Influence of network metrics in urban simulation: introducing accessibility in graph-cellular automata.

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ABSTRACT.

We propose a new approach of cellular automata models, based on a graph frame, which allows the modelling of irregular and dynamic neighbourhood of spatial entities. The Remus model permits the computation of a graph representing the buildings and the transportation network (the urban graph), and thus the calculation of the network distance-time between buildings. This model allows the extraction of various graphs, including the functional graph of the network-time-distances between buildings, and the neighbourhood-relationships graph which represents the network-neighbourhoods according to a certain time-distance-threshold and a given transportation mode.

KEYWORDS : Cellular automata, graph, modelling, network, urban, neighbourhood.

Cellular automata (CA) models have proved their usefulness to simulate urban dynamics at a high-resolution level. However, the standard representation of the urban structure by a regular lattice implies a definition of neighbourhoods in terms of contiguity of spatial units. Even if the integration of spatial constraints (Engelen *et al.*, 2002 ; Barredo *et al.*, 2003) has introduced some space heterogeneity in CA-models, their main spatial structure is based on assumptions about isotropy and stationarity of space that may be relaxed to fit more complex relationships in the city. O'Sullivan (2001a) showed that re-examining the formulation of cellular automata is necessary because of the substantial sensitivity that certain spatial processes have to even small changes in underlying spatial structures.

Graph formalism can be used to describe the complexity of proximity relationships, and can be integrated in CA models for urban simulation purposes (O'Sullivan, 2000, 2001a, 2001b). On the other hand, the graph formalism was widely used to model intra-urban and inter-urban accessibility (Mathis, 2003). We recently proposed a graph-CA model based on urban network accessibility, the REMUS model (Badariotti *et al.*, 2006). This model allows the computation of several neighborhood graphs representing accessibility in terms of network-time-distances between buildings (the cells of the automata), according to a given transportation mode and to a given distance. For this approach, the construction of a neighborhood graph involves:

- First, constructing an urban graph *G(V,E)*, which vertices include the buildings and the nodes of the road network, and which edges comprise the thoroughfares and the road-to-building connectors;
- Executing shortest path algorithms in the urban graph in order to calculate travel time, by a given transportation mode, between each pair of vertices *{Vi ; Vj}* of the graph *G(V,E)*. This process results in creation of a functional graph, complete and non-planar $G'(U \mid U \subset V, K)$, made up of vertices, representing the buildings, and of edges representing the shortest run-times over the network between all possible pairs of buildings, for a specified mode of transportation.
- Constructing a neighbourhood graph $Gt''(U, Rt \mid Rt \subset K)$, that means a sub-graph of the functional graph in which the vertices represent the buildings and the edges represent the neighbor relationships falling within a given threshold of travel time $t_{threshold}$, such that $t(U_i; U_j) < t_{threshold}$

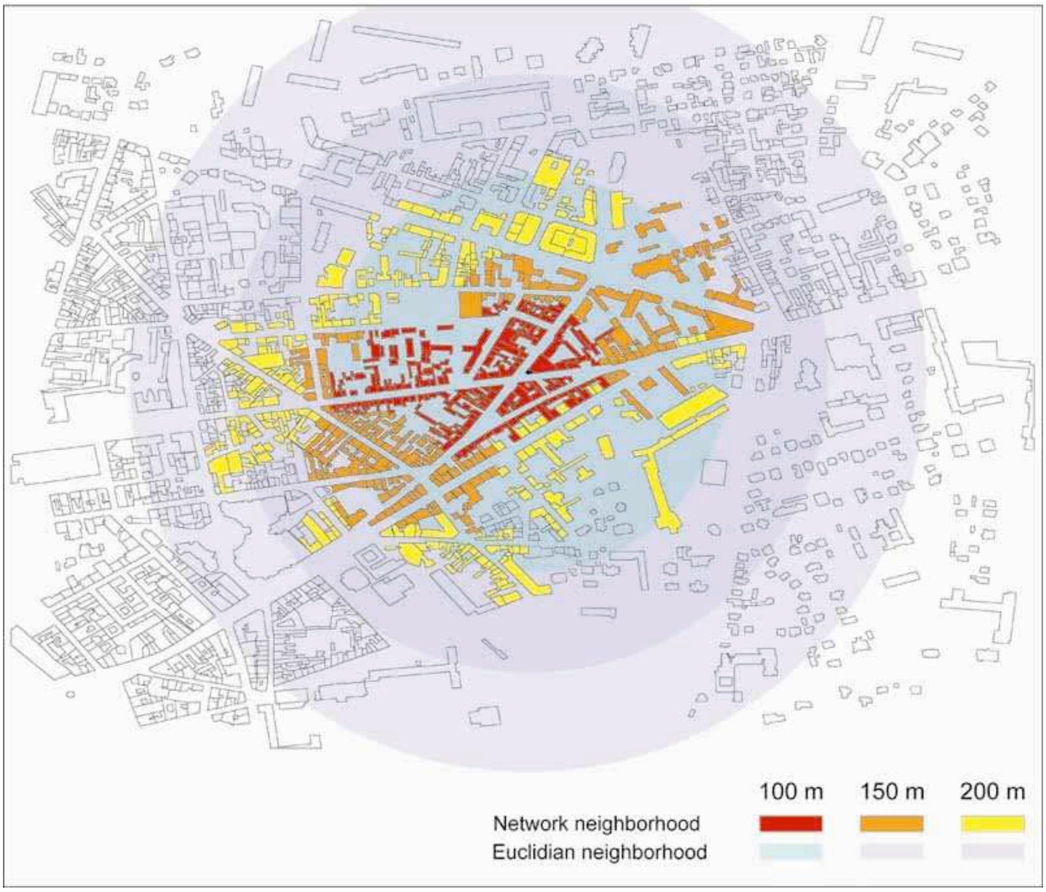

Figure 1: Comparison of network and Euclidian neighborhoods of a given building at Pau (in black) at 100, 150 and 200 m. (computed with REMUS)

The neighborhood graph is then used in REMUS to visualize the neighborhood of each spatial unit (building). Figure 1 shows the effect of introducing the network accessibility in neighborhood definition, in comparison with the euclidian accessibility.

This procedure was applied to the greater metropolitan aera of Pau-Pyrénées. In order to analyze the generated neighbourhood graphs, the average graph degree was calculated for different threshold distances. The results were compared with neighbourhood graphs based on euclidean metrics, for random and real distribution of spatial units. Figure 2 shows the differences in integration of the new neighbours when the threshold distance increases. The real distribution of buildings and the introduction of network accessibility in urban metrics induce an important anisotropy in urban space at local scales.

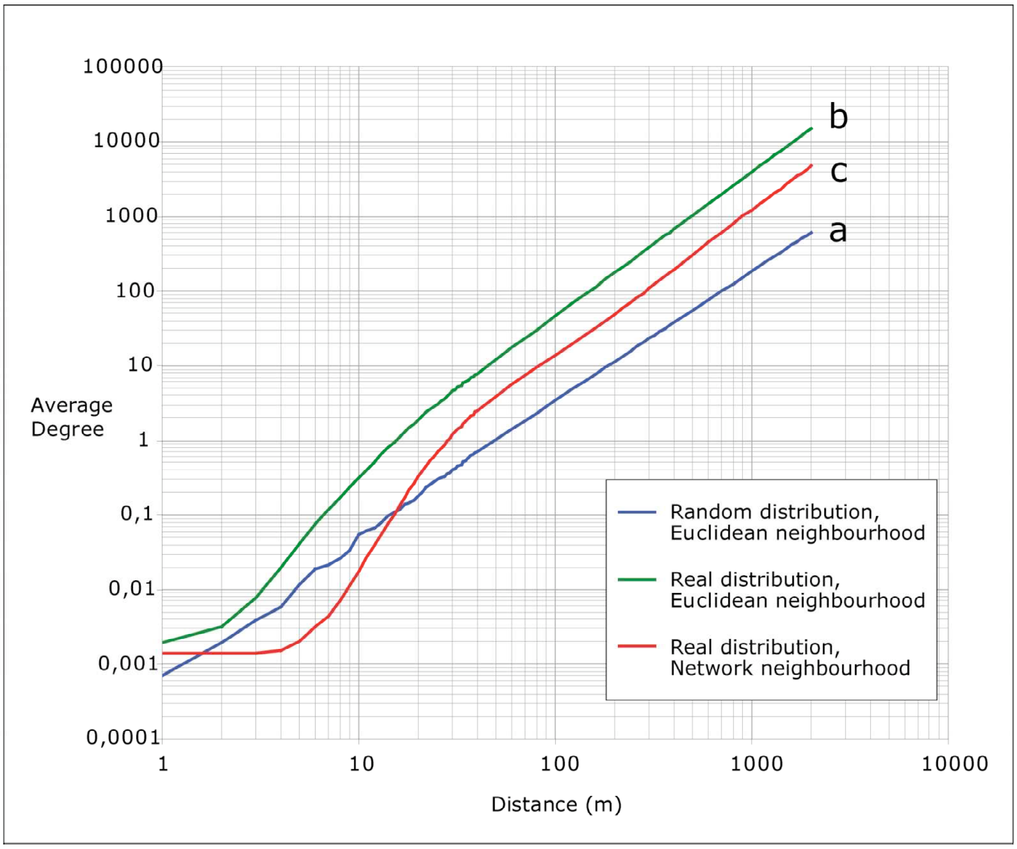

Figure 2. Average degree comparison of neighbourhood graphs: a) random distribution and euclidean-defined neighbourhoods; b) real distribution and euclidean-defined neighbourhoods; c) real distribution and network-defined neighbourhoods.

This neighborhood structure may then be introduced in cellular automata models. The aim of this work is to explore the behavior of a very classical model (Schelling's neighborhood segregation, 1971) implemented in a real urban pattern (Torrens and Benenson, 2005) and introducing network accessibility to define neighborhoods. This kind of model may be useful to reveal the sensibility of segregation processes to urban structure, defined both by its morphology and network accessibility. More precisely, the computing of spatial autocorrelation between similar buildings at the end of the Schelling's model simulation may be used to analyze the behavior of the system when varying metrics, distance and tolerance thresholds in neighborhood definition.

The new generation of geographic models allow to represent more accurately the proximity relationships in space. Geoalgebra (Takeyama and Couclelis, 1997) and graph-based cellular automata models (O'Sullivan, 2000) permits to integrate the fundamental anisotropy of space in cellular automata models. The introduction of accessibility is a key perspective to continue to explore the city morphology, and its effects on the city internal dynamics.

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