Raster Voronoi Tessellation and Its Application to Emergency Modeling

Ickjai Lee¹, Kyungmi Lee¹, Christopher Torpelund-Bruin²

1. School of Business (IT), James Cook University, Smithfield, Cairns QLD4870, Australia
2. School of Business (IT), James Cook University, Douglas, Townsville QLD4811, Australia

© Wuhan University and Springer-Verlag Berlin Heidelberg 2011

Abstract Due to the advances in Web technologies, various raster maps are available through Web Map Services such as Google maps and Yahoo maps. These online maps are used to visualize diverse types of disasters. Understanding disasters with these online maps has become an important research issue. In this article, we propose a map-based general-purpose emergency management support system based on a computational model of generalized (multiplicatively weighted, order-$k$, and Minkowski-metric) Voronoi diagrams. The proposed system tessellates Web maps and models disasters (or emergency response units) having different weights in the complete order from 1 to $k-1$ in the three popular Minkowski metrics (Euclidean, Manhattan, and Maximum distance) provide insightful information for various what-if emergency scenarios. The proposed map-based emergency management support system systematically supports neighboring queries, districting queries, location optimization queries, and routing queries. We provide specific examples to illustrate how our system supports these queries.

Keywords raster Voronoi diagrams; emergency management systems; generalized Voronoi diagrams; decision support systems

CLC number P208

Introduction

Natural and manmade disasters are constantly occurring in our daily lives and greatly affecting the security at the individual, regional, national, and international levels. Disastrous events are detrimental to people, property, environment, and homeland security. Lack of appropriate emergency management could lead to environmental, financial, and structural damage, loss, or destruction. Even if it is almost impossible to avoid occurrences of disasters, its prediction and preparedness and an effective post-emergency management program can mitigate the risk and damages.¹ Due to the widespread distribution of various raster maps through Web Map Services (WMS) such as Google Map (http://maps.google.com), Google Earth (http://earth.google.com), NASA World Wind (http://worldwind.arc.nasa.gov), and Open Street Map (http://www.openstreetmap.org), it...
has become a popular practice to visualize emergent events on these Web maps. A general-purpose map-based intelligent emergency management system providing decision support information for every stage of emergency management (mitigation, preparedness, response, and recovery) for diverse emergency scenarios is in great demand.\cite{2} Geographic Information Systems (GIS) providing data acquisition, interpretation, and dissemination have been a dominant tool for most aspects of emergency management.\cite{3} However, much of the research is limited to producing cartographic mappings and visualization rather than emergency analysis and predictive modeling. Recently, a generalized Voronoi-based emergency management system has been proposed.\cite{4} The system uses higher-order Voronoi diagram for what-if emergency management. However, it is limited to Euclidean space. By disallowing varying weights, its applicability is restricted to confined situations. In many real-world situations, disasters (or emergency units) have different weights (disasters in different sizes, impacts, and speeds or emergency units with different numbers of personnel and capacities),\cite{5} the Manhattan metric or Maximum metric would be more useful particularly in urban areas\cite{6} Higher-order geospatial adjacency provides more informative advice when the first \( k \) targets are of interest, malfunctioning, fully occupied, closed, and cooperative.\cite{4} There is still a lack of a general-purpose flexible map-based emergency management support system supporting these higher-order diagrams with different weights in various metrics for making timely decisions in highly dynamic diverse environments.

In this article, we propose a flexible emergency support system based on generalized Voronoi diagrams (GVDs), multiplicatively weighted (modeling different weights) order-\( k \) (modeling higher-order adjacency) Minkowski-metric (modeling diverse metrics) Voronoi diagrams, providing adaptive information for making decisions in various scenarios. This system is capable of handling disasters (or emergency units) having different weights in the complete order from 1 to \( k-1 \) in the three popular Minkowski metrics (Euclidean, Manhattan, and Maximum distance space). The proposed model is versatile and applicable to various environmental situations modeling any combination of these three cases. Our model systematically supports four types of essential queries (neighboring query, districting query, location optimization support, and routing support) for diverse emergency decision-making.

The rest of the paper is organized as follows. Section 1 briefly summarizes various GVDs. Section 2 describes the detailed algorithmic approach for generalized raster Voronoi diagrams. Section 3 introduces our proposed system and provides details of usability. Section 4 discusses how our proposed system supports the four types of queries with examples. Section 5 illustrates an example of case study, and Section 6 concludes with final remarks and future work.

### 1 Various Voronoi models

The Voronoi diagram provides a robust framework for various geospatial modeling and analysis.\cite{7} There exist many GVDs and have been used in various emergency management projects.\cite{4,8} However, they are limited to the ordinary Voronoi diagram and unable to handle generalized situations such as different disaster weights and higher-order service area adjacency. Recently, a paper\cite{9} employed a multiplicatively weighted Voronoi diagram for districting queries, but this model is limited to districting queries with different weights only and not general enough to handle diverse scenarios. Researchers\cite{4} built an emergency management system with the complete set of higher-order Voronoi diagrams in order to support order-\( k \) what-if scenarios. This model is especially useful when higher-order concepts are in place but limited to the equally weighted Euclidean metric. To the best of our knowledge, there does not exist a truly flexible emergency support system modeling different weights, various higher-order, and diverse metrics, which assists the four essential queries for what-if emergency management.

#### 1.1 Ordinary Voronoi diagrams

The ordinary Voronoi diagram models natural territories of events. It captures estimates of the service areas of emergency responders and models the impact areas of disasters. Let us consider a set of distinct \( P = \{p_1, p_2, \cdots, p_n\} \) of points (can be disasters or emerg-