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Paper 59

TECHNIQUES FOR AUGMENTING THE VISUALISATION OF DYNAMIC RASTER SURFACES

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Date: November 2002

ISSN: 1467-1298

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Techniques for augmenting the visualisation of dynamic raster surfaces

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Abstract

Despite their aesthetic appeal and condensed nature, dynamic raster surface representations such as a temporal series of a landform and an attribute series of a socio-economic attribute of an area, are often criticised for the lack of an effective information delivery and interactivity. In this work, we readdress some of the earlier raised reasons for these limitations - information-laden quality of surface datasets, lack of spatial and temporal continuity in the original data, and a limited scope for a real-time interactivity. We demonstrate with examples that the use of four techniques namely the re-expression of the surfaces as a framework of morphometric features, spatial generalisation, morphing, graphic lag and brushing can augment the visualisation of dynamic raster surfaces in temporal and attribute series.

1. Introduction

Cartographers and researchers in the scientific- and cartographic- visualisation fields have produced dynamic maps or animated maps over the last three decades, initially as paper-based cartoons and, after the eighties, in the form of sophisticated 2D and 3D digital representations. Although it is generally accepted that dynamic maps are a simple and appealing way of providing a mental model of the dynamic information, their effectiveness has been debated from as early as the 1960's (Bertin, 1967). Recent works that have raised doubts on the effectiveness of dynamic map include Slocum et al. (1990), Ogao and Kraak (2001), Ogao and Block (2001), and Emmer (2001). Despite the general apprehension, there is a consensus that the most suitable visual representation of large information collected over continuous long period, such as weather (Earnshaw and Watson, 1993) and landscape processes (Mitas et al., 1997), and multiple attributes would be an dynamic map. Other supporters of dynamic maps including those who have suggested ways to alleviate the limitations of dynamic maps include Hayward (1984), Koussoulakou (1990), Dibiase et al. (1992), McCloud (1993), Peterson (1993), and MacEachren (1994).

Bertins' main criticism of dynamic maps is that the presence of motion distracts a user's attention from the important visual variables such as size, colour, and others, thereby resulting in a limited interpretation. In other words, a dynamic map necessitates an active attention to interpret the stream of information. In response to this issue, Dibiase et al. (1992) and MacEachren (1994) proposed the addition of controls called dynamic visual variables, such as duration, rate of change, frequency, display time and others to manage the flux of information available during an animation. In essence, the purpose of dynamic visual variables is to allow a user-defined attention period to interpret the dynamic information. However, in the absence of formal and generic guidelines on the use of these controls, we believe that Bertins' objection is still not satisfied.

Another demanding requirement and limitation has been the interactive visualisation of the dynamic maps. Refer to Ware (2000) for an overview of the issues related to interacting with visualisation. Despite the development of excellent two-dimensional (cdv – Dykes, 1999) and three-dimensional (Kreuseler, 2000) visualisation systems, interactivity in dynamic maps remains a challenge. Recently, Ogao and Kraak (2001) and Ogao and Block (2001) have objected about the passivity of dynamic map animations and thus raised issues such as their limited exploratory capabilities.

We believe that the limitations mentioned above arise due to practical and conceptual bottlenecks. Certainly, our hardware and software to render satisfactory animation with interactivity in dynamic maps has been improving all the time (Earnshaw and Watson, 1993; Gahegan, 1999) but a desktop solution for our often-massive data sets still seems far away.

The conceptual limitations are more ill defined and vague but it is something we can address without requiring a research expertise in hardware limitation. We posed the following two conceptual questions to us:

(i) Is there an information overload (also raised by Gahegan, 1999), which is causing the distraction and poor retention?

(ii) Could the lack of a spatial and temporal continuity within our dynamic map series be the cause of a limited interpretation?

2. Methodology

2.1 Proposal

For simplicity, we decided to address a specific case of dynamic maps in our investigation viz. The widely used raster surfaces e.g., digital elevation models (DEMs) and population density surfaces. Formally, a surface in this work refers to a rasterised smooth doubly continuous function (i.e., no holes or overhangs) of the form $z = f(x, y)$, where z is the property (e.g., elevation, population density etc.) being mapped and associated with a point (x, y). However, the proposals are generic enough to be applied for piece-wise surfaces as well.

Dynamic raster surfaces can broadly belong to two types of dynamic map processes namely the temporal series and the attribute series. A temporal series depicts the transformation of a property of the surface from a state z at time t to a state z' at time t' i.e.,

$$z_t \rightarrow z'_{t'} \text{ ... (1)}$$

On the other hand, by attribute series generally depicts the different states of a property say z and z' at a particular time t i.e.,

$$z_t \rightarrow z'_t \text{ ... (2)}$$

For example, the animation of the evolution of a landscape over a period of time constitutes a temporal series (Mitas et al., 1997) while the animation of the population density for the different age groups of a city in a year should be regarded as an attribute series.

We will now introduce a visualisation strategy composed of three techniques for augmenting the visualisation of dynamic raster surfaces.

2.1.1 Ensure high or increased spatial- and temporal- continuity

A coarse spatial- and thematic- resolution of raster surfaces results into a stepped appearance that makes it difficult to understand and identify spatial patterns in the surfaces (Herzog, 1993). For instance, the population density surfaces in Figure 1 have spatial resolution of 200 m, which in a thematic sense has been found to be the most appropriate resolution for the description of the distribution (URL#1) but it is clearly not appealing for the visualisation purpose. While in temporal datasets, sometimes due to practical limitations the sampling of surface datasets cannot be done frequently enough to create a continuous temporal series. This leads to abrupt jumps in the visualisation of dynamic surfaces.

Openshaw et al. (1994) suggested the use of density estimation methods such as proposed by Gatrell (1994) and Bracken (1994) for creating a smooth map display of socio-economic data. In a recent work, Paddenburg and Wachowicz (2001) studied the use of spatial generalisation to reduce noise in raster surfaces and concluded that this pre-processing reveals the true information otherwise suppressed by the noise.

In this work, we suggest the use of visualisation-oriented solutions to create spatial and temporal continuity in the surfaces. This basically means that we enhance the continuity with out any knowledge of the surface's particular process or model partly because this information is generally missing in most datasets.

For spatial continuity, we fit a bivariate quadratic polynomial function (Wood, 1998) through the surface to derive the smooth interpolated forms of the surface in the following two ways:

(i) Interpolation to the current spatial resolution (Figure 2)

(ii) Interpolation to a higher spatial resolution (Figure 2)

A typical example of lack of temporal continuity in the case of a dynamic sand spit on Norfolk coast is shown in Figure 3. Due to practical limitations the elevation data was collected only twice a year although the sand spit undergoes constant denudation. One of the common methods adopted to resolve the lack of a temporal continuity in the dynamic raster surfaces has been the controlling the "Duration" and "Rate of Change" dynamic visual variables to fill in the temporal gaps between successive surfaces. It helps but is not the generic solution.

In this work, we propose and demonstrate the use of the technique of image morphing for generating the intermediate surfaces. Image morphing is used widely in the computer graphics field for moulding objects from a shape into another using sophisticated mathematical transformation (Gomes et al., 1999). Some commercial software such as 3D Studio Max

(URL #2) provides tools for morphing both raster and vector surfaces. However, an academic license of 3D studio Max costs approximately £200, requires suitable hardware and provides minimal data interoperability to a cartographer.

We suggest the following two simple methods for generating the intermediate surfaces between two surfaces separated by some time period.

(i) Linear interpolation of the change between the two end-surfaces

The value at a location of an intermediate surface could be derived by a linear interpolation of the values at that location in the first or the last surface or it could be a weighted combination of the values in the first and last surfaces. Parametrically i.e., Let,

g = Number of generations or intermediate surfaces

z_s = z at time $t = 0$

z_e = z at time $t = g$ $\therefore$ using eq. 1 z at time $t = i$ where $0 \le i \ge g$

$\therefore z_s = z_0, z_e = z_g$

In the case of linear equal-interval interpolation –

$$z_i = z_s + \left[(z_e - z_s) \times \left(i/g \right) \right]$$

In the case of linear weighted interpolation –

$$z_i = w_s^i \times z_s + w_e^i \times z_e\,;\; w_s^i = 1 - (i/g), w_e^i = 1 - w_s^i$$

(ii) Non-Linear interpolation of the change between the first and last frame.

In this case, the fundamental concept remains as in (i) but the interpolation takes a non-linear trend. It is expected that some sophisticated interpolations could even be punctuated. We do not present any treatment of this approach in this work.

Our aim is to demonstrate the potentials of the morphing technique, which we do here with the simple case of the equal-interval interpolation between the first and last surface.

2.1.2 Highlight the information content

We the humans have an acute limitation in grasping parallel processes that characterise most dynamic processes. Human cognition process especially the working memory (Ware, 2000) can follow at most three to seven simultaneous cues (Ware, 2000). Tobler (1970) first suggested that complicated processes could be broken down to simple rules. Dransch (2000) suggested four functions, which could enhance the cognition processes in multimedia systems viz., (i) Increase the important information, (ii) Avoid the overload of a single sense, (iii) Support double encoding of information and (iv) support creation of mental models. We believe that the underlying notions of these functions are applicable to our work. In our proposal, we show an idea, which converges the functions (i), (ii) and (iv).

Two key information streams in a dynamic surface are the structure of the surface and the local importance of points. In the most common representations of surfaces such as the colour map and contour map, the delivery of the structural information is subjective to the contour interval, spatial resolution and thematic resolution (Bajaj and Schikore, 1996).

Fowler and Little (1979) proposed that the fundamental morphometric feature networks of a surface, constructed by connecting the peaks to passes with ridges and the pits to passes with channels, are sufficient to describe the significant information about a surface. Later, Helman and Hesselink (1991) and Bajaj and Schikore (1996) demonstrated that the morphometric feature representation could enhance the visualisation of vector and scalar surfaces significantly as compared to the colourmaps and contour maps. We suggest that the re-expression of dynamic surfaces as morphometric feature networks will improve the grasp of information flow in a dynamic map series. To put this in the terms of the proposal of Dransch (2000), the morphometric feature re-expression will increase the important information, reduce the information overload, which would help in creation of a better mental model of the dynamic processes. Bajaj and Schikore (1996) summarised the following advantages of using morphometric feature representation of surface:

(i) Contours and Colourmaps tend to wash out the information present within the contour intervals and class intervals respectively. However, the morphometric features will represent both the spatial and elevation structure of the surface (Figure 4).

(ii) Morphometric features are objective and scale invariant i.e., the definition of morphometric feature doesn’t vary with scales.We suggest that the morphometric features are also useful for dynamic surfaces because:

(i) As the definition of morphometric feature is objective they can be used to reference and monitor changes (quantification of movement). The use of the surface network provides a frame of reference, which could be used to track changes in the surface for example the rate of the displacement of the ridge lines over time could indicate the behaviour of the surface under certain conditions (earthquakes, sea-level rise)The use of a point and line representation of surfaces makes it more easy to follow the dynamism in a surface as the human eye is particularly suited to monitor these motions.**2.1.2.1 Extraction of the morphometric features**

Geographic Information Science and Computer Science researchers have suggested various ways of extracting the peaks, pits, passes, ridges and channels. Wood (1996) has given a good treatment for the various ways of extracting the topographic features. We briefly mention the three popular methods for the classification of the points on the surface into the various feature types:

(i) Manually by Digitising

This is the most tedious approach for the classification of the points and lines but it remains as the final resort for the extraction of a structurally consistent (i.e., no disconnected lines and unidentified points) set of the fundamental topographic features from contour maps (Wolf, 1984). The automated classification of the topographic feature suffers from a number of limitations arising out of data-specific and algorithm-specific issues (Wood, 1998, Wood and Rana, 2000).

(ii) Triangulation

This method involves the triangulation of the surface points over a local neighbourhood and comparing the elevations of a point with all its adjacent vertices. The points are then classified based on this comparison (Douglas and Peucker, 1975; Takahashi et. al., 1995).

(iii) Polynomial Surface Fitting

This method involves fitting a smooth surface through the surface points and the points are classified based on the curvature of the fitted surface (Wood, 1998). The advantages of using a polynomial surface fitting, specifically the bivariate quadratic surface fitting, are described by Wood (1996, 1998).

2.1.2.2 Issues related to feature extraction

It is well known that automated raster processing suffers from the limitation that the results of the analysis are subjected to the size of the local neighbourhood i.e., the window or kernel, centred at the study point, used to perform the processing. This has been termed in the literature as the scale dependency of the feature extraction (Quattrochi and Goodchild, 1996). The topographic features exist across various scales of magnitude. While, there have been many efforts to model the scale-space (Lindeberg, 1994) of surfaces using wavelets (Quattrochi and Goodchild, 1996; Starck et. al, 1998), Fractals (Emerson and Quattrochi, 2000), scale-space theory (Lindeberg, 1994), Quadtrees (Csillag, 1996) to-date a unified treatment is not agreed upon. The triangulation based feature extraction method has the limitation that it only triangulates over a 3 points x 3 points window therefore features of a larger magnitude may remain undetected. In contrast, the bivariate quadratic surface fitting has the advantage that window size can be increased/decreased iteratively until a visually acceptable level of extraction has been achieved. However, it is clear that the extraction of the features at all the scales cannot be guaranteed.

2.1.3 Ensure periodicity and interactivity

In this proposal, our aim is to provide ways in which the information delivery can be adjusted to data-specific and user-specific learning requirements. There is always a danger with points and lines based dynamic maps that the duration of their display may not be suitable for data-specific requirements (e.g., too much change displayed too much quickly) or user-specific requirements (e.g., beginners). Previously, Dibiase et al. (1992) and MacEachren (1994) proposed the use of dynamic visual variables such as moment, duration and others, which could be used to control the information delivery pace. Openshaw et al. (1994) proposed the idea of a progressive decay of luminosity with time until the points or symbols disappear altogether after some fixed time. We introduce a similar capability called graphic lag between successive events that provides more flexibility in the map interpretation process. This has been widely in the video media as the Fading in and Fading out effect. Such a control will provide a reference for the grasping the change, which could be useful in observing the evolution of the map. Technically graphic lag would control the lag in time for which a previous graphic remains on the display until the new one appears. The essential aim of the graphic lag is to augment the working memory (Ware, 2000).For interactivity, we propose the use of application programming environments such as Tcl/Tk (URL #3) that can easily be coded to provide interactive graphic user interfaces (GUI) with sophisticated query functionalities (Dykes, 1999).

2.2 Implementation

The overall flow of the implementation process in our proposal is shown in Figure 5. For the attribute series, we decided to compare the population density of an area Northeast of Leicester, UK, between different age groups (Figure 1). The population density surfaces are raster of 200m spatial resolution obtained from the Small Area Statistics Dataset maintained by the Census Dissemination Unit at the Manchester Information and Associated Services, UK.

For the temporal series, we obtained the DEM of an active sand spit located at the Scolt Head, Norfolk coast, UK, to model a temporal series. The point elevation data was collected by Jonathan Raper based at City University (For a more detailed treatment of this dataset refer to Raper, 2000) twice a year from 1992 to 1999 (Figure 2).

2.2.1 Increasing the spatial and temporal continuity

The population density surfaces of 200m spatial resolution were interpolated into 50m (i.e., interpolation to a higher spatial resolution) and 200m (i.e., interpolation to the existing spatial resolution) spatial resolutions using the software LandSerf. LandSerf is a freeware developed by Jo Wood (URL #4) provides functions for a bivariate quadratic interpolation of a raster surface to an arbitrary spatial resolution.

The point elevation data were gridded into raster format of 6.6m spatial resolution using Inverse Distance Weighted interpolation in the software ArcView (URL #5). This particular spatial resolution was calculated by ArcView to be suitable to cover the geographic extent of the point dataset. Thereafter, the temporal gap (7 months) in each pair of consecutive surfaces was filled with 22 intermediate surfaces by morphing the first surface in the pair into the last surface in the pair. Morphing was done in ArcView using ArcViews' scripting language Avenue. The user has the flexibility to specify the number of intermediate surfaces and any number of pairs of consecutive surfaces. Perspective view of all the surfaces was then generated using the 3D Analyst Extension in ArcView to visualise the terrain denudation processes better. Screen grabs of a sequence of perspective grabs was then converted into animation using the software Animation Shop (URL# 6). However, it will be trivial to assemble all above steps into one single Avenue script in ArcView.

2.2.2 Morphometric feature extraction

The morphometric features were extracted from the population density and elevation surfaces using the software LandSerf (URL #4). LandSerf utilises the polynomial surface fitting method to identify the features (see # 2.1.2.2). As mentioned earlier, the scale chosen to extract the features defines the spatial extent of the surface's structure yielded by the feature extraction process. A filter size of 9 i.e., 450 m x 450 m, was used to extract the morphometric features in the population density surfaces. In the case of elevation rasters, after a few iterations with different filter window sizes and visual inspection a 7 x 7 window i.e., 46.2m x 46.2m, was observed to be suitable for representing the elevation structure.

2.2.3 Graphic Lag

Graphic Lag has been implemented in an application called surface network visualisation (SNV) (Figure 6; URL #6) developed by JD in Tcl/TK. The input in the SNV is the morphometric feature dataset of the temporal and attribute series. Sometimes the feature dataset, especially the ridges and channels, could have too many vertices, which slows down the performance of the SNV. Therefore, a simple line simplification utility has been built-in the SNV, which can downsample a ridge or channel by skipping a user-defined number of vertices. SNV provides the flexibility to select a user-defined graphic lag and allows querying the features, while the animation is on display.

3. Results

3.1 Temporal Series

Figure 7 shows an example of the temporal continuity achieved by morphing the February 1997 terrain into the September 1997 terrain. While we can feel the relief changes, however it is not possible to assess the changes in the structure of the surface, as the structure is not obvious from the field view. Figure 8 shows a part of the same sequence of the morphing with the overlay of the surface network, in which the changes in the structure can be spotted, especially note the detection of the evolution of minor morphometric features in the NE otherwise suppressed in Figure 7. The animation can be viewed at http://www.soi.city.ac.uk/~jad7/snv/. For a more detailed discussion on the coastal-sedimentological processes at the sand spit refer to Livingstone and Raper (1999) and Raper et al (1999). Figure 9 shows the application of graphic lag in monitoring the splitting of the central ridge in the sandpit with a graphic lag of? frames (can we quantify graphic lag?). As can be clearly seen the graphic lag prolongs the working memory about the splitting of the central ridge.

3.2 Attribute Series

The interpolation of population density surfaces into 200m spatial resolution (Figure 10) improves the spatial continuity from Figure 1 but the cell edges are still visible. However, interpolation into 50m spatial resolution gives a much smoother appearance albeit it increases the data file sizes by 4 times (Figure 11). As the morphometric feature extraction is based on the curvature therefore, the smoother the local neighbourhood, the more reliable will be the polynomial surface fitting. Therefore, we decided to use the 50m spatial resolution interpolated surfaces.

During the morphometric feature extraction, the characteristic spatial distribution of the different age groups was revealed successfully (Figure 12). The morphometric feature representation of the population density surfaces reveals the following interesting observations:

- The morphometric feature networks of the 5-15 years and 60+ years age group are generally more sparse than the 15-59 years age group.
- Some of the local population density peaks suppressed in the colour maps (Figure 11) are revealed by the morphometric feature representation. For example see the cluster of points in the NW quadrant with some of the highest deviation from the average population density.

4. Conclusion and Future Work

Information visualisation is not a mathematical equation, which has fixed solution domain. One could solve mathematical equations in many ways but all the methods have to achieve an exactly same result. The definition of information lies in the "eye of the beholder". Therefore, we believe (at least SR does), a good information visualisation method will always be judged based on its qualities for a particular application. Therefore, it would be most fruitful to combine visualisation methods employed in various disciplines to propose a working model.

Dynamic maps are perhaps the most abused forms of cartographic representations especially now with the availability of inexpensive sophisticated hardware and software (data and applications). It may sound daring but we would like to pose the question that does an average human has the physical capability to fully understand a dynamic maps, especially with our limited cognitive capabilities for parallel processing?

However, getting back to our work, generally, there is a lack of guidance on the optimal exploitation of animated maps. We, with the examples of two types of animated continuous surfaces, have demonstrated three ways of assessing the animated maps. They are:

- Use of morphometric data derivatives to attract user's attention and objective visualisation - This achieves to attract user's attention.
- Increasing/Enhancing the spatial/temporal autocorrelation – This helps to maintain the attention. Use of Graphic Lag for providing more ways of feeding user's attention time span – This allows the user-defined flexibility in the attention span.

It is difficult to conclude on the advantages so we have left our ideas the WEB CARTOGRAPHY FORUM (URL #8) for a field test. As part of future work, we anticipate to work on improving the interactivity of SNV with functionalities such as the addition of colour graphic lags, zooming in a particular part of the map during animation and others.

Acknowledgements

Thanks to Jonathan Raper for giving us the point elevation data of Scolt Head. Any copyrights?

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7. http://www.soi.city.ac.uk/~jad7/snv/
8. http://www.itc.nl/~carto/research/webcartoforum/

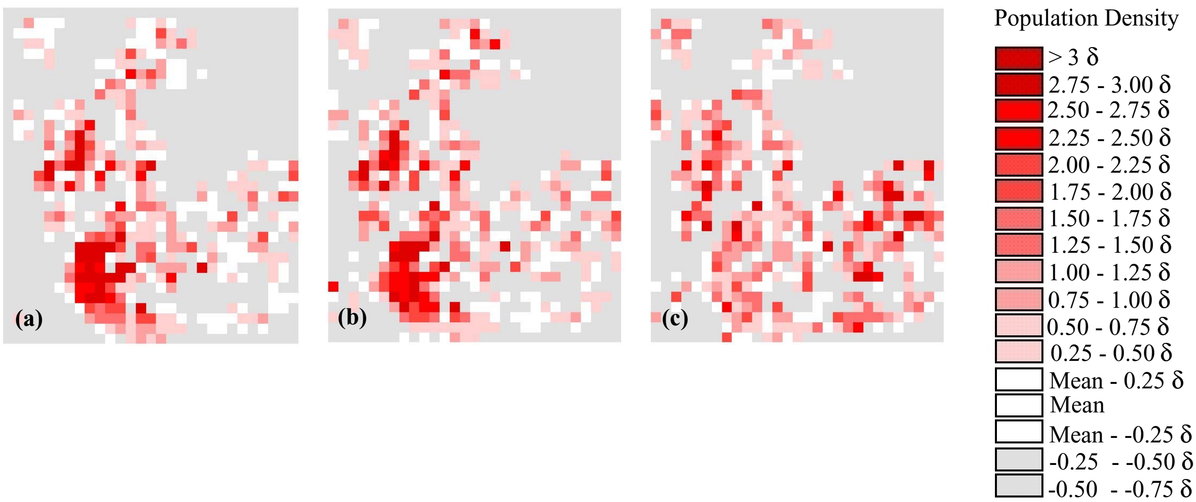


Figure 1. Population density surfaces of the different age groups in an area in NE Leicestershire. (a) 5-15 years (b) 15-59 years (c) 60-60+ years. The rasters have been classified in 1/4 standard deviation classes.

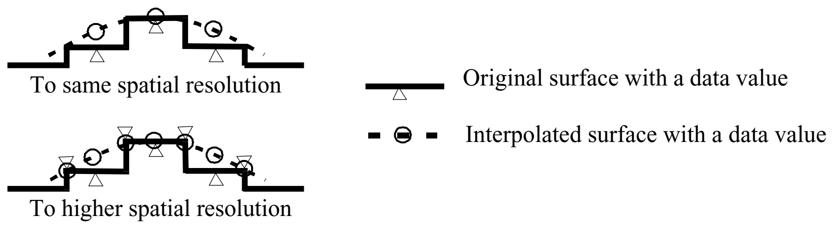


Figure 2. Increasing spatial continuity by fitting a smooth surface over a local neighbourhood.

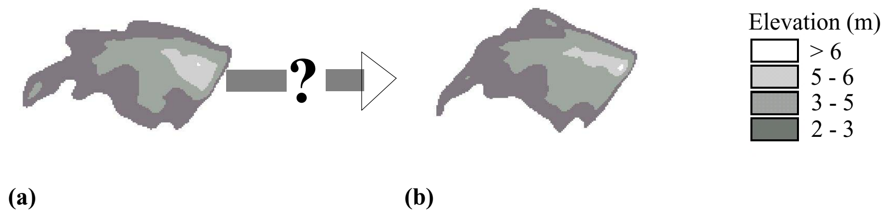


Figure 3. Digital elevation models of a sand spit at Scolt Head, Norfolk coast during (a) February, 1997 and (b) September, 1997.

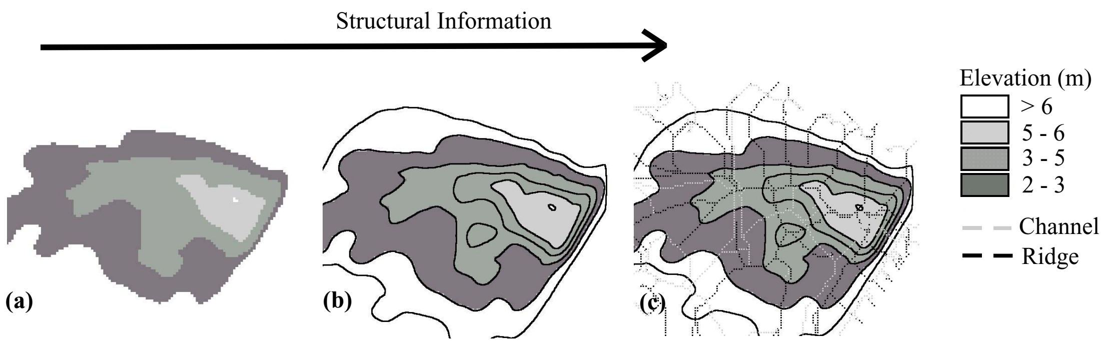


Figure 4. Increase in the structural information delivery with the addition of morphometric features. (a) Raster colour map of a part of Scolt Head sand spit, (b) Contour map of (a), and (c) Morphometric features in the sand spit.

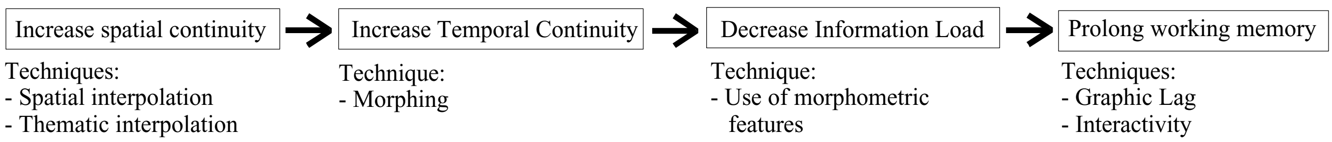


Figure 5 Proposed implementation of techniques to augment the visualisation of dynamic raster surfaces

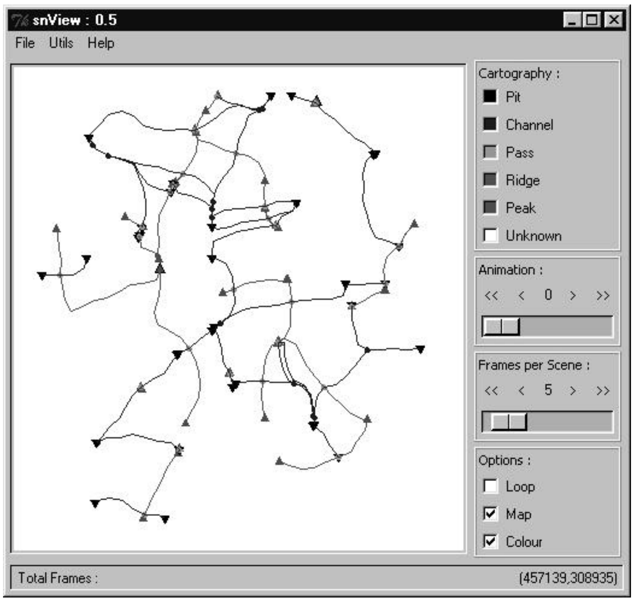


Figure 6 Graphical user interface of the morphometric feature visualisation application written in Tcl/Tk

Figure 7. 22 Intermediate surfaces (microsteps) generated by blending the February, 1997 surface (Situation 1) into the September, 1997 (Situation 2) surface.

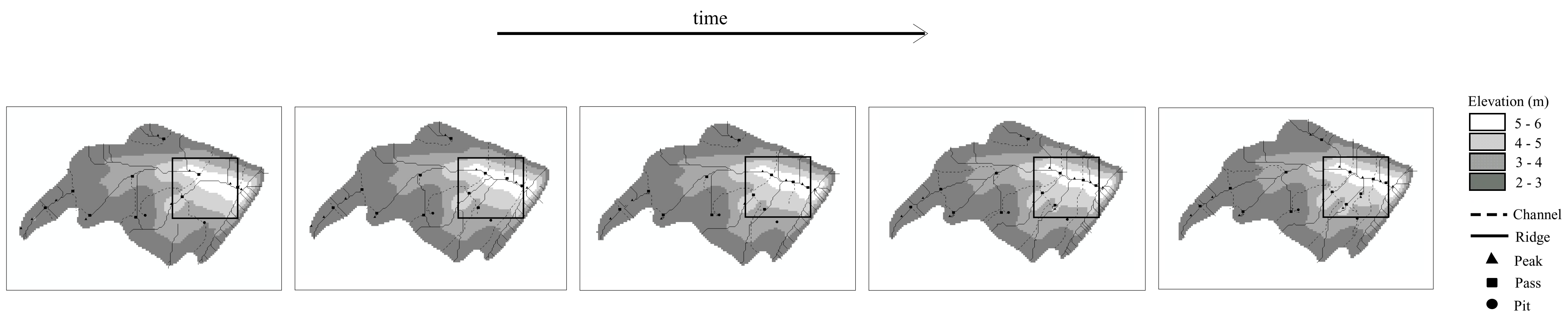
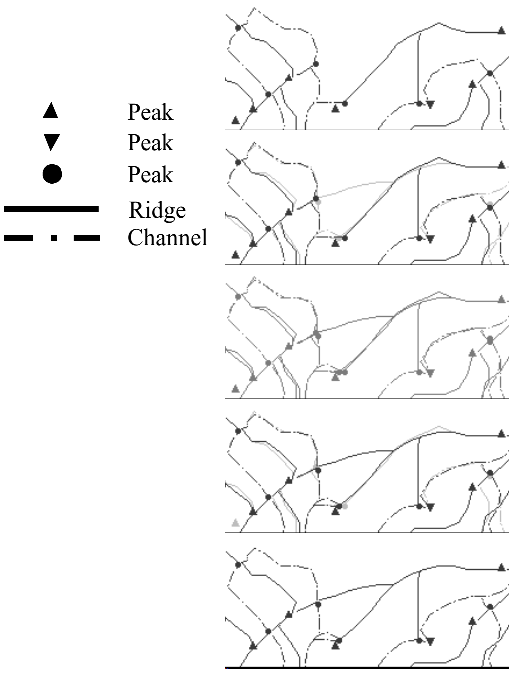


Figure 8. Use of the morphometric features to highlight the changes in the morphometry of the sand spit. A box is used to indicate an area of interest. Note that the morphometric features identify changes that are not evident from the representation that uses color to show variation in elevation.



Frame 1: initial state shows a split ridge (centre of frame - see key) with bifurcation. This is the main feature in the sand bar.

Frame 2: a light outline of the network associated with the subsequent event is added ensuring visual smoothing

Frame 3: the network associated with the first event is lightened whilst that of the subsequent event is darkened

Frame 4: the process continues with the subsequent event clearly showing the development of an additional bifurcation: a discernable ridge joining two other ridge features

Frame 5: all evidence of the initial event is removed. The process continues between successive frames in the animation.

Figure 9. Use of the graphic lag to the highlight the changes in the Scolt Head dynamic sand spit.

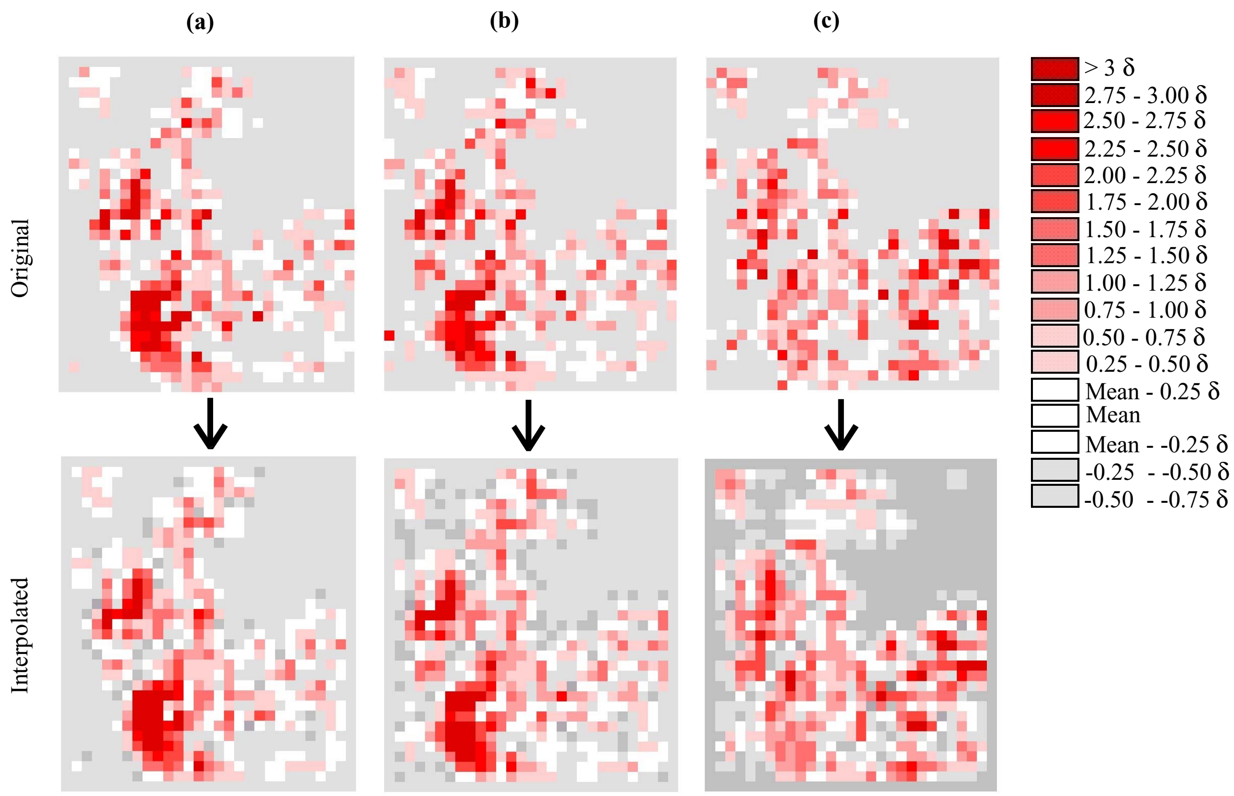


Figure 10. Interpolation of the NE Leicestershire population density surfaces to 200 m spatial resolution. (a) 5-15 years (b) 15-59 years (c) 60-60+ years. The rasters have been classified in 1/4 standard deviation classes.

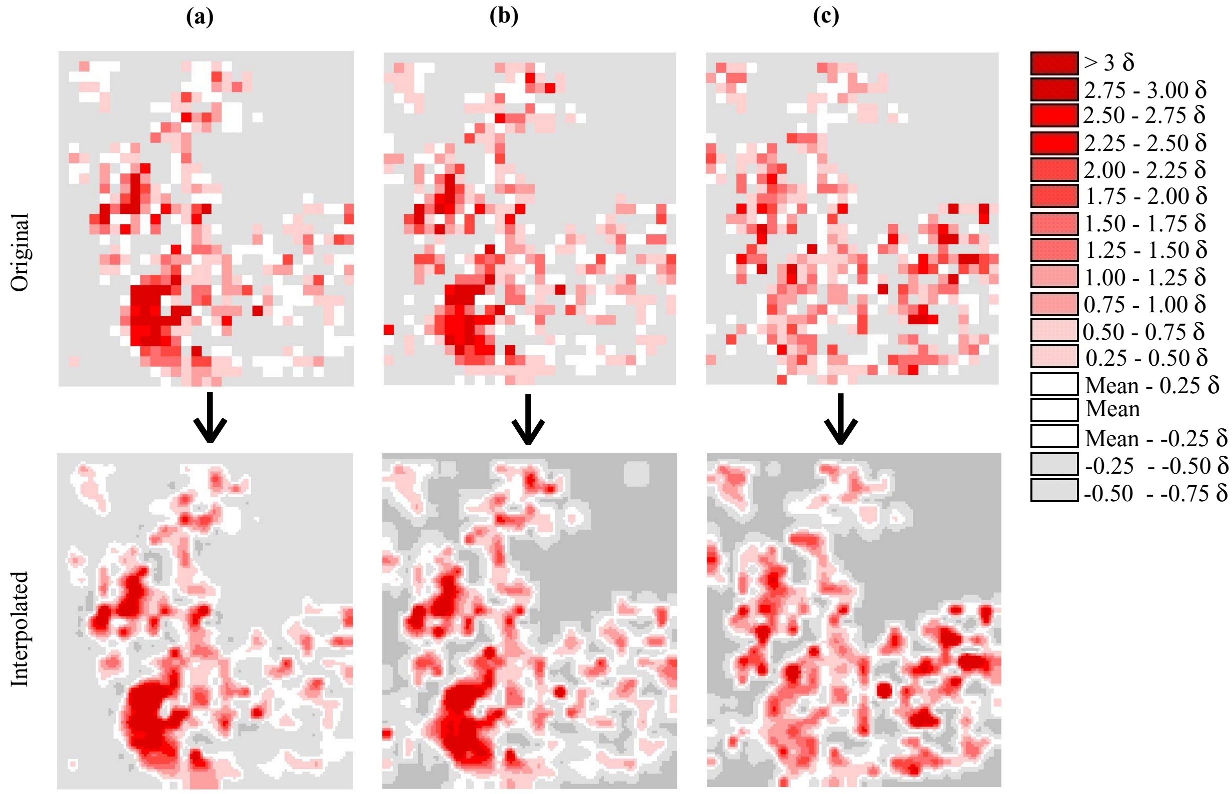


Figure 11. Interpolation of the NE Leicestershire population density surfaces to 50 m spatial resolution. (a) 5-15 years (b) 15-59 years (c) 60-60+ years. The rasters have been classified in 1/4 standard deviation classes.

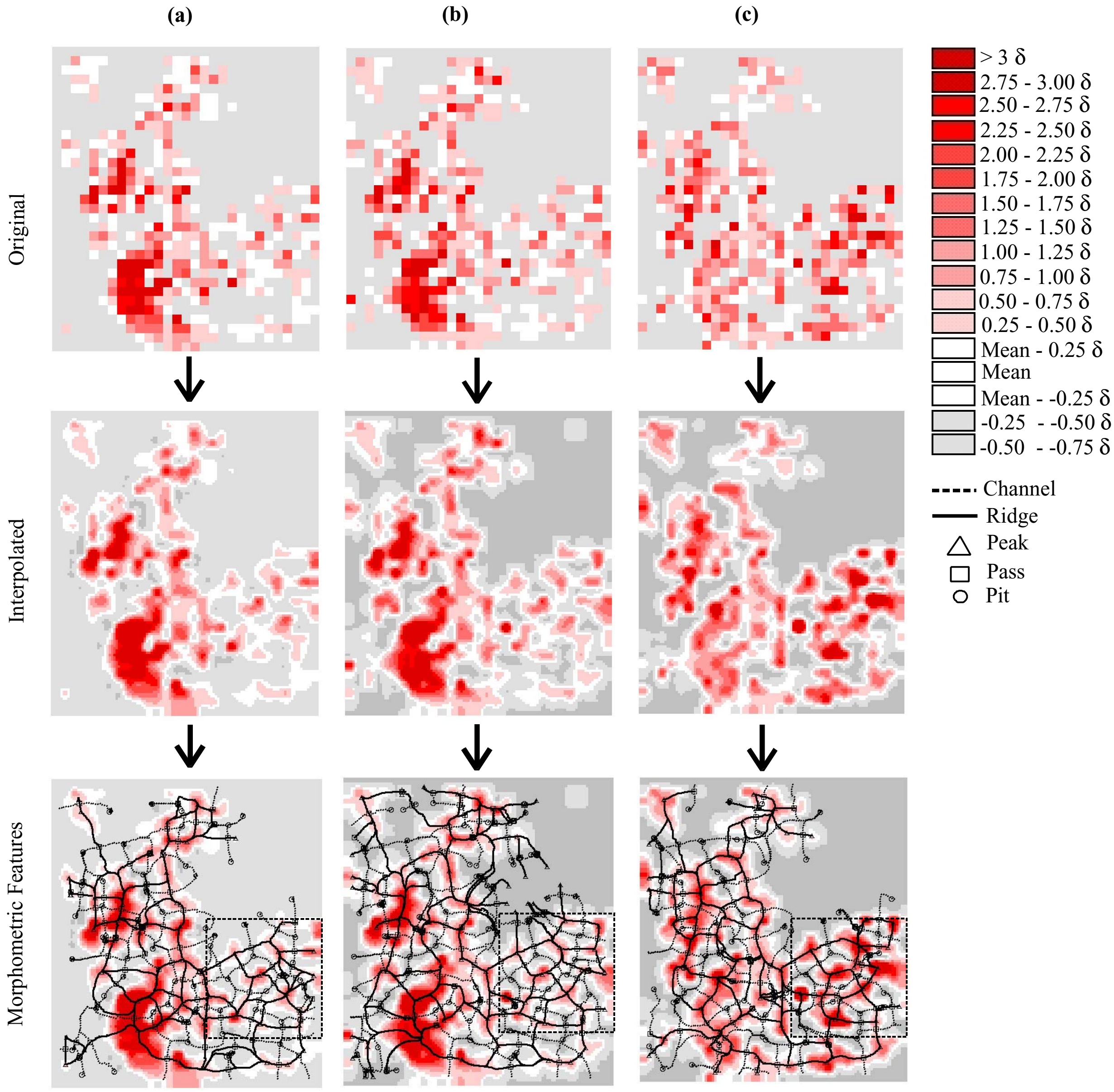


Figure 12. Use of morphometric features to compare the population density distribution of three age groups in NE Leicestershire. (a) 5-15 years (b) 15-59 years (c) 60-60+ years. The rasters have been classified in 1/4 standard deviation classes. The features were extracted from the 50 m grid resolution surfaces in Figure 11 using a filter window size 9. Note how the density of morphometric features augments the visualisation of the inhomogeneous age distribution in some parts of the study area e.g. inside the big dotted box.