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New Horizons for the Standford Bunny : A Novel Method for View Analysis

Neil Sang[1]

[1]Swedish University of Agricultural Science, Alnarp, Sweden.

Summary:

Visualisation and Visual Analysis are placing new demands on spatial data, requiring new analytical methods and with this a need to identify potential sources of uncertainty. This work applies techniques developed in the field of computer graphics to analytical problems at the landscape scale. A series of occluding horizons seen in perspective may be considered as a 2D graph in the view plane. Edges of this graph function to mediate ‘Visual Topology’, which is defined as the topological relationships between objects in the 2D view plane. Visual Topology may be stable under changes in viewpoint, scale and resolution. It therefore presents the possibility of developing landscape metrics that are view specific but which are also stable with respect to local viewpoint change and are thus amenable to mapping. A method is presented for the computation and mapping of Visual Topology that may be of wider relevance to visibility analysis.

KEYWORDS: Visisibility Analysis, Landscape, Topology, Perception, MAUP

1. Introduction

Moran et al. (2003) describe the selection of an appropriate unit of analysis as the “greatest challenge in human ecology”. It is a challenge which must be undertaken if an understanding of processes at the landscape scale is to be achieved since, by definition, landscapes are formed by the interaction of human and natural processes. Unfortunately information on the component parts of such processes is often not available in the same units (Sang, Birnie et al. 2005) leading to Modifiable Area Unit Problems (MAUP). Even where a common spatial base exists such as that for the U.S. Census Bureau’s TIGER data (www.census.gov/geo/www/tiger/) the analytical suitability of this is subject to the operational drivers of that base (Sang, Birnie et al. 2005) which may not be appropriate to the intended use. One end use of increasing significance is landscape visualisation.

Both the scale and displacement problems of MAUP occur when one attempts to model the visual characteristics from a particular point with data available on a map. Perspective influences the scale at which different parts of the map data is seen, and landform can mask parts of the data (Germino M, Reiners W et al. 2001). It could be, for example, that a polygon on the map is classed as heather, but the segment of the polygon actually visible in the view is predominantly rough grassland. These sources of uncertainty may be given focus by any particular perspective view so standard measures of global accuracy such as Root Mean Squared Difference are not appropriate. This poses the question as to whether statistics from maps can be considered relevant to human visual perception, which has a location specific projection and may be partially occluded?

Provided the visualised data is being considered by a suitably trained individual, standard graphical presentation methods might suffice for interpretation. However if one wishes to automatically detect such issues (e.g. in the automated on line visualisations predicted by Bishop and Lange (2005)) or automate production of perspective statistics for analysis, a data structure is needed to give computational access to the view.

The question may be addressed by considering the view as a 2D plane, and thence may be split into a scalar and topological component. As with cartographic projections, geometry will vary continuously with view point change, but the topological relationships between objects may be stable until some event changes this, e.g. occlusion. In cartography, topological change is generally to be avoided. In visual perception it is, according to some seminal research (Kaplan and Kaplan 1982; Gibson 1986) an event of particular interest.

2. Graph Topology of Horizons

For reasons of space, this section must assume a basic familiarity with the concept of topology in general, for background see Kinsey (1991). Visual Topology (VT) is a new term to describe the spatial relations between objects (or parts of the same object) as they appear in the 2D viewing plane. In a landscape context this means that topology may be considered as not only the relationship between landcovers which are physically adjacent, but between a landcover in the foreground and that which it partially occludes. In such a case, a horizon may be visible (if sufficient contrast exists) and such horizons may also intersect each other, as in Figure 1 :

Figure 1 – The Horizon Graph of a View

The horizons thus mediate aspects of the view which have been considered relevant to perception (e.g. fractal index (Hägerhäll, Purcell et al. 2004) or depth of view (Bishop, Wherrett et al. 2000)) and for which one might wish to automatically compute statistics. They also form a graph as in Figure 1, which Sang, Miller and Gold (*subm*) point out is locally stable to view point change. Its topological characteristics may thus be validly mapped to zones. Indeed they represent discontinuities in the visible surface, which make variance in scalar visual metrics over space difficult to predict. Sang, Hagerhall and Ode (*subm*) show that the topological complexity of the Horizon Graph (specifically the number of loops) is itself psychologically salient.

3. Spatially modelling Horizons and Visual Topology.

When performing visibility analysis on a Delaunay Triangular Irregular Network (TIN) one may assume that, unless the terrain were to contain tunnels or bridges[1], by scanning the mesh from the

[1] If there are tunnels, a simple additional operation can be employed to establish visibility. If the point is found to be below an existing line, one can check whether the area in the view below that horizon is solid by querying the vector normal of the potentially occluding triangle's neighbour. If it is groundward, the horizon must be the edge of a tunnel or depression. However for now the simpler case will be assumed. A detailed description of how the algorithms were implemented in Delaunay Quad-Edge TIN can be found in Sang, Gold and Miller (*subm*).

view point outwards, any object with the same x co-ordinate in *screen* space as a previously projected object, and lower screen space y co-ordinate, must be occluded (as expounded from object graphics to GIS visibility analysis by Madern et al. (2007). Intersect testing can be avoided except for edges which, after approximate testing via the end nodes, might still intersect the current horizon, e.g. line a-b Figure 2a (Madern, Fort et al. 2007).

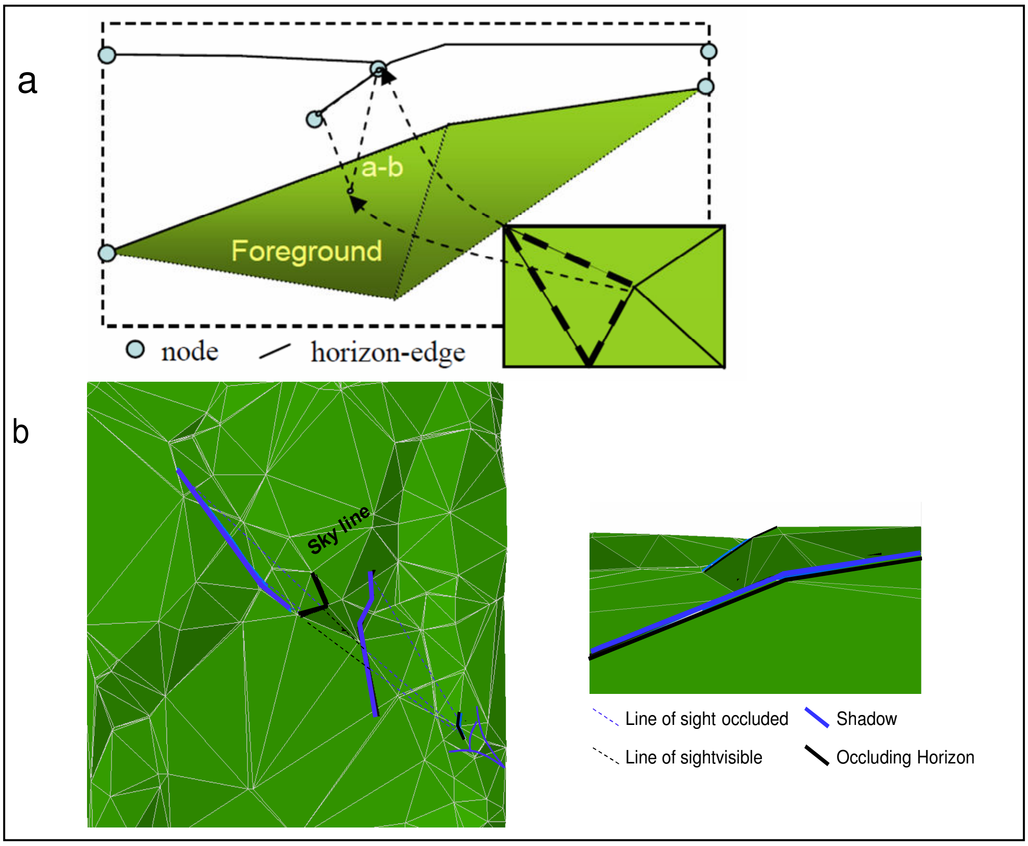

Figure 2 : (a) Maintaining a current horizon for Hidden Surface Removal and (b) the resulting information in orthographic and perspective views

A map of the visible horizon edges, and the edges on which their shadows fall, completely describes the visibility of the land surface in between. So, rather than holding a viewshed as a separate layer, one could incorporate this horizon and shadow information as attributes of the DEM (or a layer draped over it). To determine visibility at any given point, one simply establishes if the first line intersected between that point and the view point is an occluding horizon, if so, the point is occluded, else it is visible (Figure 2b).

When an intersection is identified the occluded edge has a pointer attribute set to the memory address of the occluding edge, thus VT is encoded in 'Shadow-Horizon Links' forming one or more trees from background to foreground. In Figure 3 this is shown by the green lines drawn between the mid-points of each edge, not the points at which the intersection occurs, and so does not always fall along a line of sight spatially. This is intended to emphasise that the links are topological not geometric.

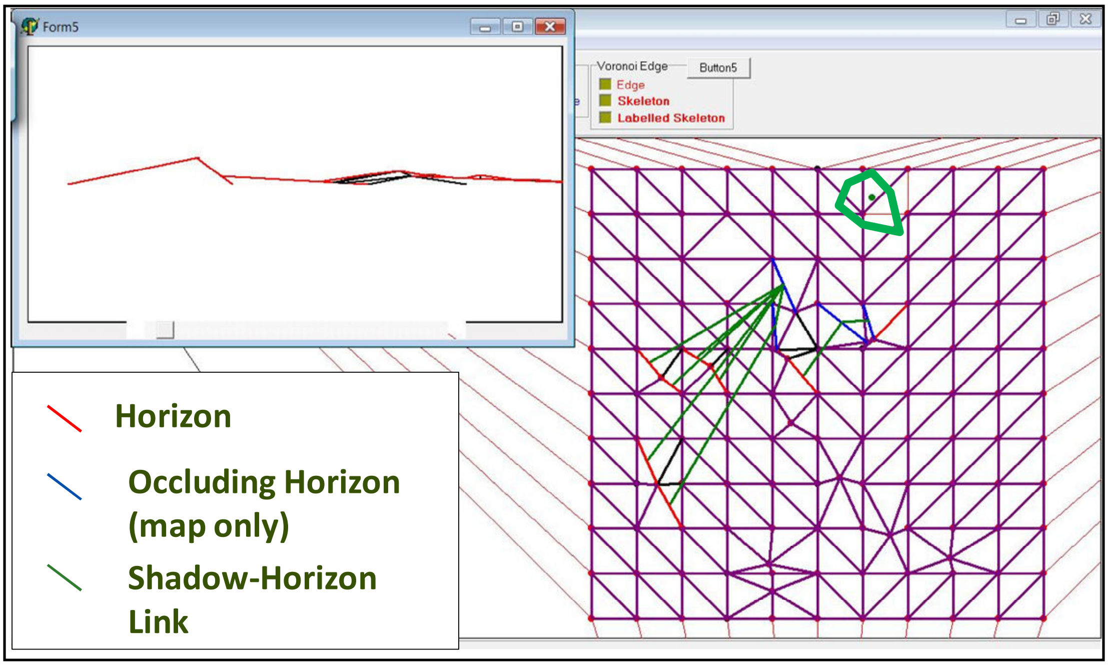

Figure 1 : Perspective and map views of a horizon graph and Shadow-Horizon links

4. Conclusions

The data structure developed has several notable advantages compared to a raster viewshed :

- The geometry of the view may be recovered.
- Unless there is a topological event, the map in Figure 3 will not change under viewpoint change. The view point (the green point to the top left Figure 3) could thus ascribe an area within which the topological horizon characteristics are stable (*illustrated* by the green polygon) creating a zonal map.
- The Shadow-Horizon Link can be used to query cross horizon adjacency and, depth of view change. This allows calculation of visual metrics such as those mentioned in section two, but also identification of when map polygons are intersected by horizons and thus when issues of MAUP may be present.
- There is no reason why multiple such sets of links cannot be embedded to provide for multiple viewpoints.
- Since, in theory, topological relationships are a-scalar the memory requirement for recording the Shadow-Horizon links is independent of the resolution of the dataset, only the number of edges needed to model the horizons shadows would change, a minimal increase.
- The Horizon-Graph is encoded.

Although important research questions remain, Visual Topology presents potentially new approach visual modelling in GIS. It allows scene analysis based on a richer representation of visual perception, which is a fundamentally individual experience. It provides the basis for data structures that can generate metrics from this rich scene information, including taking into account the qualitatively different nature of scene topology. Finally, it also provides a rationale for landscape reporting units with some measure of homogeneity and scale-independence in their scenic properties.

7. References

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7. Biography

Neil Sang has worked as researcher in GI Science at the James Hutton Institute (formerly the Macaulay Land Use Research Institute) for 10 years. His main interest is developing theory and methodology in response to applied problems in spatial analysis, and creating software solutions to deliver these to scientists from other fields. This work represents a summary of his PhD undertaken part-time at the University of Glamorgan. He also holds a part time position at the Swedish University of Agricultural Sciences (SLU), focusing on process models in forestry.