An Algorithm for Localised Contour Removal over Steep Terrain

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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. Incorporating humans in automated environments is not viable. 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 contour information. Evaluation was made by subjective comparison with Ordnance Survey products. The results were found to be very close to the quality associated with manual techniques.

INTRODUCTION

The representation of relief is fundamental to topographic mapping and many thematic map types. The challenge of representing relief is reflected in the broad variety of techniques that have variously been developed (Imhof, 1982) to represent a three-dimensional landscape in two-dimensions (Monkhouse and Wilkinson, 1971; Collier et al., 2003). Although areas of high relief may seem imposing to the eye, the distance between landscape features is significantly larger than the landscape height. Relief ranges from approximately plus or minus 10 km above or below sea level while the distance around the equator is about 40,000 km. The challenge of representing relief cartographically is to maintain the emphasis of an imposing landscape whilst creating a map that is legible and gives the appropriate level of detail for its intended purpose (Lyons, 1914). The purpose of the map governs decisions on everything from the map scale to the amount of information conveyed – the scale of the map very much governing the appropriate level of detail. Map purpose and scale also govern the most appropriate method for representing relief (Imhof, 1982). A mix of qualitative and quantitative techniques has variously been proposed. They include hill shading, hypsometric shading, hachuring, pictorial representation, and contouring (Robinson et al., 1984). The focus of this research is on the optimal portrayal of contours. Contours are the most appropriate method for displaying relief at large and medium scales – the scale, complexity of terrain, screen resolution or pen width determining the most appropriate contour interval (Robinson et al., 1984).

Traditional approaches to map production have given way to the creation of multiple databases from which a range of cartographic products can be derived (Li and Openshaw, 1992; Li and Sui, 2000; McMaster and Shea, 1992; Zâšek and Podobnikar, 2005). A huge amount of research in the field of map generalisation reflects efforts to capture the art and science of cartography and embed it within highly automated environments (Rieger and Coulson, 1993). There are considerable benefits that can arise from this paradigm shift (Kraak and Ormerling, 2003; João, 1998) and there has been extensive research into map generalisation techniques (Jones et al., 1995; Bundy et al., 1995) as well as development of conceptual models and frameworks in which the entire process can take place (Brassel and Weibel, 1988). Specific research relevant to the work presented here includes work by Li and Sui (2000); Saux, (2003); Gold and Thibault (2001) all of whom have worked on methods for line generalisation and representation of height information. The inherent value that lies in various approaches to representing surface morphology is reflected in the efforts to provide automated solutions to what were traditionally hand based techniques. Automatic hachuring (Regnauld et al., 2002) and hill shading (Brassel, 1974; Zhou, 1992; Yoeli, 1967) being just two examples. Attempts to formalise these techniques have highlighted the subtleties and complexities of their application, and the challenges of evaluating solutions that have reflected a traditional aesthetic.

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This paper is concerned with the automated cartographic portrayal of contour information, with a specific focus on the representation of line work over steep terrain. As maps at 1:50,000 scale are primarily used for location and orientation (Monkhouse and Wilkinson, 1971), relief should be portrayed in such a way that the overall landscape shape is immediately apparent and assessment of morphology and height can be ascertained. The standard method used by the OS when displaying relief at 1:50,000 scale is to use a mix of intermediate and index contours at 10 m intervals – the index contour (every 50 m) represented by a heavier line weight. Over steep terrain, and small contour intervals, contour lines can become so close that they visually ‘fuse’ together thus making interpretation of form and shape confusing. Traditionally sections of the contours were removed in the scribing process so that the continuity of other adjacent contours could be discerned. In some instances additional pictorial representations (rock symbolism) are superimposed to reinforce the notion of steep ground (Figure 1). The continuity of adjacent lines helps the eye to ‘join up’ such broken lines. This idea is based on the principle of good continuation: ‘that elements that appear to follow in the same direction … tend to be grouped together’ (Coren and Ward, 1989). Thus a series of smoothly connected elements will naturally be perceived as a single graphical object. To date, none of the research in map generalisation has addressed the problem of line segment removal to prevent this visual ‘fusing’ of isolines. In essence, this research attempts to automate a manual technique – namely the removal of small segments of contour lines in order to improve the legibility of height information.

The structure of this paper is as follows: we begin with a description of the methodology, briefly describe the implementation, and present a range of outputs which are...
The macro utilised the TOPOGRID ArcInfo in ESRI’s macro language, AML, developed by Rana (2003). Model generalisation was performed using a script written by the author. Model generalisation of the surface was performed in the TOPOGRID ArcInfo environment. The TOPOGRID ArcInfo environment was used to preserve morphology across a range of grid cell sizes by incorporating local terrain features (channels and ridges). Rana (2003) combined TOPOGRID with an iterative smoothing operation to ensure optimal feature classification. The method was intentionally designed to handle OS Land-Form PROFILE datasets with the intention of producing multi scale and morphologically consistent terrain generalization. Both Land-Form contour line shapefiles and Land-Form spot and air height point shapefiles were used as inputs to the process which returned a generalised DEM constrained to ridges and valleys used to ensure consistency with landscape topography (Steven, 2005). From this DEM, contours were derived (see later section). The original contours at 1:10,000 scale (Figure 3a) can be seen to include much more detail than the generalised contours intended for visualisation at 1:50,000 scale (Figure 3b).

Calculating the optimal contour intervals

The very fact that contours apparently fuse (Figure 3b) arises because the contour interval is too small given the steepness of the region being portrayed. 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). Steep areas require contour intervals to be large enough so that contours do not become too dense such that they obscure other map content. Conversely, where relief is much flatter, less slope detail can be seen as the intervals can be larger than some landform features. Consequently 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, $A$:

$$A = \frac{M \cdot \tan z}{1000 \cdot k}$$

where $A$ = the smallest possible difference between contours in metres;
- $M$ = the scale denominator (for example 50,000);
- $z$ = 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 $z$ with $z_{\text{max}}$ ($z_{\text{max}} = 46.8^\circ$) and using a value of 2 for $k$ (the OS 1:50,000 contour specifications state that 10-m contours are 0.1 mm in width, the 50-m contours are 0.3 mm in width and that the space between contours should not be less than 0.4 mm) gives a shortest possible contour interval of 26.6 m. The interval is awkward (even if rounded) and fails to convey detail in flatter areas. As the map scale decreases, the limitations of one contour interval become increasingly apparent. The most common method of solving the problem of choosing contour intervals is to use a combination of index and intermediate contours. Intermediate contours can show more detail in flatter areas and be removed in steeper areas (Figure 1 is an example of function [url 1], itself based on the ANUDEM algorithm [url 2] developed by Hutchinson (1989). TOPOGRID works by fitting a discretised thin plate spline surface through contour data. TOPOGRID is able to preserve morphology across a range of grid cell sizes by incorporating local terrain features (channels and ridges). Rana (2003) combined TOPOGRID with an iterative smoothing operation to ensure optimal feature classification. The method was intentionally designed to handle OS Land-Form PROFILE datasets with the intention of producing multi scale and morphologically consistent terrain generalization. Both Land-Form contour line shapefiles and Land-Form spot and air height point shapefiles were used as inputs to the process which returned a generalised DEM constrained to ridges and valleys used to ensure consistency with landscape topography (Steven, 2005). From this DEM, contours were derived (see later section). The original contours at 1:10,000 scale (Figure 3a) can be seen to include much more detail than the generalised contours intended for visualisation at 1:50,000 scale (Figure 3b).

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![Diagram](image1.png)

**Figure 2.** Overall methodology: the arrow conveying the idea of iterative refinement of the model and algorithm through evaluation of map output.

then compared with existing map products (themselves derived from hand drawn maps). We conclude with suggestions for further work.

**METHODOLOGY**

The aim was to derive from very detailed digital elevation data, a generalised set of contours suitable for display at 1:50,000 scale. The process was made up of three distinct phases (Figure 2). The first phase was to create a more generalised smoother surface of the digital elevation model (DEM), and to use this as a basis for automatically creating a set of contours (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 specific focus of this paper. The third phase was to assess the quality of the output. This was done by applying the algorithm to two different mountainous regions. The first study area chosen was a 20 km by 25 km area in the Cairngorms, Scotland. The Cairngorms are characterised by steep slopes, ‘u-shaped’ valleys and high, rounded mountains so providing a variety of different places where contours need to be removed to prevent fusing of the lines. Through empirical observation, the algorithm was tuned and then applied (using the same parameters) to a different region to assess the robustness of the solution. The second study area was 20 km 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, and a landscape more modified by fluvial processes (Summerfield 1991).

**Model Generalisation of the Surface**

Model generalisation was performed using a script written in ESRI’s macro language, AML, developed by Rana (2004). The macro utilised the TOPOGRID ArcInfo function [url 1], itself based on the ANUDEM algorithm [url 2] developed by Hutchinson (1989). TOPOGRID works by fitting a discretised thin plate spline surface through contour data. TOPOGRID is able to preserve morphology across a range of grid cell sizes by incorporating local terrain features (channels and ridges). Rana (2003) combined TOPOGRID with an iterative smoothing operation to ensure optimal feature classification. The method was intentionally designed to handle OS Land-Form PROFILE datasets with the intention of producing multi scale and morphologically consistent terrain generalization. Both Land-Form contour line shapefiles and Land-Form spot and air height point shapefiles were used as inputs to the process which returned a generalised DEM constrained to ridges and valleys used to ensure consistency with landscape topography (Steven, 2005). From this DEM, contours were derived (see later section). The original contours at 1:10,000 scale (Figure 3a) can be seen to include much more detail than the generalised contours intended for visualisation at 1:50,000 scale (Figure 3b).
this). The appropriate number of intermediate contours depends on the interval of the index contours as well as the relief being portrayed. Imhof (1982) acknowledges that the selection of contour interval is most difficult at 1:50,000 scale. To quickly select information from a map, contour intervals should be numbers that are easily divisible and calculable. The OS combination of 50-m index contours and 10-m 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 0.4 mm.

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. Initially research focused on calculating a threshold distance between contour lines as a basis for weeding out contours. This proved problematic principally because it was very hard to build up a picture of where groups of contours were close to one another. It was observed that there was a direct correlation between steepness and the number of contours likely to fuse. Therefore a different approach was adopted (based on calculating gradient polygons) that gave us a much more complete picture of the same information, was simpler to implement, and far less computationally intensive. Slope was calculated (using the digital elevation model as input) and a gradient raster was generated before being converted to a polygon shapefile [url 1] (Steven 2005), which resulted in a classified set of polygons (‘Gradient polygons’ Figure 4), each polygon representing a region of specified steepness (Figure 5).

The next stage was to separate out the 50-m index contours in the vector file, since no cartographic generalisation would be applied to these contours given their importance in the map (Figure 1). The gradient polygons were used to ‘cookie cut’ the vectors – thus creating four different sets of isolines, each receiving different treatments (‘Intersect’ Figure 4). The ‘contour segment removal’ (CSR) algorithm (described in more detail later) was used to filter out vector lines according to a simple rule set that was based on 1) the steepness of the region, and 2) the number of intermediate contours falling within the region (‘CSR Algorithm’ Figure 4). The next stage was to create masks for each of the regions (‘Erase’ Figure 4). This simple step has the effect of creating a set of ‘bands’, each band containing an increasing amount of generalisation of the vectors falling within each of the steepening gradient
Figure 4. Summary of the cartographic generalisation process
polygons. For those sections of contours falling across gradient polygons of 45° or steeper, they were simply all removed. 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 4.

The Contour Segment Removal Algorithm

There are four 10-m intermediate contours between the 50-m 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. The challenge was in generating a set of gradient polygons, (each polygon covering a small range of gradient) for which a particular operation should be carried out. Gradient can be calculated in a number of ways, and results vary depending on the size of area over which gradient is calculated. In essence, matching action to gradient was done through empirical observation. From the gradient raster (derived from the DEM) it was observed that contours came within 0.4 mm of each other for calculated 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. This visual inspection process involved overlaying the gradient polygons and inspecting the changes that had been made to the map in each of the polygons (Figure 5). Via the same method of inspection, the other threshold values were ascertained. Where the gradient was between 35° and 41° it was observed that two 10-m contours were removed. For gradients between 41° and 45°, three 10-m intermediate contours were removed and all four 10-m 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 6). The 50-m 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).

It was often the case that within a particular gradient polygon there was a choice as to which contours should be removed. Figure 7 shows a polygon of gradient between 30° and 35°. In this example, the index contour presents four cases where generalisation is required. These cases contain one, three and four contours in conflict (Figure 7). According to the ‘rules’ in Figure 6, one contour should be removed in each case. The question becomes, ‘for cases of more than one contour, which contour should be removed?’.

The choice was based on OS’s specifications for contours on 1:50,000 scale maps which stated that they should usually be omitted in the order lowest, highest, second lowest, second highest. One could imagine alternate specifications. For example, the Canadian Centre for

### Table 1: Contour Segment Removal Algorithm

<table>
<thead>
<tr>
<th>Gradient Range</th>
<th>Number of Contours Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient &lt; 30°</td>
<td>0 removed</td>
</tr>
<tr>
<td>30° ≤ g &lt; 35°</td>
<td>1 removed</td>
</tr>
<tr>
<td>35° ≤ g &lt; 41°</td>
<td>2 removed</td>
</tr>
<tr>
<td>41° ≤ g &lt; 45°</td>
<td>3 removed</td>
</tr>
<tr>
<td>g ≥ 45°</td>
<td>4 removed</td>
</tr>
</tbody>
</table>

Figure 6. The five different gradient levels and the contour removal at each gradient level (where g is the gradient of the polygon)
Topographic Information guidelines on dropping contours from 1:50,000 scale maps suggest dropping firstly one or both of the central intermediate contours, then one or more of the remaining intermediate contours, then the index contour only if necessary [url 3]. Whichever was chosen, we can summarise that the algorithm selects contours based on the gradient at which the conflict occurs, the number of contours involved and the height of those contours relative to the index contour. Table 1 presents the pseudo code summarising the conditions governing contour removal. Note that the algorithm works by successive removal of contours at increasing gradient. For example, for all the polygons greater than 30°, (not just polygons with gradient between 30° and 35°) a contour is removed, for all the polygons greater than 35° a further contour is removed, and so on. In this cumulative manner, by the time the polygons with the steepest gradient are processed, all four contours have been removed. For a more detailed explanation of the implementation see Steven (2005).

Refinement of methodology
Initial results from the algorithm produced contours that appeared dashed (Figure 8). This arose where relatively small, irregular polygons (representing various regions of steepness) intersected the contour line at frequent intervals. To reduce this effect, the polygons were simplified in ESRI ArcMap to give the polygons a more generalised form (Figure 9). This was done by applying a standard line simplification algorithm within ESRI ArcMap [url 1]. Furthermore, from empirical observation, it was determined that a limit should be set on the smallest length of contour segment that should be deleted. By studying and comparing output with the pilot area, the minimum length was determined to be 100m. These two refinements significantly improved the quality of the output.

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). As with many cartographic generalisation techniques, evaluation often consists of comparison with existing map products – reflecting the idea that the hand printed map reflects some optimal design. Because of the subjective nature of assessment, evaluation was in two parts: presentation of results and discussion with cartographers at The OS, and visual comparison between hand drawn and automatically derived maps. In the paper-based method, evaluation consisted of identifying regions of different steepness across the map (30–35°, 35–40°, 40–45° and >45°) and comparing output from the algorithm with the paper map. Once the algorithm had been calibrated using the sample data, it was then applied to a different study area, the Glen Affric area of the North-West Highlands to provide a test of how well the algorithm could be applied to regions other than the Cairngorms. The output was also submitted to cartographers at the OS for evaluation.

Gradients of 30–35°
At gradients greater than 30°, only one of the four 10-m intermediate contours was removed. The identification of contour conflict at gradients over 30° coincided in many cases with where cartographer’s manual generalisation had...
removed contour sections. Usually the lowest of the four intermediate contours was removed to remove clutter around the thicker index contours. While most cases appeared to be dealt with appropriately, there were a few cases where the solution was not considered ideal as the line happened to convey important morphological information (Figure 10). This is an issue that is discussed later in this paper.

Gradients over 35°
Where the gradient is over 35°, the cartographer’s evaluation stated there was ‘effective removal of two contours’. Simple scenarios where the most appropriate contour to remove was the highest of the four intermediate contours were handled well. In some areas where the polygon was quite small, there was a tendency to create a dashed effect – where short sections of contour segments were removed. This was less of a problem for gradients over 41° since these areas tended to be quite small in extent. Figure 11 shows output demonstrating the removal of 1-, 2-, 3-, and 4- intermediate contours. It makes very favourable comparison with the OS product. It is worth noting how pictorial cliff symbology is used in some areas to reinforce the notion of steepness (information that could only be derived from aerial photography).

Figure 9. (a) Polygons of gradients over 30°, over 35°, over 41° and over 45° (each polygon is laid on top of the others); (b) polygons after simplification

Figure 10. (a) Gradient polygons, and b) removal of contour segments that carried important information on the morphology
Where the gradient was greater than 45°, all of the 10-m intermediate contours were removed. Again these areas were found to match with corresponding areas from the OS 1:50,000 map (Figure 12). As the polygons for gradients over 45° are generally small, this leaves small gaps in contours at these gradients. Comparison with the OS 1:50,000 scale map shows that where all four intermediate contours are dropped, the gaps are small too.

Displacement of contours

Whilst there was some variance within gradient bands, an overall count was made, and an assessment was made as to whether pairs of solutions (hand drawn or computer generated) were the ‘same’ or ‘not the same’. About 80% were deemed to be ‘the same’ – that the choice of contour and length of segment removed were the same. However, to say that a particular solution (either automated or by

Figure 11. 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, © Crown Copyright/database right 2006. An Ordnance Survey/EDINA supplied service

Figure 12. (a) The corresponding results from the automated solution; (b) OS 1:50,000 instances of all intermediate contours dropped. © Crown Copyright/database right 2006. An Ordnance Survey/EDINA supplied service
hand) was right or wrong is highly problematic! In some cases, the algorithm highlighted cases where rules governing hand drawn solution were not consistently applied. In some cases the cartographer appeared to have slightly displaced the lines to avoid having to break them (Figure 13a). In discussion with cartographers at OS, it was felt that in some instances displacement was preferred to line removal. Many displacement algorithms have been developed (Mackaness and Purves 2001; Burghardt and Meier 1997), and in theory it would be possible to modify the rules such that displacement could be an alternative solution to segment removal (applicable to Figure 10 perhaps). But in cases where the contours are displaced, we have unwittingly shown the land as being flatter than it really is. This is quite different from the removal of information. In such cases, it is not better to omit this information and let the adjoining contours carry the message – namely that the ground is steep? (Figure 13b). These differences can be very subtle. By the time additional information has been superimposed on the map – such as rock and scree symbols, text, relief shading, spot heights – it is doubtful that any difference in the interpretative process can be measured.

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 14) – again highlighting cases where slight displacement might be preferred, and where short segments close to one another produced a dashed line effect.

**DISCUSSION**

The requirement for removal of segments of contours arises wherever there is sharp variation in morphology. As Imhof (1982) argues, there is not a single ideal contour interval that would work for every landscape type. The OS’s choice of interval is such that segment removal is integral to the successful portrayal of contour information in steep regions. The 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.

The algorithm presented here was iteratively refined and applied to different landscapes. The algorithm was based on map specification documents that detail the optimal order of removal of interval contours. The idea of using gradient to determine regions in need of cartographic generalisation was efficient and effective in predicting the degree of conflict and the consequent amount of remedial effort required. Across a range of gradients, the algorithm performed well, both from lay inspection of the output and from comments from expert cartographers. One situation where there was ambivalence in the cartographer’s evaluation was in the case where all four intermediate contours were removed. In some situations, the removal seemed appropriate while in others this generated some dashed contours. The contrasting opinions revolved around the fact that while short contour sections and short gaps should be avoided, in some situations this could not be avoided.

In some instances, a dashed line effect arose where small gradient polygons intersected the same contour line. This was remedied by generalising the gradient polygons, and setting a minimum length for removal. In other instances, it was felt that a case could be made for displacing adjacent contours rather than removing segments. But in these and all other instances, it is important to reflect on the overall effect – rather than focussing too much on individual cases. It should be noted that the task of conveying morphology is very much ‘shared’ among the contours. Where contour segments are required to be removed, there will always be another contour very close by that is conveying very similar information. In this sense the shape and steepness can be said to be conveyed vicariously. It is precisely this fact that enables us to remove sections of contours without overly disturbing the underlying information.
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.

In examining various output it was noted that some contours are more important than others by virtue of the fact that they reflect a particular shape feature in the landscape. Perhaps the algorithm could be modified to incorporate their relative importance in reaching decisions about which contour to remove. A contour may delineate some sort of morphological anomaly and we might therefore attach some extra importance to it, such that it was not removed. For example, it could be argued that individual contours running parallel to each other along the valley side have less importance than contours that cross the valley floor, or convey a ridge (Figure 10) or ‘nick point’ in the streambed. Much work has been done to try and segment lines according to their various characteristic forms (Plazanet et al. 1995), including the use of fractals (Dutton, 1981). In the context of relief, this has proved to be very complex, something that is both scale (Wood, 1996) and task dependent. The idea of relative importance is highly problematic. With respect to the example just given, perhaps the parallel lines along the valley side represent lateral moraines or indicate previous sea levels – thus making them just as important as any other section of contour. Thus, it is not at all clear whether 1) it would be possible to identify the relative importance of different segments of the same contour, or 2) how the significance of that importance would be modelled in the context of this research.

CONCLUSION

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 greater removal of segments to avoid ‘fusing’ of contour lines).

While the need for automated generalisation solutions is clear, there is still considerable debate as to the level of automation achievable or desirable. While we might comment on the subjectivity of a manual approach, there is no doubt that the critical role it plays in clarifying contour information over steep regions. An equivalent automated solution provides a robust, quality controlled and systematically applied solution, that ‘fits’ within current technological solutions. The current drive is for development of single detailed databases from which multiscale products can be derived. It is now possible to create fine scale surface representation automatically using a number of remote sensing technologies, most notably by Light Detection and Ranging (LIDAR) which is an airborne mapping technique which uses a laser to measure the distance between the aircraft and the ground resulting in the production of cost-effective terrain data. The full potential of utilising this type of information, presented at varying levels of detail, can only be exploited if functions for automated generalisation such as the one presented here are made available as standard within GIS.

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