Mapping Disorder: An Exploratory Study

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Introduction

The nature of geographical reality is such that disorder, complexity and dynamism are inherent properties of all geospatial datasets reflecting the environment. Both in the natural sphere and in anthropogenic environments, chaotic phenomena are evident in the form of fuzzy boundaries, indistinct objects, moving features, uncertain classifications, dynamic processes, and complex systems. Examples range from the diversity of tropical rainforest habitats with uncertain boundaries and complex classification schemes, to the manifestation of diurnal commuter patterns exhibiting complex networks showing a dynamic human activity with significant regular and irregular patterns of change. The requirement to address the possible representation of such phenomena in map form is part of the process of mapping—defined here as the abstraction of geographical reality using cartographic transformation.

The functions, tools and techniques available for cartographic transformation have, throughout history, concentrated on using static, single-view, two-dimensional graphics to communicate a distillation of reality captured as a 'snapshot'. Such maps are created to give an ordered insight into the complexity and unpredictability of reality.

In general terms, this paper suggests that a new paradigm of cartographic representation is required to address the task of moving away from such standard 'snapshot' maps to representations which reflect the disorder of spatial reality. This is a major ambition, so this paper specifically attempts to contribute, in a more limited and preliminary manner, to an investigation of one example of disorder—in this case in topographic landscapes. It involves the assessment of disorder; its

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quantification, description and comparison; its characterisation; and its subsequent representation. Contemporary technologies are opening up significant possibilities in undertaking such tasks, most notably in representation and visualisation. It is such opportunities which may well lead to the new paradigm sought, involving use of animation, hyperlinked documents, interactivity with displays, and editing capability, perhaps in a multi-user environment, possibly connected and web-enabled, certainly multi-sourced and easy to distribute.

At this stage, however, the examples chosen are familiar to the conventional topographic cartographer, with the assessment and handling of spatial data in landscapes being the focus for an initial study of disorder and its effect on mapping.

Handling Disorder in Landscapes

Landscapes, and the processes which create and influence them, can often be dissected, uneven and disturbed. Such environments can be completely natural, for example in peri-glacial areas, or can be anthropogenically influenced, for example in areas which have sustained mining activity over many years. The quantification of such disorder can be initiated by collecting spatial data using direct measurements, by survey and by remote sensing, and subsequently characterising the environments using standard metrics such as diversity, complexity and order indices.

The indices of disorder then need to be translated into graphical representations of space: this will involve a further stage, exploring and extending the range of tools, techniques and technologies available in contemporary geo-visualisation, including methods for communicating multi-variate, multi-dimensional, multi-temporal, chaotic, disordered data.

Sporadic efforts have been made to undertake the first stages of quantifying spatial disorder, most relying on the development of specific calculable indices, such as entropy and diversity indicators. Both the terminology used and the applicability of these indices are contentious, but a consistent and acceptable approach to identifying, recording and measuring disorder is essential to fully utilise this approach.

Example studies following this particular *modus operandi* have been undertaken in the field of **landscape ecology**, a discipline which has led research into quantifying diversity, complexity and order, and applying these to aesthetic and cultural readings of environments (Arnheim 1972; Lewis 1982). The application and analysis of metrical indices, including those mentioned above, is considered more recently by Ode et al. (2010) and Zurlini et al. (2012). Such indices are also applicable in **archaeology**, where notable developments in high resolution remotely-sensed surface data collection, notably by LiDAR, allow detailed measurement of landscape disturbance and perturbation resulting from human activities (e.g. mining, agriculture, military) (Doneus and Kühtreiber 2013; Kovacs et al. 2012). Translated into map representations, and integrated with documentary and interpretative sources, the relationship between anthropogenic impacts and quantitatively-derived landscape characteristics can be systematically modelled. Pfeifer et al. (2011) have taken similar approaches, using LiDAR data in the study of **geomorphology**, whilst the related field of geomorphometry—applying numerical methods and deriving similar indices of topographic structure—can exemplify issues related to characterising disorder (Hengl and Reuter 2008).

The subsequent cartographic representation of disordered raw data and such derived indices is problematic. Both the recording of current situations and the creation of predictive or explanatory models require effective map representations of actual or potential order, disorder, complexity, and change. The representation of such metrics on maps has not been explored in depth by the cartographic community, despite initial attempts at examining the use of maps to actually derive the metrics themselves (Fairbairn 2006, 2011).

Further examples of mapping required in dynamic environments (e.g. periglacial zones, coastal margins and river channels) can be envisaged, along with the need to represent uncertain human behaviour in cartographic products detailing geographic phenomena which are not primarily terrain-oriented, such as transport networks, crime occurrences, migration patterns, and epidemiology.

Archaeological Disturbance in the Landscape

The specific landscape milieu initially considered in this paper is recent archaeology of sites with varying characteristics, and the methodology will primarily seek to empirically quantify the measured variability in order and disorder over such areas. The plan is to examine a number of indices which have relation to disorder (e.g. entropy, diversity indicators, information metrics, concentration and fragmentation measures, randomness measures) and to determine their applicability in characterising those areas which are dominated by natural landscape, as well as those where anthropogenic influences have altered the environment, historically.

This paper introduces a study, therefore, which asks: To what extent do remnant mining sites reflect the human activity which is manifest in them? What landscape parameters can be used to characterise the nature of such sites? To what extent can indices of landscape ecology, geomorphometry, and landscape archaeology, be used to describe and quantify order, disorder, complexity, diversity and change? And what are the possibilities of optimising the cartographic representation of such sites?

The study has identified an area of landscape disturbance as a result of human activities (mining of lead ore and other heavy metals). Such disturbance is variable across the small area chosen, as a result of location (notably the distribution pattern of minerals which have been exploited), the methods of mining and extraction, and the development of transport networks to export the products from the site. It is recognised also that the extent of the site, the scale of sampling of spatial data, the level of resolution of the data (notably the digital terrain model), and temporal variability, may each affect the data collection, data processing, data analysis and data representation tasks. For the site, a range of possible metrics related to disorder will be examined, eventually to establish a relationship between anthropogenic mining impacts and landscape characteristics, and also to further analyse the representation possibilities.

Data Preparation

The site chosen is an area of relict mining activity, active from the fourteenth century, but primarily during the second half of the nineteenth century (mining has now ceased in this area). The geology of the location is relatively straightforward, consisting of sedimentary layers of the Carboniferous era, including some with significant mineral resources, both in the rock and in mineralised veins. The main mineral output was of barium and lead ores, along with some commercially viable iron ore deposits. The workings were in the form of medium-sized quarries in the exposed sandstone layer to the north, with small open pits from earlier centuries for the more southerly measures containing barytocalcite and lead ore: these were subsequently mined using vertical shafts and drift mining (adits) in the later nineteenth century. A large amount of waste resulted from these operations and spoil heaps typify the landscape. This site is near the settlement of Blagill, close to Alston, Cumbria, in northern England.

The assessment and quantification of the disorder in this landscape relies on a suitable-resolution digital surface model: airborne LiDAR survey data was processed to provide a one-metre planimetric resolution gridded dataset. This data did not have vegetation or buildings removed from the surface, but the actual area examined has no trees or buildings covering the site, and the current land use is uniform upland sheep grazing pasture. The initial investigation in this paper uses this digital surface model (DSM) to assess, quantify, and characterise the nature of the terrain.

Figure 1a shows the shaded relief image of the surface model, with added geological mapping (zones and fault lines) and a generalised 10 m contour map. The grid coordinates of these maps are in metres, projected to the British National Grid. It can be seen that the zones chosen for analysis have variability in their geology, their height and their surface characteristics. Detailed analysis of the rock types, their formation and their exploitation is given in Clarke (2008), which indicates that the alternating layers of the Stainmore formation comprise mudstone, sandstone and limestone, yielding rich ore deposits, whilst the Firestone zone consists of relatively mineral-poor uniform sandstone. It is suggested here that variation in mining activity results from the variable geology, and the remaining evidence of that activity has affected the configuration of the current landscape, a configuration that exhibits distinct differences in complexity and hence

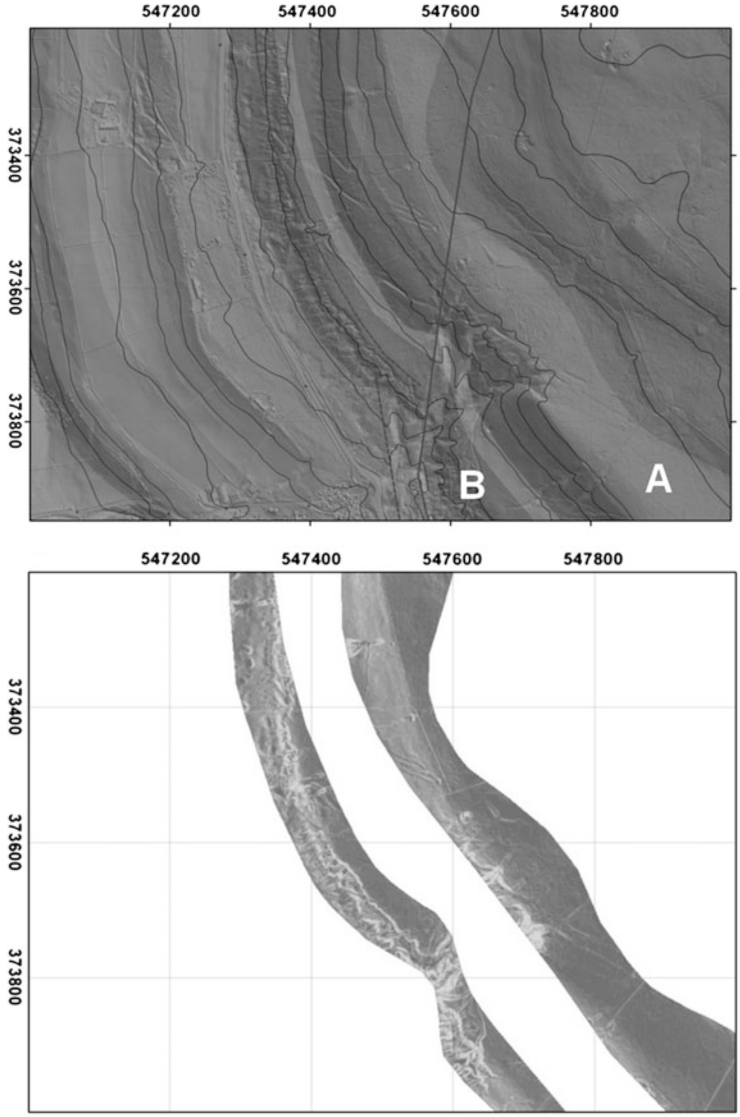

Fig. 1 (from top—west-up) (**a**) LiDAR derived DSM, geological mapping and contours; (**b**) Slope map of study area (steeper slopes in lighter greyscale)

demonstrates contrasting degrees of disorder. Zone A, within the geological zone mapped as Firestone sandstone, can be compared with Zone B, part of the Stainmore formation with its mixed, but mineral rich geology.

Data Processing

The DSM was examined using a range of software, in order to prepare and modify the data, and analyse its properties. A primary parameter which can be obtained from the surface model is a slope map, which can visually be used to detect zones of differing levels of dissection. The slope map for the relevant zones is shown in Fig. 1b. As can be seen, the zone of sandstone (Zone A), which has been subject to less mining activity and spoil heap creation, has fewer steep areas and a more uniform surface. The mean slope in Zone A is 10.11°, whilst in Zone B it is 14.69°. The comparative values of average slope may well be the simplest and most suitable metric to establish variable disorder in this landscape.

However, further confirmation was sought of the distinction between the two zones, by examining several more landscape indices. The Terrain Ruggedness Index (TRI) was initially established for large-area landscape characterisation to assist in wildlife management (Reilly et al. 1999). It was calculated and mapped in this exercise using the Raster Calculator within ArcGIS, the output demonstrating the differences which result from measuring the height differences between adjacent pixels in the DSM. By extension, this is also a function of slope but quantifies, more directly, dissection of the terrain surface and the degree of difference in height of all eight neighbouring cells to the target pixel.

The mean value of the TRI for Zone A was measured at 19.31 whilst Zone B had a higher mean TRI value of 22.55. There are, in fact, many different indices available for characterising surface roughness (see, for example, http://gis4geomorphology.com/roughness-topographic-position/). A further index applied to this dataset is sourced from terrain analysis work presented by Hobson in 1972, and coded as a Python script for incorporation into ArcGIS by Sappington (2008). This index is more comprehensive than the TRI metric, in that it takes account of aspect in addition to slope—clearly, consideration of variable orientation of equal slope values around a point, for example, should yield improved and more faithful measures of dissection. The resultant index (called vector ruggedness measure, VRM, by the script author) was assessed for Zones A and B: once again, an overall mean figure for VRM shows variability, with Zone A calculated at 0.0013 and Zone B at 0.0044.

The measurements taken so far indicate that it is possible to develop realistic measures of terrain variability from LiDAR-derived digital surface models, at sufficiently large scale. The scale must be set to consider the impact, in this small area, of relatively minor features—small spoil heaps, depressions indicating capped pit-shafts, and surface features such as tracks and specially-dug drainage channels.

The figures show that a comparison can be made between nearby zones with differing landscape use histories, and it may be possible to develop models of landscape form and genesis which can be transferable across regional and national landscape characterisation studies. In this case study, a distinction has been drawn, using simple indices of disorder, between an area relatively untouched by human activity, and one which has been comprehensively altered by anthropogenic mining practices.

Additional metrics were examined using alternative software for terrain data handling. For example, a ‘patch richness density’ index (PRD) was calculated using the Fragstats program, resulting in a metric for a landscape (or any categorised polygonal dataset) which is higher the more individual patches of a class which exist in the image (McGarigal and Cushman 2005). The PRD metric presents the number of distinct patches per 100 ha. Thus, a dissected landscape, classed for example into 32 categories of height (i.e. a layer-tinted terrain model of a complex area) will have smaller individual and more numerous adjacent hypsometric layer tint zones, and a higher density of separate individual patches, compared to a uniform sloped terrain which will have only as many patches as there are classes. In this terrain, for example, Zone A has a PRD of 307.07, whilst Zone B, with its more complex landscape has a PRD of 340.23.

Analysis of the terrain was also undertaken using the Landserf terrain data handling software package. The fractal dimension of the surface in each zone was calculated (Zone A, 2.12; Zone B, 2.20) confirming the higher disorder in Zone B. Feature extraction and landscape feature detection is effectively undertaken in Landserf, with elements such as pits, ridges, channels, passes, flat surfaces etc. being identified and visualised. Graphical output from this routine indicates that Zone A has a lower density of structural features (most of the detected ridges are, in fact, walls and field boundaries rather than mining artefacts), whilst a greater proportion of the pixels in Zone B can be categorised as forming channels and ridges.

In Zone A, the Ridges and Channels form only 3.9 % of the DSM cells, whilst in Zone B they constitute 16.6 %. The planar areas form 96 % of Zone A, but 81 % of Zone B, which has many more peaks identifiable.

The work undertaken so far has demonstrated that terrain surfaces can be captured effectively at appropriate scale and resolution for investigating their structure. Disorder in the terrain can also be quantified, either absolutely (for specific measures to be stored) or comparatively (to detect areas of relative disorder). Furthermore, background information about the nature of the terrain, its formation and its modification, can be used to confirm the disorder inherent in differing landscapes and land uses.

Representation

Once terrain disorder has been identified and quantified, the task of mapping it to reflect the variability and complexity must be faced. It was suggested in the Introduction that new methods of cartographic representation must be sought and established for the most efficient mapping of disorder. Historical and contemporary maps of the area studied in this paper are illustrated and considered here.

The early topographic mapping shown in Fig. 2a, with data (including contour values) collected solely by field observation, demonstrates the use of two-dimensional mimetic symbols to represent breaks of slope, patches of spoil,

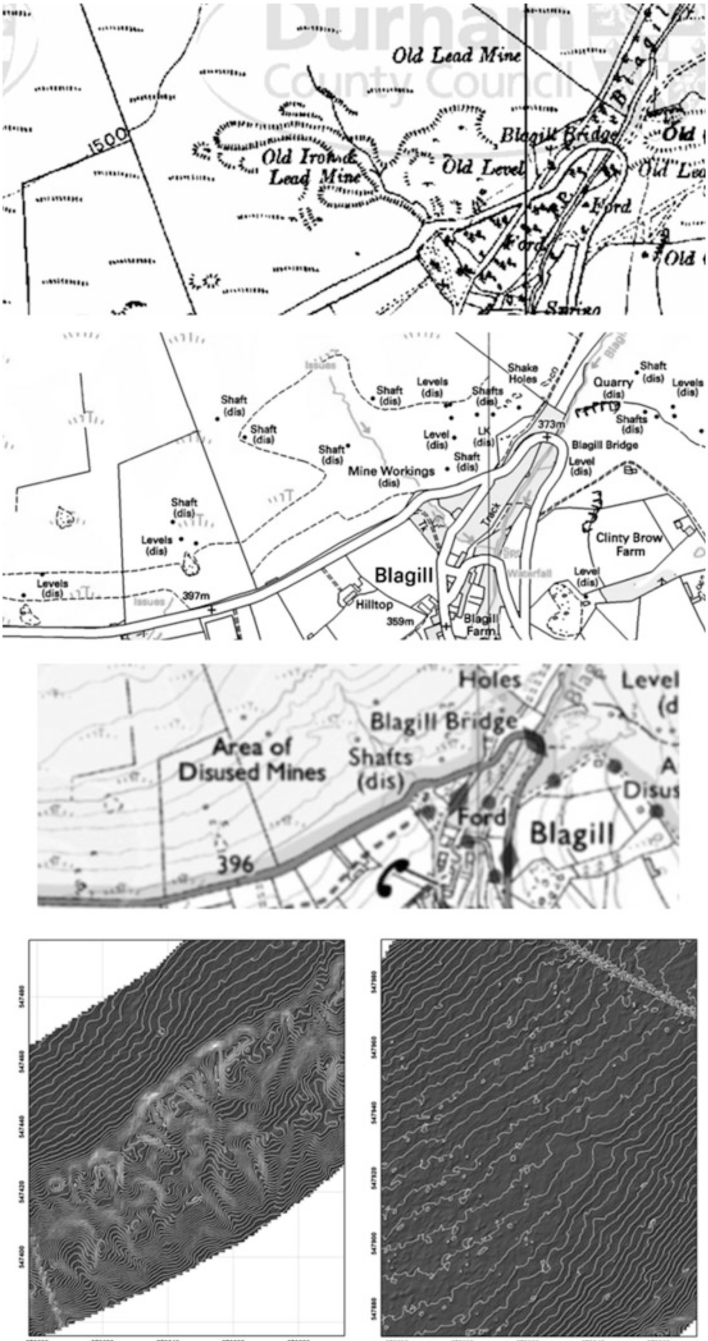

Fig. 2 (from top) (**a**) Early 20th century OS mapping, original 1:10,560 (source: Durham County Council); (**b**) Contemporary OS data mapped at 1:10,000 scale (source: OS data disseminated through the Digimap service, University of Edinburgh, Crown Copyright); (**c**) Contemporary OS data mapped at 1:25,000 scale (source: OS data disseminated through the Digimap service, and natural rock features. In addition a significant amount of information about land use and feature attributes is conveyed by text. Such mapping has some success at indicating the nature of disordered terrain, although in this case the use of a similar design for symbols representing rough moorland rather confuses the terrain portrayal.

Contemporary Ordnance Survey data is supplied in digital form and can therefore be portrayed at varying scales, and indeed with user-defined symbolisation. The default portrayal shown in Fig. 2b reveals that the combination of text and mimetic symbolisation has been maintained on maps of this area captured photogrammetrically and by GNSS survey update to archival material. The main differences between Fig. 2a, b are the reduction in sketching of spoil heap features—the remaining cliff lines and rock faces on Fig. 2b are mainly showing natural features—and the concentration on point features. The areal depiction of the area of mining is shown by a generalised pecked line surrounding the zone of interest—this mainly outlines Zone B in the study described above.

Figure 2c shows the influence of scale on landscape portrayal. It shows the raster-scanned 1:25,000 mapping of the region which has been the focus of studies here. In this case, the contour pattern does not fully reveal the dissected landscape, and it is primarily text which offers, in a descriptive manner, the major clue to the nature of the terrain.

It is clear that these map representations, like most topographic map products, have had to sacrifice dimensionality, by graphically portraying the third dimension—a major factor in determining the disorder of a landscape—using two-dimensional symbolisation. Techniques of symbolising the third dimension have been developed and applied by cartographers for centuries. The contour line has proven a most effective device for quantitatively communicating terrain data, although an understanding of the whole terrain requires that contour lines be read as a pattern. Further quasi-two-dimensional symbolisation can try to pictographically portray terrain variability, the most obvious example being hill shading. Comparison of Fig. 2d, e using contour lines (1 m interval) combined with shaded relief of the raster DSM to highlight terrain characteristics, re-iterates the differences between Zones B and A, quantified above, and also shows the effectiveness of such methods of representation in portraying disorder.

It is concluded here that map representation, which involves abstracting characteristics and properties of the real world to cartographically transform spatial data into a graphical product, inevitably sacrifices dimensionality. The representation of three-dimensional surfaces using two-dimensional symbols is an obvious example. The mapping of disorder requires a serious attempt at developing cartographic symbols and map representations which can optimise the portrayal of multi-

Fig. 2 (continued) University of Edinburgh, Crown Copyright); (**d**) Extract from contour (1 m interval) and shaded relief of the DSM in Zone B; (**e**) Extract from contour (1 m interval) and shaded relief of the DSM in zone A dimensional phenomena, such that the complexity of the real world can be most efficiently and effectively portrayed.

Conclusion

In addition, the multi-variate, multi-temporal and chaotic nature of geographic reality means that all the contemporary tools at the cartographer's disposal—including animation, imagery, multiple views, generalisation routines, display platforms, interactivity, and other technologies—will be required to address the representation of disorder. This study has embarked on a consideration of the cartography of disorder by examining one mappable phenomenon, landscape terrain. It has been shown that terrain can be characterised according to its measured disorder, but the representation of that disorder in cartographic terms requires the development of further techniques of representation.

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