TIME-SERIES DATA ANALYSIS IN GIS

- Using fractal theory to change-up cities -

Noboru KOBORI
Japan Map Center　Sales Promotion Div.
4-9-6, Aobadai, Meguro-ku, Tokyo, JAPAN
Tel +81-3-3485-5414　　Fax +81-3-3465-7591
E-mail : kobori@jmc.or.jp

Abstract

Time-series data analysis is commonly used in a research of population growth, changes in commerce, etc.　Such a research needs topographic maps and statistics, but each type of data has not been well co-related.　When using topographic maps for time-series analysis, we must observe the maps very carefully to make comparison and detect changes over a long time.

Recently, GIS has been widely used to analyze the growth of urban areas such as Tokyo. In these analyses, the data generally used is grid data.　But it is difficult to analyze city growth in GIS.　Because it is not efficiency to use the data species and we don't have the method how to analyze the city growth.　Thus, fractal theory could analyze the city growth in GIS.　For example, Tokyo is growth from central in the city to fringe areas; it is increase the fractal value.　So we could analyze to time-series map data analysis in GIS.

Introduction

Production of 1:50,000 scale topographic maps started about a century ago, and more detailed maps of 1:25,000 was first produced in Japan about 70 years ago.　These maps are commonly used in various fields such as tourism, education, business, etc. They have been also used in research, in cartography in particular, because changes in the shape, enlargement, densification of a city can be understood by comparing maps which were produce in different time periods.　However, quantitative change cannot be explained by this method.　Therefore, statistical values such as population and area have often been used to analyze quantitative change of a city.

Quantitative analysis can be performed if digital data of maps is available. However, at present, digital data of the past maps are not readily available. In addition, there is no proper method for comparison. Because of these reasons, quantitative analysis has been difficult to use.

As to data, if we have mesh data, we can easily compare the present with the past. For example, if we have land use data in digital form (Fig.1), we can extract change of a particular mesh and detect change between the two time periods (Fig.2). This mesh method has been the only method that enables us to make comparison between the two times period.

Fig.1 Land use (1994)

Fig.2 Change area (from 1979 to 1994)

There is another method, which is called fractal, which allows us to make quantitative comparison between the two different times.

The method

Mandelbrot (1967) defined that fractal is generic name for graphic forms, structures and phenomena that have no length characteristics (Takayasu 1986). In other words, fractal is a shape of self-similarity that are commonly found in nature such as a cumulonimbus, coast line, river, leaf vein and blood vessel, all of which do not have clearly defined shapes. Fractal dimension is a graphic form indicating values. Fractal dimension is not necessarily integer, but a point is zero dimension, line, one dimension, area, two dimension and ambience is three dimension. In the field of geography, river geography in particular, the number of dimensions of rivers both domestic and abroad has been researched. In human geography, case studies using administrative boundaries, rail roads, and land use data were reported.

In fractal, when a graphic form is composed of a^D pieces of similar figures, that is a 1/a reduction of the graphic from, the exponent D is dimension.
B= a^D, therefore, fractal dimension of this figure is expressed as

$$D = \frac{\log b}{\log a} \qquad (1)$$

For example, from (1) formula, Kock curve of Figure 3 is expressed,

$$D = \frac{\log 4}{\log 3} \cong 1.2618 \qquad (2)$$

This relation is equal to that we need b-times of measurements for a graphic form whose base length is a, the formula can be also expressed as,

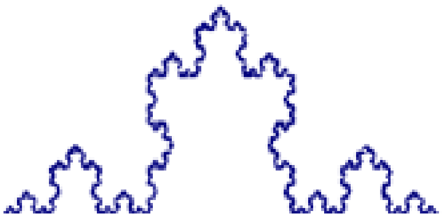

Fig.3 Kock Curve

$$D = \frac{\log N(r)}{\log r} \qquad (3)$$

In this case r is defined as a degree of roughness of data (scale of an observation), $N(r)$ as number of counts which can be observed. Fractal Dimension "D" is absolute values of slope of this line, which is a regression line found from logarithm graph of denominators and numerators by using least squares method.

Case studies using fractal dimension is few. Longley and Batty (1989) found fractal dimension using land use boundaries, Benguigui (1995) analyzed fractal dimension using rail roads in Paris metropolitan area, Batty and Longley (1987) argued the relation of fractal dimensions changing complexity of graphic forms, and Semboloni (2000) analyzed assortment road network and land use polygons divided by Voronoi method. In the past, many papers mostly reported fractal dimensions or introduced analysis using a combination of polygons, recently, however, there are case studies that analyzed development of cities by combining fractal and other values. Longley et al. (1991) researched structures of cities in green belt areas in England by using the value of population and fractal dimension.

This method of calculating fractal dimensions is also used to detect changes from the past to the present. For example, Benguigui et al. (2000) determined the built-up city area in Tel Aviv using fractal dimension. Batty and Longley (1987) also analyzed fractal dimension based on the city limit boundaries of an expanding city area.

In this way, there are two methods to calculate fractal dimensions: (1) one which changes a unit length, (2) one which changes grid size after transforming vector data into grid data. The first method is common when few boundaries are available such as administrative boundaries and rail roads. When analyzing the change in a city, the latter method is more effective.

At first, topographic maps should be digitized and road data should be extracted. Road networks are useful index for urbanization because there are strong correlation between road networks and urbanization. Vector data after digitization should be transformed into grid data for obtaining fractal dimension. We can judge severity of change in road networks by overlapping grids.

The result

We carried out a research in Tokyo and Sendai (Figure 4 and 5). We digitized the road in built-up areas, which can be easily identified because these areas are shown with hatch on a topographic map. We defined that a hatched are is a city area and we investigated changes in this area.

Fig.4 Study area 1919(L) and 1997(R)
(inside JR-Yamanote-line)

Fig.5 Study area 1925(L) and 1994(R)

JR Yamanote-line forms a loop and it demarcated a built-up area and suburbs in the past. As figure 4 shows, in 1919, some stations on the Yamanote-line had wide space in front of them. However, in 1997, inside the Yamanote line became a center of business activities and highly built up. On the other hand, Sendai city is located north of Tokyo and became a central city in northern Honshu area. The present population of Sendai exceeds one million. When comparing 1925 and 1994 , the size of city has not been changed so greatly, we can find dense road networks in the fringe of Sendai city. This means that the city structure of Sendai city had been completed by 1925.

Figure 6 and 7 show the fractal dimension of Tokyo.

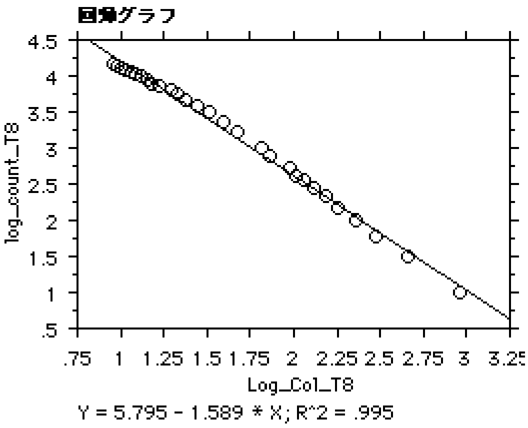

Fig.6 Fractal dimension of Tokyo (1919)

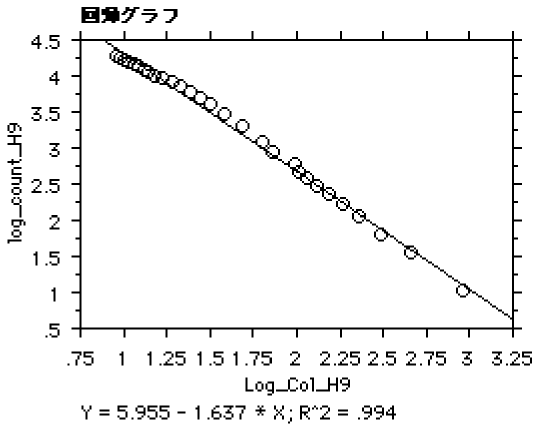

Fig.7 Fractal dimension of Tokyo (1997)

Dimension was 1.589 in 1919, but it became 1.637 in 1997. This showed that road networks became highly dense. This result shows only within the Yamanote line. If we cover wider area, then we expect greater change between the two time periods would be found.

Figure 8 and 9 show fractal dimension in Sendai area.

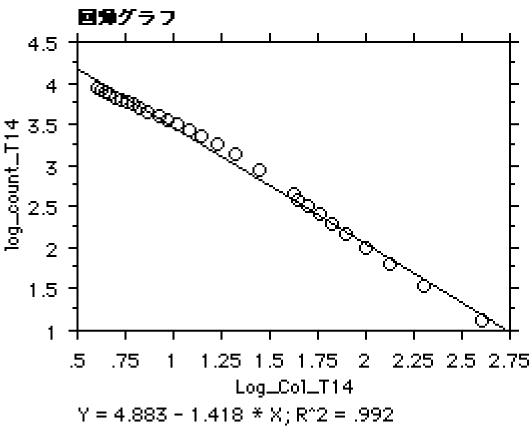

Fig.8 Fractal dimension of Sendai (1925)

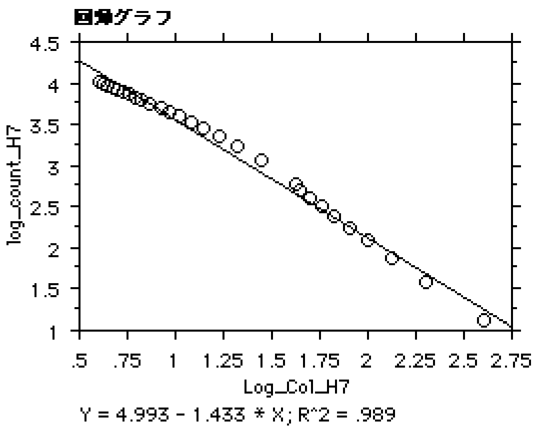

Fig.9 Fractal dimension of Sendai (1994)

In Sendai, too, fractal dimension was 1.418 in 1925, while the dimension became 1.433 in 1994. This shows that urbanization also speeded like Tokyo. When comparing Tokyo and Sendai, Tokyo has higher dimension, which means road networks in Tokyo became more dense than Sendai, thus urbanization has been higher in Tokyo.

In this way, we can make quantitative comparison in urbanization between two cities by comparing dimensions of both cities. Is there any difference between the two cities?

We extracted the tautological grid in most dense conditions. As table 1 shows, more than half of the roads in 1919 was also used as roads in 1997. We can find an increase of 4000 grids, this is because that large urbanization took place in Tokyo after the WW Ⅱ, in which most of the central part of Tokyo was burnt down. However, common grids are not found. On the other hand, more than 60% of grid of 1925 overlapped, and more than 50% overlapping was also found comparing the data in 1994. This means change in the city has not been so great.

Tab.1 Number of duplication grid (Tokyo)

	Total grid	Common grid
1919	14704	7400
1997	18548	

Tab.2 Number of duplication grid (Sendai)

	Total grid	Common grid
1925	8546	5456
1994	10499	

In this case, to use fractal dimension could clasp how change in this city.

Conclusion

If urbanization is defined as a built up area that is expressed with hatch on a topographic map, a quantitative analysis is possible by getting data from a map.

We didn't have a method for a qualitative analysis, however, fractal dimension will allow us to deal with secular change in GIS by comparing the amounts of change occurred in the course of time.

Comparison between Tokyo and Sendai revealed that the density of both cities is increasing. Further, in spite of the fact that urbanization has been spreading in Sendai, there has not been much change in the positions of road networks. Therefore, we concluded that the internal structure of Sendai has not substantially changed.

Reference

Takayasu, H. 1986. Fractal. Asakura-shoten, *Japanese*.

Batty, M. and Longley, P. 1987. Fractal-based description of urban form. *Environment and Planning B*, 14: 123-134.

Batty, M. and Longley, P. 1987. Urban shapes as fractals. *Area* 19-3: 215-221.

Batty, M. and Longley, P. 1994. Fractal Cities, Academic Press.

Benguigui, L. 1995. A fractal analysis of the public transportation system of Paris. *Environment and Planning A*, 27. 1147-1161.

Benguigui, L. and Czamanski, D., Marinov, M., Portugali, Y. 2000. When and where is a city fractal?. *Environment and Planning A* 27: 507-519.

Longley, P. A., and Batty, M. 1989. On the fractal Measurement of geographical boundaries, *Geographical Analysis* 21-1: 47-67.

Longley, P. A., Batty, M., and Shepherd, J., Sadler, G. 1991. Do Green Belts Change the Shape of Urban Areas? A Preliminary Analysis of the Settlement Geography of South East England. *Regional Studies* 26-5: 437-452.

Mandelbrot, B.M. 1967. How long is the coast of Britain? Statistical self-similarity and fractional dimension. Science, 155: 636-638.

Semboloni F. 2000. The growth of an urban cluster into a dynamic self-modifying spatial pattern, *Environment and Planning A* 27: 549-564.