Real-time visibility analysis and rapid viewshed calculation using a voxel-based modelling approach

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Summary: This paper examines the utility of visibility analyses for calculating intervisibility and zones of visual influence across a range of application areas. Most proprietary off-the-shelf GIS software packages provide basic visibility analysis tools, but these are generally slow making real-time animation of viewsheds impossible and detailed analysis of whole landscapes using high resolution DEMs impractical. This paper describes a simple, easy to use and highly efficient viewshed algorithm and desk top tool for interrogating viewsheds in real-time for large high resolution digital surface models and batch processing of exhaustive cumulative viewshed analyses for landscape visualisation and assessment.

KEYWORDS: voxels, real-time viewsheds, visibility assessment

1. Introduction and background to the problem

Visibility analyses in GIS calculate the theoretical area visible from an observation point across a landscape taking terrain surface height into account. There are many applications of visibility analyses in GIS ranging from visualisation and optimum siting of facilities through to impact assessment and landscape evaluation. Examples include evaluation of the inter-visibility between archaeological sites (Fisher et al., 1997), siting of mobile communications towers (Oda et al., 2000), assessment of Zones of Visual Influence (ZVIs) from wind farm developments (Bishop and Miller, 2007) and modelling absence of human artefacts in wilderness quality indices (Carver et al., 2012).

One of the problems with visibility analysis is that they are computationally intensive and times taken to run even a single observation point across large, high resolution terrain models can be long, especially if wanting to take distance decay effects into account. When dealing with a small numbers of observation points ($n < x10^3$) off-the-shelf visibility analyses provided by proprietary GIS are more than adequate. However, when dealing with much larger numbers of observation points ($n >> x10^3$) and very large, high resolution DSMs (ncells $> x\ 10^6$) the speed at which standard tools run can be a significant bottleneck. This was the case with a recent project to develop indices of wildness for the Scottish national parks where it was necessary to model the absence of modern human artefacts within the landscape based on visibility measures and distance decay effects at a resolution of 20m. Estimated run times measured in years rather than days or weeks using proprietary software meant a more efficient approach had to be found (Carver et al., 2012). An innovative solution was created utilising ray-casting methods and a voxel-based viewshed transform to produce a practical tool for calculating millions of viewsheds on a standard desktop PC.

2. Method

A number of authors have identified speed and efficiency of the algorithms used as a possible area for improvement. A variety of efficient algorithms have therefore been reported in the geocomputation literature. These include examples such as R2, R3, XDraw, line-rasterisation, tracking-in, tracking-out, etc. (e.g. Andrade et al., 2011) many of which rely on making trade-offs between accuracy and speed. While some authors have experimented with algorithm efficiency, others have looked towards advances in computing power to address the problem, such as the application of grid computing and parallel computing architectures (e.g. Mills et al., 1992).

The algorithm employed herein is very similar to the "R2" algorithm described by Franklin & Ray (1994). Such raycasting algorithms have been implemented in computer gaming software since the early 1990s, but have been largely usurped by polygon-based approaches supported by modern graphics hardware. It is unclear whether the brevity of their success in that field has any bearing on why they have been seemingly overlooked by developers of mainstream GIS software and tools, but they can be shown to be of enormous practical benefit here.

Theoretically, the computation time of an algorithms like R2 is linear in the number of cells which constitute the region of interest for which visibility is to be computed. However with a little pre-computation the performance is in practice *sub*-linear, owing to the fact that as we cast a ray further and further from an observer point, we are increasingly likely to have encountered a feature substantial enough to constitute a "horizon", at which point we can terminate the ray.

Linear and sublinear algorithms are particularly well placed to take advantage of Moore's law, and to contend with parallel advances in terrain model resolution. Franklin & Gousie (1999) describe the computation of visibility for *every* point on a terrain model. Whereas the point-viewshed algorithm at the heart of their approach took approximately a second to compute on a 1201x1201 cell terrain using a modest desktop PC, the present implementation is able to perform several hundred (more than sufficient for real-time viewshed exploration) and whole-terrain viewshed transforms in a matter of hours. Such whole-terrain transforms allow for the ZVIs of 100,000's of features over an entire landscape by considering the cumulative viewshed of all features impacting on every grid cell in a terrain model.

The algorithm has been embedded within a user-friendly GUI and can be run either from the desktop on a single PC or across the network on multiple machines to further speed up processing times for very large areas (Figure 1). A tiling-tool has been added to facilitate this process. The interface allows users to input a large DSM as a floating point raster and a feature layer containing up to seven separate feature classes. Observer height and maximum/minimum search radius can also be set. Distance decay effects can be calculated as $1/d$ or $1/d^2$ giving the relative height and surface area of a feature cell, respectively (where d = distance from the observer). When run in batch mode, the viewshed of every grid cell in the input DSM is calculated and the relative proportion of the viewshed occupied by a feature or the background terrain is stored. Output viewshed transforms from the tool can be generated either as separate feature layers or combined layers and saved on logged and unlogged scales in floating point grids. These can then be input into a GIS package for combination with other data layers.

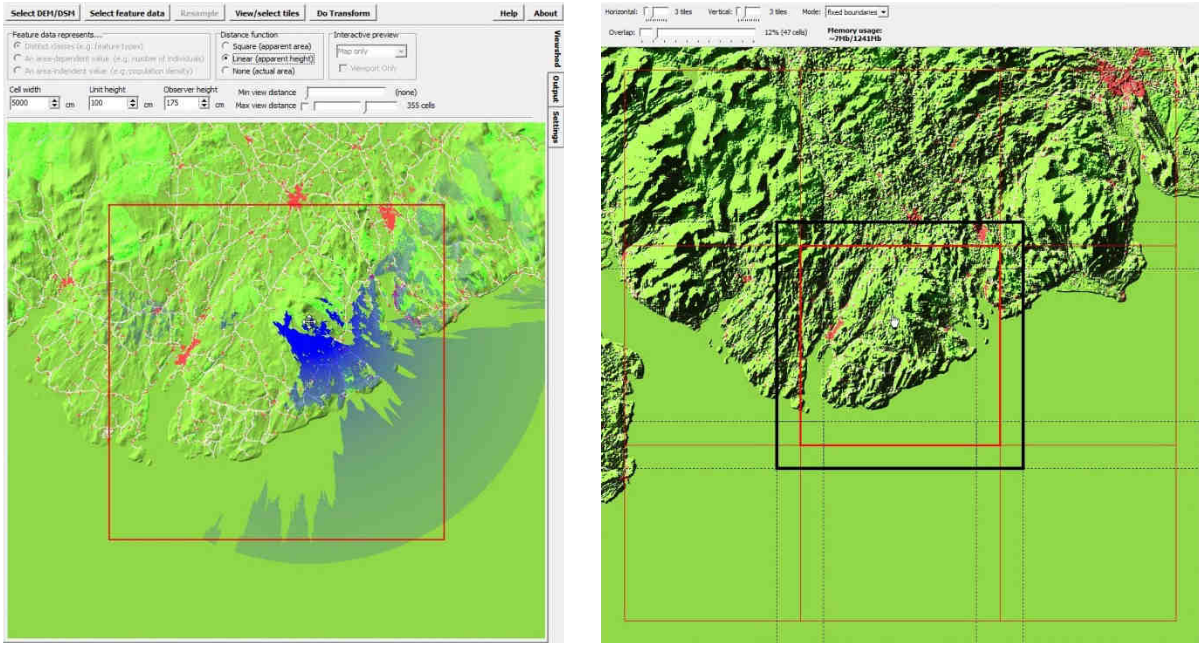

Figure 1. Voxel Viewshed Explorer Beta 1 GUI

3. Results

The algorithm has been validated against the visibility tools provided by a number of proprietary GIS packages. These include ESRI's ArcGIS10, Idrisi Kilimanjaro, and SAGA. Binary viewsheds for 20 randomly selected points across Scotland where calculated using ArcGIS, Idrisi, SAGA and the Voxel Viewshed Explorer and the results compared. The viewshed extents produced using the Voxel Viewshed explorer compare very well and are within 98% overlap (Figure 2). Comparisons with ArcGIS indicate that the Voxel Viewshed Explorer tool is between 1000 and 1500 times faster leading to huge efficiency gains and much reduced run times.

The algorithm and GUI have also been tested on a range of datasets and several projects. These include work carried out for the Scottish national parks developing an index of absence of modern human artefacts for use in wildness mapping (Figure 3).

5. Discussion and conclusions

The obvious advantage of the algorithm and tool described here is that speed of viewshed estimation together with distance decay calculations is massively increased over proprietary software without any undue sacrifices in terms of accuracy. This opens up a whole range of possible application areas for viewshed analyses where these have hitherto been impractical due to the massively long run times involved. Current applications by the authors have focused on landscape visualisation and assessment in support of wildness mapping both in the UK and abroad. Other applications currently under development include visibility-based assessment of landscape geomorphometrics (Washtell et al., 2009) and siting of wind turbines in sensitive landscapes (Carver and Markieta, 2011).

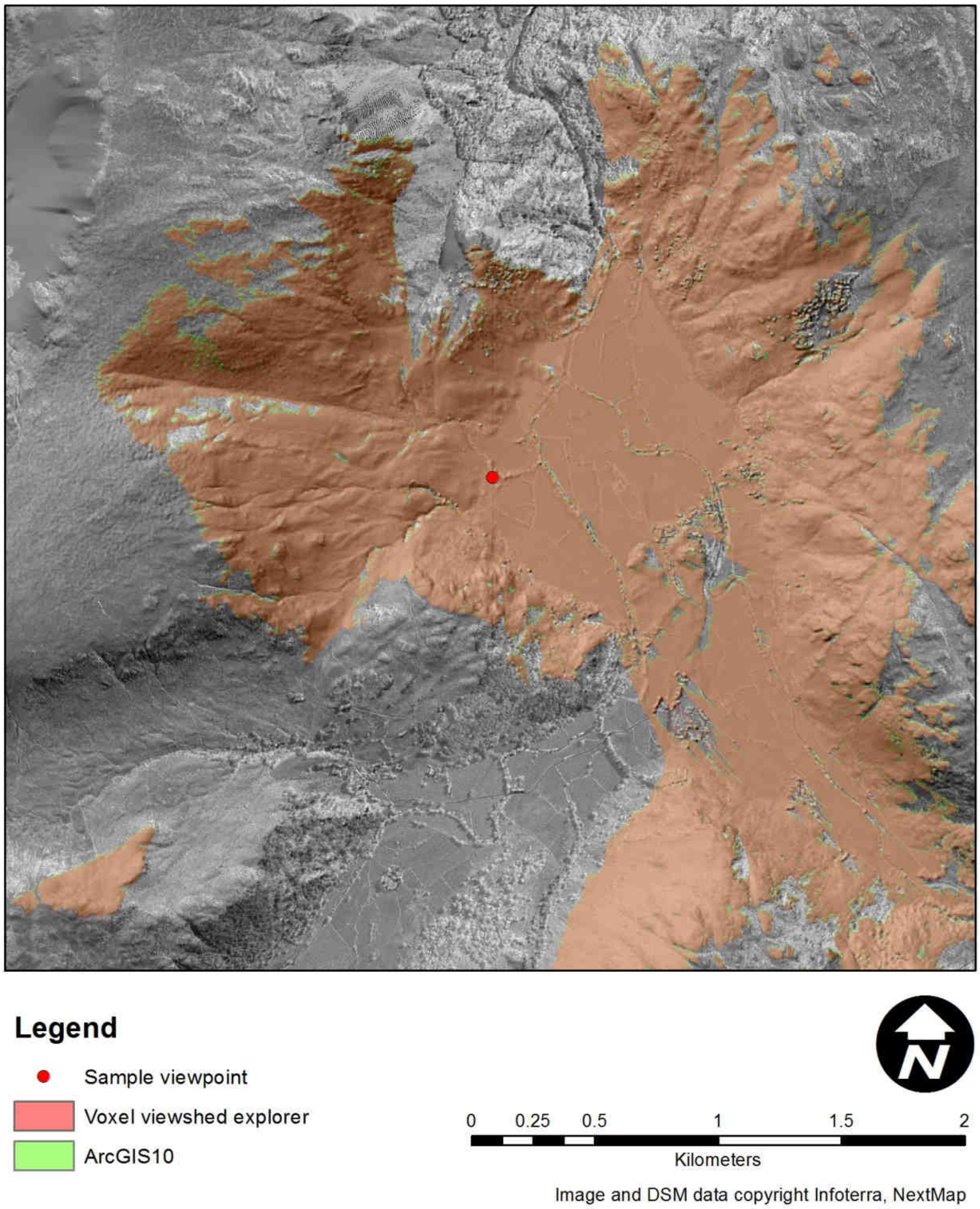

Figure 2. Comparison between ArcGIS and Voxel Viewshed Explorer output

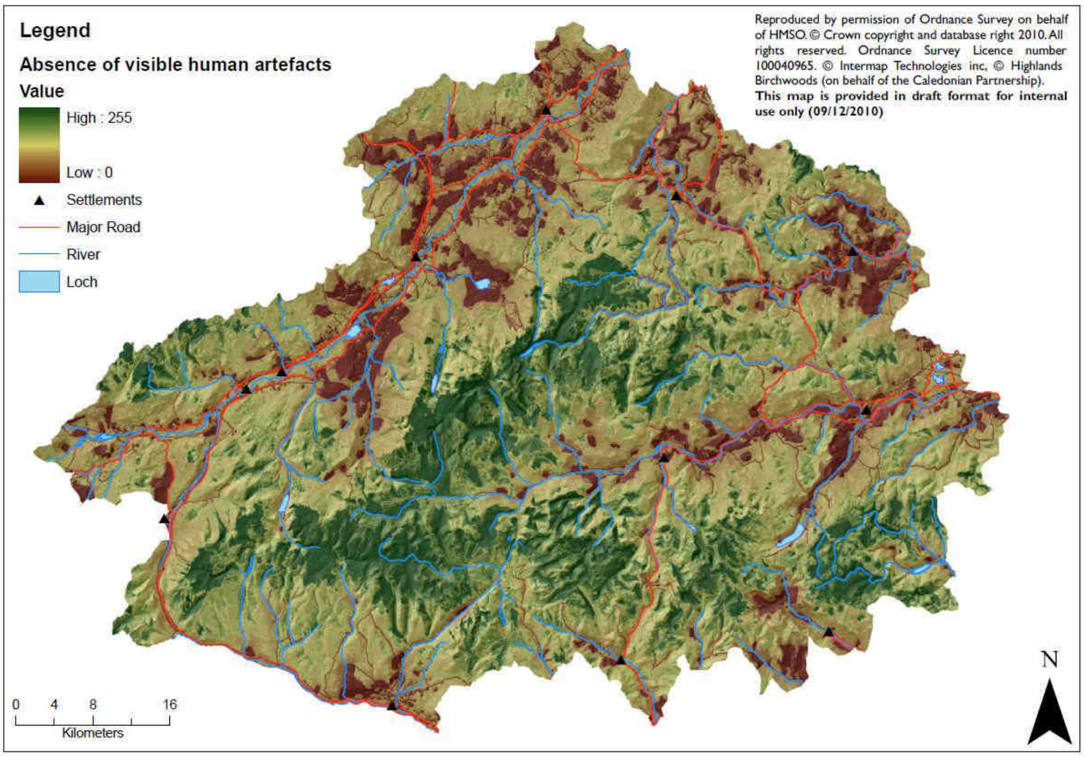

Figure 3. Absence of visible human artefacts in the Cairngorms National Park

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Justin Washtell is an ESPRC Doctoral Prize Fellow in Computing at the University of Leeds. His interests are mainly focused on computational natural language semantics, but additionally includes computational geography.