# Fractal and Its Application in Description of Spatial Information

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**ABSTRACT** Fractal theory-very new mathematical method, is being regarded as a powerful tool in description in spatial phenomena. It has got great development and It can be expected that fractal could be supporting technique for Digital Earth.

**KEYWORDS** Fractal, self-similarity, fractal dimension, simulation

## 1. Background of Fractal's Rise

'Fractal' is a new geometry proposed by French mathematician Mandelbrot in 1970's, which is really a revolution in topological space theory and provides the possibility of describing and simulating objects and phenomena precisely in the natural world by using a mathematical model.

As we know, geometry is the science which deals with the shape of objects. But people often describe it as 'uninteresting' or 'monotonous'. One of the reasons is that the traditional or classical geometries based on Euclidean system cannot accurately describe the nature objects such as clouds, mountain, coastline, etc. Because the shapes of most objects in the natural world have a common feature: they are neither regular and smooth geometrical shapes. So classical geometries, which are thought 'strict and accurate', in fact, inaccurate description of the objects in the world, for example, the surface of the earth is treated as absolute spherical surface or ellipsoid in 'ideal situation'. In may not matter much in many cases when the requirement is not very strict. However, along with the progress of science; and technology, and human's knowledge about the world, this kind of methods treating irregular shapes as ideal, regular ones are becoming more and more unsatisfactory. Then the new geometry, 'fractal geometry', which was put into application as soon as it appeared, was proposed[1].

## 2. The Development of Fractal

As the word itself shows, 'geometry' is 'geo' + 'metry', which means the measure about the earth. Fractal's rise is from the measure of some geographical phenomena, the length of coastline, at which point, early as 1967, Mandelbrot began to propose the new concept[2] used to capture and analyze the 'new' information that traditional science cannot provide. After the new geometry appeared, it has been attracting more and more attention of many scientists. In 1980, Goodchild[3] described the close relation between fractal and geographical measure and pointed out that the fractal dimension can be used to predict the effect of cartographic generalization and spatial sampling. Later on Shelberg, Lam and Mollering advanced the algorithms using fractals to measure the fracticalities of curves[4] and surfaces[5], which is a meaningful beginning of applying the concepts of fractal dimension to describe the complexities and irregularities of the shape of curves and surfaces of 'real objects'. In cartography, Dutton[6] used the properties of irregularity and self-similarity of fractal to develop an algorithm to enhance the detail of digitized curves by altering their dimensionality in parametrically controlled self-similar fashion.

In other areas, computer scientists made effort to use fractal in computer graphics. Batty[7], in his paper, showed a number of examples of simulated landscape, mountainscape and other graphics generated by using the property of 'self-similarity' of fractals and pointed out the potential of development of applying fractal in this area.

Based on the study and research by many scientists in geography and cartography, Goodchild and Mark[8] reviewed the application of fractal in three headings: the response of measure to scale; self-similarity and recursive subdivision of space. They especially pointed out that the self-similar property of fractal surfaces generated by using fractal Brownian motion makes them useful as null hypothesis landscapes in the study of geomorphology. Then they concluded that fractals should be regarded as a significant change in conventional paradigms about spatial form and as providing new and important standard of spatial phenomena.

Scientists working in remote sensing and GIS area were also making effort to put fractal into practical use. Lam[9] demonstrated the research about describing and found that different land types have different levels of fractal dimension in different bands, and compared the fractal model with other spatial techniques and spatial statistics in characterizing remotely sensed data about land resource, land cover types and landscape, etc. The practical use also included the measure of the fractal nature of the Louisiana coastline[10], such as the length, the base from line which the boundary of the state should be drawn, etc., which involved detailed measures and interpretations. Based on the results, the conclusion was led: length, and other cartographic measurement is related to scale; and resolution, also fractals play important role in geography. So detailed research was carried out[11]. It was pointed out that what scale and resolution are suitable depends on the need of study, the type of environment and kind of information desired, and fractal dimension can be used to summarize the scale changes of spatial phenomena.

In the book entitled 'Fractal in Geography' [12], which may be the only one book about the theory and application of fractal in geography, the authors describe the fundamental concepts of fractal, fractal measurement of geographical objects including the methods for curves and for surfaces. They also show the other uses of fractal: simulation and interpretation and introduce some methods of simulation, such as Carpenter mid point subdivision and Dutton mid point displacement method for curves and Shear-displacement method for surfaces as well as some other methods.

In addition to the basic concepts and some application, the authors summarize 'a fractal paradigm for geography'. They explained the relationship among geography, geometry and cartography and lead the readers to tour in the areas with fractal nature and 'close' to geography, such as astronomy, geology, cartography, etc. to let them understand fractal better. Then they discussed the future work in geographical area including improving the fractal techniques, combining it with other techniques and developing the theory itself.

## 3. Potential Development and Issues of Interests

Fractal, the new science also technique, has got great development since it was advanced. But as many scientists points out, it is still new and also immature in both theoretical and practical areas. So it can be expected that more development would be obtained in the future.

Along the direction of existing work, there are some areas to develop:

1) The fractal theory is still descriptive rather than inferential. It really provides some models to simulate landscapes, but the models do not provide people with something more than descriptive tools. So the theory should be developed to meet the demands of applications and new methods or techniques also need to be tested and improved. On the other hand, the fractal analysis of landscapes, as a part of the developing field of fractals, is also in its preliminary and descriptive stage, and lacks theoretical explanation. The physical significance of landscape fractal characteristics remains to be explained. So besides the fractal theory, the research of geographical information theory, which is used to describe objects phenomena or processes at the earth's surface, also needs to be strengthened.

2) It is found that Fractal dimension or self-similarity only exist or in other words, are only stable in some certain ranges of scale. So this properties can be used to determine the scale at which the geographical phenomena or geomorphology can be better analyzed and the break points in a pattern or distribution can be identified where the processes contributing to these patterns become unstable. for example, a homogeneous pattern becomes heterogeneous and vice versa.

3) Fractal dimensions provide the measure of the complexity of curves or surfaces. But it is only a 'descriptor'. In other words, with the fractal, one can only get the impression of how complex or how coarse the curve or surface may be and cannot get the whole 'vision' of it. While Fourier Transform can reconstruct or regenerate the curve or the surface with the Fourier coefficients but one cannot get the impression of how complex it is in mind. The two methods have their own advantages and disadvantages. They also have something common, for instance, the more complex the curve or the surface, the higher the fractal dimension; while in the side of Fourier Transform, the more high frequency components in frequency domain. So the two techniques could be combined to make the results more precise and more reasonable.

4) Fractal has showed the potential of compressing data by recording the fractal dimension and some data, which could be much less than the original one and when needed it can be restored. For example, Using the fractal dimension and only the data for ten points, the boundary of Australia can be stored and then can be reconstructed. As the comparison with the original map boundary, several hundreds or even thousands point data have to be stored. The efficiency is obvious. The same idea can be extended to the compression of remote sensing imagery. Of cause along this direction, people have long way to go. The main problems include:

-- Time consuming. In a experiment, several hours were spent for decoding and image of a leaf! So it can be imagined that if the image is as complicated as remote sensing images, and the amount of the data is as great as remote sensing images, the running time for decoding would be unbearable. Then both encoding and decoding need more effective algorithms.

-- Accuracy. In fractal image compression, the basic idea is to segment the whole image as several fundamental shapes and make the matches with the existing models. If there is no suitable model for a shape, or the match is not good enough, the accuracy then cannot be guaranteed. For general images such as photos, it may not matter much, but for the images used to survey, it may lead some wrong result. So the database including as many as possible fractal shapes needs to be developed to solve to problem.

5) There are a lot of applications in geographical area and some ‘hybrid’ fields with social sciences, such as environment protect, global change, etc. Fractal can play an important role in these area as long as it gets development in both theoretical and practical areas.

## 4. The Comment about the Limitation of Fractals

As mentioned above, fractal has got great development since it arose. But it only has the history shorter than twenty years. So it is ‘developing’ theory, in other words, it needs to be developed.

It seems that Mandelbrot himself was involved in an ‘antinomy’: he was trying to make a new model to replace the old one which can only deals with ‘ideal situation’, but what he advanced still deals with some other ‘ideal situation’ which rarely or even does not exist in the real world---pure fractal and absolute self-similarity. This may be the limitation which is from the mathematician’s point of view: to seek something perfect, ideal and strict to meet the requirement of mathematics. But the real world is not really as what the mathematicians imagine, it is chaotic rather than ordered. So he had to make some modifications to fit the theory to the reality in order to put it into use. Undoubtedly the rise of fractal geometry is a break point of scientific period, but it is not the end. Things need to be developed. At this point, the cooperation between mathematicians and scientists in practical areas is needed urgently. The former can provide the latter with new theories or new development of existing theories; while the latter can provide the former with experiment data and the demands of practical use. With the cooperation, more development of fractal can be expected.

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