Optimal Portrayal of Contour Information over Steep Terrain

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1.0 Introduction

Isolines have proved to be a highly effective way of conveying the shape of a surface (most commonly in the form of height contours to convey geographical landscape). Selecting the right contour interval is a compromise between showing sufficient detail in flat regions, whilst avoiding excessive crowding of lines in steep and morphologically complex areas. The traditional way of avoiding coalescence and confusion across steep regions has been to manually remove short sections of intermediate contours, while retaining index contours. But incorporating humans in automated environments is not viable. One approach has been to automate manual approaches using map generalisation methodologies. This research reports on the design, implementation and evaluation of an automated solution to this problem involving the automatic identification of coalescing lines, and removal of line segments to ensure clarity in the interpretation of the geographical surface. The algorithm was applied to isolines derived from OS Land-Form PROFILE data, for intended inclusion at the target scale of 1:50K. Evaluation was made by subjective comparison with OS 1:50K Landranger product. The results were found to be very close to the quality associated with manual techniques. The methodology can be applied to the representation of isolines at all scales, and has application in other areas of map generalization.

1.1 Context

The hand drawn solution in Figure 1, shows Ordnance Survey 1:50,000 Scale Colour Raster in which contour line segments have been partially removed in order to improve interpretation and to avoid confusion.

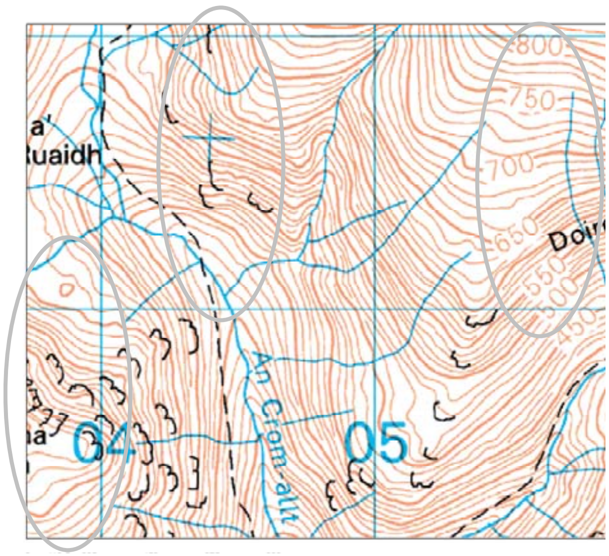


Figure 1: Hand drawn solutions: Ordnance Survey 1:50,000 Scale Colour Raster (grey circled regions show partial removal of isolines over steep ground).

2.0 Methodology

The aim was to derive (from very detailed mapping) a generalised set of contours suitable for display at 1:50,000 scale. The process was made up to two distinct phases. The first phase was to create a more generalised smooth surface from which a set of contours could be derived (this is termed model generalisation). The second phase was to improve the clarity and legibility with which the contours were portrayed over steep ground (this is termed cartographic generalisation). Model generalisation is straightforward in this case; it is the cartographic generalisation process that is the focus of this paper. Assessment was made through visual assessment of various outputs from different areas of Scotland and reviewed by cartographers at the Ordnance Survey.

2.1 Model Generalisation of the Surface

Model generalisation used a script written in ESRI's macro language, AML, developed by Rana (2004). The macro utilised the TOPOGRID ArcInfo function (support.esri.com), itself based on the ANUDEM algorithm (cres.anu.edu.au/outputs/anudem.php) developed by Hutchinson (1989). It took as input OS' land-form PROFILE data, 10m vector product (an example is given in Figure 2a) from which a raster product was generated. The macro works iteratively to derive ridges and channels. These were then used to produce a constrained generalised surface using TOPOGRID. The resulting smoothed surface was then processed using 3D Analyst (within ESRI's ArcGIS system). This allows the contour interval to be specified and produced as output, a set of vector based isolines (an example is given in Figure 2b). It was this set of contour lines that were used in the second phase of the project – namely cartographic generalisation.

2.2 Calculating the optimal contour intervals

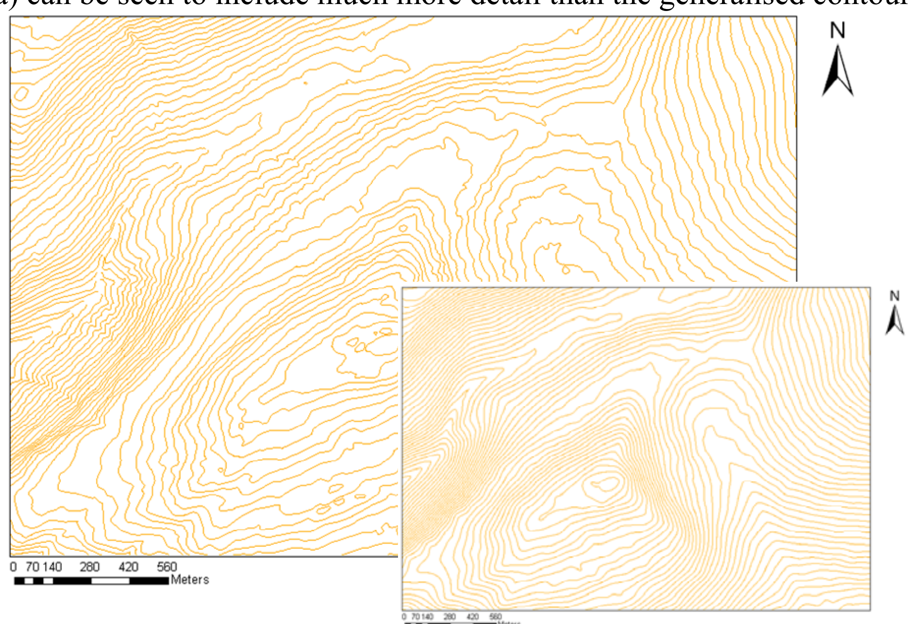
The selection of the 'right' contour interval is critically important. Generally, contours work well at portraying mountainous areas but where there is a greater contrast in relief they are less effective (Monkhouse and Wilkinson, 1971). There is a trade-off between the amount of information contained in a map and its legibility. Imhof (1982) devised an equation to calculate the smallest contour interval, A:

$$A = \frac{M.\tan\alpha}{1000.k}$$

where A = the smallest possible difference between contours in metres;
M = the scale denominator (for example 50,000);
α = the angle of the slope;
k = the maximum number of contours legible per 1 millimetre of horizontal interval.

For the study area of the Cairngorms, substituting α with α_{max} ($\alpha_{max} = 46.8°$) and using a value of 2 for k (the OS 1:50,000 contour specifications state that 10m contours are 0.1mm in width, the 50m contours 0.3mm in width and that the space between contours should not be less than 0.4mm) gives a shortest possible contour interval of 26.6m. Yet the OS use an interval of 10m. The OS combination of 50m index contours and 10m intermediate contours allows flatter landforms to be well represented but requires partial removal of contour segments across steeper regions sufficient to meet OS's recommended minimum separation between lines of 0.4mm.

The first study area chosen was a 20km by 25 km area in the Cairngorms. The Cairngorms are characterised by steep slopes and high, rounded mountains so providing plenty of different examples of places where contours need to be removed to prevent fusing of the lines. A second study area was 20km by 20 km just north of Glen Affric in the West and East Benula Forest area. This region has a different geological and geomorphological history to the Cairngorms, resulting in a landscape characterised less by the classic 'u-shaped' valleys of the Cairngorms. An example output from this process is given in Figure 2. The original contours at 1:10,000 scale (Figure 2a) can be seen to include much more detail than the generalised contours (Figure 2b).



(a) (b)

Figure 2. Land-Form PROFILE contours at 1;10,000 scale (Ordnance Survey © Crown Copyright), and contours generated by the model generalisation process, prior to cartographic generalisation.

3.0 Cartographic Generalisation of the Contour Lines

Once the output had been generated from the model generalisation process, it was necessary to devise a method for detecting areas where contour lines fused. Initial ideas centred on buffering of the lines, but far greater control over the process could be gained by recognising the fact that there is a direct correlation between the number of contours likely to fuse and the steepness of the ground. Therefore a digital elevation model was used to detect regions of varying steepness. The first stage was to identify and separate out, the 50m index contours in the vector file, since no cartographic generalisation would be applied to these contours given their importance in the map.

From the DEM a series of polygons were generated, each polygon covering a section of ground at a specific gradient (‘Gradient polygons’ Figure 3). These polygons were used to ‘cookie cut’ the vectors – thus creating four different sets of isolines, each receiving different treatments (‘Intersect’ Figure 3). The ‘contour segment removal’ (CSR) algorithm was used to filter out vector lines according to simple rule set based that was based on 1) the steepness of the region, and 2) the number of intermediate contours falling within the region (‘CSR Algorithm’ Figure 3). The next stage was to create masks for each of the regions (‘Erase’ Figure 3). This simple step has the effect of creating a set of ‘bands’, each band containing an increasing amount of generalisation in each of the gradient polygons. Once the line de-selection is completed, the various sections of lines are reconstituted back together again, together with the original index contours to give the final map. This whole process is pictorially represented in Figure 3.

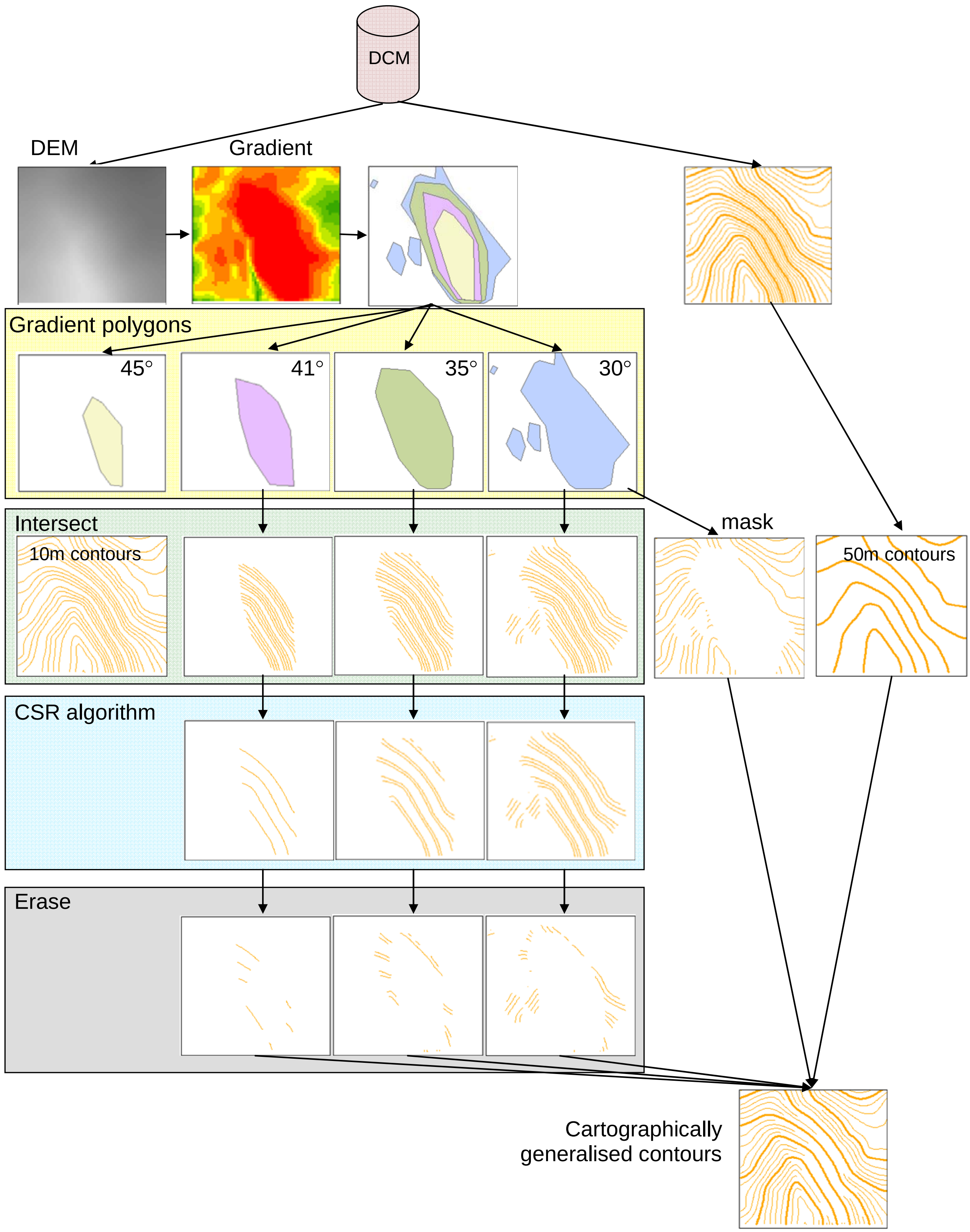


Figure 3: Summary of the cartographic generalisation process.

3.1 The Contour Segment Removal Algorithm

There are four 10m intermediate contours between the 50m index contours. The contour segment removal algorithm (CSR) was designed such that as the ground steepened, an increasing number of intermediate contours would be removed. Thus, four threshold gradient values were required where at each value another intermediate contour would need to be removed. From the gradient raster (derived from the DEM) it was observed that contours came within 0.4mm of each other for gradient values of 30° or more. This was ascertained by visual inspection of various parts of the OS 1:50,000 map of the Cairngorms. The process involved overlaying the gradient polygons and inspecting the changes that had been made to the map in each of the polygons. Via the same method of inspection, the other threshold values were ascertained. Where the gradient was between 35° and 41° two 10m contours were removed. For gradients between 41° and 45°, three 10m intermediate contours were removed and all four 10m intermediate contours were removed at gradients over 45°. The CSR algorithm need only be applied to the interval contour sections that intersect with the various gradient thresholds (Figure 4). The 50m index contours were left unchanged for the rest of the process as they were not to be removed under any circumstances (OS 1:50,000 contour specification).

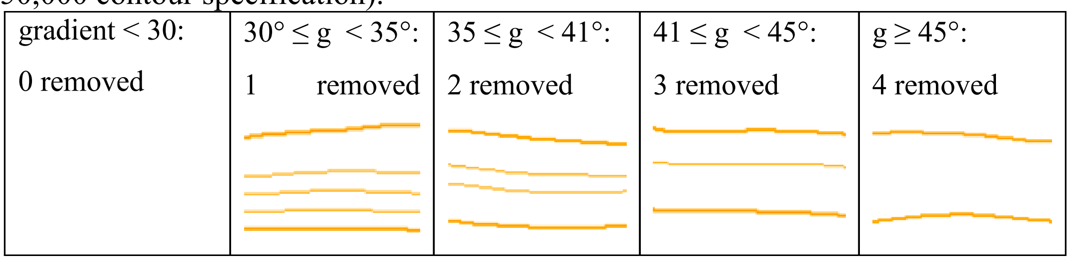


Figure 4: the five different gradient levels and the contour removal at each gradient level (g).

4.0 Implementation and Evaluation

ESRI's ArcGIS software suite was used to process the data. The algorithm to remove sections of contours was written in Java and was applied only to those sections of intermediate contours (not the index contours) falling within the gradient polygons (Steven 2005).

Where the gradient was greater than 45°, all of the 10m intermediate contours were removed. Again these areas were found to match with corresponding areas from the OS 1:50,000 map (Figure 5 and 6). As the polygons for gradients over 45° are generally small, this leaves small gaps in contours at these gradients. While this is usually to be avoided, slopes as steep as that rarely occur so in this case it is less important. Furthermore, comparison with the OS 1:50,000 map shows that where all four intermediate contours are dropped, the gaps are small too.

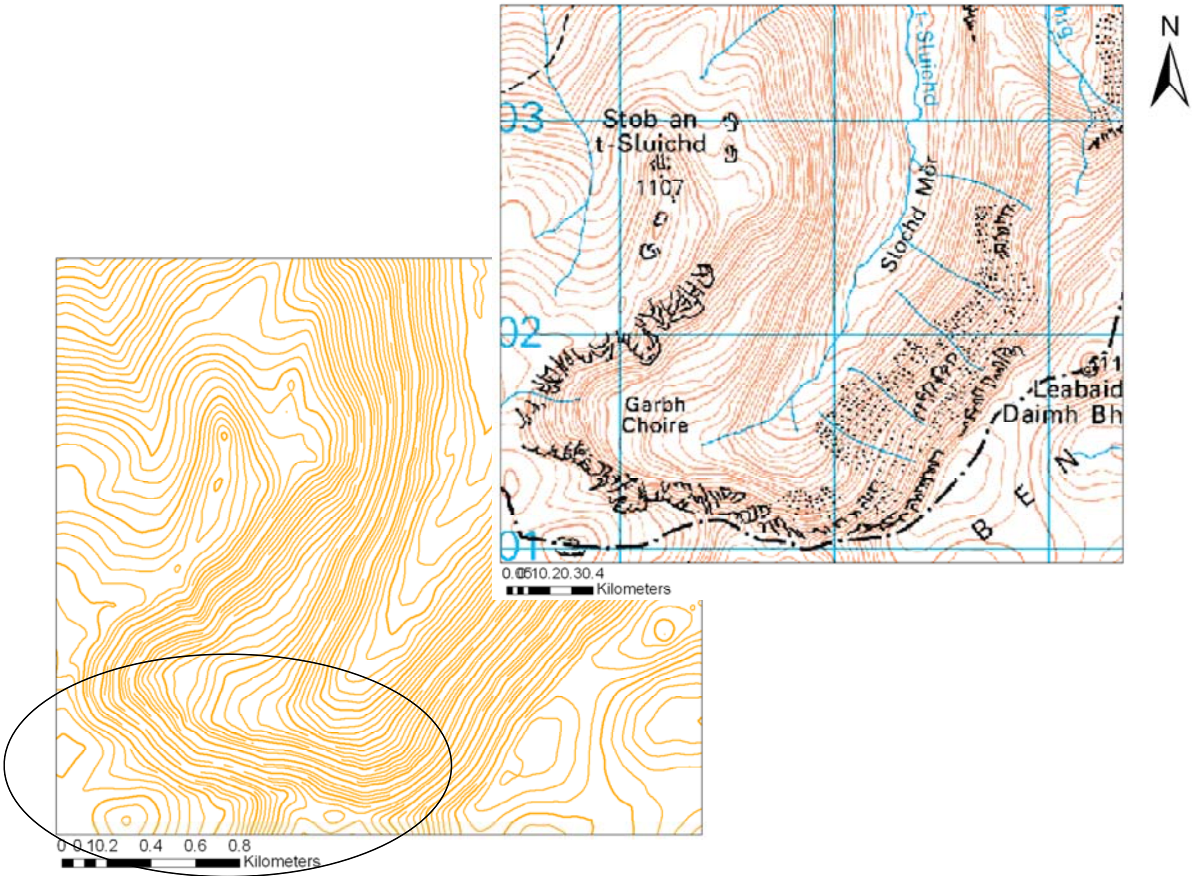


Figure 5: The circled region contains examples of where groups of 1- 2- 3- and 4- intermediate contours have been removed, and the same area for the 1:50,000 Scale Colour Raster, Ordnance Survey © Crown Copyright. All rights reserved.

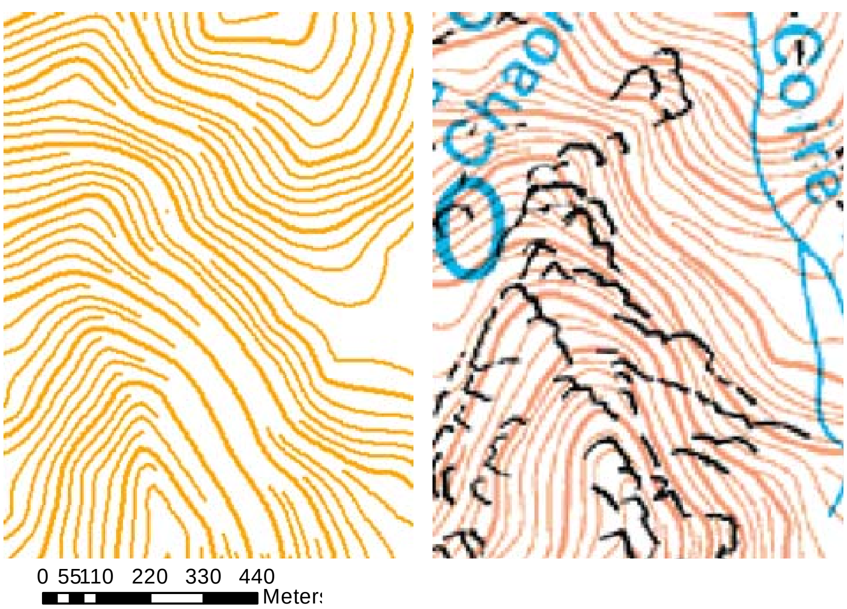


Figure 6. (a) the corresponding results from the automated solution; (b) OS 1:50,000 instances of all intermediate contours dropped. Ordnance Survey © Crown Copyright. All rights reserved.

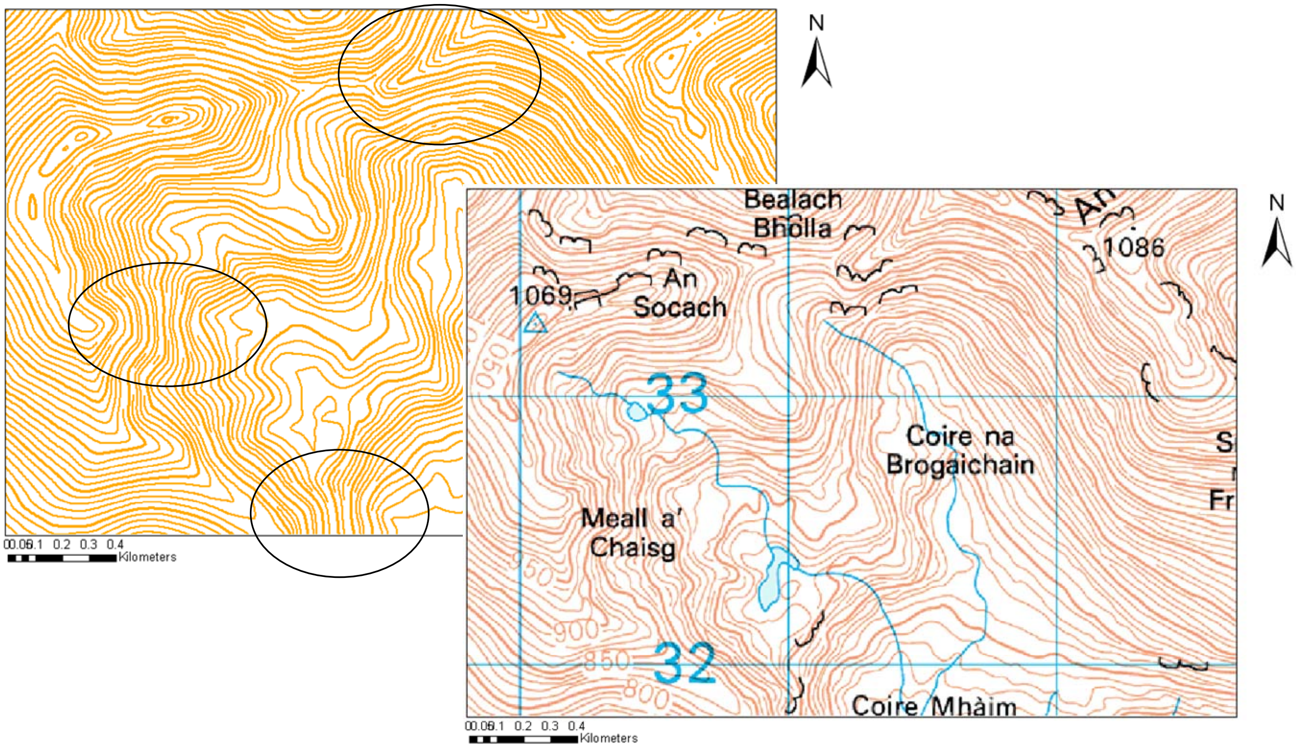


Figure 7: A comparison in the Glen Affric area. Highlighted circles show removal of various intermediate contours, examples of regions that have particularly good agreement with the OS solution (Ordnance Survey © Crown Copyright. All rights reserved).

The algorithm was iteratively improved, using the Cairngorms study area. It was then applied to a different region to assess its robustness. The North of Glen Affric was chosen because of its differing morphology. A comparison with the paper map revealed a very similar success rate (example output is shown in Figure 7) - again highlighting cases where slight displacement might be preferred, and where short segments close to one another produced a dashed line effect.

5.0 Discussion and Conclusion

The requirement for removal of segments of contours arises wherever there is variation in morphology. For as Imhof argues, there is not a single ideal contour interval that would work for every landscape type. The Ordnance Survey's choice of interval is such that segment removal is integral to the successful portrayal of contour information in steep regions. That choice of interval is in anticipation of the application of this technique. Whilst hand based solutions have worked in the past, current technological paradigms call for automated equivalents to the art and science of cartography.

Topographic maps contain an optimal 'volume' of information and the map reflects a compromise at a number of levels – that superimposed on the height information is other content that acts to clarify and reinforce ideas about the steepness and rich morphology of the landscape. It is therefore argued that analysis of the solution needs to be seen from a holistic perspective – alongside associated text, pictorial information (rock and scree symbology), spot heights and contour labelling. The synergy and reinforcement between these other variables cannot be ignored. Perhaps there is a danger that we critique too precisely the output of the algorithm and fail to take into account the overall final solution that would of course include this other information.

This research has demonstrated that a combination of model and cartographic generalization techniques can be used to derive and visualize surface morphology at a range of levels of detail, appropriate for printing or digital display. More specifically this work has demonstrated that the removal of contour segments to improve the clarity with which contour information can be presented can indeed be formalised and automated. The algorithm can be readily adapted and the rule set refined, for example to handle different map specifications (such as the Canadian specification), different contour intervals and gradient ranges, or where display device resolution does not support the fidelity in the line weight (requiring a heavier line and therefore great removal of segments to avoid 'fusing' of contour lines).

7.0 Acknowledgement

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8.0 References

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