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Preliminary investigations into the potential of improving rendering performance of 3D datasets using 2D generalisation

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Abstract. Three dimensional (3D) city models have many uses including city walk-throughs or fly-throughs to show what a new building would look like in situ, or whether a view or light will be blocked by a new structure, flood and signal modelling. Often, these models are created using a process of extrusion of detailed 2D topographic mapping. The resulting 3D datasets contain many thousands of polyhedra, which in turn results in performance issues when attempting to visualize such models in Google Earth. To address this issue we first generalise the 2D dataset (using simplification and aggregation) and then extrude the generalised 2D maps to 3D, comparing the rendering performance and visual aspects of the resulting datasets.

1. INTRODUCTION

Three-dimensional (3D) City Models are becoming more prevalent and have applications including utility infrastructure validation ("call-before-you-dig"), planning [2, 7, 16] and augmented reality [5]. The process of extrusion ("growing" the 2D data to a given height) is an efficient method of creating a 3D dataset when a larger area is to be covered (for example an entire city), and where high levels of detail (e.g. sloping roofs) are not required. It also has the advantage of integrating 3D buildings with a 2D footprint [20], resulting in Level of Detail 1 (LoD1) buildings [22]. However, such models are generally complex with respect to individual components and the required rendering resources [13]. Indeed, the resulting 3D data is generally quite large in volume, and thus potentially difficult to visualize in its entirety utilizing 3D packages such as ArcGlobe [9] or Google Earth [14].

This paper provides a preliminary investigation into the impact of 2D generalisation carried out prior to extrusion. We first simplify and aggregate a detailed 2D topographic dataset and then extrude the resulting polygons to an average height for each block, comparing this with directly extruding the detailed 2D building objects and removing internal walls. The main focus on improving rendering performance and a brief comparison is also made of the resulting visual appearance of the dataset.

2. GENERALISATION

A number of approaches can be identified to reducing the volume of data to be rendered for 3D City Model, including data compression [32] and mesh simplification [27]. The concept of *Levels of Detail* (LoD) [22] where different representations of the data is used at different scales, can also be used to limit the size of datasets - indeed the effective visualization of complex 3D City Models requires an

Figure 1. Pettswood data simplified using a 5 m tolerance (left). Data aggregated using a 1 m tolerance (centre) and aggregation using a 5 m tolerance (right).

abstraction of City Model components [13]. As [23] note a "In the interests of compressing data, it is often necessary to remove detail, fitting them into a storage device of limited capacity, processing them faster or creating less confusing visualizations that emphasize general trends".

Generalisation thus derives a map or dataset with reduced complexity and contents from a detailed spatial data source, while retaining the major semantic and structural characteristics of the source data. Steps include: classification (grouping features according to their type); simplification (removing points to create a simpler shape according to an algorithm such as that developed by Douglas-Peucker1973 (cited in [23]); aggregation (replacement of several polygons by a single polygon [10]); exaggeration (to highlight important features in a map [24]); symbolization (replacing features with point symbols); induction (which infers relationships between features) [18, 24, 26]. Algorithms are generally mature in a 2D context [21, 28, 29, 31, 33] and are embedded in commercial software. Work has also been carried out on 3D generalisation [1, 12, 13, 15, 16, 19, 20].

3. METHODOLOGY

The dataset used for our experiments is a detailed topographic mapping dataset[1] for a suburb in the South East of London (Pettswood). The 2 km by 2 km dataset includes height information for each building polygon (see [8]). For convenience, and given that the primary interest at this stage is the potential improvement in rendering performance rather than task-specific generalisation or the visual output, ESRI's ArcMap software [10] is used for generalisation.

3.1 Generalizing (simplifying and aggregating) and extruding the data

The first stage of our generalisation process involved the removal of any building features with a total area of less than 25 m^2. This stage was followed by a simplification process using a tolerance of 5 m, and then by an aggregation process using a 1 m and 5 m tolerance (Figure 1 below). The average height of the resulting building blocks was calculated by a weighted average height according to the areas of the aggregated blocks.

Oracle Spatial [24] was used to extrude both the original and the generalised datasets (see [8]) and GoLoader software [30] used to load the data. For the detailed dataset, the shared interior walls resulting from the extrusion process were removed [8] leaving the outer shell. For the generalised datasets, a number of invalid polygons caused by the displacement, reshaping and resizing operations [18] could not be extruded (23 for the 5 m aggregation, 103 for the 1 m dataset) and were removed.

[1] UKMap, from The GeoInformation Group, *www.**geoinformationgroup**.co.uk*

Table 1. Results of the generalisation and extrusion process.

	# Polygons (2D)	Area (m^2)	Volume (m^3)	# Faces (3D)
Original data	12757	413273.34	3055072.32	76622 (inner walls removed)
$< 25\,m^2$ area deleted	5819	341745.83	2749486.86	N/A
Simplified data (5 m)	5819	345070.01	2773196.98	N/A
Aggregated data (1 m)	2491	342630.71	2756731.06	24992
Aggregated data (5 m)	1113	384964.48	3099044.63	20913

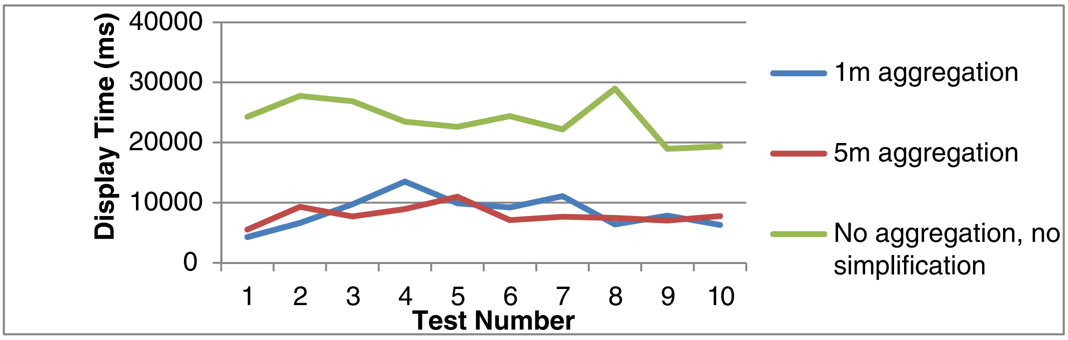

Figure 2. Rendering performance of the generalised and extruded datasets.

3.2 The resulting datasets

Table 1 highlights the changes resulting from the generalisation process, additionally listing the number of Faces that result from the extrusion process. As can be seen, the number of building polygons is reduced significantly by aggregation. It can also be noted that aggregation, in particular using a 5 m tolerance, results in a significant increase in the total building area.

3.3 Visualisation and performance testing

ArcGlobe, part of ESRI's ArcGIS suite [9] was used visualise the results of the generalisation and extrusion processes. A browser-embedded Google Earth plug-in [14] was used for performance testing, with the browser restarted for each test to ensure that the cache was cleared. A test script was written that tracked the time to display the datasets and as Google Earth displays a series of 'base' images underpinning any other data each KML file was set to fly to an identical location on start-up, ensuring that identical image sets were loaded. Each test (1 m aggregation, 5 m aggregation and no aggregation) was run 10 times, for a total of 30 test runs.

4. RESULTS

4.1 Performance

Figure 2 below shows the resulting time to render the three datasets[2]. The overall aim of this process is to reduce the number of Faces that are passed to the rendering pipeline [5] and hence the number

[2] Note that the loading time – i.e. the time taken to download the data from the web server and prepare it for rendering – was measured separately and is not included in the above results.

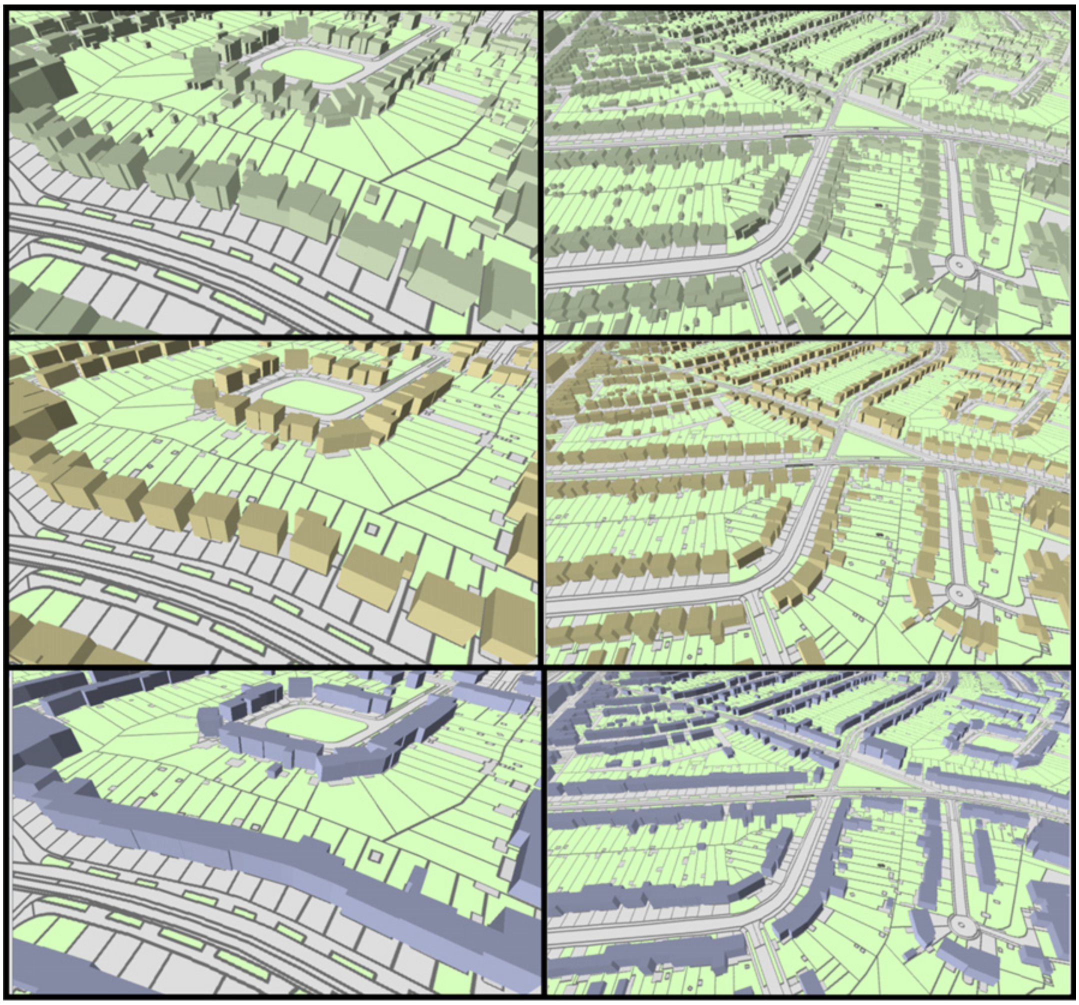

Figure 3. Visual appearance of aggregated datasets – no aggregation or simplification (top), 5 m simplification and 1 m aggregation (middle) and 5 m simplification and 5 m aggregation (bottom).

of Faces input to any visibility pre-computation or clipping. This reduces the overall computational load for the rendering process. The generalisation process results in a significant reduction in rendering performance time, with the un-generalised dataset taking an average of 23,885 ms to render, the 5 m aggregation taking 7,948 ms on average and the 1 m aggregation taking 8,486 ms. The similarity of results for the aggregated datasets reflects the similar number of Faces.

4.2 Visual appearance

Figure 3 shows the resulting 3D maps for the disaggregated (top), 1 m aggregated (middle) and 5 m aggregated (bottom) datasets. As can be seen, a significant loss of detail occurs for the 5 m aggregation when compared to the original dataset – both in relation to building outline and importantly to the gaps between the various buildings. There is also loss of detail in terms of height variation and building outline detail between the disaggregated data and the 1 m aggregation, although the generalisation process has not resulted in loss of significant features or the general sense of the neighbourhood being constructed of small blocks with spaces in between.

Considering these results in the light of the very similar performance results obtained for both 1 m and 5 m aggregation, it is suggested that a 1 m aggregation (along with the 5 m simplification) may yield relatively optimal results in terms of performance, without too much loss of visual detail in the resulting map.

5. DISCUSSION AND CONCLUSION

The results obtained show that there are significant performance gains to be obtained by applying a process of 2D generalisation prior to extruding a dataset into a 3D City Model. Although some detail is lost in terms of the model, the performance improvement resulting in a rendering process 2.8 times faster than the original highlights the potential of this approach; in particular as overall the major semantic and structural characteristics of the source data are retained.

The ability to rapidly display large 3D models is particularly important when considering applications of 3D city models. Unlike in the 2D case, where there is a smooth transition between scales and all data is represented at a level appropriate for the scale in question, in the 3D case a mixed-scale (or level of detail) representation is more appropriate for applications such as urban planning [2, 7, 16] or navigation [3, 4]. Specifically, the user is interested in a high level of detail for their immediate surroundings, but less detail further away. The equivalent 2D generalisation concept is that of 'exaggeration' – where important features are given prominence on an otherwise generalised map, and the generalisation methods shown here could therefore be applied to improve the rending performance of the more distant data elements.

To show the potential of using 2D generalisation to improve 3D rendering, we have utilised a standard out-of-the box generalisation process. This does not take into account the fact that generalisation is very much context/task specific and that different settings are appropriate for different uses. Further investigation into the requirements for context-specific generalisation of 3D datasets, and whether the method described above could meet these needs, is required, along with comparison with the outcome when using 3D generalisation directly. Performance tests should also be extended to more urban datasets, where there are continual blocks of buildings down the street, and the results tested for sensitivity to the smoothing and aggregation tolerances used.

In conclusion, while improving performance is a relatively straightforward issue with easily quantifiable results, providing users of 3D City Models with appropriate content and detail for the task at hand is perhaps more difficult due to the varying nature of uses of such models. The importance understanding what is cognitively useful within a City Model should not be underestimated.

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