CSE 481E
UrbanSim

Parcel Disaggregation Project

Mark Perry
N. Lance Nguyen
Tripurari Volpe

0. Contents

1. Introduction

The goal of this project was to provide a system for modeling the geometry of land subdivision in development during UrbanSim simulations. The system would accept as input a spatial description of a region to be subdivided, constraints on the number and/or size of the resulting lots, information about existing roads (if available), and an indication of which development template will be used to pattern the subdivisions. Development templates include traditional grid and cul-de-sac models, as well as potentially other models commonly used in urban and suburban development.

During simulation, other information about local land use would be used to determine the parameters passed to the subdivision module. The subdivision system would then produce as output a collection of polygons describing the lots into which the parcel has been divided.

The primary objective of the project was to design and implement an algorithm for subdividing parcels according to the given parameters and producing reasonably realistic results. Another, subsidiary goal was to develop a utility application to provide visual interaction with the subdivision system.

2. Problem Approach

In the initial approach to the problem, it was necessary to design a robust and flexible system that could handle edge cases while still producing moderately realistic results, since parcels of land in urban development are seldom uniformly-shaped rectangles. Thus, the first step was to develop a polygon geometry module and an interactive viewer to allow for easier development and debugging of the subdivision algorithm and polygon library.

The polygon library was built to provide a robust mathematical foundation for the subdivision algorithm itself, supporting polygon various polygon operations including centroid and area computations, bounding boxes, rotations, intersections, and slicing. The interactive polygon editor and subdivision simulator was developed as a loosely-coupled component, since integration of only the subdivision module with UrbanSim was a goal.

Initial work on the algorithm was based on an examination of the methods used by Duncan Cavens in his paper, *Site-Specific Simulation and Visualization of Suburban Growth*.[1] Cavens presented a general technique for producing cul-de-sac patterns, which involved evenly distributing lot centroids throughout a parcel and adjusting their positions around a central road using dynamic programming techniques, before finally placing boundary lines around those centroids.

Following this general idea, the first version of the algorithm attempted to evenly distribute pseudo-centroid points in a parcel by finding an even spacing along lines drawn through the parcel's actual centroid. However, this approach was incapable of handling many common edge cases, including any significant concavity, so it was rejected pending the investigation of other more robust methods.

One approach that was examined involved splitting up the parcel into small chunks that could be used to calculate lot centroids. The idea behind this was that all edge cases could be eliminated by careful construction of the polygon splitting algorithm. To achieve this result, after the parcel was split up into smaller parts that could be more easily handled, the parts could then be arranged together using k-means clustering. K-means is a way to group parts together based on a distance metric using the distance between part centroids.[2] These clusters could then be merged together to produce lots of the desired size. While this approach was promising from an algorithmic perspective, it was ultimately that it did not produce lots accurately representing the way subdivisions occur in the real world.

Finally, a it was decided that the algorithm would employ a hierarchical approach, first dividing the parcel into a set of shapes that are as regular as possible, and then continuing to subdivide those parts if necessary. This approach is flexible, as it contains the details of specific subdivision templates to the lowest level of the algorithm, first doing what is necessary to eliminate irregular shapes. This makes it relatively easy to implement new templates, as the subparcels any given template will be applied to will be of a more regular shape. It also incorporates a natural way to deal with parcels that are extremely large – simply continue subdividing them into smaller, easy-to-handle pieces until the subparcels are small enough to consider as a whole.

3. Development Models

The first, simple approach to the subdivision system implements two relatively straightforward development templates: cul-de-sac and traditional grid models.

3.1. Traditional Grid

In a traditional grid patterned subdivision, a parcel is typically divided into regular rows and columns of similarly-sized blocks, separated by streets laid out at right angles. Grid patterns are extremely common in development, especially in dense urban areas where space is at a premium, and the efficiency of rectangular space packing is put to good use.

3.2. Cul-de-sac

A cul-de-sac is a dead-end street with a single point of access to an arterial or other through road, typically surrounded by a small cluster of homes. They are more common in suburban areas, and can sometimes fill awkwardly shaped parcels of land more effectively than a grid layout could.

3.3. Social and Ethical Considerations

Depending on how the data input to the subdivision algorithm is determined, and how the data it outputs is used, the distinction between these basic development templates might have significant social ramifications. The use of one pattern or the other has an immediate impact on local traffic, and may affect other aspects of residential society as well.

For example, opponents of cul-de-sac style subdivision claim that it impedes traffic flow in the overall network by adding large numbers of houses without additional through roads.[3] A potential consequence of this is the possibility that mischievous or criminal behavior, which might have been deterred by the presence of high volumes of traffic, might increase in cul-de-sacs. Another consideration is the increased stratification that can be contributed to by the small, insular communities that cul-de-sacs and similar patterns typically form.

These factors, risks, and potential consequences would need to be carefully considered by planners using this or a similar system to evaluate urban development.

4. Algorithm Structure

The input to the subdivision algorithm consists of a list of vertices defining the parcel polygon, the number or size of resulting lots desired, one of an enumerated set of development models, initially to include cul-de-sac and traditional grid models.

The following terms are used in the description of the algorithm:

- *Parcel* refers to the original input shape which is to be subdivided.
- *Subparcel* refers to shapes subdivided out of the original input that are not the final resulting shapes. Effectively "working shapes".
- *Lot* refers to one of the final output shapes, the fine-grained elements of the subdivision model.

The algorithm can be described in five essential stages:

1. Orientation Correction
2. Concavity Elimination
3. Recursive Subdivision
4. Application of Development Model
5. Reorientation

4.1. Orientation Correction

For optimal operation of the subdivision steps, the parcel polygon should be oriented so that its sides are vertically as straight as possible; e.g., if the shape consists of many long edges that are close to a particular direction, the working coordinate system should be biased in that direction. To give a more specific example, a polygon in the shape of a rectangle rotated by 45 degrees should be "corrected" so that some of its edges are vertical in the working coordinate system.

This is done by examining the angle that every edge makes with respect to the initial assumed coordinate system, and computing for each distinct angle present in the polygon a *weight* based on all the edges in the polygon. The component of the weight of an angle θ contributed by each edge E is determined by the length of E and the similarity of E's angle to θ.

For similarity, the minimum arc difference between two angles is used:

The contribution of a single edge *e* to a distinct angle's weight is given by

And the total weight of an angle is given by

To orient the polygon, the algorithm selects the angle with the largest weight value, and rotates the polygon so that edges with that angle are oriented vertically or horizontally in the working coordinate system. The amount of rotation will be stored so that all generated shapes may be rotated back after subdivision is completed.

4.2. Concavity Elimination

After orientation, the next step is to eliminate any excessive concavity that may exist. A concave vertex in a polygon is any vertex on the polygon that has an outside angle of greater than 180 degrees. By eliminating concavity early on, regular polygon shapes can then be used for the models. This simplifies the problem for the models and estimates how planners divide up irregularly shaped parcels.

To eliminate concavity, concave vertices will be identified and at such vertices a division will occur. The algorithm will then make cuts that maximize the minimum area of the two subparcels created. This will be continued until either there are no more points of concave vertexes, or the number of desired lots was reached. At each cut horizontal or vertical division will then be drawn to divide the parcel, increasing the regularity of subparcels with respect to the established coordinate system. The size of resulting subparcels will also be taken into account to ensure that unreasonably small subparcels are not generated. For example, very narrow strips of land extending from a parcel may result in a concavity removal operation that would create an excessively small lot - such cases will simply be ignored.

4.3. Recursive Subdivision

Once the parcel has been divided into more convex shapes, if there is any subdivision left to be done, it will be performed recursively on each of the subparcels generated in the concavity correction step. At each stage of recursion, the goal will be to divide a subparcel into smaller shapes that are as close to square or rectangular as possible.

When a subparcel is created that is smaller than a specified threshold size, recursive subdivision will stop and the originally chosen development model will be applied to it to generate the final lots. The reasoning for this decision is that extremely large parcels cannot themselves be immediately subdivided using certain models (such as the cul-de-sac), so instead they will be divided into grids which will then individually be divided according to the specified model.

If an explicit number of lots is specified, and this number of subdivided shapes is reached during this process, the subdivision process may stop, presuming that full development down to the lot level is not desired.

4.4. Template Application

Once subparcels of an appropriate size have been reached, the specified development model may be applied to produce the final result.

Cul-de-sac

To produce a cul-de-sac shape, initially a road line is drawn into it from the center of the cul-de-sac to an outside boundary. The orientation of this road is an optional parameter, and if not specified the orientation will be chosen that maximizes the potential length of the road. To calculate the position of the cul-de-sac center, first the subparcel's centroid will be examined, with the direction of the road to the boundary known. The road will then be extended the opposite direction of the road proportionately to the number of desired lots.

Then for each lot a ray will be cast from the road and center circle, intersecting with the outside edges of the subparcel to produce lot boundaries. These rays go off a base distance step while walking around the road boundary, with the cul-de-sac center getting additional weight to produce the desired lots surrounding it. This distance step can be then adjusted based on the area produced for each lot to increase or decrease the area produced, or to constrain it within a desired range.

Traditional Grid

To divide a subparcel into a grid, lots are first be gridded out according to the required number or size, and then road lines are placed between them as needed. For example, if all the lots could be placed in two rows while preserving reasonable dimensions, a single road through the middle of the subparcel would be sufficient.

4.5. Re-orientation

After subdivision is complete the resulting lots will be rotated to reverse the original change in orientation, and translated if necessary to re-align them to the original position specified in the input data. The lots produced will then be returned, allowing either the viewer to display them or UrbanSim to convert the parcel into the lots produced by this algorithm.

5. Deployment and Testing

At present time, this system is not yet deployed in the UrbanSim framework. This will be one of the goals of continuing work on the project, along with further improvements to the algorithm.

As the system is deployed and continuously improved, it will be important to analyze and experiment with the data produced by the subdivision algorithm. The most sensible way of evaluating its usefulness is to compare its output to actually observed subdivisions, when given input as much as possible closely matching the initial conditions of the observed subdivision.

Presently, the system's output is fairly rough, and not easy to compare to many actual development subdivisions, which often incorporate many peculiar internal shapes that are difficult to model in a “one-size-fits-all” algorithm like the one being developed here.

Aside from simply comparing the shapes of the subdivided lots, one potentially more useful metric of comparison would be the actual network of streets produced by the algorithm. Thus an attractive goal for future work on the system would be to select a set of criteria for evaluating the accessibility or efficiency of the output street network, possibly in conjunction with the UrbanSim traffic model, to compare the results of the subdivision algorithm with networks observed in real subdivisions.

6. Conclusion

The subdivision algorithm as developed thus far does a fairly adequate job of modeling the process of land development, given certain assumptions, and considering the coarseness of the available input data. As described, the next goals for continued work on the project are integration into UrbanSim, improvement and tweaking of the subdivision algorithm, and the incorporation of some formal testing procedures to evaluate the performance of the subdivision algorithm.

Once the system is integrated into the UrbanSim framework, continued improvement and experimenting should be able to increase its reliability and descriptive power. In addition to those already mentioned, another desirable goal for future work is the incorporation of additional information from other UrbanSim models and other sources into the algorithm, which could include information about existing roads, zoning, and possibly even social indicators. Further investigation of these options during development could help make the system's output more meaningful, and increase its utility as a valuable tool in urban simulation and planning.

7. References

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