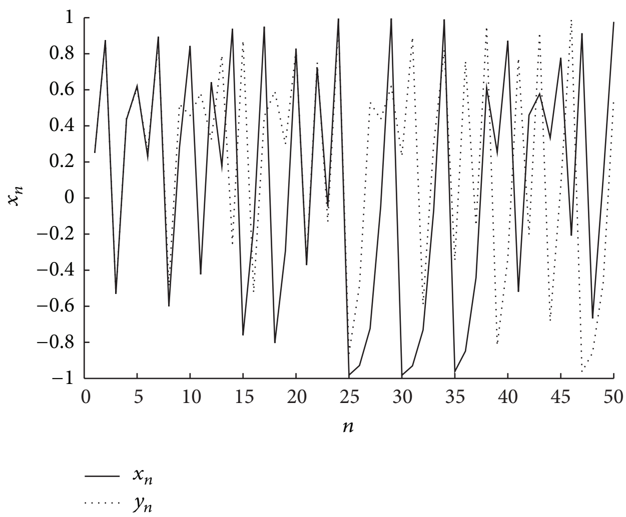

Figure 2: The exponential separate diagram of logistic map. (In this diagram, the solid line represents $f(x_n)$ and the dotted line represents $g(y_n)$).

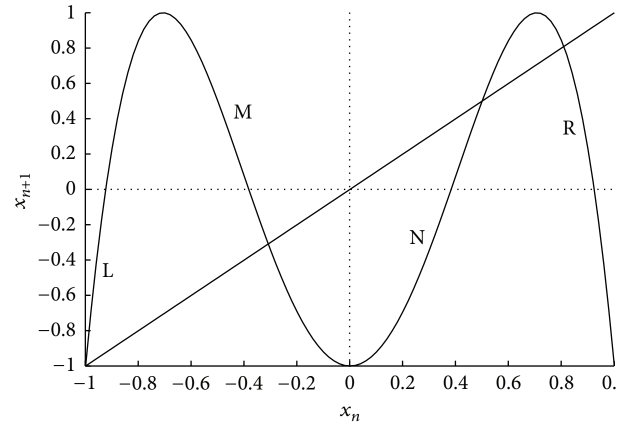

Figure 3: The shape of 4-letter surjective map $x_{n+1} = -8x_n^4 + 8x_n^2 - 1$; four monotonic embranchments are marked by L, M, N, and R.

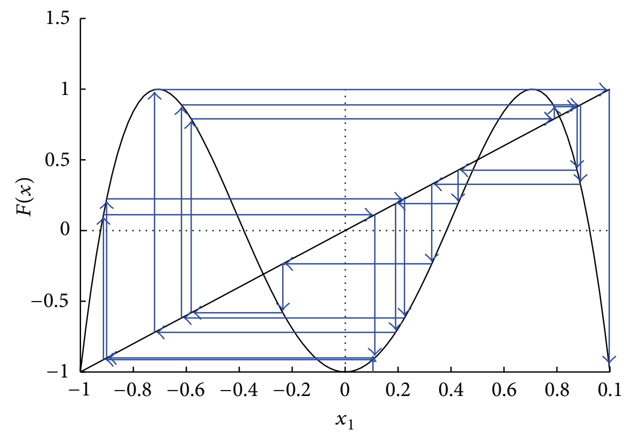

Figure 4: 16 iterations of 4-letter surjective map ($x_1 = 0.105$).

Given initial values $x_1 = 0.25$, $y_1 = 0.25 + 0.001$, after 50 iterations, we can get the sequences of $f(x_n)$ and $g(y_n)$ ($n = 2, 3, 4, \ldots$); see Figure 2 and Table 1.

According to Figure 2 and Table 1, it is not difficult to find some differences. Although the iterative original value only has a small deviation 0.001, during the iterative process, a remarkable change begins at the 7th step. Until at the 10th step, it has been very difficult to find that these two sequences came from small deviation original value. Classical researches have proved that these two trajectories generated from two adjacent original values will depart exponentially with time evolution. It is an important measure of the exponential separate characteristic in chaotic system that calculates Lyapunov exponent:

$$\lambda = \lim_{n\to\infty} \frac{1}{n} \sum_{i=0}^{n-1} \ln \left| \frac{dF(x)}{dx} \right|_{x=x_i}. \quad (4)$$

3. Symbolic Dynamics of 4-Letter Surjective Map

The generic iterative form of 4-letter surjective map is

$$x_{n+1} = F(A, x_n) = -8x_n^4 + 8x_n^2 - 1. \quad (5)$$

The shape of 4-letter surjective map is shown in Figure 3.

4. Synchronization Analysis of 4-Letter Chaotic System Based on Grey System Theory

4.1. Iterative Process of 4-Letter Chaotic System. The general dynamical iterative form of 4-letter surjective map is expressed in (5). Given an initial value $x_1 = 0.105$, the number of iterations is $n = 16$ and one can obtain Tables 2 and 3. Figure 4 is the concrete iterative process.

Let us transform these iterative values. First, each $F(x_n)$ is made as absolute value transformation. Then, let us carry out cumulative sum $Z(x_k) = \sum_{i=1}^{k} |F(x_i)|$ and get Tables 4 and 5.

Table 1: The exponential separate sequences of logistic map ($n = 2, 3, 4, \ldots$).

n	2	3	4	5	6	7	8	9
$f(x_n)$	0.8750	−0.5313	0.4355	0.6206	0.2297	0.8945	−0.6001	0.2797
$g(y_n)$	0.8740	−0.5277	0.4430	0.6076	0.2618	0.8630	−0.4894	0.5209
n	10	11	12	13	14	15	16	17
$f(x_n)$	0.8435	−0.4231	0.6421	0.1755	0.9384	−0.7611	−0.1585	0.9498
$g(y_n)$	0.4573	0.5818	0.3231	0.7912	−0.2521	0.8728	−0.5237	0.4515
n	18	19	20	21	22	23	24	25
$f(x_n)$	−0.8041	−0.2931	0.8281	−0.3717	0.7237	−0.0476	0.9955	−0.9819
$g(y_n)$	0.5924	0.2982	0.8221	−0.3517	0.7526	−0.1328	0.9647	−0.8615
n	26	27	28	29	30	31	32	33
$f(x_n)$	−0.9283	−0.7235	−0.0469	0.9956	−0.9824	−0.9304	−0.7313	—
$g(y_n)$	−0.4843	0.5310	0.4361	0.6196	0.2322	0.8921	−0.5918	—

Table 2: The iterative values of 4-letter chaotic system ($n = 1, 2, \ldots, 8$).

n	1	2	3	4	5	6	7	8
x_n	0.1050	−0.9128	0.1121	−0.9008	0.2242	−0.6182	0.8888	0.3272
$F(x_n)$	−0.9128	0.1121	−0.9008	0.2242	−0.6182	0.8888	0.3272	−0.2354

Table 3: The iterative values of 4-letter chaotic system ($n = 9, 10, \ldots, 16$).

n	9	10	11	12	13	14	15	16
x_n	−0.2354	−0.5814	0.7902	0.8762	0.4265	0.1906	−0.7199	0.9973
$F(x_n)$	−0.5814	0.7902	0.8762	0.4265	0.1906	−0.7199	0.9973	−0.9579

Table 4: The cumulative sum results of $Z(x_k)$ ($k = 1, 2, \ldots, 8$).

k	1	2	3	4	5	6	7	8
$Z(x_k)$	0.9128	1.0248	1.9256	2.1498	2.7680	3.6568	3.9840	4.2193

Table 5: The cumulative sum results of $Z(x_k)$ ($k = 9, 10, \ldots, 16$).

k	9	10	11	12	13	14	15	16
$Z(x_k)$	4.8007	5.5909	6.4671	6.8936	7.0843	7.8041	8.8015	9.7593

4.2. Random Generating Sequence's Grey Prediction of 4-Letter Chaotic System. In the grey system theory, the expression of accumulated generating operator (AGO) is $x^{(1)}(k) = \sum_{m=1}^{k} x^{(0)}(m)$, and so one gets Table 6.

The formula of grey estimate value is

$$\text{Estim.} = \left[x^{(1)}(0) - \frac{u}{a}\right] \times e^{-at} \times \left(1 - e^{a}\right), \tag{6}$$

thereinto, $x^{(1)}(0) = 0.9128$, $a = -0.11155$, $u = 1.95557$, and $t = 1, 2, 3, \ldots$, namely,

$$\text{Estim.} = 18.4437 \times e^{0.11155t} \times \left(1 - e^{-0.11155}\right). \tag{7}$$

So, the prediction values and corresponding error of 16 iterations can be calculated (see Table 7).

Figure 5 shows the actual values and the prediction values of 16 iterations.

Here are grey prediction results of the following 3 steps:

$$\begin{aligned} k &= 17: \text{Estim. value} = 11.60, \\ k &= 18: \text{Estim. value} = 12.97, \\ k &= 19: \text{Estim. value} = 14.50. \end{aligned} \tag{8}$$

It will be intuitionistic and natural to return these grey prediction results to actual symbolic space. Combining the exact position of peak and trough, the value of positive or negative can be confirmed.

Now let us present a research example.

Example 1. According to a group of DNA based sequences "CCGGGGTCGCGCGGCA", which double helix structure has been presented in Figure 6. Of course, the DNA based sequences have perfect matchings. In our researches, the dynamical matching rules of four symbolic dynamical

Table 6: Main variable values of grey prediction process.

k	$Z(x_k)$	AGO	AGO mean	Mean square	Mean AGO	Mean square AGO	Mean AGO square
1	0.9128	0.9128	*	*	*	*	*
2	1.0248	1.9376	1.4252	2.0312	1.4252	2.0312	2.0312
3	1.9256	3.8632	2.9004	8.4123	4.3256	10.4435	18.7108
4	2.1498	6.0130	4.9381	24.3848	9.2637	34.8283	85.8161
5	2.7680	8.7810	7.3970	54.7156	16.6607	89.5440	277.5789
6	3.6568	12.4378	10.6094	112.5594	27.2701	202.1033	743.6584
7	3.9840	16.4218	14.4298	208.2191	41.6999	410.3225	1738.882
8	4.2193	20.6411	18.5315	343.4146	60.2314	753.7371	3627.816
9	4.8007	25.4418	23.0415	530.9084	83.2728	1284.6455	6934.359
10	5.5909	31.0327	28.2373	797.3423	111.5101	2081.9878	12434.49
11	6.4671	37.4998	34.2663	1174.176	145.7763	3256.1637	21250.73
12	6.8936	44.3934	40.9466	1676.624	186.7229	4932.7877	34865.44
13	7.0843	51.4777	47.9356	2297.817	234.6585	7230.6047	55064.59
14	7.8041	59.2818	55.3798	3066.917	290.0382	10297.5214	84122.16
15	8.8015	68.0833	63.6826	4055.467	353.7208	14352.9886	125118.4
16	9.7593	77.8426	72.9630	5323.592	426.6837	19676.5806	182059.0

Table 7: Prediction values and corresponding error of 16 iterations.

k	$Z(x_k)$ Actual value	$Z(x_k)$ Estimate value	Error	Relative error	Precision
1	0.9128	0.9128	0	0	100%
2	1.0248	2.18	−1.1552	−112.724%	−12.7244%
3	1.9256	2.43	−0.5044	−26.1944%	73.80557%
4	2.1498	2.72	−0.5702	−26.5234%	73.4766%
5	2.7680	3.04	−0.272	−9.82659%	90.17341%
6	3.6568	3.40	0.2568	7.022533%	92.97747%
7	3.9840	3.80	0.184	4.618474%	95.38153%
8	4.2193	4.25	−0.0307	−0.72761%	99.27239%
9	4.8007	4.75	0.0507	1.056096%	98.9439%
10	5.5909	5.31	0.2809	5.024236%	94.97576%
11	6.4671	5.94	0.5271	8.150485%	91.84952%
12	6.8936	6.64	0.2536	3.678775%	96.32123%
13	7.0843	7.42	−0.3357	−4.73865%	95.26135%
14	7.8041	8.30	−0.4959	−6.35435%	93.64565%
15	8.8015	9.28	−0.4785	−5.43657%	94.56343%
16	9.7593	10.38	−0.6207	−6.36009%	93.63991%

systems and DNA sequences are "L ↔ A, M ↔ G, N ↔ C, and R ↔ T". Based on the former synchronization analysis process and grey system theory, the prediction model can be expressed as

$$\text{Estim.} = 13.4428 \times e^{0.10910t} \times \left(1 - e^{-0.10910}\right). \tag{9}$$

The final four symbolic prediction results are "NNMMMMNNMNMNMMNL", and the corresponding DNA based sequences are "CCGGGGCCGCGCGGCA". Figure 7 represents the DNA prediction structure. To sum up the previous synchronization analysis results, the error rate is

$$\widehat{p}^* = \frac{1}{16} = 0.0625, \tag{10}$$

namely, the accuracy rate has reached 93.75% $(1 - \widehat{p}^*)$.

It should be stressed that the biological system is highly complex; we cannot look to one method or two methods to solve all problems. But at least, we have provided an interesting thought.

5. Conclusion and Discussion

The synchronization analysis of four symbolic complex dynamical systems has been clarified carefully in this paper. We are mainly using grey system theory to study data sequences that are generated by 4-letter chaotic dynamical system, and the usual prediction accuracy has exceeded 90%. In this place we have found a generating rule that may at least realize chaotic synchronization in short and medium terms.

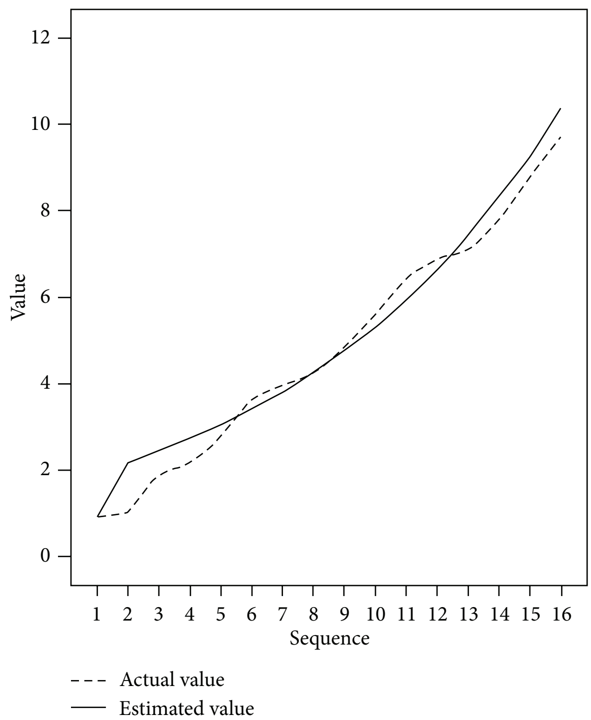

FIGURE 5: 16 iterations' actual values and prediction values of 4-letter chaotic system.

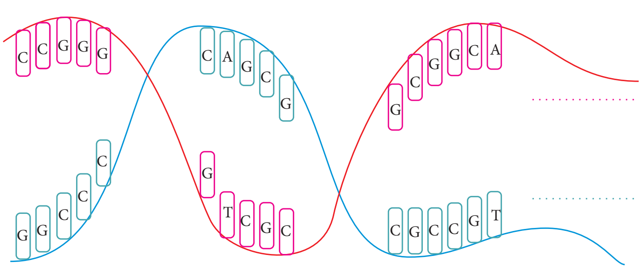

FIGURE 6: DNA double helix structure.

And in this way we can analyze and predict different kinds of complex systems.

The world is essentially nonlinear and highly complex. A small stochastic force is usually able to have an unexpected impact on deterministic equation, and in certain conditions, it could determine the evolution of systems and even change the fate of macroscopic system. Nonlinear dynamics theory, the combination of Newtonian mechanics and statistical mechanics method, linear stochastic equation and nonlinear deterministic equation, and periodic solution and chaotic solution have achieved the high inherent unity of determinacy and randomicity, determinism, and indeterminism. The change of weather, the growth of species, the diffusion of molecular, the fluctuation of electrocardiogram and electroencephalogram signals, the periodic reform of society, the growth, the sudden plunge, and even the collapse of stock markets all have inherent nonlinear dynamics rules [16]. The complexity of social economic system mainly lies in the dynamic evolution of multivariable system,

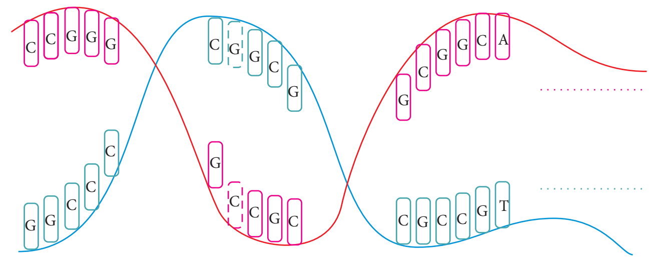

FIGURE 7: DNA prediction structure.

the incompleteness and uncertainty of social information. The multilevels of social economic system result in each level having its own structure composition. Each social unit, whether it is a whole unit or the smallest fundamental sector, is realizing its functions according to its structural property. The various randomicity and uncertainties in social system make it impossible to fully master the entire system information. Therefore, it has been the main task of nonlinear dynamics theory and grey system theory to analyze the complexity of social system in the conditions of incomplete information and uncertainty and to study the intrinsic laws of social development.

Considering the current study of DNA [17–25] based sequences A-G-C-T and the symbolic characteristic of four symbolic dynamical systems, which are formally in good corresponding relation. In this paper we have offered an effective research means. A part of our current work is studying certain properties of different kinds of data sequences, such as DNA based sequences, 20 amino acids symbolic sequences in proteid structures, and time series that can be symbolic in finance market. The grey system theory provides a set of effective methods to approach problems of this kind, which will open up a vast vista.

Acknowledgments

This research was supported partly by the NSFC (51277193), the Specialized Research Fund for the Doctoral Program of Higher Education (20110036110003), the Fundamental Research Funds for the Central Universities (11MG37, 12MS120), and the Natural Science Foundation of Hebei Province.

References

[1] J. L. Deng, *Basic Theory of Grey System*, Huazhong University of Science and Technology Press, Wuhan, China, 2002.

[2] S. F. Liu and Y. Lin, *Grey Information: Theory and Practical Applications*, Springer, London, UK, 2006.

[3] S. M. Ulam and J. V. Neumann, "On combination of stochastic and deterministic processes," *Bulletin of the American Mathematical Society*, vol. 53, no. 11, p. 1120, 1947.

[4] B.-L. Hao and W.-M. Zheng, *Applied Symbolic Dynamics and Chaos*, vol. 7 of *Directions in Chaos*, World Scientific, River Edge, NJ, USA, 1998.

[5] K.-F. Cao, X.-S. Zhang, Z. Zhou, and S.-L. Peng, "Devil's carpet of topological entropy and complexity of global dynamical

behavior," *Chaos, Solitons & Fractals*, vol. 16, no. 5, pp. 709–726, 2003.

[6] S.-L. Peng, K.-F. Cao, and Z.-X. Chen, "Devil's staircase of topological entropy and global metric regularity," *Physics Letters A*, vol. 193, no. 5-6, pp. 437–443, 1994.

[7] Q. Liu, K.-F. Cao, and S.-L. Peng, "A generalized Kolmogorov-Sinai-like entropy under Markov shifts in symbolic dynamics," *Physica A*, vol. 388, no. 20, pp. 4333–4344, 2009.

[8] K. Wang, W. Pei, X. Hou, Y. Shen, and Z. He, "Symbolic dynamics approach to parameter estimation without initial value," *Physics Letters A*, vol. 374, no. 1, pp. 44–49, 2009.

[9] Y. Zhang, C. Wang, and Z. Zhou, "Inherent randomicity in 4-symbolic dynamics," *Chaos, Solitons & Fractals*, vol. 28, no. 1, pp. 236–243, 2006.

[10] Y. Zhang and Z. Wang, "Knot theory based on the minimal braid in Lorenz system," *International Journal of Theoretical Physics*, vol. 47, no. 4, pp. 873–880, 2008.

[11] H. V. Trivedi and J. K. Singh, "Application of grey system theory in the development of a runoff prediction model," *Biosystems Engineering*, vol. 92, no. 4, pp. 521–526, 2005.

[12] S. He, Y. Li, and R. Z. Wang, "A new approach to performance analysis of ejector refrigeration system using grey system theory," *Applied Thermal Engineering*, vol. 29, no. 8-9, pp. 1592–1597, 2009.

[13] L.-C. Hsu and C.-H. Wang, "Forecasting integrated circuit output using multivariate grey model and grey relational analysis," *Expert Systems with Applications*, vol. 36, no. 2, pp. 1403–1409, 2009.

[14] L. Wei, M. Fei, and H. Hu, "Modeling and stability analysis of grey-fuzzy predictive control," *Neurocomputing*, vol. 72, no. 1–3, pp. 197–202, 2008.

[15] S. F. Liu and N. M. Xie, *Grey System Theory and Its Applications*, Science Press, Beijing, China, 2008.

[16] Y. Zhang, Y. Xu, and Z. Wang, "Dynamical randomicity and predictive analysis in cubic chaotic system," *Nonlinear Dynamics*, vol. 61, no. 1-2, pp. 241–249, 2010.

[17] M. Daniel and V. Vasumathi, "Nonlinear molecular excitations in a completely inhomogeneous DNA chain," *Physics Letters A*, vol. 372, no. 31, pp. 5144–5151, 2008.

[18] Z.-B. Wu, "Global transposable characteristics in the complete DNA sequence of the yeast," *Physica A*, vol. 389, no. 24, pp. 5698–5705, 2010.

[19] J. Lu, W. L. Dentler, and E. A. Lundquist, "FLI-1 Flightless-1 and LET-60 Ras control germ line morphogenesis in C. elegans," *BMC Developmental Biology*, vol. 8, article 54, pp. 1–15, 2008.

[20] S. R. C. Lopes and M. A. Nunes, "Long memory analysis in DNA sequences," *Physica A*, vol. 361, no. 2, pp. 569–588, 2006.

[21] M. L. E. Gracey, J. M. Maniar, Z. Y. Chen, J. Lu, A. Z. Fire, and M. A. Kay, "Minicircle DNA vectors achieve sustained expression reflected by active chromatin and transcriptional level," *Molecular Therapy*, vol. 21, no. 1, pp. 131–138, 2013.

[22] J. Lu, F. Zhang, and M. Kay, "A mini-intronic plasmid (MIP): a novel robust transgene expression vector in vivo and in vitro," *Molecular Therapy*, vol. 21, no. 5, pp. 954–963, 2013.

[23] V. R. Chechetkin and V. V. Lobzin, "Spectral entropy criteria for structural segmentation in genomic DNA sequences," *Physics Letters A*, vol. 328, no. 1, pp. 79–86, 2004.

[24] Y. Yang, J. Lu, J. Rovnak, S. L. Quackenbush, and E. A. Lundquist, "SWAN-1, a Caenorhabditis elegans WD repeat protein of the AN11 family, is a negative regulator of Rac GTPase function," *Genetics*, vol. 174, no. 4, pp. 1917–1932, 2006.

[25] J. Lu, F. Zhang, S. Xu, A. Z. Fire, and M. A. Kay, "The extragenic spacer length between the $5'$ and $3'$ ends of the transgene expression cassette affects transgene silencing from plasmid-based vectors," *Molecular Therapy*, vol. 20, no. 11, pp. 2111–2119, 2012.