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Procedural urban modeling of population, road network and land use

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Abstract

This paper introduces an urban simulation system generating urban layouts with population, road network and land use layers. The desired urban spatial structure is obtained by generating population map based on population density models. The road network is generated at three spatial levels corresponding to the road hierarchy. The land use allocation is based on rule-based algorithm. And global and local parameters are designed to guarantee the flexibility and modification of urban layouts. The expected results are urban layouts suitable for academic scenario analysis.

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Keywords: procedural modeling; urban modeling; population density; road network; land use

1. Introduction

Procedural modeling has a history of decades, and it was introduced into urban simulation at early this century (Parish and Müller, 2001). Many algorithms are developed since then to simulate buildings, road network and land use. In some literature the authors acknowledged that their work was chiefly motivated by entertainment, such as computer games (Aliaga et al., 2008; Beneš et al., 2014; Lechner et al., 2003; Parish and Müller, 2001; Weber et al., 2009). This motivation led to plausible urban layouts and three-dimensional geometry of urban environments. However the existed models have problems if they are applied in academic fields.

For example, a research of land use impacts on traffic using scenario analysis method, will need simulation data instead of real data to get desired scenarios. To generate the simulation data, an urban layout simulation model

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combined with a traffic simulation model is needed. And such an urban layout simulation model should satisfy the following two important conditions.

The most important is to generate desired urban layouts, including desired urban spatial structure, road network, and land use, so users should have a full control of the model to ensure the desired output. In the urban spatial structure, some existed procedural urban models don't take population into account(Aliaga et al., 2008; Beneš et al., 2014; Weber et al., 2009), and other ones use real data as input. Of course real population data is not hard to obtain today, but it cannot promise a desired urban spatial structure, and users have limited control of real data. As for the road network, it can be generated by a variety of methods which can be basically classified into static and dynamic methods. The dynamic methods generate road networks from several growing points and during some growing periods(Beneš et al., 2014; Lechner et al., 2003; Weber et al., 2009), so it is hard to precisely control the final results. The static methods generate road networks at one go, which is relatively easily to control, but the existed algorithms still do not meet the requirement. For example, in the L-system, highways connect population centers(Parish and Müller, 2001), then the road network is mainly determined by the population density map. In the example-based algorithm, the streets and blocks are mainly influenced by the input urban images(Aliaga et al., 2008). And in the tensor fields, before generating road network, a tensor field should be drawn and modified(Chen et al., 2008), which is an abstract process and is not easy to precisely control. The land use allocation algorithms, however, can basically get desired results(Lechner et al., 2006, 2004; Weber et al., 2009).

Another important thing is flexibility. It is well considered in most procedural road network models which provide easy ways for users to modify the simulation results. But in the field of land use, some requirements are not met. For example, in the scenario analysis mentioned above, the users may need to change land use proportion in some districts or neighborhoods, such as from 80% residence and 20% retail to 60% residence, 30% retail and 10% open space, and they should not have to change the land use of lots and parcels one by one. Such kind of flexibility is not achieved yet.

In this paper, we introduce an urban simulation system motivated by academic research. The system will generate population layer, traffic infrastructure layer, and land use layer. In section 2 we introduce the basic concepts and the pipeline of our system, and then the generation of population density, road network and land use are described in section 3, 4 and 5 separately. Finally the expected results are shown and discussed in section 6.

2. Overview

2.1. Definitions

Our city generation model consists of three basic layers: population, land use, and infrastructure. At this stage, the layer of infrastructure has only road network. The road network and land use are both hierarchical layers based on city regions and road network system.

The road network in our system, in accordance with the widely used road hierarchy (Lay, 2009; Marshall, 2005), consists of the *highway*, *arterial*, *distributor (district and local)*, and *local access*. Accordingly, in our definition, a *city* is divided into *districts*, and a district into *neighborhoods*, then into *lots*. The district is an area surrounded by highways and arterials, and the neighborhood is surrounded by distributors, and the lot is surrounded by local accesses. Finally, at this stage we consider a set of five land uses: the *residential*, the *industrial*, the *office*, the *retail and services*, and the *park and open space*.

2.2. Pipeline

Fig. 1 shows the pipeline of our system. The input to our model includes: the population P, the urban area A, and the desired land use percentages L. Other important parameters, such as the urban spatial structure and the road pattern, are preset, and users can just choose desired values or change them interactively during the modeling procedures.

First, a population density map is created based on the preset population density models. The layer of population density is an input to the generation of road network and land use layers. The two layers consist of three spatial levels. At the city level, the highway and arterial are generated to form a spatial framework of urban layout, and the