Automatic identification of Hills and Ranges using Morphometric Analysis

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1. Introduction

The breadth of cartographic techniques developed over the centuries for representing the earth's morphology is testament to its importance (Imhof, 1982). The shape of the earth's surface reflects a multitude of geomorphological processes interacting with the surficial geology. Altitude, slope and aspect have a huge bearing on patterns of land use and habitation. The correct interpretation and 'reading' of the landscape is critical to navigational tasks and safe route planning and execution (Purves et al., 2002). A variety of cartographic techniques have been developed to convey morphology – from the very fine scale, using hachuring (Regnauld et al., 2002), hill shading and contouring (Mackaness & Stevens, 2006), through to the very coarse scale in which colour tints and text are used to convey highly generalised caricatures of components of the earth's surface (Figure 1).

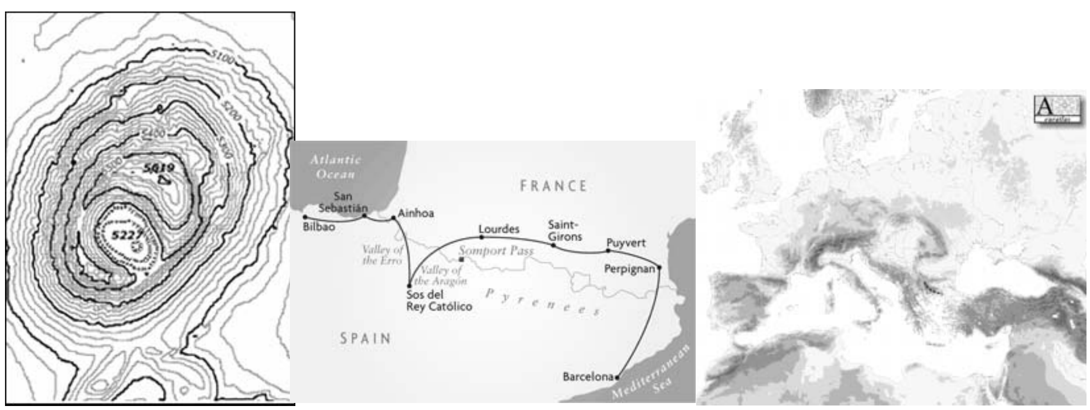

Figure 1: A variety of techniques used to convey generalised views of morphology increasingly (from individual hills to mountain ranges)

It is not simply the case that as the scale changes it convey less detail in a feature; more the case that at smaller scales one begins to see different types of features - from the individual hill to the connected set of ridges, and from the collection of hills to a mountainous region. Partonomically speaking (Chaudhry & Mackaness, 2006b), macrogeomorphic features (such as those in Figure 1) are comprised of a collection of prominences having sufficient distinction from adjoining landforms, of sufficient density, frequency and extent that they collectively define a labelled region. From a generalisation perspective, and in the context of multiple representation databases, the intention is to record attributes of geographic space at only the very finest scale, and to then automatically derive higher order objects whether it be deltas from collections of meandering rivers, or cities from dense collections of buildings (Chaudhry & Mackaness, 2006b). Here we present an approach to the automated identification of objects representing landscape features such as hills, mountains and ranges from a high resolution digital terrain model (DTM). The development of such an approach has important implications in terms of spatial analysis and for the generalisation of spatial databases which are prerequisite to cartographic generalisation.

2. Methodology

What constitutes a hill, a mountain chain or region depends on the scale of observation (Fisher et al., 2004). Many researchers have arrived at different definitions for identification of these kinds of features (Bonsall, 1974; Campbell, 1992; Cohen, 1979; Dawson, 1995; Purchase, 1997) reflecting their fuzzy nature and our conceptual prototypical view of them. Various approaches have been proposed for modelling the fuzziness in landscape features (Fisher, 2000; Robinson, 1988, 2003; Robinson et al., 1988; Usery, 1996; Wood, 1998). But still most of the GI Systems rely on discrete objects for analysis and for cartographic portrayal of these features. Here we present an approach for the creation of discrete objects from a high resolution DTM. The overall methodology is presented in Figure 2. In the following sections we will present different stages of the approach in more detail.

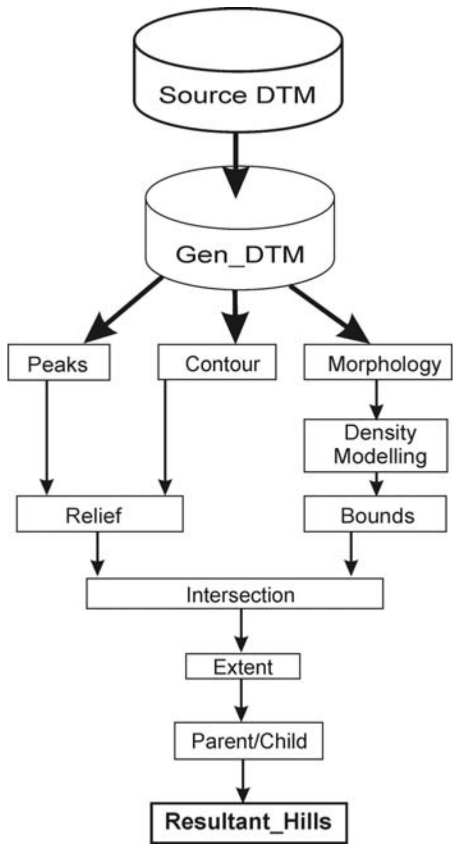

Figure 2: The overall method by which hills are identified.

2.1 Relief/Prominence Calculation:

Relief or Prominence is a concept used in the categorization of hills and mountains. It is the vertical distance between the highest and lowest points in the map area (Press & Siever, 1982). Prominence for each peak can be calculated by its key col or key pass. Col or pass is defined as the point that connects a ridge or a path of a peak to higher terrain. The key col or key pass for a peak is the highest among all its cols. If the peak is the highest point in the given area then its key col will be the ocean, and its prominence will be its absolute height. The key col occurs at the meeting place of two closed contours, one encircling the peak of interest and the other containing at least one higher peak (Bivouac.com, 2004) (Figure 3). In this research the prominence was calculated as the elevation difference between the ‘key contour’ (i.e. the contour that encircles the given peak and no higher summit) and the summit of the peak of interest (Figure 3 and Figure 4).

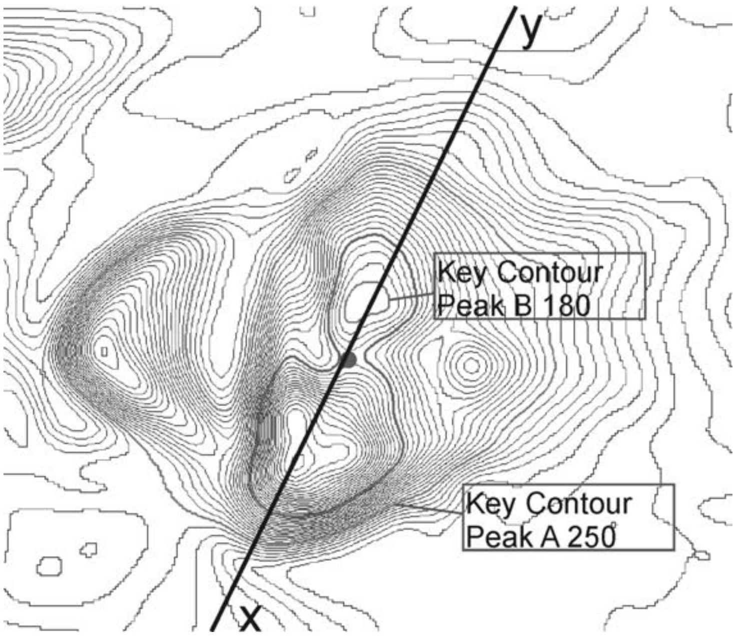

Figure 3: Contours created from a given DTM. Key contours for peak A and Peak B are highlighted in red. The key col for peak B (in green) is present at the meeting point of two contours (highlighted in blue). (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved).

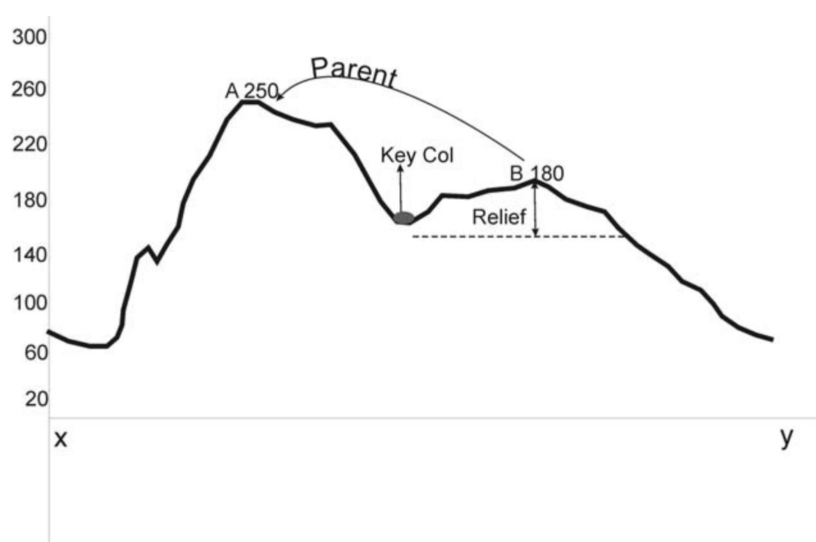

Figure 4: Relief and Key Pass of the line transect in Figure 3

2.2 Morphological Bounds

It is possible that part of a surface may be quite plane between the peak and the key contour (Ben Nevis and the UK's coast). Therefore in addition to prominence we also need to model the change in surface in terms of its morphology. Several methods exist for the identification of morphometric features (Evans, 1972; Maxwell, 1870; Peucker & Douglas, 1974; Tang, 1992). Here we have used the techniques developed by Wood (1996). The approach is based on the quadratic approximation of a local window (kernel) and assessment of the second derivative. The second derivative is a function of the rate of change of slope. Wherever the surface is plane the second derivative is ϕ (Wood 1996a). Due to the scale dependent nature of the phenomena different kernel sizes result in different classification of each pixel. The kernel size for this research was empirically determined and was set to 25 cells. All non plane (non-zero) cells were converted into polygons. A clustering algorithm (Chaudhry & Mackaness, 2006a) was applied to create boundary polygons. The area of the resultant polygon is used as a threshold for elimination of small polygons since a hill or mountain needs to have a significant area to be identified as such (Figure 5).

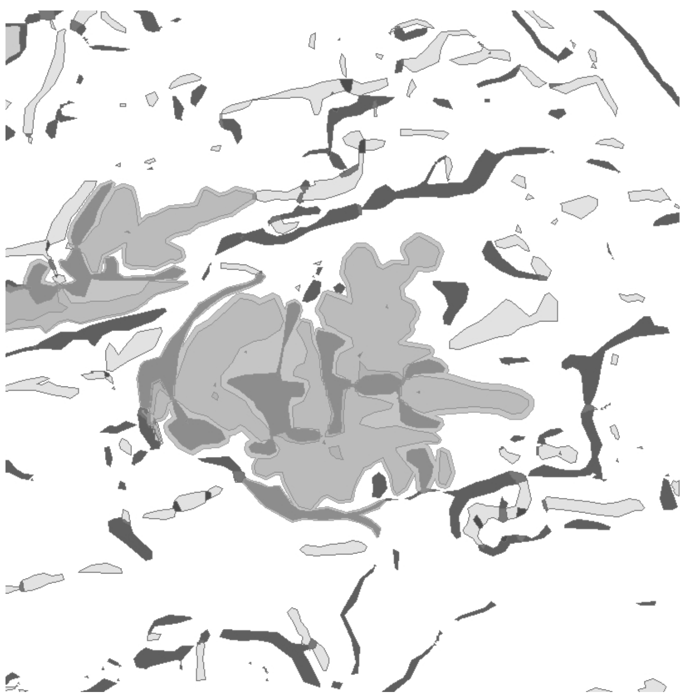

Figure 5: Morphology classes (second derivative >ϕ yellow, <ϕ zero in blue, ϕ in white). Resultant boundary polygons (pink).

2.3 Extents of Hills and Mountain Ranges

Once the morphological bounds, relief and key contour have been identified we can identify the extent of a hill. For each peak we start with its key contour and we asses how much the landscape varies within that contour. This is done by finding the amount of overlap between the contour polygon and the morphological boundary polygon. If the result is below a threshold then the surface is not changing (i.e. most of the surface is quite flat) and the next higher contour is selected. This process is repeated until the degree of change is above or equal to a threshold. The contour polygon selected is assigned as the extent of the given peak. This sequence of events is illustrated in Figure 6.

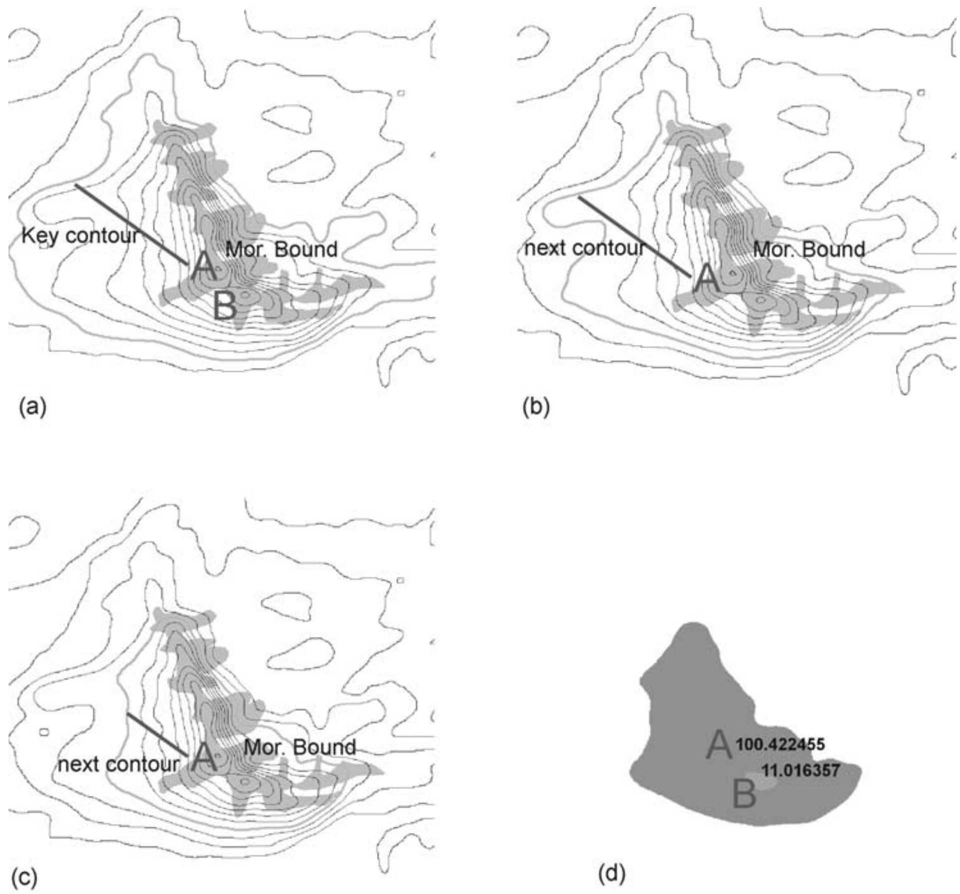

Figure 6: (a) Start with the key contour (highlighted) for the peak (red circle) and calculate the amount of area intersection, (b) Select the next inner contour and calculate the area of intersection, (c) calculate the next inner contour since the area intersection is greater than the threshold. This is the extent of the highlighted peak, (d) Resultant extents for two peaks along with their prominence values.

3. Case Study

This methodology was applied in the derivation of hills and mountain range extents directly from a large scale digital terrain model (OS LandForm Profile). The platform selected for the implementation was Java, ArcGIS 9.0 and LandSerf. (Wood, 1996). In this section we present results for a region around Edinburgh (Figure 7). Text points representing hills in this region were selected from OS Strategi dataset (1:250,000). Figure 8a shows the resultant hill extents and Figure 8b shows extents for only those hills that have a relief greater than 100m.

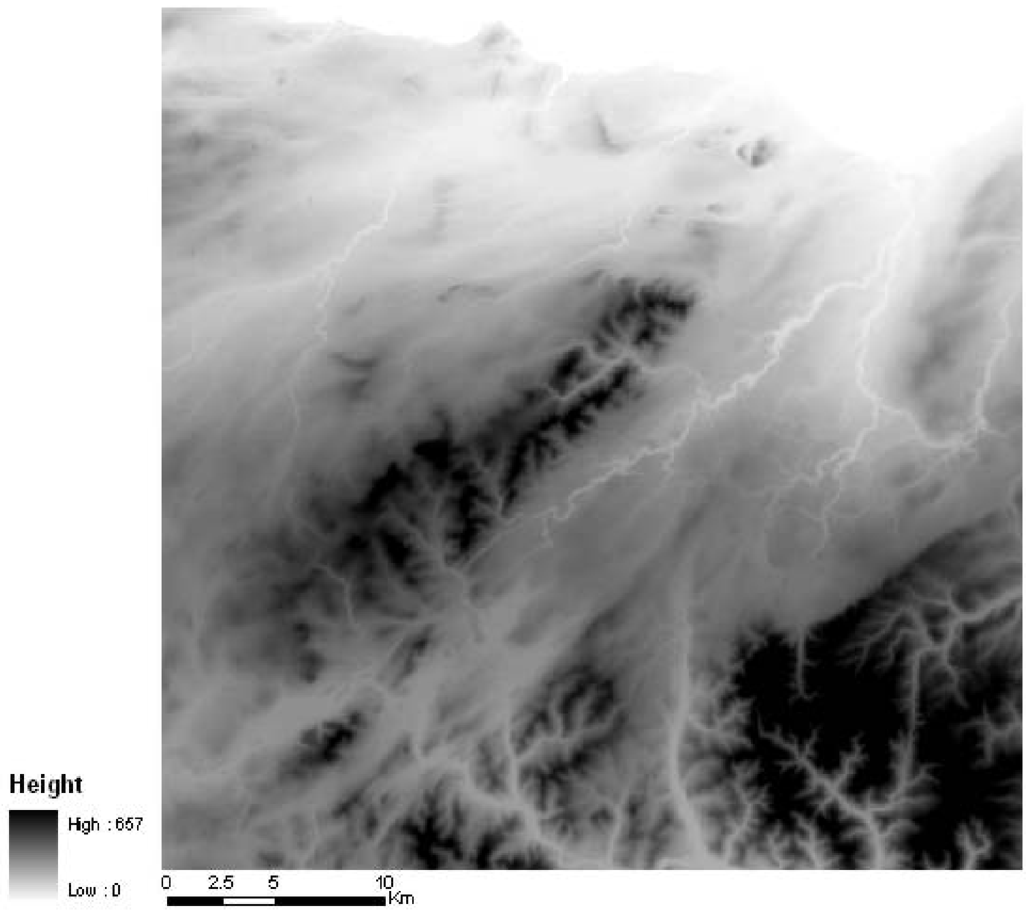

Figure 7: DTM (OS LandForm Profile) Edinburgh and Pentland Hills. (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved).

a b

Figure 8: (a) Resultant hills and range extents for Figure 7 (b) Hill and Range extents with relief greater than 100m (Edinburgh and Pentland region)

4. Evaluation

Using the name points from OS Strategi (1:250,000) and OS Explorer (1:25,000) we performed the evaluation by checking if the named points representing hills and ranges fall within the boundary created by the algorithm (Figure 9 and 10). It is important to point out here that both Strategi and Explorer are cartographic products thus there are several cartographic considerations (size, clutteredness, significance) taken into account before a text point is created for a feature. As shown in the Figure 9 and 10 most of the font points lie within the boundaries generated by the proposed approach. The important thing to note here is these cartographic products (Strategi and Explorer) were created without any link between the text point and the place being named. But once the boundaries such as those generated here are identified they can then be used to create this link. This will facilitate both the cartographer and development of automatic cartographic generalisation techniques.

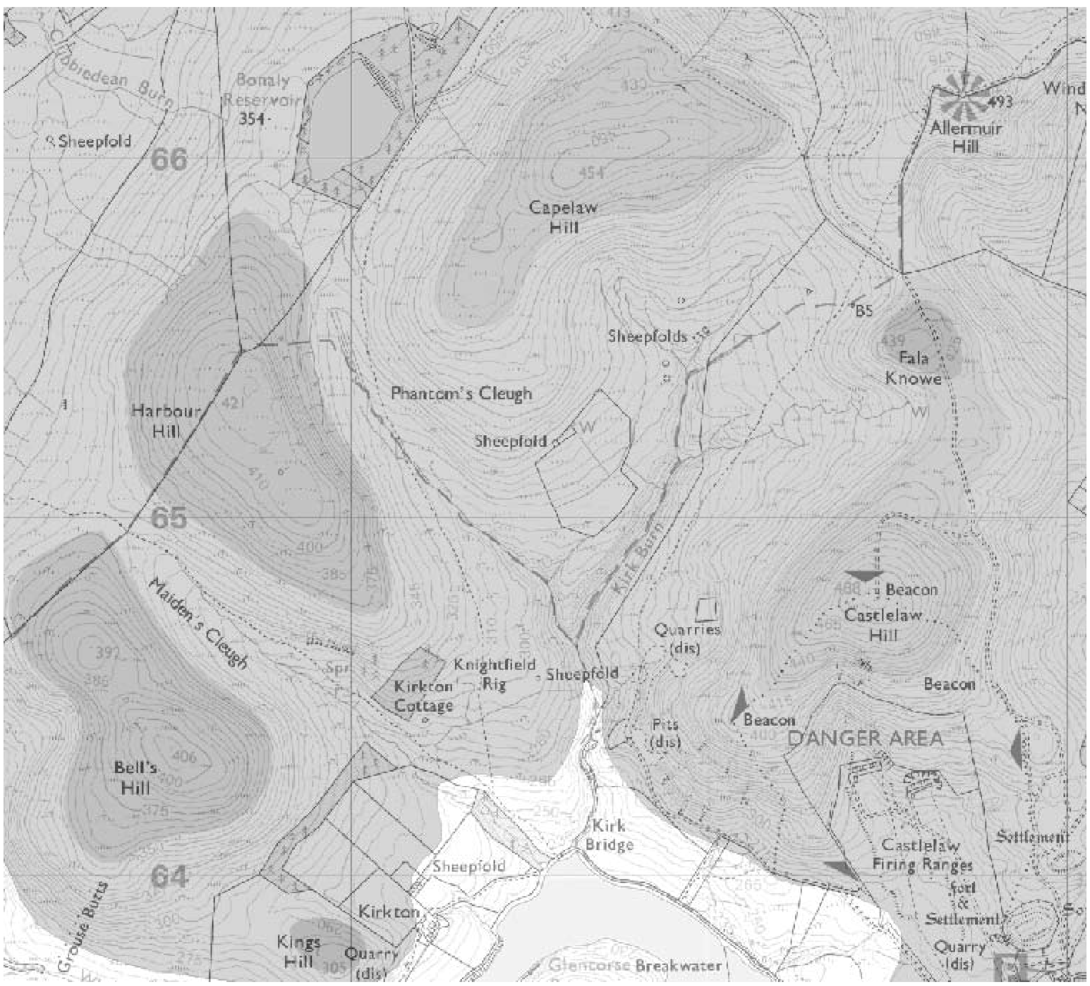

Figure 9: OS Explorer (1:25,000) overlaid on hill extents derived by the proposed methodology. Bell Hill, Harbour Hill, Cape Hill. King Hill and Castlelaw Hill annotations lie within the footprint generated. (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved).

Figure 10: Text points selected from OS Strategi lie within the footprint of the hills derived from the implementation (relief above 100m). (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved).

The resultant extents can also be used to find the parent and child relationships between hills. This enables us to create ranges. Once the relationships have been identified, hills with prominence or height less than a threshold can be aggregated into their parent hills. This results in the creation of composite objects present at higher level of abstraction (such as those in Figure 1).

5. Conclusion

In this paper we have demonstrated an approach for finding the extents of continuous phenomena such as hills and mountain ranges so that objects representing these concepts can be made explicit in the database. Research presented in this paper illustrates the possibility and utility of defining and extracting boundaries of continuous real world phenomena into database objects. Once these objects are generated they are useful not only in cartographic generalisation in terms of symbol placement but also for model generalisation for aggregation of source objects and also for spatial analysis. Future extensions will take into account their fuzzy membership. Future work will also look into applying similar approaches for the extraction of settlements or forest regions.

6. Acknowledgement

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Biography

Omair Chaudhry is in the third year of his PHD at The University of Edinburgh. The area of study is on the automatic derivation of small scale topographic databases directly from OS MasterMap. The focus, as part of model generalisation, is the automatic detection of higher order phenomena from large scale databases.

William Mackaness is a senior lecturer at The University of Edinburgh, and is PhD supervisor to Omair.