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A shape analysis and template matching of building features by the Fourier transform method

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ABSTRACT

Shape cognition and representation play an important role in spatial analysis because shape contains some characteristics of geographic phenomena that can be mined to discover hidden geographic principles. As a difficult cognition problem, the shape representation problem in GIS field has the properties of abstraction, indetermination and symbolization. How to use a model to represent shape cognition in our mental world and how to use a single number to compute the shape measure are interesting questions. In the image processing domain, there are many shape measure methods, but there are few proposals for corresponding vector data. This study aims to build a polygon shape measure and offers a Fourier transform-based method to compute the degree of shape similarity. The procedure first represents the boundary of the vector polygon shape as a periodic function, which is expanded in a Fourier descriptor series, and then, it obtains a set of coefficients that capture the shape information. Through the experiment on spatial shape match and shape query, the study shows that Fourier transform-based shape identification and template matching is consistent with human cognition.

1. Introduction

At human scales, the world is composed of objects, events, processes, and background environments. From the GIS perspective, we use spatial analysis to study the world by extracting spatial rules and geographic principles (Montello & Freundschuh, 1995). Spatial analysis, on the one hand, investigates the ontology properties of the spatial object as an existing entity; on the other hand, we must consider the thinking process in our brains as a cognition procedure. Spatial cognition, which addresses the cognition of spatial properties of the world, including the location, size, distance, direction, shape, pattern, movement and inter-object relations, has an important role to play in spatial analysis. However, in the GIS domain, the traditional spatial analysis concentrates on geometric, topologic or semantic information but pays little attention to the spatial cognition-related information.

Cognitive structures and processes are part of the mind, which emerges from a brain and nervous system inside of a body that exists in a social and physical world (Freksa, 1991). The result of spatial cognition is usually to act as a mental map, which represents a spatial shape and pattern in human memory. The spatial shape obtained by thinking and reasoning contains some characteristics of geographic phenomena, which can be mined to discover hidden geographic principles. The famous example in geo-science history is that of Alfred Wegener, who built the theory of continental drift, which was first driven by continental shape analysis. Wegener in 1912 first noticed that the shapes of the continents on either side of the Atlantic Ocean appeared to fit together, for example, Africa and South America. To some degree, shape is the result of the evolution of geographic entities and the interaction with phenomena in history. For example, the river shape and drainage pattern are related to hydrological and geological conditions in the natural environment. In human geography, the shapes of ancient buildings reflect the cultural characteristics of construction in the corresponding era. By shape identification and analysis, we can discover some special spatial characteristics and pattern principles that are hidden behind the objects.

Shape allows the prediction of many facts about an object and, in some situations, its effect exceeds other features, for example, size or location. We usually must find an object that matches the mental symbol in our memory by human reasoning, to express the "similar to" judgment. A shape-based spatial query usually expresses the recognition that one object is similar to another object or to two objects in their shape structure. For example, we want to extract some buildings that are "T" shaped or "U" shaped from a spatial database. The retrieved result is usually uncertain, depending on the human's emotion, background knowledge and perception abilities. The shape template and the degree to which two objects are similar vary with different people. The traditional

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spatial query, for example, the spatial SQL language (Shekhar & Chawla, 2002), can conduct only the query on geometric or topological measures and cannot involve the cognition measure. From the perspective of spatial communications, the SQL on a spatial query must extend to operations that can compare and extract shape information.

Because of the uncertainty of shape judgment, a spatial shape can be qualitatively compared only by such methods as fuzzy mathematics. In this process, the key task is to describe mathematically the shapes and to derive a similarity measurement to compare the shapes under the idea of fuzzy properties. In the multimedia and image processing domain, shape representation and measurement actively generate many methods and algorithms (Bengtsson & Eklundh, 1991; Hu, 1962; Jones & Ware, 1998; Latecki & Lakämper, 2002; Paul, Rosin, & Žunić, 2011; Žunić, Hirota, & Rosin, 2010). These methods aim at a region, boundary, and structure. For the description of global shape properties, there are geometric parameters, which include size, perimeter, convex perimeter, elongation, roughness and compactness. For polygon objects, the turn function or bend angle function based on contour points can be applied to measure a region shape with invariance to translation, rotation, and scale (Latecki & Lakämper, 2002). In these fields, the moment-based algorithm is an efficient method to represent the shape, aiming at the area boundary, which includes invariant moments, higher order moments, and generalized complex moments (Cho-Huak & Roland, 1988; Kim & Kim, 1998; Žunić et al., 2010).

In the image database field, the measurement of shape is conducted on the basis of a pixel or raster grid through the integration of a set of pixels to obtain a complete shape concept. However, in the GIS database, which mainly stores vector data, the shape measure directly faces individual geometric entities, such as lines, polygons, arcs, and point clusters. Thus, the shape measuring method in the GIS domain is different from that of image databases. It is easy to transform pixel data to the frequency domain representation, which usually acts as the basis of the shape measure. In an image database, the object boundary is usually represented as the chain code, which has changes along the boundary tracking or central angle that can be converted to the frequency domain.

In contrast to the image pixel data, this study aims at GIS vector data investigating the shape representation and studying the shape matching for building features. The applied algorithm is the Fourier transform, which has been widely used in image data analysis. However, in this study, the Fourier transform is based on the continuous function of vector data rather than the discrete pixel chain. The studied question behaves as template matching, which is controlled by the Fourier descriptor.

The remainder of this paper is organized as follows. Section 2 examines the characteristics of the region shape, taking the building features as an example. Section 3 presents the method of the Fourier transform on vector polygon data and discusses the formula for the shape measure. The template-based spatial shape matching is offered in Section 4 with experimental analysis. Section 5 discusses the characteristics of this method and concludes with proposals for future research.

2. Shape representation

Shape is probably the most important property that is perceived about objects (Palmer, 1999). Aiming at different content, the shape representation can be divided into three classes, namely, the boundary, the region and the structure objective. The classification is based on whether shape features are extracted from the contour only or are extracted from the whole shape region (Latecki, Lakämper, & Eckhardt, 2000; Zhang & Lu, 2004). The boundary shape of an object describes the complexity of the curve pattern, which is the extension trend in one dimension. Its comparison can be measured by smoothness, fitness, curvature and other computations. The region shape regards the object as a point set, a connected component and, in two dimensions, represents the pattern of object distribution and extension. The region shape can be described with vague terms such as elongated, round, or compact. The measures on the region shape usually include area, circularity (perimeter^2/area), eccentricity (length of major axis/length of minor axis), major axis orientation and blending energy. These geometric measures represent the shape in only a general way from the perspective of a quantitative measure that does not describe the shape from a cognition perspective. We cannot judge the similarity of two shapes by these measures. The structure shape regards the whole object as a compendium of different parts or components and studies the organization pattern. A given object can be mapped into a graph in which nodes correspond to divided pieces and arcs encode spatial relationships by skeleton conversion at reduced dimensions. Common methods of structure shape decomposition are based on polygonal approximation, curvature decomposition and curve fitting (Pavlidis, 1982). The present study will investigate the region shape in GIS data structures and will build a shape measure to quantitatively compare the similarity of two shapes.

Compared with other domains, such as image processing, computer vision and computer graphics, GIS addresses spatial objects with a vector representation at a larger spatial scale. The shape representation in GIS has the following properties.

2.1. Abstraction

According to Gestalt cognition principles, we first look at an object as a whole to obtain the complete sense of the region shape, and then, we look into the details that compose the shape. This approach implies that the shape representation should be abstracted first through a simplification, to obtain a generalized concept. In image processing, we use noise reduction methods to remove minor or deflection details. In the GIS field, the vector data can apply map generalization technology to obtain the abstracted structure (Brassel & Weibel, 1988; Wang & Muller, 1998), as shown in Fig. 1. Compared with the objective of the map representation from a large scale to a small scale, the generalization that aims at shape extraction need to be conducted at a large degree (Ai, Guo, & Liu, 2000; Li, Yan, & Ai, 2004). There is a special map cartogram called a value-by-area map (Dent, 1975) that depicts the attribute of a geographic object as the object's area. The abstraction makes the region size completely different from the original area, but the shape remains similar to the original. Another map, called the schematic map, is a linear abstraction of functional networks

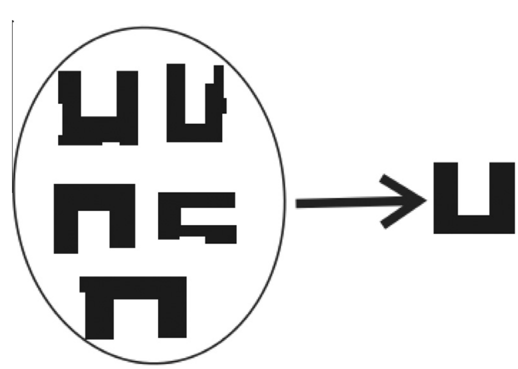

Fig. 1. The shape abstraction from different region scenes.