Return of the Stanford Bunny - Definition, Computation and Application of Visual Topology.

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1. Introduction

The visual characteristics of a landscape are widely experienced but, difficult, and controversial to define (Walker 1995). Recognition of their importance, in treaties such as the European Landscape Convention (Council of Europe 2003) and European Council Directive 97/11 (which enacted the Environmental Impact Assessment (EIA) system in Europe (EC 1997)), has led to the need for an 'objective' assessment of their values and the potential impact of changes to them.

Both the scale and displacement forms of the Modifiable Area Unit Problem (MAUP) (Openshaw 1984, Sang et al 2005) occur when one attempts to model landscape value as it appears from a particular viewing point, using data available on a flat map (Sang Ode and Miller 2008). Perspective influences the geometry and scale at which different parts of the map data are seen, and topology is affected when landform masks one part of the data (Sang Ode and Miller 2008). 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. This limitation in the data may be more significant if that unit is in the foreground than in the background, since it fills a greater percentage of the view.

However, while apparent geometry and scale vary continuously with any small change in viewpoint, the points at which particular landscape units become partially or entirely masked are discreet events, as are those when two land covers appear to become adjacent in the view, or when linear features appear to meet (for example the classic "layered" v-intersections of hills). This makes variance in geometric measurements with different view points difficult to estimate, but also identifies when the connectivity of shapes in the view change and, conversely, when it is locally invariant to change in view point (hence the term 'Visual Topology'(VT)). There is some evidence to suggest that the topology (Egenhofer and Herring 1990, Kinsey 1991) of landscape is cognitively significant (Appleton 1996, Sharif Egenhofer and Mark 1997, Mark and Turk 2003, Mark and Egenhofer 1995). Identifying the areas where VT is locally stable (and hence geometric variance with view point is statistically tractable) could help place the selection of view points on a more objective basis, a particular problem for ensuring legitimate representation in landscape research and planning processes (Appleton and Lovett 2005).

2. Establishing Visual Topological Relationships

There are two basic forms of VT, inter-visibility (along lines of sight as per a standard visibility graph) and 'lateral topology' (which elements appear to be next to each other from a given perspective). They are both, however, mediated by the same elements – horizons and their shadows.

Inter-visibility may be viewed as a topological concept as it describes an information link between the two points. O'Sullivan and Turner (2001) argue that, since the process of determining what locations are visible from where is so computationally expensive, it may instead be pre-calculated and stored as a topological matrix. However the number of viewpoints is limited by computational cost and by concentrating only on the inter-visibility topology, the arrangement of objects cannot be re-constructed from the matrix (O'Sullivan and Turner 2001). In practical terms, this means that because the relationship between the viewer and those objects ascribing the view is not retained, one cannot predict whether a landscape or view point change is likely to affect the inter-visibility graph, and where. Dynamic processes would therefore need to repeat the computationally expensive visibility calculations at each step.

To establish the apparent adjacency between objects in the view (lateral topology) is problematic for traditional ray tracing based visibility analyses as the visible areas are often fragmented on the map, while screen projections are usually "dumb" having lost the relevant classification information, and means to re-connect this information are often slow (Sang Ode and Miller 2005). Thus while existing approaches to visibility analysis (Burrough and McDonnell 1998) hidden surface removal and image rendering (Foley et al. 1990, Purcell et al 2002, Yang et al. 2006) provide the means to map visibility or quickly render objects such as "the Stanford Bunny" for visualisation, they do not provide all the required functionality for landscape analysis.

Both problems arise from the fact that the visibility information has been removed from its spatial context. Rather than building visibility information in a separate map or matrix we propose building the horizon and shadows into the primary data by setting pointers from one to the other.

3. Scanning Horizons

Horizon edges can be detected efficiently on triangulated terrains by comparing the vector normal of each triangle, with the viewing vector (Southerland et al. 1974) (Figure 1). If the vector Normal is less than 90 degrees from the viewing vector, the face must be visible, if over 90 degrees the triangle must be facing away from the viewer. TIN provide implicit topology so which triangles are adjacent to each other can be established (Wang et al 2001). If one triangle is facing the viewer, and its neighbour facing away, then the common edge must form a horizon in the view. The data set which must be projected to establish the relative location of surfaces across horizon boundaries in perspective view, is thus reduced to a limited set of point pairs.

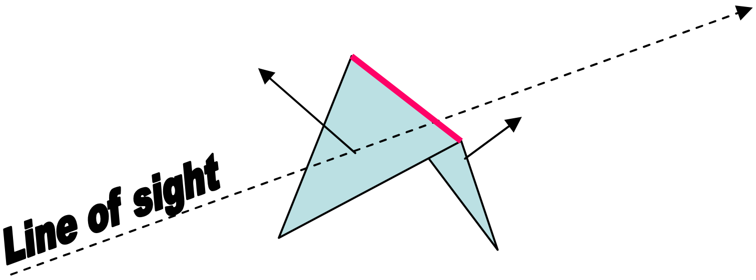


Figure 1. Horizon identification

4. Casting Shadows

Gold, Nantel and Wang (1996) describe an algorithm where by the triangulation may be traversed such that those elements nearer to a particular point are processed first. Applying this to visualisation, when a horizon is identified and projected to screen coordinates (e.g. line 'a-b' in Figure 2), if it falls below existing horizon lines, the edge must therefore be hidden behind a closer feature. If above previously projected features, it forms a new horizon, and if it intersects the existing horizon, this identifies a node in the horizon graph. The lines and edges in the completed horizon graph may then be subjected to Euler's equation (Euler 1735) as a metric of its topological complexity.

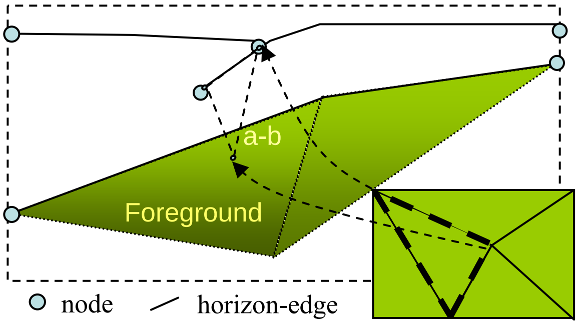


Figure 2. Horizon Graph

The result from the intersection is, in fact, the shadow the more distant horizon casts on the screen intersecting the shadow of the nearer horizon. Since both the projected element and the element it intersects are known at this time, a pointer may be set in the TIN between the two. The more distant elements will, when projected, be smaller than those projected first, so many more distant elements may intersect a nearer one providing a tree of pointers along lines of sight, by which the terrain may be navigated from the horizon to the view point. This avoids the geometric problems of building visual topology from a visibility map of equally sized pixels and retains the classification information in the original TIN.

5. Dynamic Update

Since we are storing the visual topology within the original TIN structure, much can be done to predict when a change in view point or landform might require a new visibility calculation and where. If a change in landform occurs an initial prediction as to its visibility can be made from its position relative to the horizon and shadow elements and then (more precisely) by whether it intersects the plane between them.

If the viewpoint changes incrementally, it may be initially assumed that the shadow will also move only incrementally. It makes sense therefore to initially only test those elements nearest the previous shadow line, to see if the new shadow line is found, and move progressively away from that point. In this manner, a complete new visibility analysis will be avoidable in most cases.

If the change is only regarding attributes, and will not affect visibility, the change in apparent visual relationships can be established directly from the pointers between horizons and shadow edges, making such change update very efficient.

6. Application

A common methodology to relate landscape characteristics and visual preference, is to rank scenes according to what score each receives using indices, developed within landscape-ecology, such as Mean_Shape Complexity (e.g. as edge to area ratio) and Shannon Diversity Index (i.e. the number of patches of different land covers per area) (McGarigal et al 2002; Ode Tveit and Fry 2008). Photographs or computer generated visualisations of the study area are then presented to survey respondents to be ranked according to preference. However, landscapes may rank differently for some indicators, depending on whether the index scores are calculated on the planar map or in perspective view, so changing the direction of any correlation with preference (Germino et al 2001, Sang Ode and Miller 2008). VT may help identify where these effects are significant, and objectively select view points which are typical of those to be found in a landscape region.

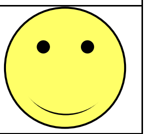
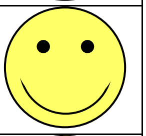
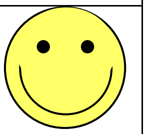
Landscape Image	Indicator: Patch Size	Preference
	10	
	6	
	4	

Figure 3 – Landscape metrics and preference correlation

Figure 4 – Landscape preference measurement with the Virtual Landscape Theatre.

8. Conclusion

The provision of pointers along lines of site to link spatial information with visual topology provides the option to automate operations that model spatial data based on visual effects, and to incrementally update visibility analyses. In particular it provides the potential for:

- More objective selection of viewpoints in landscape planning and research. Based on the mean and variance of landscape metrics in perspective view for regions that are topologically invariant under local viewpoint change.
- Testing of the graph complexity of horizons as an explanatory variable of landscape preference and the facility to map this factor if it proves significant.
- Automatic analysis of local landscape change in perspective view, including framing effects.
- The possibility of efficiency savings in dynamic visibility analysis for some kinds of landscape.
- The possibility of embedding VT for sights of particular significance into the DTM (for example as part of an SDI serving EIA).

The author is aware of exceptions with which this approach does not presently deal. For example where a new horizon arises which was not previously apparent, this cannot currently be detected by local methods, however the advantages the method appears to offer for a qualitatively richer analysis of visual-data suggest the method merits further research. While the intention is to facilitate rural landscape management and planning, it is hoped there may be wider applications, for example urban design and automated route planning, where such perspective information could warn for blocked lines of sight, or predict the most visually interesting route.

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Biography

Neil Sang is a researcher in Geographical Information Science at the Macaulay Land Use Research Institute (Aberdeen, Scotland). A core theme of interest is to develop methods for measuring and improving the “fitness for purpose” of spatial data, for example through spatial sampling design and spatial data infrastructures. He is currently undertaking a part-time PhD at the University of Glamorgan, for which the particular “purpose” in question is modeling and analysis of visual landscape character from cartographic data.