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Fractal and Population Flow

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Abstract:

Is the fractal dimension of natural phenomena time dependent? How is it related to interesting physical processes? In this article, we calculate the fractal dimensions of two Koch coast lines and local human population at different times. The change of the fractal dimension in the former cases could serve as an indicator of the erosion or accumulation of the coast line, while in the latter the regional development of an area.

Keywords: fractal, coast line, population, regional development

1 Introduction

When Benoît Mandelbrot (1967) first introduced the idea of fractals, he did not address the time dependent nature and their associated physical meaning of the geographical curves, even though one of the data he examined, the land frontier of Germany in about A.D. 1899 was apparently time dependent. Along with the rapid growth of fractal theory and its applications, many researchers have investigated the time dependent fractal dimensions of various natural and social phenomenon and found interesting results. Katz(1988) assessed the fractal dimensions of waveforms including Electrocardiograms (EKGs), electroencephalograms (EEGs) and a set of evolutionary data of the marine foraminifera Globorotalia during the last ten million years.Higuchi(1988) presented a technique known as Higuchi's Method to measure the fractal dimension of an irregular time series and applied it to the magnetic field data of the earth's magnetosheath.Sabanal and Nakagawa(1995) investigated the time dependence of the fractal dimensions ofvocal sounds such as Japanese vowels as well as Japanese and English words.More recently, Liaw and Chiu(2009) proposed the so-called Inverse Random Midpoint Displacement method to calculate the fractal dimensions of a time series and applied it to the Dow Jones Industrial Average stock index. Loo et al.(2011)evaluated several commonly used fractal dimension estimation methods to characterize time series for feature extraction in motor imagery-based brain computer interface.In what follows, we analyze the fractal dimensions of two Koch coast lines in section 2 and local human population in section 3. Conclusions are drawn in section 4.

2 Erosion or Accumulation of Coast Lines

We begin by postulating that the coast line at two different times can be represented by two Koch lines with equilateral triangular and square grains respectively.

Figure 1 depicts the Koch lineswith equilateral triangular grains and square grains respectively. Table 1 shows the process of measurement and the resulting fractal dimension D= Log(N)/ Log(1/r). The first row is the scale length 1/$r$of measurement by 1/3, 1/9, 1/27 of full length. The second row is the number of measurement N by different scale. The rest of the table is self- explanatory.

The fractal dimension calculated above is apparently the slope of the line if we take Log(1/r) as abscissa and Log(N) as ordinate in Figure 2, where the blue and red linescorrespond to triangularand square Koch lines respectively.

It is seen that the fractal dimension is larger for a more complicated line, or according to our postulate, a more complicated coast line. In nature, a coast line can change along the time due toerosionor accumulation with increasing or decreasing fractal dimension.

3 Regional Development Trend of an Area

The human population can also change because people move in or out of an area. Batty(2005)presented a comprehensive wayto demonstrate the dynamic process of complex urban systems which combines the techniques of cellular automata, fractal, and agent-based models. In this study, we investigate the population variation of Taoyuan county, Taiwan from 1991to 2011.

There are 13 districts in Taoyuan county. Table 2 lists the district names and populations of Taoyuan County in 1991. We use the box counting method as Richardson (1961) did to the characteristic length of polygonal geographical curves to measure the fractal dimension of Taoyuan County. The smallest town, Fuxing has the least 11691 people. We therefore take 10000 as the starting point and 5000 as the increment. Thus, in the first step, all the towns will be counted to gives $N(r)$=13, and the corresponding populations are recorded as N＝10000, 15000, 20000… etc. Next, we start from 15000 and repeat the counting. This is done up to the largest population and we take the natural logarithm of the resulting N and $N(r)$.

Figure 3 through Figure 7 are scatter plots of Log (N) vs. Log ($N(r)$) for the years 1991,1996, 2001, 2006 and 2011, respectively. The slopes of the regression lines give the fractals of the corresponding years upon taking the absolute values as listed in table 3. The resulting graph is shown in Figure 8.

The variation of fractal dimension with time can be interpreted as an indicator of regional development trend of an area (Friedmann, 1966). Owing to the development of industry and business, people move toward large towns for easier living. During such period, the population uncontrollably congregates toward large towns, which decreases the population of small towns and increases that of large towns. This is just what happened to Taoyuancounty from 1991 to 2006, and the fractal dimensiondecreases accordingly, as shown in Figure 8. As time goes by, when urban development grows pass the point which overloads the population limit of the large towns, people no longer satisfy with their living and more and more of them begin to drain back to small towns. This is again what happened to Taoyuancounty from 2006 to 2011. It decreases the population of large towns and increases that of small towns, and the fractal dimension increases, as is evident from Figure 8.

4 Conclusion

We have calculated the fractal dimensionof two model coast lines and demonstrated that the fractal dimension is smaller for a less complicated coast line and larger for a more complicated one.Considering the fact that accumulationusually leads to less complicatedwhile erosion leads to more complicatedcoast lines, it is thusreasonable to relate an increasing fractal dimension to the process of erosion, while a decreasing fractal dimension to the process ofaccumulation of the coast line.In the case of regional development, the connection is less obvious yet more interesting. We have calculated the fractal dimension of the local human population in the 13 districtsof Taoyuan county from 1991 to 2011, and found that it decreases from 1991 to 2006 and then increases from 2006 to 2011. Comparing to the regional development trend of Taoyuan county, we conclude that the fractal change reflects the population flow from small towns to large towns and then back to small towns in the area.

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Tables

Table1：The scale and number of measurement, and the fractal dimension D.

$1/r$	$(1/r)^3 = 1/27$	$(1/r)^2 = 1/9$	$(1/r)=1/3$	$(1/r)^3 = 1/27$	$(1/r)^2=1/9$	$(1/r) = 1/3$
N	64	16	4	125	25	5
LOG(1/r)	1.80618	1.20412	0.60206	1.431364	0.954243	0.477121
LOG(N)	1.431364	0.954243	0.477121	2.09691	1.39794	0.69897
D	1.26186			1.464974		

Table 2 The population of Taoyuan county in 1991.

District	Population	District	Population
Taoyuan	246056	Dayuan	61219
Zhongli	276878	Guishan	95756
Pingzhen	150703	Longtan	82698
Bade	135897	Xinwu	45750
Daxi	77658	Guanyin	43911
Yangmei	98943	Fuxing	11540
Luzhu	58156		

Table 3 The fractal of Taoyuan county from 1991 to 2011

Year	1991	1996	2001	2006	2011
Fractal	0.7438	0.7057	0.6857	0.6328	0.6765

Figures

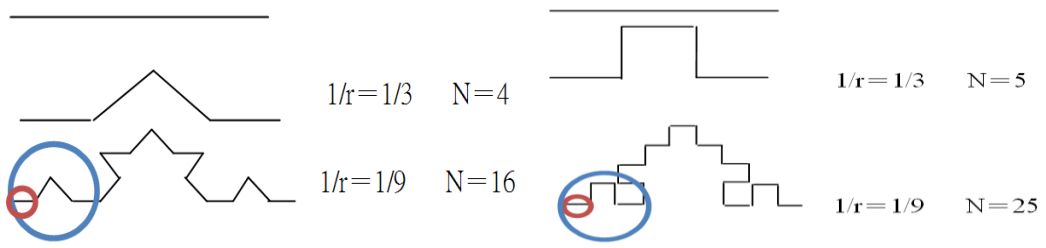

Figure1：The Koch line with equilateral triangular/rectangular grains, the blue circle is 1/3 of the straight line; the red circle is 1/9 of the straight line.

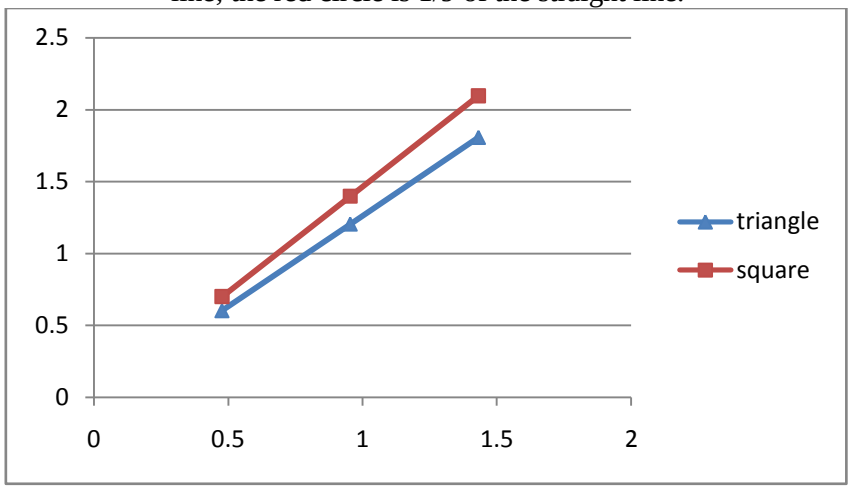

Figure 2：Fractal lines for the triangular and square Koch lines

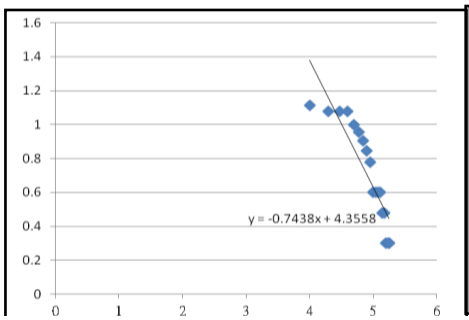

Fig. 3 The fractal line of 1991.

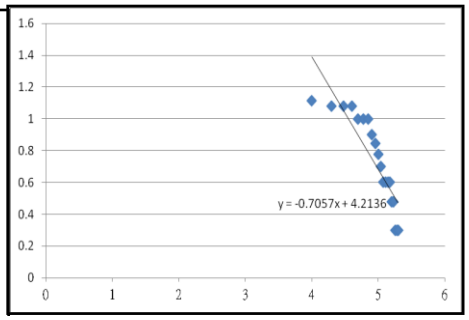

Fig. 4 The fractal line of 1996

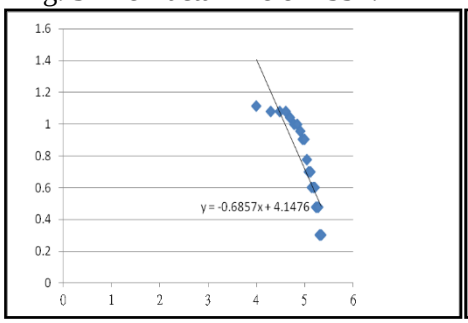

Fig. 5 The fractal line of 2001

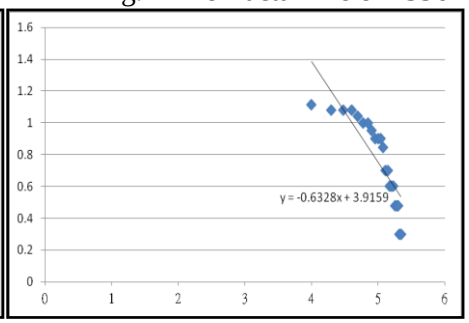

Fig. 6 The fractal line of 2006

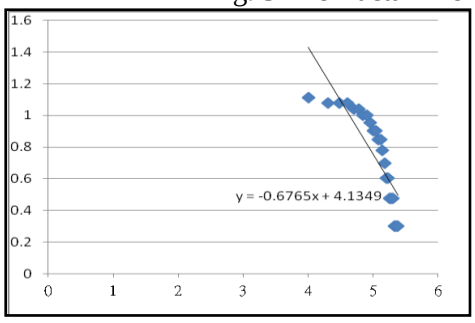

Fig. 7 The fractal line of 2011

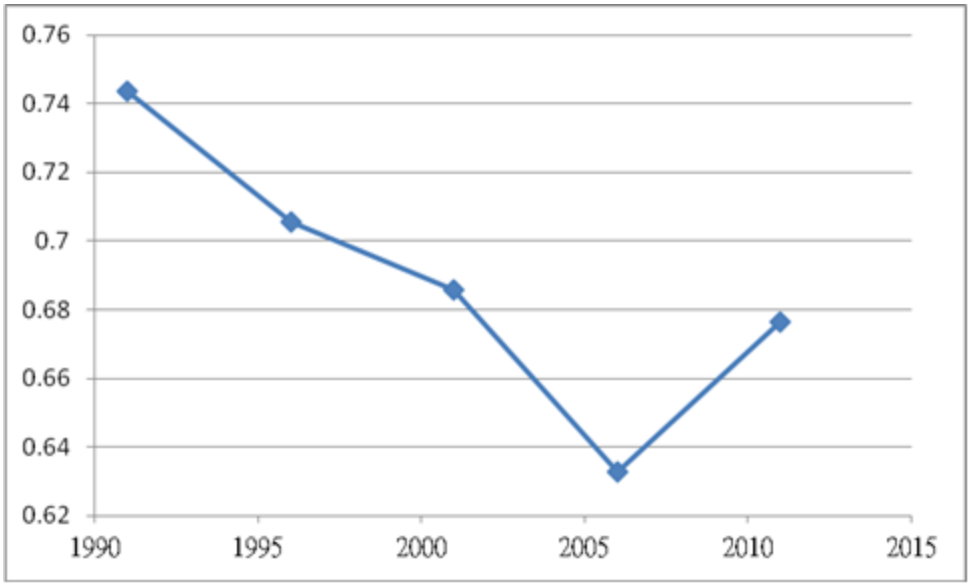

Figure 8 The variation of fractal from1991to 2011.