3D Cellular Automata and Mobile Terrestrial Lidar: Simple rules for urban geography

Gregory McQuat[1] and Robin Harrap[2]

1 Geography, Queen's University

2 Geology, Queen's University

Abstract

Advances in LiDAR acquisition are providing high-resolution data of urban environments from the street perspective. In contrast to lidar acquisition from an aerial platform, mobile terrestrial lidar (MTL) captures the richness of urban space as it relates to social, economic and transportation uses and behavior at larger scales. However, with high resolution comes large data volumes and there are relatively few automated or even semi-automated methods for efficiently extracting surfaces and features into a usable and representative form.

In this study, data acquired using Terrapoint's TITAN system is resampled into a gridded three-dimensional virtual environment consisting of sampled and non-sampled space. Cellular automata are then used to build agglomerative surface structures using simple path-finding rule sets. Practically, this technique provides an abstract representation of space useful for describing and visualizing crude urban geometry at a high level of detail. Fundamentally, this work presents an interesting and novel paradigm for the exploration of sampled environments and demonstrates how simple decision rules can be used to build complex structures.

Background and Relevance

LiDAR datasets are generally synonymous with large data volumes and this is only exacerbated in mobile-terrestrial LiDAR given the closer proximity of sampled surfaces to the sensor(s) and the slower acquisition speed relative to aerial LiDAR systems. Such large datasets are difficult to manage since they require exhaustive spatial search to define local point sets for statistical analysis or for computational geometry or computer vision algorithms. Therefore, there is a definite need for the point cloud to be "organized" into a structure that is conducive to rapid spatial query. Ideally this organization should support a variety of subsequent tasks such as segmentation, extraction, and compression.

Traditionally 3D city models are some combination of extruded 2D polygons and higher fidelity 3D geometric models reconstructed through photogrammetric methods or from surface models derived from aerial LiDAR data (Luo & Gavrilova 2006; Madhavan *et al.* 2006). Specific methods have been derived, for example, for reconstructing roof structure from point cloud data (Vosselman & Dijkman 2001). However, from the terrestrial point of view there has been very little focus on modeling "as-built" urban infrastructure for block scale urban settings, despite the fact that terrestrial lidar scanners are built to operate at precisely this scale. Examples of innovative work in extracting and visualizing building facades can be seen in Zhao & Shibasaki (2001) and Früh & Zakhor (2001) . This work is extended by Früh (2002) to include both aerial and ground-based techniques for a full 3D city model. These methods rely on textured polygonal meshes for visualization purposes and do not make attempts to model architectural features or smaller urban objects such as benches or light poles. Other research has used static LiDAR systems to produce "as-built" cadastral and polygonal mesh objects for industrial and small-scale architectural applications (Stemberg *et al.* 2004) but involve substantial 3D modeling knowledge and manual processing time to produce the finished models.

There has been no research focused on creating representations and structures from ground-based LiDAR data that allow for further analysis and subsequent modeling. In other words, in most cases human processing of Lidar data produces geometric models for comparison to plans (as-built drawing) or for visualization and game uses (3D features) but not, in general, for spatial analysis and modeling. This study attempts to work in that relatively new domain – 3D spatial analysis situated in ultrahigh resolution worlds. In particular, we examine the use of cellular automata to analyze urban LiDAR data.

A cellular spatial representation can be used to model the sampled urban environment (see voxels) and cellular automata (CA) techniques can be used to segment space and to build models for further analysis.

CA are spatially situated, finite state, information processing software machines. That is, CA operate under locally constrained conditions and process information from their local neighborhood using state-transition functions. The central tenet behind modeling with CA is that global structure emerges from simple local interaction. CA can been used to simulate the growth of urban environments and have also been used in urban simulation using mobile CA, also known as "cellular agents" (Batty 2005; Batty *et al.* 2002).

We propose that geometric constraints can be introduced into a cellular agent system to segment distinct surfaces from terrestrial-based lidar point clouds. Tavakoli *et al.* (2008) outline a similar basic framework and path-planning algorithm for cellular agents in a geometrically bounded environment. Essentially, cellular agents are constrained by the *affordances* provided by the environmental structure where they exist and the affordance similarity correlation between adjacent spatial regions can be used to group sampled urban structure (Gibson 1979; Raubal & Moratz 2007).

Methods and Data

Data was collected using Terrapoint's TITAN mobile terrestrial LiDAR system. TITAN was mounted to a pickup truck platform and data was collected for large sections of the city of Kingston, ON, Canada. The terrestrial collection platform provides high-resolution range measurements of urban surfaces and objects.

Data points are stored in matrix format for fast access and to provide a structured spatial representation of the sampled environment. The downside to this “grid” representation is that non-sampled space must also be taken into account and thus increases the data volume. While it is possible that sparse-matrix methods could be used to compress such grids, the performance impact would be considerable.

We explore using a cellular agent approach for extracting and abstracting physical structure from TITAN point clouds. Our approach uses mobile cellular “agents” whose movement is constrained by physical structure of the environment. An example of a constraint would be to limit vertical movement to a specific angle from the currently approximated plane. In essence, this approach uses simulation to investigate the effects of spatially constrained transition functions. These transitions functions are constructed to mimic the natural transitions in the world.

We simulate the systems at multiple levels of detail in order to explore the efficacy of our algorithms across spatial scales. Furthermore, moving from low detail towards higher detail representations of space provides a framework for focusing computation to areas where data samples exist and thus helps to mitigate data volume and computation issues. As a result of this, it is likely that such algorithms, once refined, could be implemented in parallel, for example on a programmable GPU, in order to achieve higher performance.

Results

Initial results point to a need for a more flexible representation of space. Cellular partitioning of space predicates fixed spatial relationships to a grid or other tessellation of space. Furthermore, in order to represent the data accuracy in a matrix format requires trading off larger data volumes for search time. The larger data volumes result from the need to model not only points in space but also all non-sampled regions as well. Future work will take advantage of different spatial decomposition techniques in computer science and 3D graphics to help organize data into smaller and more flexible data structures.

Conclusions

From a GIScience perspective this work provides an investigation into the tools and methods needed to introduce dynamic simulation modeling with CA into the spatial analysis suite and as such can be considered to contribute to the developing science of geocomputation. In particular, we move CA and spatial analysis into the emerging field of 3d urban visualization, which marries computer graphics, GIScience, planning, and infrastructure studies. Although preliminary, this work points towards future tools to improve the state of knowledge about cities, and so to support urban decision support efforts across the board.

References

Batty, M. (2005). *Cities and Complexity: understanding cities with cellular automata, agent-based models, and fractals*. Cambridge: The MIT Press.

Batty, M., DeSyllas, J., & Duxbury, E. (2002) The discrete dynamics of small-scale spatial events: Agent-based models of mobility in Carnivals and street parades. *Working papers of Centre for Advanced Spatial Analysis*. http://www.casa.ucl.ac.uk/working_papers/Paper56.pdf.

Früh, C. (2002). Automated 3D Model Generation for Urban Environments. Dissertation, University of Karlsruhe.

Früh, C., & Zakhor, A. (2001). Fast 3D Model Generation in Urban Environments. *Proceedings of International Conference on Multisensor Fusion and Integration for Intelligent Systems* (pp. 165-170).

Gibson, J. (1979) *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin Company.

Luo, Y., & Gavrilova, M.L. (2006). 3D Building Reconstruction from LIDAR Data. In Gavrilova, M., Gervasi, O., Kumar, V., Tan, C.J.K., Taniar, D., Laganà, A., Mun, Y., & Choo, H. (Eds.) *ICCSA 2006, LNCS 3980* (pp. 431-439). Springer-Verlag.
doi:10.1007/11751540

Madhavan, B., Wang, C., Tanahashi, H., Hirayu, H., Niwa, Y., Yamamoto, K., Tachibana, K., & Sasagawa, T. (2006). A computer vision based approach for 3D building modelling of airborne laser scanner DSM data. *Computers, Environment and Urban Systems*. 30, 54-77.

Raubal, M., & Moratz, R. (2007). A functional model for affordance-based agents. In Hertzberg, J., & Rome, E., (Eds.), *Affordance-Based Robot Control*. Berlin: Springer.

Stemberg, H., Kersten, Th., Jahn, I., & Kinzel, R. (2004). Terrestrial 3d Laser Scanning- Data Acquisition and Object Modelling for Industrial As-built Documentation and Architectural Applications. Proceedings of XXth ISPRS Congress, Istanbul, Turkey, 12-23 July 2004.
http://www.isprs.org/congresses/istanbul2004/comm5/comm5.aspx

Tavakoli, Y., Javadi, H. & S. Adabi. (2008). A Cellular Automata Based Algorithm for Path Planning in Multi-Agent Systems with A Common Goal. *International Journal of Computer Science and Network Security*, 8(7), 119-123.

Vosselman, G., & Dijkman, S. (2001). 3D Building Model Reconstruction From Point Clouds and Ground Plans. *International Archives of Photogrammetry and Remote Sensing*. 34(3/W4), 22-24.

Zhao, H., & Shibasaki, R. (2001). Reconstructing Textured CAD Model of Urban Environment Using Vehicle-Borne Laser Range Scanners and Line Cameras. In B. Schiele & G. Sagerer (Eds.) *Computer Vision Systems: Second International Workshop, ICVS 2001*, *Vancouver, Canada July 7-8, 2001: Proceedings* (pp. 284-297). Springer-Verlag.