A Structural Approach to the Model Generalization of an Urban Street Network*

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Abstract

This paper proposes a novel generalization model for selecting characteristic streets in an urban street network. This model retains the central structure of a street network. It relies on a structural representation of a street network using graph principles where vertices represent named streets and links represent street intersections. Based on this representation, so-called connectivity graph, centrality measures are introduced to qualify the status of each individual vertex within the graph. We show that these measures can be used for characterizing the structural properties of an urban street network, and for the selection of important streets. The proposed approach is validated by a case study applied to a middle-sized Swedish city.

Keywords: model generalization, structural analysis, space syntax, graph modeling, urban modeling

1. Introduction

Within geographic information systems (GIS), two types of generalization have been developed over the past years, namely cartographical and model-based generalizations [19]. Cartographical generalization can be defined as a geometrical simplification in a scale reduction process while model generalization is mainly oriented to a structural-based filtering [25]. These two generalization approaches are closely related, often model generalization being a pre-process of cartographic generalization.

Cartographic generalization is a constraint-based process used by cartographers to reduce the complexity of a map in a scale reduction process. It involves intensive human knowledge obtained through professional cartographic expertise and practice. Since the seminal Douglas–Peucker algorithm for line simplification [6], automatic generalization has long been a research effort by both scientific researchers and cartographic practitioners [1], [5], [19]. In particular the idea of one single master database used to automatically derive maps at different scales has been a dilemma faced by many national mapping agencies. Graph-based approaches have been investigated for linear object generalization

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such as street and hydrological networks where the objective is to reduce the complexity of a network in a scale reduction process while retaining its general structure. MacKaness and Beard [16] discussed the potential of graph theory principles for derivation of information at the topological level to support generalization of linear objects. They applied weighted graph, directed graph, and minimum spanning trees in the description of street and drainage networks, and derived some preliminary rules for generalization process. In particular, MacKaness and Mackenzie [18] developed an algorithm for the generalization of road junctions using some graph theory principles. Thomson and Richardson [23] used the concept of minimum spanning trees in road network generalization. A three-step approach to automated road networks has been proposed [15] by considering basic geometric, topological and semantic requirements in the generalization of road networks.

Although the generalization of an urban street network is often applied as a cartographical task, it can be also considered as an operation where the objective is to understand the structure, function and organization of the city. Model-based generalization is of interest for many application areas as a street network can be considered as a structuring element for many other cartographic objects (e.g., built environment, electricity and gas networks) and socio-economical activities in the city. This is an important aim of many urban studies that focus on the understanding of urban structures and configurations. Amongst many domains of research and study, space syntax [10] has developed graph-based measures to analyze and understand the complexity of urban street networks. These principles support the belief that spatial layout or structure has great impact on human social activities. The application of space syntax covers many urban studies such as modeling pedestrian movement, vehicle flows, crime mapping, and human wayfinding process in complex built environments [9], [20]. Many empirical studies have demonstrated the interest of the space syntax for modeling and understanding of urban patterns and structures [11], [12], [21].

Cartographical and model-based generalization are often considered independently although a combined approach might be beneficial to both cartographers and urban planners. In particular, model-based generalizations can provide a complementary view of the structure and patterns of the city to a cartographer involved in cartographical-based generalization task. Also, there is still a need for an exploration of model-based generalization algorithms that retain the main structural properties of an urban network while combining functional and geometrical views. This paper proposes a model generalization approach, based on a computational application of graph modeling principles, whose objective is to retain the main characteristic elements of a given urban street network. On the one hand, this should help to observe and analyze the functional structure of the city. On the other hand, the approach can also be used as a preliminary and exploratory process prior to a cartographical generalization process. The modeling approach [14] uses vertices to represent named streets and edges to represent street intersections, so a dual representation of a given street network. Integrating named streets (e.g., Kennedy avenue, 45th avenue) as a basic modeling unit gives a form of functional representation of the city that complements the structural view of the urban street network given by the graph-based approach (let us remark that this approach applies to cities where streets are labeled using either names or identifiers). This functional component comes