

Summary of Thesis submitted for PhD degree

by

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on

Beyond Factual to Formulated Silhouettes

When sketching terrain, a view-dependent framework of silhouette-related cues is required. This framework is prominent in manual sketches and is especially important in small-scale depictions viewed obliquely from above. Occluding contours, namely the lines delineating depth discontinuities in the projected surface, are insufficient for forming this framework. The role which the occluding contour, or Factual Silhouette, plays in structuring the sketch becomes increasingly minimal as more of the terrain becomes visible, as the viewpoint is raised.

The aim of this research is to extend the set of occluding contours to encompass situations that are perceived as causing an occlusion and would therefore be sketched in a similar manner. These locations, termed Formulated Silhouettes supplement the set of occluding contours and provide a successful structuring framework. The proposed method processes visible areas of terrain, which are turning away from view, to extract a classified, vector-based description for a given view of a Digital Elevation Model. Background approaches to silhouette rendering are reviewed and the specific contributions of this thesis are discussed.

The method is tested using case studies composed of terrain of varying scale and character and two application studies demonstrate how silhouettes can be used to enhance existing terrain visualization techniques, both abstract and realistic. In addition, consultation with cartographic designers provides external verification of the research. The thesis concludes by noting how silhouette contours relate to perceived entities rather than actual occlusions.

THE UNIVERSITY OF HULL
Department of Computer Science

**Beyond Factual to Formulated
Silhouettes**

being a Thesis submitted for the degree of the
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by

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Abstract

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CHAPTER 1

Introduction

The task of sketching, creating a minimal but highly communicative visual representation, is not an easy one. Attempting to automate processes involved is even more difficult. However, the benefits of developing such automations and the exciting challenges presented have driven many researchers towards this goal.

When sketching terrain, one of the most eminent figures in cartographic relief representation, Eduard Imhof, writes “One should sketch natural contours, silhouettes, outlines and edge lines sharply and accurately” (Imhof 1982, p. 45). Also, from military cartography, Stuart (1918), notes that “many of the sketches, in practice, are nothing more than approximate horizon outlines with a few of the intervening sub-crests” (Stuart 1918, p. 131). In most cases, the first sketch construction lines drawn relate to such outlines or silhouettes. This set of view-dependent cues provides an essential visual framework for structuring the sketch, helping to convey depth and form. Occluding contours, lines delineating projected depth discontinuities, play a critical role in the creation of these silhouettes.

However, sketching, like cartography, offers an interpreted abstraction of reality. This interpretation implies that the lines that are transcribed during the creation of a sketch are not simply based on facts, but are the output of thinking, rather than just seeing.

This thesis illustrates that if silhouettes are equated solely to occluding contours, an incomplete set of lines is created. Therefore, actual occlusion forms only a subset of the perceived silhouettes. Surface orientation changes that are almost causing an occlusion, but still remain visible, form important constructs (Visvalingam and Whelan 1998) which, through intelligent filtering and thinning, can be used to formulate additional silhouette lines. These situations are especially important when sketching from high-angle oblique views.

Most existing approaches to silhouette rendering use only Factual Silhouettes. Those that supplement this with additional curvature information do so with little regard for how someone would draw silhouettes, often using large amounts of shading and introducing redundant visual cues and artifacts.

The aim of this thesis is to move beyond Factual Silhouettes, supplementing them with additional perceived cues termed Formulated Silhouettes. The identification and extraction of these cues defines the main scope of this research. This framework of silhouettes does not provide a complete sketch on its own; it is merely intended to structure and group other marks forming the sketch. These cues should be in vector form.

1.1 Thesis Structure

Chapter 2 opens with reasons for sketching and illustrates how the scope of computer graphics is rapidly broadening and now includes many abstract representational styles. The basic concepts of perception are then discussed illustrating how the mind responds to abstract visual constructs. This provides the background to the terms and definitions used in this thesis. Following on from responses to abstract imagery, the chapter illustrates how cartographers use knowledge to produce interpreted abstractions. Examples of traditional cartographic sketches of terrain (the focus of this thesis) are used to highlight the important role that silhouettes play in visual perception. The chapter closes by summarising how a cartographic sketch is a product of interpretation, not just fact.

Chapter 3 reviews the state-of-the-art in automatic creation of contour drawings. The chapter begins by relating the definitions from visual perception to surface characteristics, noting the cues of concern to this thesis. The main body splits the background research in automatic contour rendering into two different approaches, either image or model-based. This is followed by a summary that presents the pros and cons of each approach.

By demonstrating the need to go beyond Factual Silhouettes, Chapter 4 presents the justification for focusing on this problem. The experimental system developed for this project is described and, using real-world test data, the problems associated with equating silhouettes to occluding contours are demonstrated. Through preliminary testing and investigative visualizations, objectives for formulating additional silhouettes are given.

Chapter 5 explores an original technique for the extraction of Formulated Silhouettes. A computational method, using information based upon geographical observation, identifies features that would be perceived, and drawn by a cartographer as if they were causing an occlusion.

Chapter 6 evaluates the implementation of the method, and through using various case studies, assesses its performance. This chapter closes with a summary of the observations from the evaluations and lists the pros and cons of the approach adopted.

To seek external verification of the research, Chapter 7 reports on a workshop conducted with a forum of cartographic designers. The results from this interaction are discussed with respect to the various processing stages presented in Chapter 5.

Chapter 8 illustrates the benefits of integrating Factual and Formulated Silhouettes within existing terrain visualization styles; this is demonstrated by two application studies.

Chapter 9 discusses accomplishments of the research project with respect to the current background ideas. The specific contributions of the thesis are presented and the merits and

flaws discussed. The chapter closes with pointers to future work, formed through the various research challenges met throughout the course of the project, and presents the conclusion of the thesis.

CHAPTER 2

Perception and Representation

This chapter reviews ideas from the fields of computer graphics, visual psychology and cartography that form the background research on sketched visualizations. Firstly, the various styles of abstract representation appearing in the computer graphics literature are discussed. Secondly, an overview of theories of visual perception defines the issues and terms relating to the perception of form, both from reality and from a line-sketch. This is followed by examples from cartography, which serve to explain how the production of an interpreted abstraction is based upon more than an analysis of an array of intensity values. The role which silhouette-related cues play in structuring traditional cartographic sketches of terrain is illustrated using examples from classic texts in geology. The chapter closes with a summary describing how these examples compare to the sketch metaphor used in vision research.

The motivations for research into the automated abstraction of sketches are present in many fields. From a computer graphics perspective, the benefits of constructing sketched visualizations are numerous. Through sketching a scene, the process of omission provides clarification. With redundant information removed, a succinct depiction, using a minimal amount of the original data, can be derived. In addition, the use of such a small subset of the source data greatly reduces the amount of bandwidth needed to transmit and store scaleable, vector descriptions of the scene.

Recently, Foley (2000) classed the ability to create successful visual abstractions as one of the top ten unsolved problems in computer graphics. He stated that “When we want to create an abstraction that conveys the key ideas while suppressing irrelevant detail, we need to draw on the less-quantified tools of perceptual psychology, cognitive psychology and the vast knowledge of cartographers and animators. An exciting Challenge!” (Foley 2000, p. 67)

Within the psychology of vision, several researchers (Marr 1982; Burr and Morone 1990; and Watt 1988, 1992) have likened stages in human perception to sketch metaphors. This is most notable in Marr’s Primal and 2½D Sketch (Marr 1982). In addition, through assessing the merit of various cues within minimal sketches, it is possible to gain an insight into the processes involved in perception.

However, it is the cartographic aspect of sketching which is the main motivation for this research. Cartography offers an interpreted abstraction of reality. It is far easier to gain an understanding of an area from a map, as opposed to an aerial photograph. Traditional landscape sketches, which form the inspiration for this work (Murchison 1839; Holmes 1876; and Lobeck 1939), depict the main features whilst suppressing irrelevant detail. This clarification

allows the viewer to gain an overall impression of the landforms present in a given view. In addition, the sparseness of the sketch gives rise to a high proportion of white space that can be useful for annotation and inclusion of thematic information (Lesage and Visvalingam 2000).

2.1 The Broadening Scope of Computer Graphics

Research into non-photorealistic rendering (NPR) is rapidly re-balancing the field of computer graphics, making it increasingly analogous with the broad scope of hand-drawn and painted images. In the past, the drive for realism has restricted the applications for which computer generated images could be used. Recently (in the last 5 years) as NPR techniques have moved from research into development, abstract graphic tools are becoming popular with animators, publishers, architects and designers.

The classification defined by the computer graphics community, of photorealistic compared to non-photorealistic, has been used in many research papers, but is often criticised, as "It is rather absurd to describe a field of research and development after that which it is not" (Green, 1999, p. 2-2). If the broad scope of art is considered, and paintings of a photo-realistic nature are removed, the wealth and variety of pieces being classed under one label can be clearly seen.

Photorealistic paintings, by artists such as Vermeer and Canaletto, portray a time in western art that was similar to the early half of the last decade in computer graphics. Here, the physics of light and atmosphere were used in conjunction with perceptual tricks, such as perspective, to create what were termed 'tromp l'oeil' paintings (Gombrich 1972) - images that could not be distinguished from reality. In art, style is often dictated by purpose, or desired outcome. Realistic paintings, with their faithful recording of objective detail and the play of light on a subject, certainly have their place, such as where reality is to be mimicked. This is also true in computer graphics, when a location is to be simulated, or a sense of presence needs to be conveyed. Just as highly realistic paintings serve to show the skill of the artist, photorealistic computer graphics are often used to illustrate the 'skill' of the rendering software (e.g. Fairclough, Online).

Paintings of a 'non-realistic' nature also have equally valid purposes and possess their own distinct qualities. For example, when depicting landscape, artists use a variety of representational styles. Pen and ink sketches, such as those accompanying the walker's guides of Wainwright (Wainwright 1993), convey form through texture and tone. These are not particularly abstract and often use heavy shadowing, but provide a picturesque description of the dramatic landscapes of the Lake District National Park, often using multiple projections to aid navigation (Wainwright 1992). In contrast, the abstract style of Monet makes striking use of the aesthetic primitive of colour. Here, mood and emotion are woven into the representation, while objective detail is often sacrificed. Russell (2000) provides an excellent source for comparing Monet's landscapes with photographs of the actual scene.

Issues relating to style being fit for purpose in computer graphics have been the driving force behind the development of many NPR techniques and were examined by Schumann et al. (1996). Here, a study was carried out to assess how architects would react to realistic depiction of buildings, compared to computer generated sketches. The purpose was a preliminary description of an architectural design. The study concluded that a rough sketch was the preferred choice as it promoted discussion and did not give the impression of being the finished design. When the perception of form is the objective of representation, cognitive theorists (Biedermann and Ju 1998), and researchers in computer graphics (Rodger and Browse 2000) agree that abstracted images perform as well as their realistic counterpart.

In computer graphics, realistic rendering has been a goal-orientated strand of research, aiming to mimic the deterministic properties of a camera and the physics of radiosity (Cohen and Wallace 1993). Schofield (1999) notes that there are no constrained rules for abstract art. It is because there is no pre-defined path to the solution, that the multidisciplinary research into NPR holds so much interest.

As the NPR field grows, taking its inspirations from many areas of art, several online collections of published material have been established. A developing project at The University of Utah (Gooch and Gooch, Online) aims to maintain a directory of active researchers in the field and to develop a code and model repository. Reynolds (Reynolds, Online) has collated an extensive collection of online papers and animations into an informal taxonomy.

2.1.1 Non-Photorealistic Rendering Styles

Several researchers have offered reviews of the various published techniques; often performing groupings based on location within the rendering pipeline (Richens and Schofield 1995; and Treavett 1998). Many techniques access the scene geometry whilst others use either specially rendered images such as the projected z-buffer or normal map, or photographs of actual scenes or subjects. Teece (1998) reported in Green (1999) classed systems into two main groups based on whether the system was 2D or 3D. These groups were then sub-classed into those that required input from a human or those that were automated. Many systems, however can fit into several groups as they offer the choice of user input into the image creation process or a fully automated approach. The main contribution of some of these techniques has been the research undertaken into the simulation of natural media which looks in detail at the physical modelling of ink, paint or graphite, or brushes and erasers.

The section that follows is not intended to be a detailed review, but serves merely to define the styles that lie outside the scope of the thesis, and to briefly discuss the relevant techniques. This is not presented as a definitive collection, but serves to illustrate the breadth of this stimulating area of research. Reference should be made to the online sources for a more complete

catalogue of work. Techniques that relate to the focus of this thesis, namely minimal line or contour drawings, are reviewed in more detail in Chapter 3.

Painterly Style

The main aim of painterly rendering techniques is to give a 'hand-painted look' to either computer generated graphics, photographs of scenes/subjects or live/recorded video. There are two distinct approaches to this problem, the first being to 'paint' onto a 3D model (Meier 1996; and Klein et al. 2000) or to use projected 2D brush strokes (Haeberli 1990; Treavett and Chen 1997; Litwinowicz 1997; Curtis et al. 1997; Hertzmann 1998; and Hertzmann and Perlin 2000). The former of the two approaches gives the impression of viewing a "painted world" (Hertzmann and Perlin 2000, p. 2) whilst the latter can be thought of as constantly re-painting a view of the world (either real or synthesised).

The primary reason for using the approach of Meier (1996) is to maintain frame-to-frame coherence and to avoid the 'shower door' effect (Meier 1996). Here, the 3D scene is rendered as a set of particles, each storing surface colour and orientation; strokes are then created by 'sticking' paint to the surface. Figure 2.1, shows a frame from one of Meier's animations. When 3D information is unavailable, as with video, (Litwinowicz 1997; and Hertzmann and Perlin 2000) techniques need to be developed to minimise the artefacts created when animating projected 2D brush strokes. Litwinowicz (1997) uses optic flow to move strokes around the image and Hertzmann and Perlin (2000) use frame difference to aid painting, and paint over the output from the previous frame.



Figure 2.1: Frame from a painterly animation.

Source: Meier 1996, p. 487

Where 3D information is available, strokes are usually oriented along surface normals, elsewhere, luminance gradients are used. To suppress local orientation artefacts, Litwinowicz (1997) interpolates the luminance gradient from the edges of regions that possess a low magnitude. Clipping of strokes can be achieved with masks containing edge-maps of the input image (Litwinowicz 1997). Edges can also be used to enhance the input image (Haeberli 1990) or to position strokes (Treavett and Chen 1997).

Although these techniques offer great potential to the animator or special effects producer, they do not model the process of stroke placement in art. Schofield (1999) notes that statistical and automated techniques are appropriate for the modelling of paint and paper (Curtis et al. 1997) and for more technical styles such as engraving. However, the use of fully automated techniques to 'create' painterly images produces results which "tend to be either chaotic and unintelligible or flat and predictable" (Schofield 1999, p. 4-11).

Graphic Art and Half-toning

This broad field encompasses styles such as architectural drafting (Richens and Schofield 1995), fine ink drawing (Strassmann 1986) and pencil techniques (Sousa and Buchannan 1999). This section also covers half-toning and screen-printing techniques (Ostromoukhov and Hersch 1995; Elber 1995; Buchannan 1996; and Elber 1998).

Graphic art systems which pass full control to the user (Strassmann 1986; and Hsu and Lee 1994), rely on an input of human artistic skill to produce pleasing images. These techniques are based upon novel methods of rendering user-defined stroke paths. Strassmann (1986), an early proponent of NPR, presented a technique inspired by minimal Japanese ink painting (sumi-e). Through modelling the supply of ink to the bristles of a brush object, according to a user defined dip and pressure, a realistic model of ink painting was produced. Hsu and Lee (1994) also used user-defined paths, however, rather than guide a brush, the path formed a stroke centre-line. This 'skeletal stroke' allowed pre-defined vector primitives to be deformed along the course of the path. Both techniques produce impressive results when used by skilled artists. Sousa and Buchannan (1999) also describe a technique that relies on human artistic ability. Their main contribution relates to the complex modelling of the interaction between graphite, paper texture and erasers. They take scanned pen-and-ink drawings and apply their models of erasers and blenders to produce a full tonal pencil sketch.

Graphic art systems that offer a fully automated approach (Masuch et al. 1997; Hall 1997; and Feth 1998) provide the means to create abstracted images or animations from 3D models. Masuch et al. (1997) propose a system for creating resolution independent line animations with a 'rough' feel whereas Hall (1997) uses a form of texture mapping termed Q-Mapping to cover a model with NPR styles – thus achieving frame-to-frame coherence and avoiding the 'shower door effect' in a similar fashion to Meier (1996). The technique described by Feth (1998) uses

stepped shading to reduce the number of tones present in a rendering to achieve a graphic art style.

One of the most successful graphic art systems, developed for creating artistic architectural renderings, is described by Richens and Schofield (1995). This commercial product mixes automation with user interaction and works both with a 3D model and at the level of the projected image. The resulting system is described as a '*3D painting package*'. The user, who is assumed to possess some artistic ability, interactively paints onto a canvas that dynamically interrogates various image buffers. These buffers consist of the projected z-buffer, a material buffer (used for matting), and the red, green and blue values of the rendered image. Using the stored information, the system can orientate hatches, clip strokes to materials and scale inserted 'cut-outs' such as scanned 2D images of trees.

A number of researchers have investigated the use of half-toning techniques for the production of stylised images from either scanned photographs (Ostromoukhov and Hersch 1995; and Buchannan 1996), or 3D models (Elber 1995, 1998). The principle of half-toning is to produce an approximation of a grey-scale image with sets of black and white pixels. This technique succeeds in conveying the source image as "our eyes perceive a local average" (Buchannan 1996, Abstract). This style offers various benefits such as low storage bandwidth and reproduction costs when compared with photorealistic styles. Buchannan (1996) modifies traditional half-toning techniques (image dependent and independent) by adding controlled artefacts to an image and thus creating stylistic effects. Ostromoukhov and Hersch (1995), however, present a novel use of artistic screen elements to generate half-tones from 2D tonal reference images. This technique produces an interesting style of graphic art whereby images can have two meanings; one when viewed up close, so the observer can discriminate the icons used to create the half-tone, and the other when viewed at a distance so only the local average is perceived. This application is similar to the use of micro-letters on bank-notes, used to prevent counterfeiting. Illustrations resembling the work of M.C. Escher are also presented. Here shape tiles are morphed with respect to the underlying image tone (see Figure 2.2).



Figure 2.2: Artistic screening with a screen dot pattern inspired by Escher reproduced on an image representing a greyscale wedge.

Source: Ostromoukhov and Hersch 1995, p. 221

The works of Elber (1995, 1998) describe techniques for creating half-tone style images using iso-parametric curves (Elber 1995) and from parametric and implicit forms (Elber 1998). The use of curves across a surface (controlled by lighting model, a surface mapped texture or principal

curvature directions) produces crisp, high-resolution postscript plots. Figure 2.3 gives an example of this work.

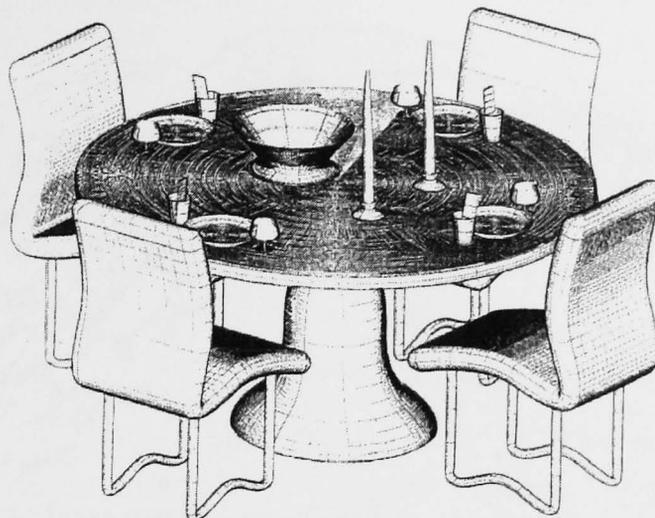


Figure 2.3: A scene of a dinner table rendered using cross-hatched isoparametric curves.

Source: Elber 1995, p. 237

Pen and Ink Sketching and Technical Illustration

Most of the techniques described here aim to simulate the concept of conveying form through texture and tone, similar to the work of Wainwright (1993). A notable exception however, is the work of Visvalingam and Dowson (1998) which uses short strokes, termed P-strokes (short for profile strokes), to convey the form of terrain through the indication of perceptually important surface features. This is achieved using a cartographic line generalisation algorithm (reported in Visvalingam and Whyatt (1993)). The application of this algorithm to rows and columns of a regular grid digital elevation model (DEM) 'scores' points on a surface according to their perceptual significance, resulting in the view-independent identification of shape defining convexities and concavities. The subsequent view-dependent selection and extension of these locations forms what is termed the 'P-stroke sketch', (Visvalingam and Dowson 1998). User input occurs in the form of interactively choosing selection tolerances and stroke attributes. Figure 2.4 illustrates this method.

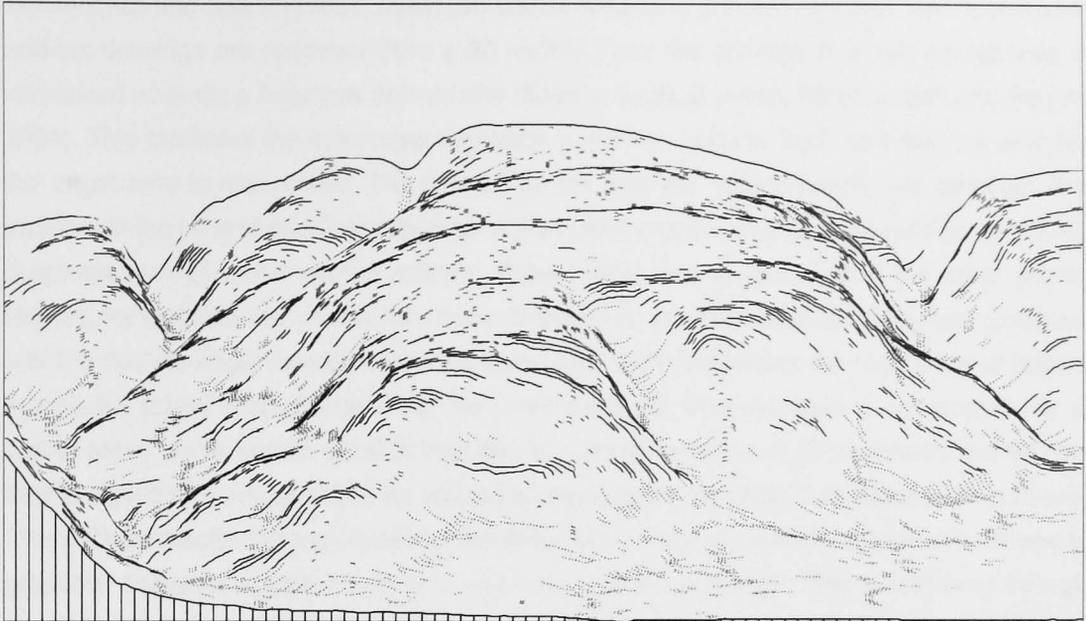


Figure 2.4: P-stroke sketch of a Digital Elevation Model.

Source: Visvalingam and Dowson 1998, p. 277

Data: © Crown Copyright; Ordnance Survey

A much more interactive technique is described by Salisbury et al. (1997). Here, pen-and-ink drawings are created by the user, from a 2D tonal reference image such as a scanned photograph. The system relies heavily on user interaction to edit direction fields to control the orientation of predefined, vector stroke sets. Strokes are clipped where the direction field turns sharply and the texture is built up through rendering the stroke sets until the intensity matches the tone of the reference image. Figure 2.5 is an output from their system.

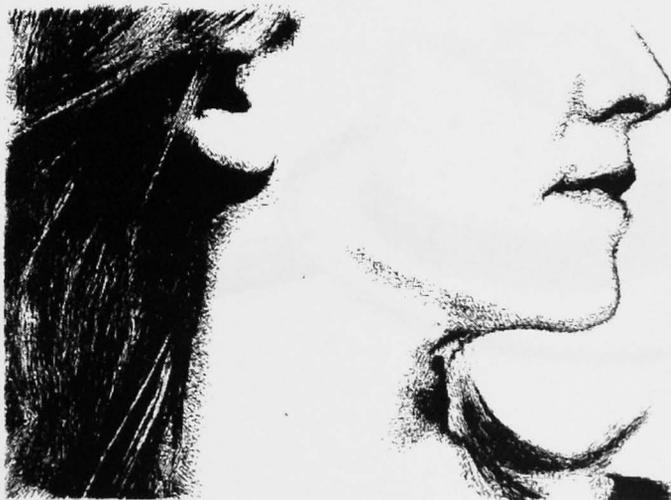


Figure 2.5: Hair and face (after untitled photograph by Ralph Gibson).

Source: Salisbury et al. 1997, p. 404

Winkenbach and Salesin (1994, 1996) use stroke textures in a more automatic form where pen-and-ink drawings are rendered from a 3D model. Here the concept of prioritised textures is introduced whereby a texture is defined with differing levels of priority (Winkenbach and Salesin 1994). This facilitates the automated rendering of defined textures such as brick, but ensures the target tone is appropriate. The stroke textures with the highest priority are rendered first (outlines in the case of brick) and the tone of the output image is checked against the tone of the illuminated model at the current location. If the model tone is darker, then the lower priority strokes, for example the internal structures of the brick, are then rendered. The loop continues until the desired target tone has been achieved. This technique allows the suggestion of texture in well-illuminated areas (where only the most important lines are drawn) and conversely in darker areas, more texture detail is included. In a more recent work (Winkenbach and Salesin 1996), algorithms are described for rendering pen-and-ink sketches from parametric surfaces. This work introduces the technique of controlled density hatching whereby strokes are allowed to gradually disappear in light areas or where many strokes converge. This is achieved through controlling the line width to maintain the apparent tone. Figure 2.6 gives an example of this work.

Within the field of technical illustration, the commercial system 'KaTy' (5D Solutions 1994) and the technique presented by Leister (1994) both use hatching and stippling of 3D models to give the rendered images a technical drawing feel. Recently, the application of pen-and-ink styles to volume datasets has been investigated by Treavett and Chen (2000). Rendering techniques such as 3D textures (controlled by lighting), pen-strokes (controlled by 3D information) and curvature-filtered z and normal buffers are used together to create effective visualizations. A novel application is demonstrated where a CT dataset of a skull is rendered in a photorealistic style, with the skin layer drawn as a translucent pen-and-ink layer.

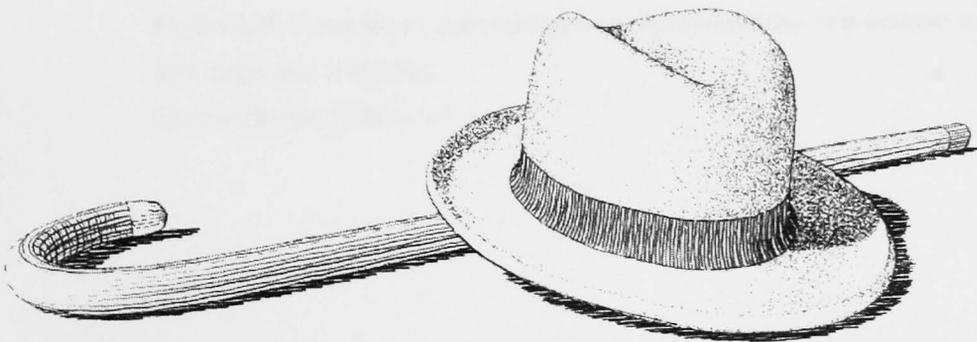


Figure 2.6: Hat and Cane; modelled with B-spline surfaces.

Source: Winkenbach and Salesin 1996, p. 476

Abstract Art

Abstract art such as Cubism, or the forms portrayed in 'Blue Nude IV' by Matisse (Gowing 1979, p. 195) do not translate well into algorithmic rules and therefore pose problems for NPR. However, the work of Burton, (1995) presents a technique to automatically produce 'child like art', of a very abstract nature, from a 3D model. The system is based upon a child's perception of the spatial environment, and is described as "a metaphor for the human process of experience, perception and representation", (Burton 1995, p. 29). The representation is derived from a series of generalisations of the 3D model and feedback from the image creation process. The resulting image is object-centred, in that every object from the model is represented in 2D, spatial relations are loosened, but connected objects remain so. The resulting image contains no occlusion and every object is fully visible. Figure 2.7 shows an example of the stages within the system.



Figure 2.7: Experience, perception and representation of a woman with two dogs and a big hat.

Source: Burton 1995, p. 31

2.2 Visual Abstractions

2.2.1 Principles of Perception

The fields of vision research and perceptual psychology include many different theories attempting to explain how we see and interpret the world around us. Most agree that reality must be simplified to an abstract level if the visual system is to function economically. An early proponent of this concept, Attneave (1954), examined the properties of visual redundancy from the viewpoint of an information theorist. He stated in his discussion of '*Perception as Economical Description*' that "It appears likely that a major function of the perceptual machinery is to strip away some of the visual redundancy of stimulation, to describe or encode incoming information in a form more economical than that in which it impinges on the receptors" (Attneave 1954, p. 189). This abstraction, more often than not, is likened to creating an "elaborate line-drawing-like description of the retinal image" (Hayes and Ross 1995, p. 344). The theories relating to how this line drawing is stored, range from the concept of 'picture in the head', to a series of hierarchical codes (Watt 1992) or a multi-resolution pyramid (Nakayama 1990). However, most researchers agree that to produce this abstraction, the visual system needs to operate at a number of different spatial scales (Marr 1982; Burr and Morone 1990; and Nakayama 1990).

The concept of the observer creating a sketch-like abstraction from the output of the retina received much attention from Marr (1982) in his computational approach to understanding vision. The impetus which Marr's theory created has driven many researchers to investigate algorithmic or theoretical techniques for creating such abstractions. Likewise, there is a large body of work concerned with how the brain re-constructs 3D-shapes in such an effortless manner from minimal line drawings. As this thesis is concerned with the perception of form from a minimal set of cues, this section briefly introduces the background to the principle ideas of vision research.

The perception of form from shading across a surface is not investigated here as it is outside the scope of this thesis. Readers interested in this should refer to Ramachandran (1995) or Horn (1975, 1982).

2.2.2 The Sketch Metaphor in Vision

The goal of vision is defined by Marr as "a process that produces from images of the external world a description that is useful to the viewer and not cluttered with irrelevant information" (Marr 1982, p. 31). Marr proposes the existence of two intermediate stages of processing namely the Primal Sketch and the $2\frac{1}{2}$ D Sketch that precede the abstraction of this 'useful' description.

The objective of the primal sketch is to make "explicit important information about the two-dimensional image, primarily the intensity changes" (Marr 1982, p. 37). These intensity changes

are the first cues that the visual system receives. Attneave (1954) had previously stated that “information is concentrated along contours (i.e. regions where color changes abruptly)” (Attneave 1954, p. 184). The susceptibility that the visual system displays to these changes can be explained through the process of lateral inhibition (Hartline et al. 1956). Latto (1995) gives a good description of this process. Here, examples of artists exploiting the physical properties of lateral inhibition, i.e. the phenomena of receptor cells emphasising edges, are presented. Examples include Seurat’s use of irradiation to simulate Mach bands and Man Ray’s use of solerization in photography to produce images that relate directly to the properties of the visual system. (Latto 1995, p. 73). Figure 2.8 shows an example of Man Ray’s work taken from Latto (1995).



Figure 2.8: Portrait of Lee Miller. Man Ray 1929.

© Man Ray Trust/ADAGP, Paris, and DACS, London, 1994

Source: Latto 1995, p. 73

This tendency for seeing edges is at the core of Marr’s model. The stage following the Primal Sketch, the 2½D Sketch, is composed of various classes of delineations termed **shape contours**. These lines, projections of boundaries present in the image, are defined as “two-dimensional contours that yield information about three-dimensional shape” (Marr 1982, p. 215).

The following list names the four classes of shape contour that are present in the 2½D sketch (Adapted from Marr 1982, p. 215).

1. Contours delineating discontinuities in distance – termed occluding contours or silhouettes
2. Contours delineating changes in surface orientation
3. Contours occurring as a result of changes in surface reflectance
4. Contours occurring as a result of illumination effects like shadows, light-sources and highlights.

Contours 3 and 4 are further sub-classed as **surface contours** as they “lie along the surface” (Marr 1982, p. 218).

The general assumption in vision research is that these contours are discernible through analysis of the intensity values in the retinal image, and that this analysis is scale dependent. In the construction of the primal sketch, Marr used zero-crossings of second order derivatives of image intensity to locate these boundaries. The raw primal sketch is a combination of these tokens, extracted from various spatial scales. Watt (1988) also used derivatives in his MIRAGE system, defining an occluding edge or silhouette as projecting “a sudden change in image intensity” (Watt 1992, p. 29). These methods, based on the previously mentioned concepts of lateral inhibition, are complemented by the different and equally biological plausible approach of Burr and Morone (1990). Here, phase relationships of Fourier harmonics are used to extract peaks in local energy, which correspond to the location of features.

The ease with which the visual system can interpret 3D shape from a well-abstracted line drawing is an impressive indicator to the value of the perceptual sketch metaphor. Additional supporting evidence can be found in artists' use of lines “despite the fact that lines are relatively rare in nature” (Latto 1995, p. 72).

2.2.3 Perception from Contours

Supporting the research into how the brain abstracts a concise representation from data-rich input, are several theories relating to how the 3D shape is reconstructed from sparse line drawings. Examples of the specific use of contours to convey shape can be found in section 2.3 and 2.4. The following text presents the main background concepts.

The most important cue in the perception of a scene is gained through an awareness of the depth relations present in a particular view (Watt 1992; Parker et al. 1992; Barbour and Meyer 1992; Murray 1994; and Rodger and Browse 2000). It is a logical conjecture then, that in a line drawing, the most important contours should be those which portray depth relations. Marr (1982)

classes this cue as his primary shape contour - the occluding contour. Other researchers refer to this as a silhouette line or outline.

Most theories relating to form perception from contours look at the changing shape of the projected lines. These observations are noted here as a general subject background and are not exploited further in this thesis. Hoffman and Richards (1982), although primarily concerned with segmentation, stated that concavities in silhouette lines result from the joining of parts or the interpositioning of objects. Koenderink (1984) complemented this idea stating that inflections of the occluding contour give strong clues to local surface shape and indicate “actual properties of the surface” (Koenderink 1984, p. 328). In addition, researchers in machine vision have used the revealing properties of the occluding contour to reconstruct shape from sets of contours calculated from multiple viewpoints (Bro-Nielsen 1997). Another important shape from contour cue is provided by the well-known kinetic effect of occluding contours deforming through motion (Rodger and Browse 2000). However, this is not considered here as this thesis is primarily concerned with static renditions.

Although the occluding contour gives powerful cues to both scene structuring and local surface perception, it must be supplemented with other contours, especially if the scene is natural or irregular and the display is static. Another large body of work within the field of shape-from-contour was undertaken by Stevens (1981). The contours under analysis here were the last two of Marr’s shape contours, namely those that lie physically on the surface of the scene such as shadow contours or wrinkles or seams. Locations of texture compression in images where regularly spaced contours lie across a surface, orthogonal to the line of sight, were demonstrated to convey qualitative impressions of surface shape (Stevens 1981). These locations, which Marr terms as “most vivid and puzzling” (Marr 1982, p. 216), give strong indications as to the location of silhouette-related cues. Figure 2.9 gives an example of this situation.

The natural success of perceiving shape from a line drawing is intriguing. However, a well-abstracted line drawing is quite different to the previously discussed sketch metaphor. The following section illustrates how, within the field of cartography, the abstraction rendered by the cartographer is a product of interpretation rather than just low-level analysis of a retinal image. This interpretation is aided by a wealth of knowledge and training, it is this that separates the tutored and untutored eye.

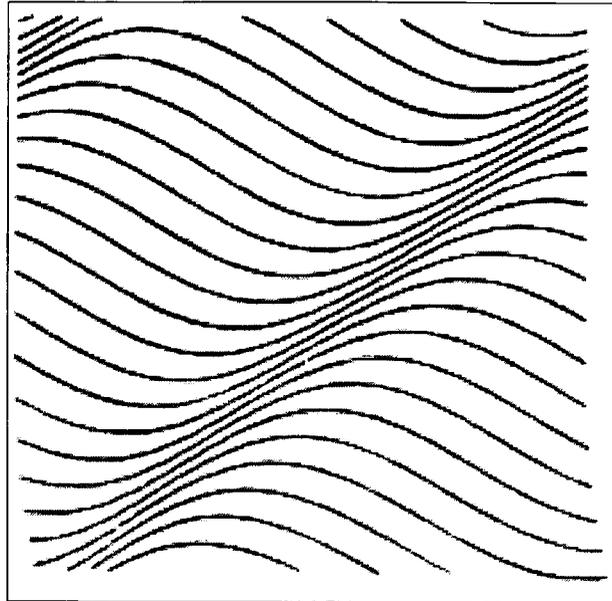


Figure 2.9: Diagram illustrating texture compression occurring where the surface is turning away from view.

Source: Marr 1982, p. 227

2.3 Cartographic Abstractions

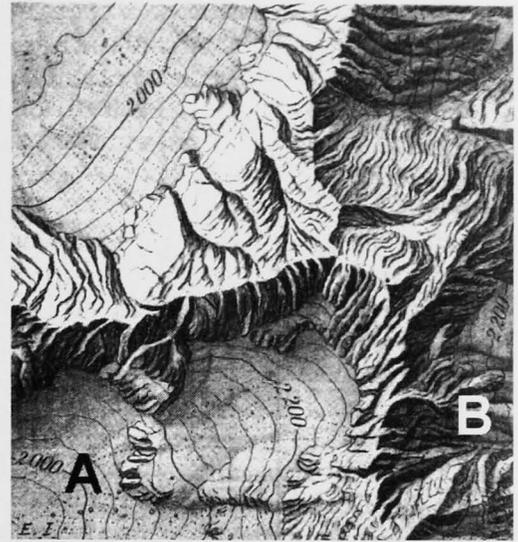
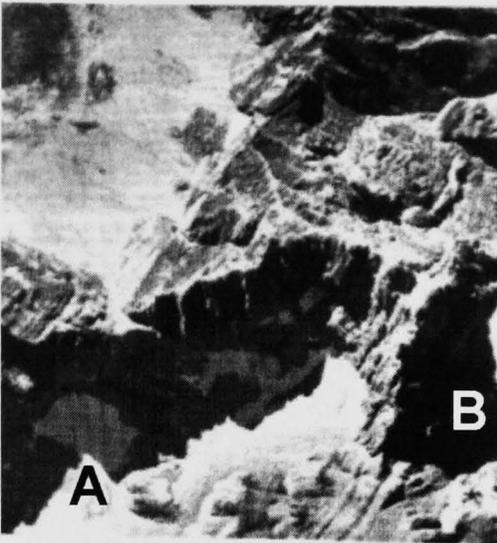
By definition, cartography is an abstraction of reality and cartographic representations present the viewer with a generalised image of the world. Whether it is a map, sketch, or diagram, the cartographer has used his skill to include only the information that is needed to communicate spatial relations, the form of the terrain or abstract topological concepts. This removal of redundant information and visual coding of lines presents to the viewer, a perceptually pre-processed intensity image, from which a speedy perception can be readily derived. Added to this presentation is the cartographer's skill in the choice of line attributes, level of generalisation and the use of appropriate symbologies and typification. These factors ensure the viewer perceives what is intended to be perceived, whether this is true to reality or not.

Support for the concept that a line sketch is more than a product of intensity analysis of the retinal image is provided by Hayes and Ross (1995). They state that "lines of line drawings have neither point-to-point correspondence with the original scene, nor are they arbitrary symbols - they correspond to a description calculated by the visual system itself" (Hayes and Ross 1995, p. 343). This suggests that when sketching, the pipeline followed can be generalised to, see, think and then draw. Marr (1982) considers this issue by noting that situations occur where the intensity change over a discontinuity, such as occlusion, is insufficient to recover the contour. In addition, it is noted that "the strongest changes in an image are often changes in illuminations and have nothing to do with meaningful relations in a scene" (Marr 1982, p. 272). These situations, where shape cannot be recovered by, or is inferred incorrectly from, image intensity values, need to be resolved through interpretation. The processes of perceptual filling-in, and

consistency checking (Marr 1982, p. 285) go some way to removing these ambiguities. However, as the understanding of the scene moves further away from seeing to thinking, the resulting sketch drawn by the observer bears less resemblance to image intensity changes or the actual boundaries present in the scene. The following text and figures give some examples from cartography illustrating how the process of creating a visual abstraction is an output from thinking rather than seeing.

A good illustration of a cartographic abstraction compared with reality is provided in Imhof (1982). Here, an aerial photograph is compared to an abstracted map, a product in which clear and precise delineations are paramount (Figure 2.10). The map removes artefacts present in the aerial photograph which may influence the formation of an incorrect perception. Surface contours, formed from shadow artefacts, have been removed at location A, and the features hidden through lighting effects at location B have been revealed in the map. An additional clarification is provided through the delineation where the cliffs give way to glacier ice.

To illustrate the benefits sketching offers over reality, Figure 2.11 presents a comparison between a rough cartographic sketch and the photograph from which it was derived. When viewing the photograph, which is similar to the retinal image, edges and discontinuities need to be inferred through an analysis of the intensity changes present. However, as noted above, ambiguities may occur where boundaries cannot be discerned due to areas of homogenous tone or texture, on either side of the discontinuity. In the case of the sketch however, contours and features have been explicitly expressed, and are the product of a highly trained and experienced mind. The retinal image received when viewing the sketch has already undergone interpretation and has been transcribed using forms which reflect the properties of the visual system i.e. lines (Latto 1995). When viewing the photograph, the viewer becomes engrossed in the detail, rather than seeing the main structure. Lobeck, an eminent cartographic artist, writes that photographs “sometimes befog rather than clarify the situation. They usually lack the simple, direct appeal which a sketch carries with it, because, unlike sketches, photographs cannot select out of the landscape just those elements which may be deemed significant” (Lobeck 1924, p. 165).



(a) - Aerial photograph, approx. 1:10,000 of Murtschenstock-Ruchen (Clarus Alps, Switzerland)

(b) - Topographic map 1:10,000 of Murtschenstock-Ruchen (Clarus Alps, Switzerland)

Figure 2.10: Comparison between a map and an aerial photograph.
Source: Imhof 1982, p. 51

In summary, the contours that a cartographer uses in creating a sketch do not always result from a physical discontinuity in the image intensity. Conversely, observed intensity changes need not result in the formation of a sketch contour. The following section describes the structure of cartographic sketches illustrating the cues that are of concern to this thesis.

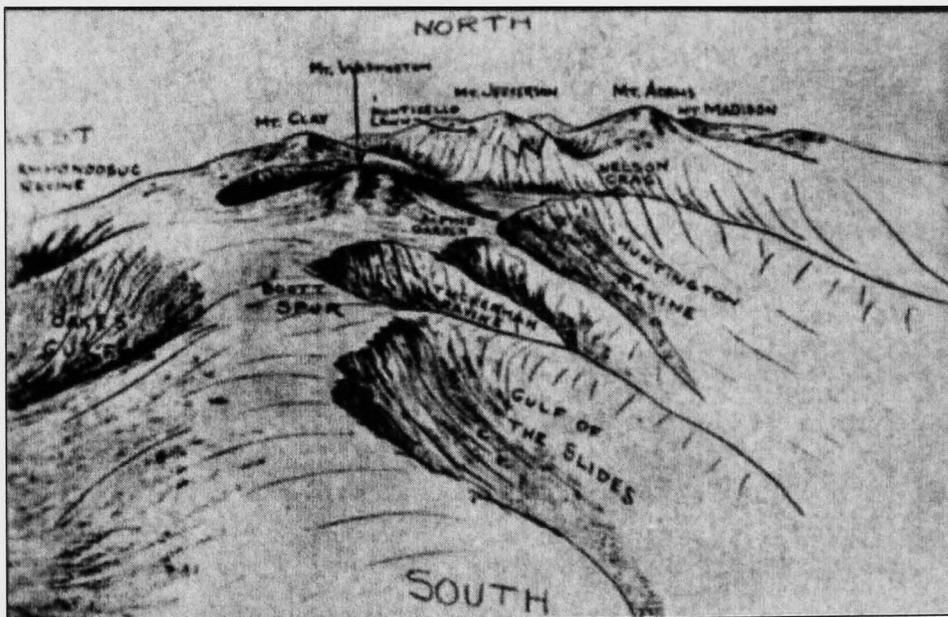
2.4 Landscape Sketches

The term landscape sketch can encompass a variety of styles (Section 2.1, p. 5). The style of interest to this thesis are those which convey form using minimal line-work, namely the field sketches of geologists and geographers. These sketches, which often provide a framework for water-colour washes, used to convey rock type (Murchison 1839), once graced geological expedition reports (Holmes 1876) and classic geomorphological text books (Lobeck 1939). Interestingly however, Hutchings (1960), notes that the “photograph has now almost entirely displaced drawing as the medium of pictorial illustration” (Hutchings 1960, p. 1). The visual success of sketches has already been discussed from a perceptual viewpoint. Additionally, sketches, serve as excellent base maps, proving much easier to annotate and label than a photograph.



(a) - An Aerial Photograph of the White Mountains of New Hampshire.

Source: Lobeck 1924, p. 186



(b) - Negative of a Blackboard Sketch of the White Mountains of New Hampshire.

Source: Lobeck 1924, p.186

Figure 2.11: Comparison between a sketch and a photograph.

The examples that follow serve to illustrate the work that has inspired this thesis and provide a means to highlight the silhouette-related cues that form the body of this research. Figure 2.12 shows a geological block diagram and Figures 2.13 and 2.14 show examples of panoramic

sketches. In essence, both use similar cues, but a differing projection is used in the block diagram, and the sides are 'cut away' to reveal the underlying geology.

In general, the lines and contours used in the creation of these sketches can be grouped into two distinct classes. Firstly and most important, are the view-dependent cues. These lines form the main framework of the sketch, into which other elements are grouped. The most important view-dependent contour, the horizon, being drawn first, with the projected silhouettes of the other lower hills being filled-in in front (Lobeck 1924; and Stuart 1918). These contours, which are bold and connected (along the course of a feature) provide a means of structuring the second distinct class, namely the object-based cues. The locations that make up this cue are related to physical properties of the land, i.e. breaks of slope. The depiction of this cue is more sparse and suggestive than the long, connected stroke of the silhouette-related cues.

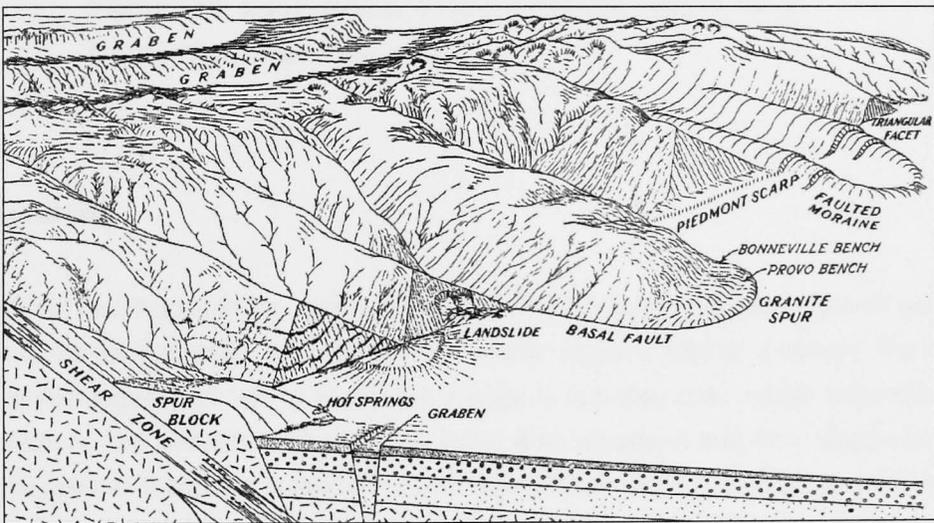


Figure 2.12: Block diagram of features along the front of The Wasatch Range, Utah.

Source: Lobeck 1939, p. 554

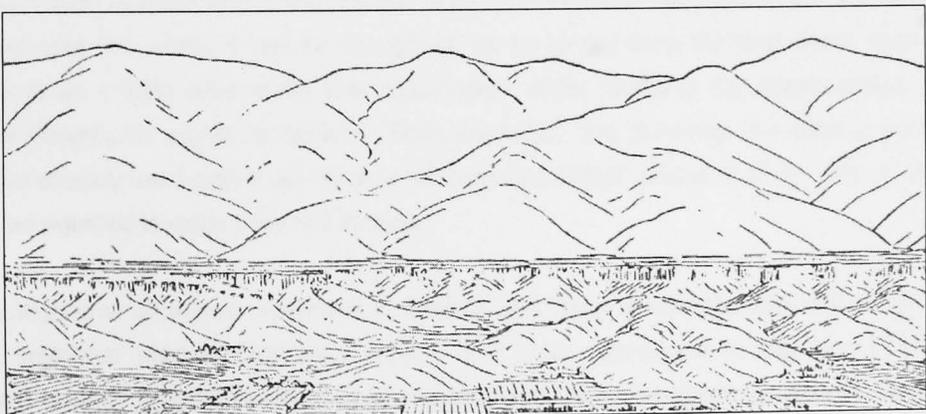


Figure 2.13: Detail of sketch of the Val d'Arno in Northern Italy.

W.M. Davis

Source: Lobeck 1924, p. 176



Figure 2.14: An illustration from a classic geology textbook.

Source: Murchison, 1839, p. 224

2.5 Summary

This chapter has illustrated the rapidly widening field of computer graphics research and briefly discussed the various styles on offer to the animator, graphic artist or architect. The reasons why humans respond so well to abstracted images is that they often reflect properties of our visual system. The abstractions involved in vision were discussed and their relationship to the basic principles of creating a cartographic landscape sketch noted. The intuitive nature in which structure is perceived from such drawings is primarily due to the fact that important cues have been made explicit, by a trained mind. In addition, these cues are drawn using lines, forms that the visual system is highly responsive to. However, an important point demonstrated in this chapter, which is referred to by researchers such as Marr (1982) and Hayes and Ross (1995), is that a well abstracted sketch is the product of more than just an analysis of the intensity values projected onto the retina; it can be thought of as an output from thinking rather than seeing. Sanocki et al. (1998) also make this observation whilst studying the effectiveness of edge detected images for object recognition. They state that “line drawings are created by humans who have already used high-level vision to perceive the object” (Sanocki et al. 1998, p. 342) and cannot be equated to edge detected images.

The cartographic sketches presented in Section 2.4 have similarities and differences to the sketch metaphor proposed by Marr (1982). The main agreement is that one of the most important cues to shape perception is provided by the depth relationships present in particular views of the scene. Researchers in vision and perception term the line marking this discontinuity the **occluding contour** or **silhouette**. Although there is some degree of interpretation described in the sketch metaphor, the cartographic sketch displays evidence of a much greater amount. Thus, not all lines drawn by a cartographer are based on fact. An example of this is provided by

the way in which the different shape contours described by Marr (1982) are treated by the skilled cartographic artist. For instance, visible, front-facing convexities (Captured by Marr's surface orientation contour) would rarely be drawn as a closed contour, unless the break of slope occurred at a cliff edge.

The following chapter reviews the techniques for automatic creation of contour drawings, primarily focusing on silhouette-related cues.

CHAPTER 3

Automatic Creation of Contour Drawings

Techniques for the extraction and depiction of silhouettes and contours form an extensive part of the research into NPR and, as discussed in the previous chapter, they play a critical role in visual perception. The clear depiction of these entities is rarely considered in photorealistic rendering, as their occurrence is largely guaranteed. Atmospheric models such as aerial perspective (distant surfaces taking on a bluish tint) ensure that large depth discontinuities present a contrast boundary, sophisticated lighting picks out surface orientation changes and texture mapping provides additional, strong boundaries. These synthesised images of reality leave the inference of such cues to the viewers' perceptual system. However, as the realistic elements are removed, and the scene becomes increasingly abstract, the need to explicitly delineate these perceptually important contours becomes more apparent.

Research into this field has moved from techniques for extraction and display (Pearson and Robinson 1985; Sasada 1987; Weibel and Herzog 1989; and Saito and Takahashi 1990) to specific theories relating to different inputs such as implicit surfaces (Bremer and Hughes 1998), faster extraction (Markosian et al. 1997; Gooch et al. 1999; and Benichou and Elber 1998) or solving known problems with existing methods (Northrup and Markosian 2000; and Hertzmann and Zorin 2000). This chapter re-visits the definitions of the various classes of contour provided by Marr (1982) and discusses them with respect to the cues extracted in the NPR background. The existing techniques, which operate either with two-dimensional images or with surface geometry, are then reviewed, assessing the cues extracted. The chapter closes with a summary of the pros and cons of operating at either the model or image-level.

3.1 Definitions of Cues used in Contour Drawings

The relatively early work of Dooley and Cohen (1990), presents a vocabulary of lines and proposes that a “new focus on *what* is drawn and *how* it is drawn” (Dooley and Cohen 1990, p. 82) is needed. Apart from discussing issues relating to the importance of line type and style, they highlight four classes of line for use in illustrations (Dooley and Cohen 1990, p. 78). These are listed below:

- 1 - Boundary lines.
- 2 - Silhouette lines.
- 3 - Discontinuity lines (folds)
- 4 - Contour or isoparametric lines that help convey curvature.



If Marr's Primal Sketch contours (Section 2.2.2, p. 16) are compared with Dooley and Cohen's classes of line, obvious similarities can be seen. Boundary lines, however, are not considered by Marr. These relate to a full description of the surface - something not available to the early stages of vision. Dooley and Cohen (1990) include boundary lines as their system offers the ability to render internal parts of objects. As these parts are hidden from view, there is a need to place more emphasis on the external surface, or the boundary of the object. Their remaining lines relate almost directly to Marr's three main classes of shape contour.

Silhouette lines or occluding contours are termed depth discontinuities by Marr (1982). When viewing a projected surface, a depth discontinuity occurs where locations change from being visible to being hidden. This discontinuity is located between the point on the surface immediately before a hidden zone, and where the surface returns into view (internal silhouette) or a point on the background (external silhouette). Figure 3.1 illustrates how a sign change in the dot product between the eye vector and the surface normal occurs where there is an occlusion. The locations of these orientation changes are termed by Marr as the *contour generator* (Marr 1982, p. 219), and the projection of these onto the image plane creates a 2D occluding contour. These contours are view-dependent and hence need to be re-calculated for changes in the viewpoint. Gu et al. (1999, p. 3), discuss how occluding contours sweep over a surface as the viewpoint changes.

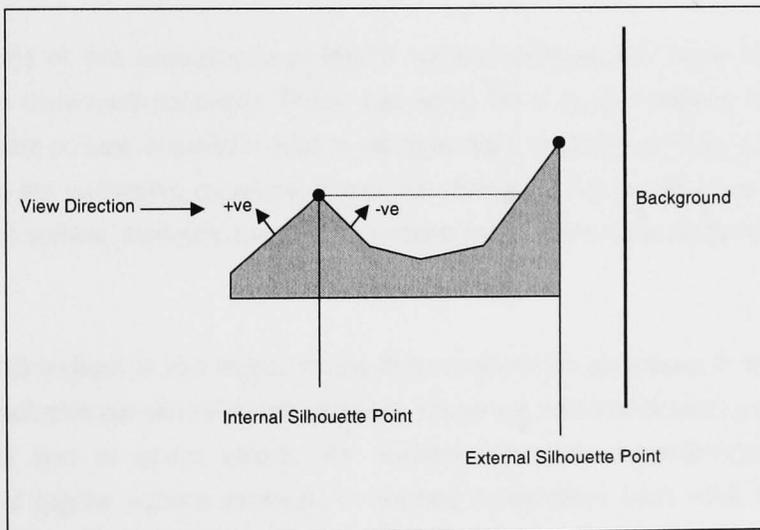


Figure 3.1: Surface normal change resulting from occlusion.

The class which Dooley and Cohen (1990) term as 'Discontinuity lines (folds)' is referred to by Marr as surface orientation contours (Marr 1982, p. 225) and Watt as creases (Watt 1988, p. 4). These situations occur where the rate-of-change in surface orientation is greater than a threshold, but the surface remains visible (Figure 3.2). These are not of direct concern to this thesis as frontal breaks of slope are treated very differently to silhouette related cues in cartographic landscape sketches (Section 2.5, p. 24). This class of cue is object-based and can be pre-computed, therefore it does not need to be re-calculated as the viewpoint changes.

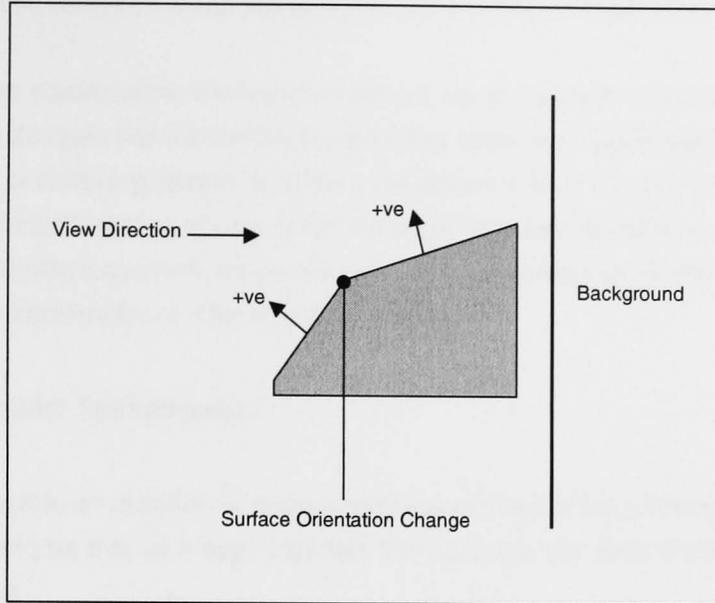


Figure 3.2: Surface normal change resulting from an orientation discontinuity.

The fourth class of line corresponds to Marr's surface contours, i.e. those which are not a product of the underlying geometry. These can either be a regular texture, which can yield information about surface orientation (due to compression), or simply as lines across a surface, giving clues to the underlying curvature. Figure 2.9 (Section 2.2.3, p. 18) gives an example of regular parallel surface contours compressing where the surface turns away from the viewing direction.

The contours of interest to this thesis, hence those that will be discussed in this chapter, are those lines which pick out silhouette-related cues. These are primarily occluding contours (depth discontinuities) and to some extent, the surface curvature characteristics revealed by compression of regular surface contours. In general, researchers have used only the factual definition of occlusion to capture silhouettes. However, as this chapter shows, some have included shading across locations hinted at by surface curvature.

The background into the automatic extraction of contours from a scene can be grouped, with respect to location in the rendering pipeline, into two main classes - namely object and image-based. This classification was also used by Hertzmann (1999) in his review of silhouettes and outlines within NPR techniques. This divide represents a simple distinction between the information which extraction algorithms have access to (either 2D or 3D) and the outputs that can be created. Many techniques do not add new concepts to the definitions already discussed. However, as noted previously, some describe computational speedups or process different

inputs such as implicit surfaces. One method (Northrup and Marksoian 2000) offers a hybrid approach that works at both pipeline locations. For the purpose of this review, it has been placed in the model-based class as it works primarily with object-precision information.

In addition to this classification, there are two distinct sub-groups within the image-based class, namely those techniques that rely on image processing operations, and those that use hardware based methods or rendering 'tweaks' to achieve the desired effect. The later of these techniques can be thought of as rendering effects, whilst the former is a post-rendering process. Rendering effects are only briefly discussed as they rely more on manipulating the rendering process rather than the specific identification of silhouette-related cues.

3.2 Image Based Techniques

This section provides an overview of image-based approaches which is followed by a review of the various techniques that have been reported. The cues that this class of system extracts are then summarised.

The input to the primary class of image-based systems is a discrete bitmap of either a photograph of a natural or contrived scene, or a specially rendered image i.e. a z-buffer or normal map. The operations performed on this image usually consist of various forms of edge detection - processing the image with a defined kernel and then thresholding the output. For descriptions of edge detection operations refer to Boyle and Thompson (1988), Parker (1994) or Bassmann and Besslich (1995). The secondary class contains those techniques termed rendering effects. These systems differ from the previous class in that although they generate rasterized output and provide limited scope for intelligent rendering, their input is scene geometry. Table 3.1 presents an overview of the approaches reviewed in this section.

Research	Input	Detection of Occlusion	Additional Silhouette-Related Cues
Image Processing			
Lesage and Visvalingam 2000	Illuminated Model	YES	YES
Correa et al. 1998	Normal Map	YES	Not their objective
Curtis 1998	Z-buffer	YES	YES
Chang 1998	Z-buffer	YES	YES
Saito and Takahashi 1990	Z-buffer	YES	YES
Pearson and Robinson 1985	Illuminated Natural Scene	YES	YES
Rendering Effects			
Everitt 2000	Texture Map	YES	YES
Raskar and Cohen 1999	Transformed Geometry	Rendering Artefact	NO
Dietrich 1999	Transformed Geometry	Rendering Artefact	NO

Table 3.1: Overview of image-based techniques.

3.2.1 Rendering Effects

There are two main approaches to this style of silhouette rendering. The first operates with direct calls to specific graphics hardware (Dietrich 1999; Everitt 2000) and the second (Raskar and Cohen 1999) employs various rendering tricks.

Dietrich (1999) and Everitt (2000) have both produced white papers on Silhouette Rendering using the GeForce2 Graphic Card. Everitt (2000) describes a technique based upon analysis of the dot product of the surface normals and the eye vector using a specially texture-mapped image and hardware specifics. Dietrich (1999) offers a review of how various functions of the GeForce card can be used to render silhouettes.

Different approaches using rendering effects are described by Raskar and Cohen (1999) and Gooch et al. (1999). Here the rendering API is 'tweaked' to display models with the silhouette areas marked. Raskar and Cohen (1999) detail several rendering tricks that may be employed to achieve this. Their main discussion is concerned with what they term the 'fattening' of back-facing polygons. These *fat* polygons are drawn in black, with the front-facing ones drawn in white. The enlargement of the back-facing polygons causes a visible overshoot where a front-facing polygon is adjacent to a back-facing polygon, thus forming a silhouette edge. Other techniques include pulling forward the back-facing polygons. Although their main technique is

based at a model level, Gooch et al. (1999) describe an approach similar to Raskar and Cohen (1999) based on multi-pass rendering.

3.2.2 Image Processing Operations

This section reviews the techniques for abstracting contour drawings using image processing operations. The review is split into those approaches that are primarily concerned with identification of contours, and those that use the identified contours for further processing.

3.2.2.1 Identification of Contours

Silhouette and contour detection through image processing techniques is primarily based around convolving an input image with a kernel approximating a 1st or 2nd order derivative. These filters pick up changes in the energy or intensity of the input image, whether it is a photograph, natural or contrived, or a specially rendered image such as a z-buffer or normal map. If a large kernel is used (e.g. 9 by 9 cells) then the filter will respond to larger features in the input image. A similar scale dependency can be achieved by smoothing the input prior to filtering, often using a kernel representing a specified Gaussian filter, approximated to a discrete representation.

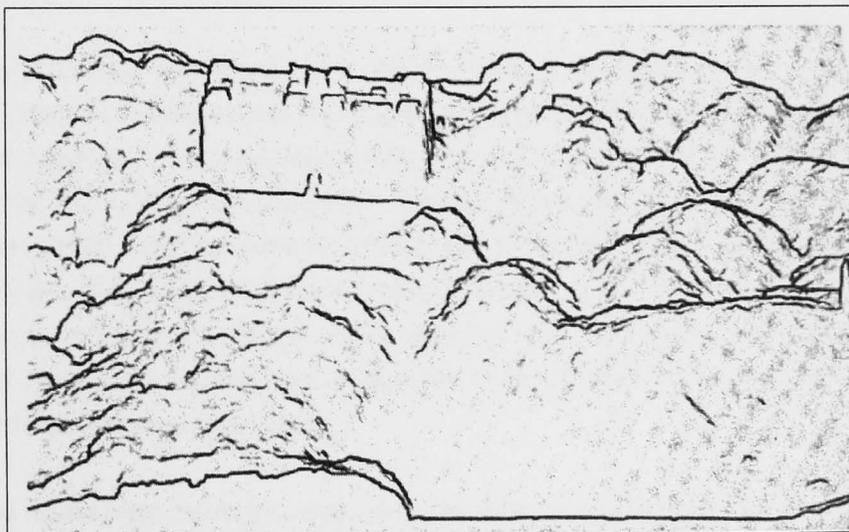
The work of Pearson and Robinson (1985) presents one of the earliest pieces of research into the automatic abstraction of silhouette-related cues from a scene. Their aim was to identify the minimal set of cues needed to convey the expression and character of a face, or the pose and gesture of a hand. The motivation for this work was the need to transmit frames from video over a very low bandwidth (4.8-19.2 kbits/s (Pearson and Robinson 1985, p. 795)), whilst still maintaining frame character and fidelity. The approach adopted set the background for many of the techniques described in this section.

As noted in the previous chapter, the field of edge detection has a lot in common with vision research (both human and machine), with many algorithms having their origins in this area such as Burr and Morrone (1990). Although luminance edges do not always correspond to the lines of line drawings (Hayes and Ross 1995; and Sanokie et al. 1998), Pearson and Robinson (1985) note that when a scene is subject to controlled lighting, edge detection of luminance maps yields responses in locations where an artist is likely to draw important lines. They observe that “feature points (in practice lines) occur wherever the surface normal vector is nearly perpendicular to the camera viewing direction” (Pearson and Robinson 1985, p. 796). Their technique illuminates faces from a camera-centred source or headlight and assumes Lambertian reflection. Under these conditions, the luminance map is a function of surface orientation, parallel to the line of sight; therefore, locations that turn away from view, but remain visible, will appear darker. Pearson and Robinson cite Speed (1910) who also notes that the best conditions for executing a line drawing are when the light source is behind the viewer.

The technique proposed by Pearson and Robinson (1985) uses a 5*5 or 3*3 Laplacian kernel to detect oriented valleys, areas of low intensity, in the luminance map. The results are filtered and supplemented with a binary thresholding of the input image to add an element of mass.

The work of Saito and Takahashi (1990), is based on similar principles to Pearson and Robinson's (1985) however their aim is to increase comprehension and legibility in rendered 3D scenes. Their input takes the form of specially rendered images termed G-buffers. These buffers hold projected images whose pixel colour is determined by various scene attributes. The most useful buffer (z-buffer) contains pixels coloured according to z-depth, this ensures that depth discontinuities project an intensity change. These discontinuities are detected using a first order differential operator such as Sobel's. Surface orientation changes can be identified by convolving the image with a kernel approximating second order differential.

Other buffers such as surface normal maps are used to control hatching. The two classes of extracted edges (first and second order derivatives of the z-buffer) relate to Marr's (1982) first two contours namely occluding and surface orientation contours. The filtering and combining of these layers is demonstrated particularly well with a rendering of a machine nut. Here, the occluding contours and orientation changes give rise to marked discontinuities. In an example of the techniques applied to a 3D visualization of elevation data, only the depth discontinuity edges (first order derivatives of the z-buffer) are used. The fact that orientation discontinuities are not included in the terrain visualizations reiterates the point made in the previous chapter (p. 24), that these contours are more suited to sharp features rather than terrain depiction. Figure 3.3 shows one of the layers used in the creation of these '*bird's eye maps*' (Saito and Takahashi 1990, p. 203). Additional layers, not shown in Figure 3.3, included directional shading and height contours.



**Figure 3.3: First order derivatives of the z-buffer.
(One Layer of a 'Bird's Eye Map').**

Source: Saito and Takahashi 1990, p. 203

The work of Chang (1998), which provides interactive processing of a rendered z-buffer, is very similar to the techniques presented by Saito and Takahashi (1990). However, in addition to edge detection of the z-buffer, mean and Gaussian curvature are calculated. The user of the system can interactively toggle and threshold each of the three layers. In addition to successfully abstracting cues from a model of a bolt, the technique also produces good abstractions from complex and irregular 3D models (see Figure 3.4).

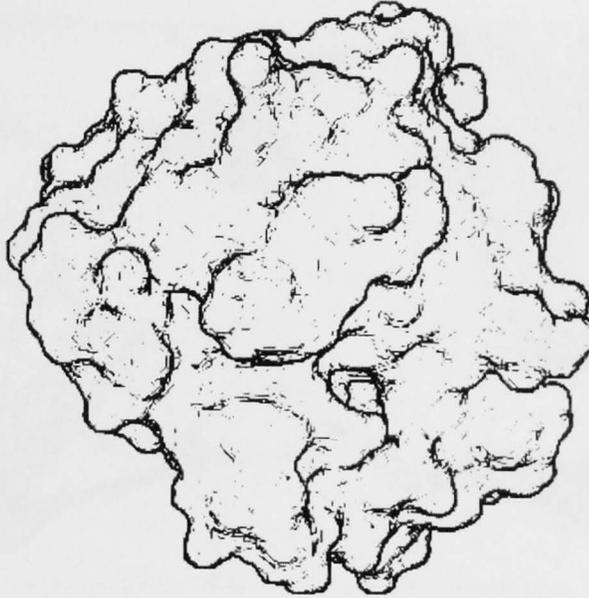


Figure 3.4: Positive mean and Gaussian curvature and Laplacian convolution of a z-buffer of a rendered 3D model.

Source: Chang 1998, p. 7

The work of Lesage and Visvalingam (2000) adopts a technique similar to Pearson and Robinson (1985) in that the input to their system is an illuminated scene not a z-buffer or normal map. Their objective is to abstract occluding contours and surface creases from an illuminated terrain model. Watt (1988) also describes a system based upon these principles. Lesage and Visvalingam (2000) adopt the same assumption of a light source tied to the camera (headlight), however, unlike Pearson and Robinson (1985), they have access to the scene geometry. This information is sacrificed as the aim of the research is to investigate how the use of select sources of illumination can pick out perceptually important features for the creation of static outputs or batch-processed animations.

Impressive results were produced using the Canny operator applied to USGS data (Lesage and Visvalingam 2000, p. 17). In this case, the landscape in question provided the filter with a large number of strong discontinuities. However, when processing less rugged landscapes it is noted that “weighting the lines on edge strength can connect spatially disjoint contours into inappropriate occluding contours” (Lesage and Visvalingam 2000, p. 18). The results produced

are more suited to an animated environment rather than static plots as during animation, the movement of the extracted discontinuities provides strong additional form cues. The addition of a secondary light source (vertical illumination) picked out the valleys well. However, it omitted too much detail on plateau surfaces and is noted as giving “the impression of a planed surface” (Lesage and Visvalingam 2000, p. 18). Figure 3.5 shows the output of the horizontal combined with the vertical light.

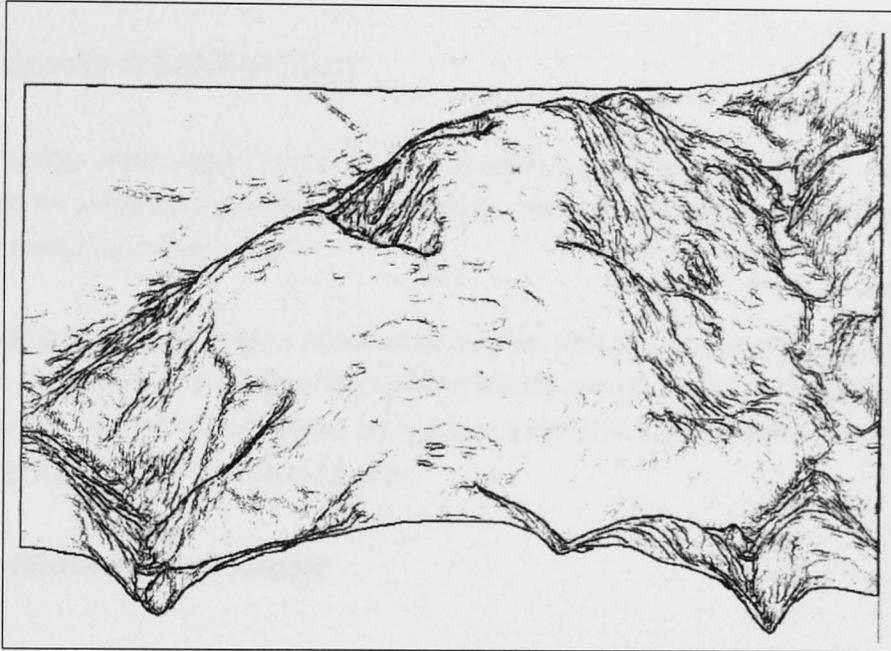


Figure 3.5: Sketch with headlight and vertical light.

Source: Lesage and Visvalingam 2000, p. 20

3.2.2.2 Use of Identified Contours

Unlike the previously described approaches, Curtis (1998) and Correa et al. (1998) take the output from image processing operators and use it to aid other techniques. Curtis (1998) uses the standard approach of creating an edge map from a z-buffer however, force-field vectors are then created to move particles, guided by physically-based modelling techniques. This approach gives the edge lines a *'loose and sketchy feel'*.

The most notable variation in the image-processing techniques is presented by Correa et al. (1998). The aim of this research is to map a 3D-textured model onto a hand-drawn animation cell. The motivation for this work is that in cell animation, complex textures are not applied to moving characters, as frame-to-frame coherence is lost. This problem occurs due to the texture not being exactly reproduced in the next frame and therefore an effect termed *'boiling'* or *'swimming'* occurs. The method proposed allows an animator to create a textured 3D model to approximate the character, this is then warped to fit over the hand drawn artwork. The use of silhouette and border lines form a critical phase in this process as control curves guiding the

image warping. The silhouettes are detected at image precision through the analysis of discontinuities in a buffer shaded according to surface parameters. The novel contribution of this paper is that in order to control the model warp, curves need to be fitted to the discrete, pixelated output of the detection routine. This is achieved through fitting cubic B-splines to the pixels in the output image. Although it is rare for the output from an image processing technique to be in a stroke form, as opposed to a bitmap, it must be noted that the models used within this paper are extremely simplistic.

3.2.3 Summary of Extracted Cues

The rendering effect approaches offered a simplistic and easy to implement method for enhancing the silhouette edges of a rendered model. However, the reviewed techniques did not explicitly extract silhouette curves.

The image processing techniques extracted silhouettes, silhouette-related cues, and orientation changes. However, they did so in a largely indiscriminate manner. In most cases, except for the simple models of Correa et al. (1998), the output is a sampled, pixel resolution bitmap, with no knowledge associated with extracted entities.

3.3 Model-Based Techniques

Unlike image processing operations, model-based techniques have access to the full geometrical description of the surface. Techniques have been proposed to extract silhouette-related cues from a variety of model types. Examples include implicit surfaces (Bremer and Hughes 1998), discrete polygonal models (e.g. Markosian et al. 1997), height arrays or digital elevation models (Sasada 1987; and Weibel and Herzog 1989; Visvalingam and Whelan 1998) and smooth surfaces (Hertzmann and Zorin 2000). Detection from the model is based upon the same definitions discussed by Marr (1982), Koenderink (1984) and Watt (1988). However, these approaches differ from the image-based techniques as definitions and rules can be tested explicitly, at object-precision.

This section gives an overview of the cues extracted by model-based approaches. As noted previously, the development of work in this field has shifted from implementations of definitions to optimisation. The more recent approaches do not add much conceptually, but offer innovative approaches to decrease compute times. In the same fashion as the review of image-based approaches, a review of the reported approaches is followed by a summary of the cues extracted. Table 3.2 summarises the model-based approaches reviewed.

Research	Input	Detection of Occlusion	Additional Silhouette-Related Cues
Hertzmann and Zorin 2000	Polygonal Surface	YES	YES
Northrup and Markosian 2000	Polygonal Surface	YES	NO
Girshick et al. 2000	Polygonal Surface	YES	YES
Gooch et al. 1999	Polygonal Surface	YES	NO
Benichou and Elber 1998	Polygonal Surface	YES	NO
Bremer and Hughes 1998	Implicit Surface	YES	YES
Markosian et al. 1997	Polygonal Surface	YES	YES
Ma and Interrante 1997	3D Unstructured Grid	YES	NO
Weibel and Herzog 1989	Digital Elevation Model	YES	NO
Sasada 1987	Digital Elevation Model	YES	NO

Table 3.2: Overview of model-based techniques.

3.3.1 Model-Based Extraction Techniques

One of the earliest pieces of model-based, abstract scene rendering research was described by Sasada (1987). Here, techniques are presented for rendering digital elevation models (DEMs) in the style of a hand drawing. Various classes of form cue are extracted such as silhouettes, water-flow lines and simulated shaded zones. Raster images of vector trees are then placed on the terrain, with respect to the identified locations, and natural looking wave and water effects generated where needed. These sketch-style images were used as backdrops for CAD models of Japanese cities that were in turn, animated. In this approach, silhouette lines are defined to occur at locations marking hidden areas. This definition corresponds with that of the researchers in human vision, namely equating silhouettes to occluding contours. When distant views of

mountains are required, only the horizon line is drawn. No details are given as to the actual methods implemented.

Weibel and Herzog (1989) also employed silhouette lines for abstract terrain depiction. The main aim of their work was to investigate various techniques for creating automated panoramic visualizations of views of mountains. They chose silhouette lines as they are “comparable to pen and ink drawings” (Weibel and Herzog 1989, p. 77), reference is also made to Imhof (1982), one of the great texts relating to the cartographic depiction of terrain. As their system renders panoramas, radial lines are cast from an observation point into the model. Locations of silhouette points are defined as being “points that are still visible and whose immediate successors have a lower vertical angle and are therefore invisible” (Weibel and Herzog 1989, p. 77). Figure 3.6 illustrates their detection algorithm and Figure 3.7 gives an example of the results.

Due to the panoramic nature of the projection, a radially increasing search space is required to chain these identified points.

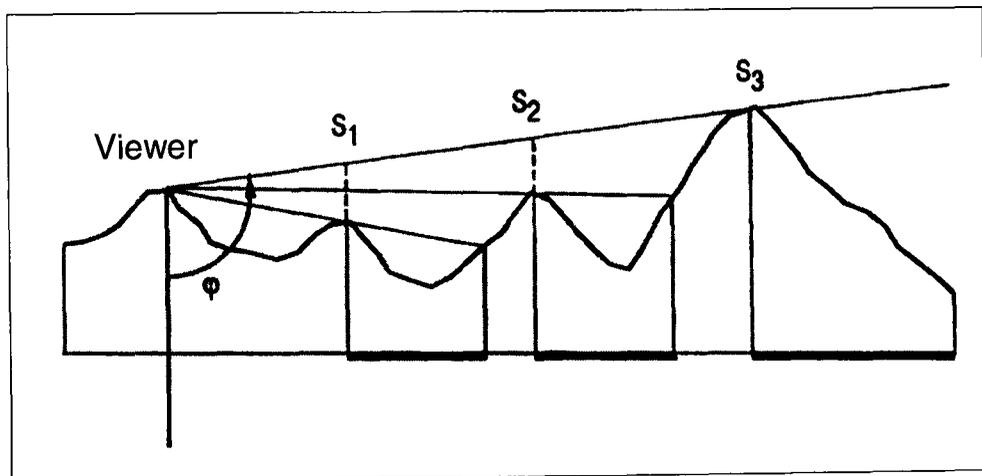


Figure 3.6: Silhouette point detection (S_n indicating detected locations).

Source: Weibel and Herzog 1989, p. 79

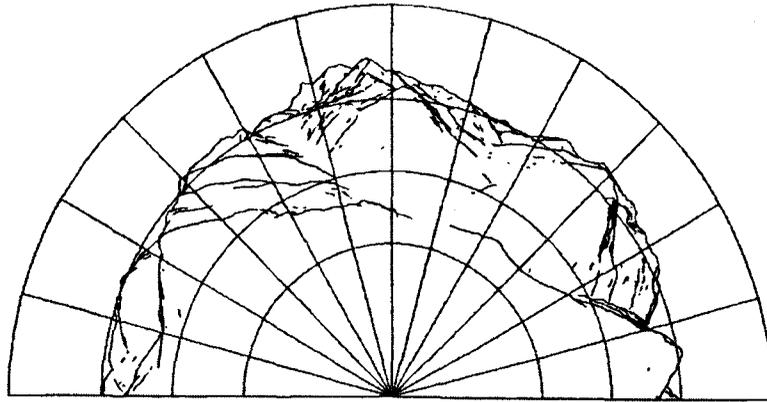


Figure 3.7: Panoramic view of DTM “Simplon” in conic projection (Lambert’s conformal conic projection; silhouette line symbolisation).

Source: Weibel and Herzog 1989, p. 76

Ma and Interrante (1997), use what they term feature lines (silhouettes and orientation changes) as a means of visualizing large, dense meshes in a clear manner. They note that “probably the most important lines in any line drawing are the silhouette and contour lines” (Ma and Interrante 1997, p. 287), having defined silhouette as the extremal projected boundary and contour as internal silhouettes or depth discontinuities. They use the standard definition of a change of sign in the dot product of the surface normal and the eye vector. In addition to the depth discontinuities, which have to be re-calculated as the viewpoint changes, they include ridge and valley lines. These are defined as occurring where the surface normals change abruptly and are extracted in a pre-processing operation, thus avoiding the need for re-calculation. A mixture of both local and global detection is used to identify these features. The global approach simply thresholds the angle across two adjacent triangles whereas the local approach considers an edge to be important only if the angle across the triangle is greater than the angle across the two adjacent triangles.

The work of Girshick et al. (2000) notes that silhouettes are not enough to convey shape in line drawings and describe techniques for depicting internal surface curvature using principal direction lines. Where the surface turns away from view, the curvature lines compress, giving similar cues to those noted in Figure 2.9 (Section 2.2.3, p. 18). However, it appears that the only silhouettes they extract are the extremal boundary and they rely exclusively on the curvature lines to indicate the presence of internal silhouettes. The use of these lines causes some ambiguous situations where it is hard to tell if a feature is a concavity or convexity. Figure 3.8 illustrates this ambiguity (note the extremal boundary is not included in this figure).

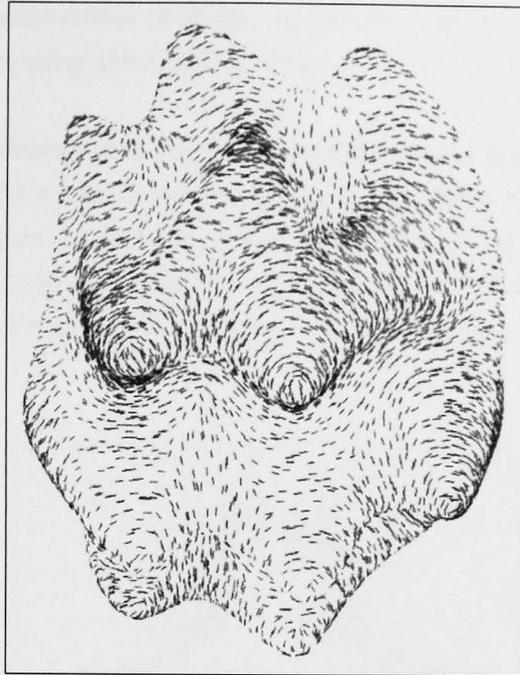


Figure 3.8: Ambiguities when using first principle direction vector fields.

Source: Girshick et al. 2000, p. 3

3.3.2 Computational Speed-ups

The approaches described so far all apply simple, 'brute force' testing of all points in the model. The work of Markosian et al. (1997) presented the first technique that aimed to reduce the extraction time of silhouette lines and include additional silhouette-related cues. Here, a system is described which allows for real-time user interaction with silhouette renderings of 3D scenes. They define silhouettes as occurring between front-facing and back-facing polygons (where there is a sign change in surface normals) and adopt a randomised search approach to avoid testing every model edge. This idea is based on the assumption that "not every silhouette is rendered in every frame, although large silhouettes are rendered with high probability" (Markosian et al. 1997, p. 1). The presented algorithm checks random locations in the model, testing to see if they match the silhouette definition. If a test results in a detection of a silhouette edge, the algorithm *walks* along the course of the curve. Search time for successive frames is decreased through exploiting frame-to-frame coherence and checking edges located near those found in the previous frame.

Additional silhouette-related cues are added through the inclusion of line-work where the surface is turning away from view. This is similar to Pearson and Robinson's (1985) assumption of drawing lines where the surface normal is "nearly perpendicular to the viewing direction" (Pearson and Robinson 1985, p. 796). Markosian et al. (1997) draw lines onto the model surface, in a similar fashion to Meier (1990) and render the visible strokes where the surface luminance, with respect to a parallel headlight, falls below a set threshold. Their use of an even distribution of parallel strokes, which darken in regions of high curvature parallel to the line of

sight, is similar to the observations of Stevens (1981) and Marr's surface contours which he termed "most vivid and puzzling" (Marr 1982, p. 216).

As the techniques of Markosian et al. (1997) are model based, the application of stylistic strokes to the extracted silhouette curves is possible and is demonstrated in their work. Their system produces good frame rates for relatively simple models. Figure 3.9 shows the results of this approach. Location (a) (Figure 3.9) highlights how the inclusion of line-work in areas curving away from the viewpoint introduces artefacts that do not correspond to how an artist would draw a torso.

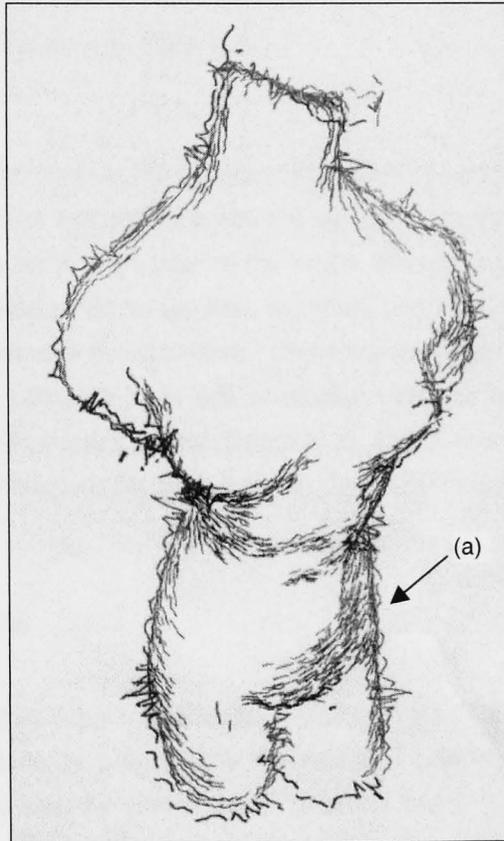


Figure 3.9: Static output showing figure rendered with expressive outline and shading strokes.

Source: Markosian et al. 1997, p. 6

Although silhouettes need to be computed each time the view-point changes, Benichou and Elber (1998) and Gooch et al. (1999) offer extraction methods that rely on one-off, pre-processing of the model. Both techniques project the arcs between the normals of adjacent faces onto a Gaussian sphere, which can be thought of as a large sphere surrounding the model. Figure 3.10 illustrates the concept of the Gaussian sphere in 2D.

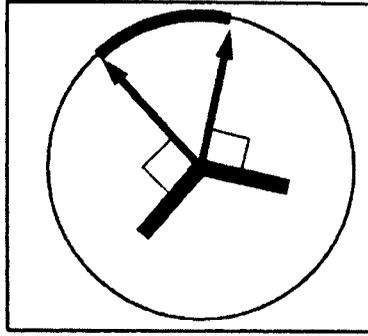


Figure 3.10: Example of Gaussian sphere simplified to 2D.

Source: Gooch et al. 1999, p. 4.

Benichou and Elber (1998) simplify the problem of querying the arcs in 3D, by projecting them onto the 2D planes of a cube that circumscribes the sphere. These planes are then examined to find the silhouette edges for a given view of the model. Benichou and Elber (1998) observed computation reduction factors that “range from ten times and up to almost one hundred times less than the straight forward or naïve method” (Benichou and Elber 1998, p. 12). Gooch et al. (1999) supplement their silhouette lines with orientation changes termed 'creases' (similar to Watt (1988)), and their own shading model (Gooch et al. 1998). These creases are extracted in a pre-processing operation where the angle between two front-facing polygons is filtered with a global threshold.

3.3.3 Alternative Inputs

The technique presented by Bremer and Hughes (1998) applies the principles of Markosian et al. (1997) to implicit surface rendering. They describe an interactive renderer using the same ideas such as starting to look for silhouettes at locations where they were found in previous frames and shooting rays then '*walking*' across the surface. The silhouette definition is the same as Marr's, however their additional silhouette-related cues differ slightly to Markosian et al. (1997) due to the nature of the input model. Here, several copies of the silhouette are drawn in parallel, in front of it. This achieves the effect of representing tightly curved parts of the surface, which lead up to the silhouette, with darker shading. Interior shading is also added, created by drawing strokes in the direction of curvature, proportional to parallel illumination (headlight). In the evaluation of their work, the authors note the fact that when drawing additional cues, lines often '*fan out*' at cusps and create an appearance that differs from a hand drawing. Figure 3.11 illustrates this problem.

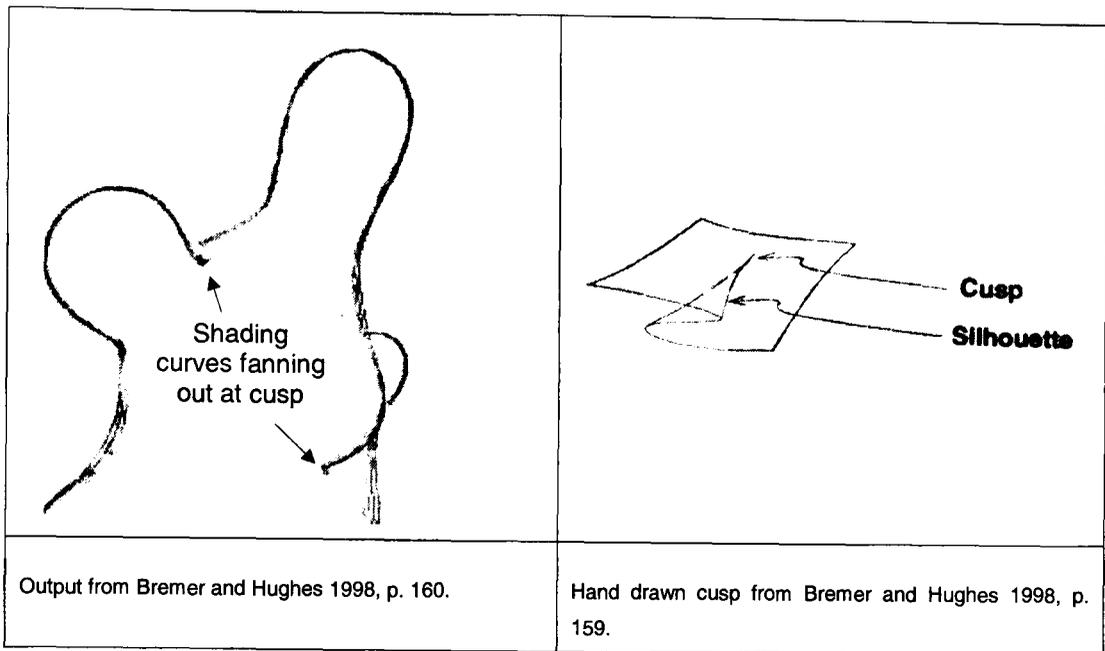


Figure 3.11: Cusp rendering problems.

Source: Bremer and Hughes 1998

3.3.4 Improvement of Problems

Recent works in this field (Hertzmann and Zorin 2000; and Northrup and Markosian 2000) have sought to solve problems with previous techniques. The former uses interpolation routines to infer a smooth surface from a polygon mesh, whereas the latter describes a hybrid technique, working both at the model and image level.

Hertzmann and Zorin (2000) state that polygonal approximations cause problems with silhouette extraction and that “Some differential quantities associated with the smooth surface must be recovered in order to generate visually pleasing hatch directions and topologically correct silhouette lines” (Hertzmann and Zorin 2000, p. 517). Due to the nature of their created surface, achieved with piecewise-smooth subdivision, they define a silhouette to occur where there is a zero-crossing in the dot product of the eye vector with the surface normal. The curves that the detection algorithm extracts are supplemented with extensive cross-hatching based upon direction fields across the smooth surface.

The work of Northrup and Markosian (2000) does not supplement their previously defined silhouettes (Markosian et al. 1997) with any additional cues. However, they use scan-conversion, visibility checking and a degree of generalisation to “process the edges in image space to create long, connected paths corresponding to visible portions of the surface” (Northrup and Markosian 2000, p. 1). In addition, they note that “the resulting paths have the precision of object-space edges, but avoid the unwanted zig-zagging and inconsistent visibility of raw silhouette edges” (Northrup and Markosian 2000, p. 1).

They adopt a similar approach as in their last paper, namely randomised silhouette checking and discount the Gaussian sphere approach of Gooch et al. (1999) as being complex and difficult to implement. The techniques presented in Raskar and Cohen (1999) are also discounted as they lack the functionality for applying stylistic strokes to the silhouette paths.

Many of the problems that this technique is seeking to alleviate appear to be API (OpenGL) related and it is noted that image-based approaches such as Saito and Takahashi (1990) solve the problems by ignoring them. Particular problems discussed relate to overlapping paths (Figure 3.13 (a)), artefacts in the curve termed 'swallowtails' (Figure 3.12 (b)) and visibility problems.

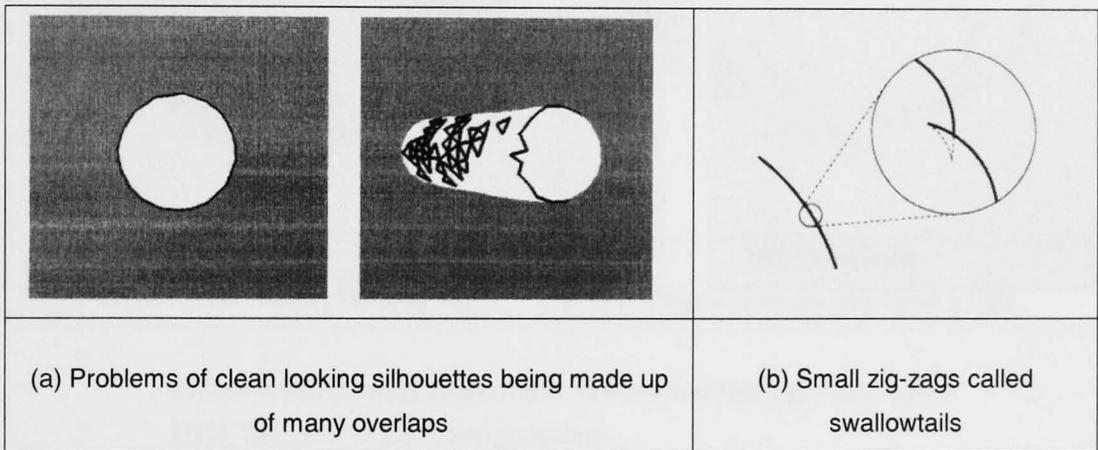


Figure 3.12: Problems with silhouette curves.

Source: Northrup and Markosian, 2000, p. 2

Through scan-converting the identified silhouettes and projecting them as an image, visibility can be checked. Generalisation is also performed where overlapped lines are merged and close parallel lines are removed. To achieve the objective of storing the silhouettes as smooth connected paths, a three-by-three neighbourhood search is used to chain the silhouette edges in image space. Links are tested for suitability using factors such as angle and distance from the current point. The main contribution of this work is that through using the hybrid approach, a greater flexibility in the use of artistic strokes can be achieved. Examples presented include the use of depth cueing through varying the thickness of silhouette strokes and the application of texture-mapping to create soft strokes.

3.3.5 Summary of Extracted Cues

Out of the techniques reviewed, those that equate silhouettes to the definition of occlusion (as presented by vision researchers such as Marr (1982)) do not capture all of the silhouette-related cues. If an example is taken from Weibel and Herzog (1989) (Figure 3.13), it can be seen that there are silhouette-related locations which are not being picked out in the extracted silhouette

plot. Locations (a) and (b) indicate examples which although perceived as silhouette cues, are not picked out by occlusion.

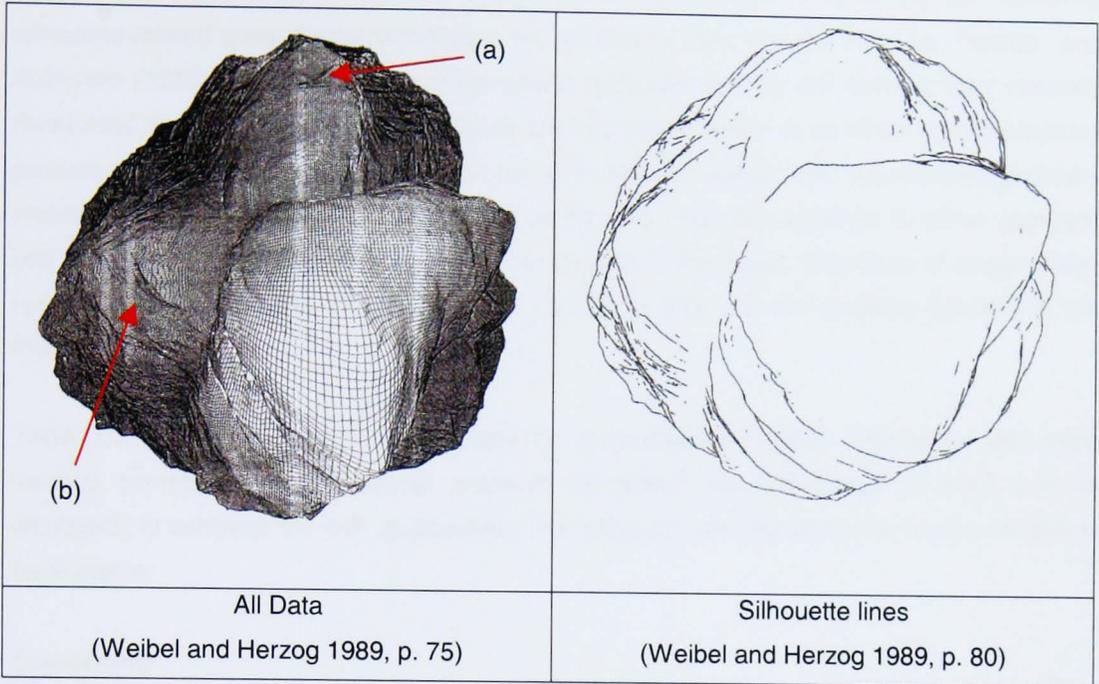


Figure 3.13: Missing locations in Weibel and Herzog's Occlusion.

DTM "Simplon" in azimuthal projection

Source Weibel and Herzog 1989.

These locations are often picked out along with true silhouettes by the previously reviewed image-based systems (Pearson and Robinson 1985; Saito and Takahashi 1990; Chang 1997; and Lesage and Visvalingam 2000).

This section has illustrated how a number of model-based systems attempt to recover these silhouette-related cues by including surface curvature information (Markosian et al. 1997; Bremer and Hughes 2000; Girshick et al. 2000; Hertzmann and Zorin 2000). These techniques, however, do not logically extend the incomplete set of silhouette lines, but add curvature shading with little rationalisation.

Other cues unrelated to silhouettes are also included in many of the reviewed rendering techniques. The most common being the detection of frontal breaks of slopes or surface orientation discontinuities. This detection is often achieved by globally thresholding the angle between two adjacent, front-facing polygons. Ma and Interrante (1997) however, described the benefits of using both local and global thresholds. This thesis is not concerned with these cues as their depiction within cartographic sketches is very different from the frequently used CAD type models in computer graphics research (as discussed in Chapter 2, Section 2.5, p. 24).

3.4 Pros and Cons of Reviewed Approaches

As this review has shown, there are many different approaches to extracting and rendering silhouette-related cues. Some techniques are attuned to their specific input i.e. Pearson and Robinson (1985) are limited to an image-based approach as they are working from specially illuminated images of reality. Other methods however have chosen to be either a post-rendering process (image-based) or to extract features and contours directly from transformed geometry (model-based). This section will briefly look at the pros and cons attached to either approach and state why a particular pipeline location is adopted in this thesis. The class of image-based system termed 'rendering effects' are not included as they are not of direct concern to this thesis.

Table 3.3 lists the various pros and cons for each pipeline location. The table uses three themes, complexity (of processing), precision (of output) and knowledge (of what is to be displayed) to compare the two approaches. The following text discusses the issues relating to each theme.

Complexity

Where a high-resolution output is required, image-based approaches place large demands on computational resources; however, problems such as visibility and overlapping of lines do not need to be considered and implementation is simple. Although more complex to implement, the model-based approach does offer a greater degree of flexibility and there is scope for speeding up the computation time (Markosian et al. 1997; Benichou and Elber 1998)

Precision

Although sufficient for many applications (Hertzmann 1999, p. 7-1), the output from image-based approaches depends heavily upon the resolution of the input image. This can cause problems if the detection routine cannot discriminate between features, due to the sampled resolution of the rendered image. Problems are also noted by Northrup and Markosian who observe "aliasing as the silhouette positions jump from pixel to pixel" (Northrup and Markosian 2000, p. 2) and that "the silhouette positions are not accurately tied to the underlying geometry" (Northrup and Markosian 2000, p. 2). The output from model-based approaches is in the form of scalable vectors, at the resolution of the model; this approach can therefore "produce curves with much higher precision" (Hertzmann 1999, p. 7-6).

	Image-Based		Model-Based	
Theme	Pros	Cons	Pros	Cons
COMPLEXITY	Simple to implement. Can be implemented in hardware. No visibility problems. No overlap problems.	Costly processing if high-resolution output is to be created.	Novel speedups possible.	More involved processing. Computationally expensive if not using the various speedups which have been described. Can pose visibility problems.
PRECISION	Sufficient for many applications.	Sampled resolution therefore lacks precision. Output is not scaleable.	Scaleable vector output.	
KNOWLEDGE		No knowledge of what is drawn. Little scope for extracting features as primitives.	Ability to identify and classify various cues explicitly i.e. enrich the data. Access to model information to aid selection. Option to generalise output in an informed manner.	

Table 3.3: Image-based verses model-based contour extraction

Knowledge

As the output from the image-based approaches contains little knowledge about the constructs which make up the final image, chaining a complex projected image into a set of strokes would prove problematic. Thus, there is little scope for identifying features as whole primitives rather than pixels.

Model-based approaches identify cues directly from the model, therefore additional attributes can be attached to the extracted lines, thus enriching the data. This enrichment permits the use of stylistic strokes and can inform subsequent generalisation of the cues.

3.4.1 Summary

Although the image-based approaches of Pearson and Robinson (1985), Saito and Takahashi (1990), Chang (1997) and Lesage and Visvalingam (2000) do a good job of identifying actual and additional silhouette cues, this is not the optimal location for the work of this thesis.

In the abstract to this thesis, it was stated that the project's aim is to extract a classified, vector-based description of the silhouette-related cues, for a given view of a Digital Elevation Model; with the complex nature of terrain, this aim is only attainable if a model-based approach is adopted. In addition, the ability to use model information to inform selection is also an essential component of any sketching system. Thus, the model-based approach is the clear choice of pipeline location.

The next chapter describes the preliminary experiments undertaken in 1997 (reported in Visvalingam and Whelan (1998)) to illustrate the problems of only using occlusion to extract the silhouette-related cues from a view of a Digital Elevation Model. At this time, during the inception of the project, most model-based approaches were using only the factual definition of occlusion to describe silhouettes.

CHAPTER 4

Preliminary Investigations

Chapter 2 discussed how silhouette-related cues play an important role in the perception of form. The use of such cues within cartographic sketches of terrain was also illustrated. Following on from this, Chapter 3 reviewed the research that has been directed at the automatic extraction of silhouettes and contours. The remainder of this thesis demonstrates the need to go beyond the factual definition of silhouettes and to include additional Formulated Silhouettes.

One of the motivations for this project was to use the framework of contours provided by the silhouette-related cues, both Factual and Formulated, to structure and enhance the P-stroke sketching technique (investigated by Dowson (1994) and reported in Visvalingam and Dowson (1998)). This was described briefly in Chapter 2 (Section 2.1.1, p. 10) and receives a more detailed description in Chapter 8 (Section 8.1, p. 121). The P-stroke sketch does not explicitly consider silhouettes, their presence being inferred from the large number of strokes in the final sketch. The inclusion of specific silhouette cues within this technique would structure the drawing and add clarity through the removal of some of redundant strokes.

From the start of this project, it was known that occluding contours alone, did not provide all the silhouette-related cues which the P-strokes were indicating (Visvalingam and Whelan 1998). This chapter describes the problem that prompted the specific objectives of this project.

4.1 The Experimental System

The silhouette extraction approaches presented in Chapter 3 were split into two main categories, either model or image-based; the chapter closed by justifying the reasons for tackling this project from the model-level. The concept for calculating occlusion from a model is simply to transform the object, with respect to the viewing position, and then identify the locations where the surface changes from being visible to hidden. In standard 3D techniques this location is defined as a change in sign in the dot product of the surface normal and the view vector (Chapter 3, Section 3.1, p. 26). As the prototype system developed for this thesis works in two-and-a-half dimensions, and the input is a regular-grid elevation model (DEM), calculation of occlusion is simple.

4.1.1 Source Data

There are many ways of modelling areas of terrain on a computer. Not all, however, are suitable as input to a sketching system. A detailed comparison is beyond the scope of this thesis and for an in-depth study, reference should be made to Dowson (1994). In brief, representational models are often either mesh structures or regular grids of heights. Mesh structures such as triangular irregular networks (TINs), model the surface of the terrain and are a popular choice for interactive 3D visualization systems. Although these structures can be efficient in removing redundant data, the selection of points used in their creation is not without problems and can often produce inappropriate generalisations (Visvalingam, Personal Communication). Deriving sketches from an already, and perhaps inappropriately, generalised data source is not ideal. For the purpose of this project, the most appropriate style is the regular grid model known as a DEM (Digital Elevation Model) or DTM (Digital Terrain Model). These structures are usually the result of an interpolation of a surface from a digitised contour set. Recently however, high resolution DEMs, constructed using LIDAR (Light Detection And Ranging), are becoming available. DEMs present a scale specific description of terrain that is simple to process and render. Errors do exist and have been reported by researchers such as Wood (1996). However, these are not of major concern in this project. The source for the majority of DEMs used within initial experiments is the Ordnance Survey of Great Britain. The data is in a proprietary format and supplied at scale of 1:10,000 in 5 km square tiles or 1:50,000 in 20 km square tiles. This data undergoes conversion into ASCII using a utility provided by Geomatics (Online) to prepare it for input into the sketching system.

4.1.2 The Rendering Pipeline

As discussed in the previous chapter, techniques for extracting occlusion occur at various locations in the computer graphics pipeline. To match the requirement for a stroke-based description of sketch cues, this project has chosen to tackle the problem at the level of the transformed model geometry. At this stage, the scene has not yet undergone scan-conversion, so no model information is lost and object-precision is maintained. Figure 4.1 is a flow diagram describing the rendering pipeline of the experimental system. The following text details the specific stages and operations performed.

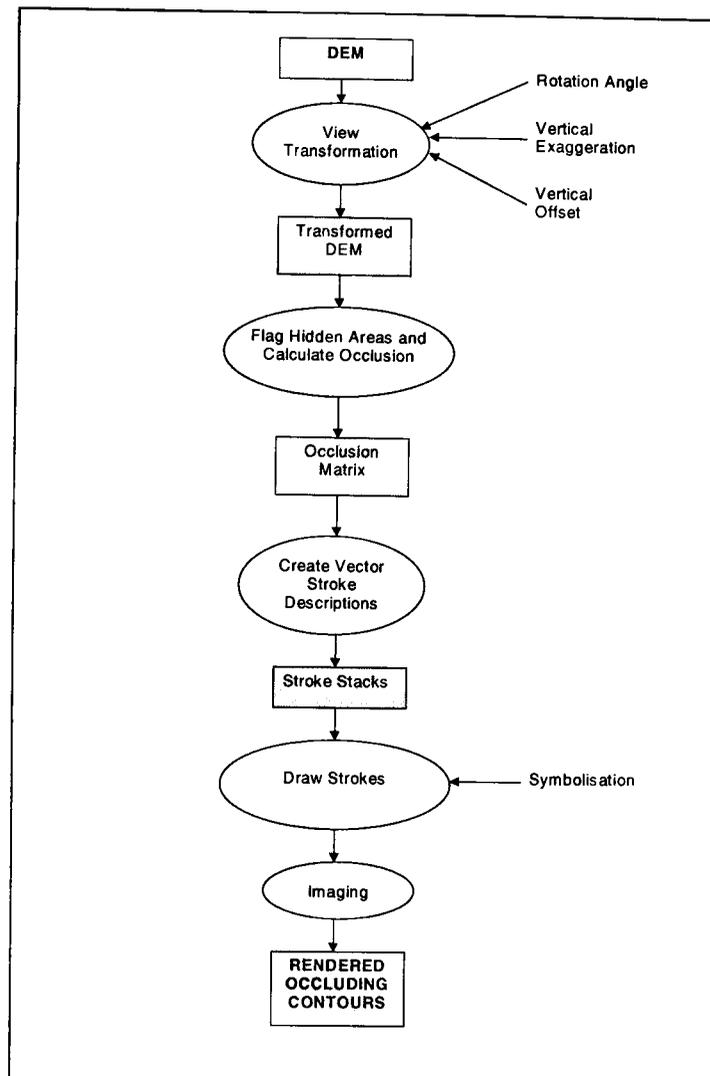


Figure 4.1: Rendering pipeline for the experimental system.

The input DEM consists of a matrix of cells, each recording a height value in metres. To produce a sketch, the model needs to undergo a transformation to project the result with respect to the viewing parameters. As occluding contours are inherently a view-dependent cue, the extraction of cells causing an occlusion needs to take place after the view transformation stage.

4.1.2.1 View Transformation and Projection

The use of various projection styles (Macaire 1998; Wiebel and Herzog 1989; and Wainwright 1992) facilitates the communication of landscape form in many interesting and informative ways. However, in the case of this experimental system, the oblique parallel projection system chosen reflects the traditional cartographic style used for creating elevated sketches of terrain. This style was used by Dowson (1994) and Visvalingam and Dowson (1998) who were inspired by the methods of Tanaka (1932), Robinson and Thrower (1957) and those detailed in Monkhouse and Wilkinson (1966) and Lobeck (1924). The transformation does not use linear

perspective, a tool often employed within traditional computer graphics but questioned by authors such as Arnheim (1956) and Gombrich (1972). Although the omission of perspective results in some size distortion and the loss of an important depth cue, the orthographically projected image maintains the correct spatial dimensions across the plot, compression of distant features does not occur and the sketch retains a 'map-like' clarity and quality.

As the experimental system is using 2.5D graphic concepts, the view transformation stage does not follow the traditional camera model (Foley et al. 1990 p. 250), or try to mimic the optics of the retina. There are two main phases to the transformation, namely, orientation and deformation. To view the scene, a viewing direction must be specified, which may be one of the four cardinal directions. This is achieved simply by flipping and/or mirroring the grid to match the view direction. The following stage, deformation, applies a transformation to the orientated model to achieve the desired view. This stage could be developed to use complex projection styles as demonstrated in Macaire (1998), or as in this experimental system, simply scale the elevations and raise the viewpoint. Figure 4.2 illustrates this deformation applied to profiles (cross-sections) parallel to the line of sight. The application of a vertical exaggeration factor ensures the results look appropriate for the scale and character of the terrain and the addition of a positive base slope, parallel to the line of sight, provides a means of increasing the viewing elevation. This slope is comparable to the successive vertical displacement of orthogonal cross-sections of the model as used by Dowson (1994) and Visvalingam and Dowson (1998).

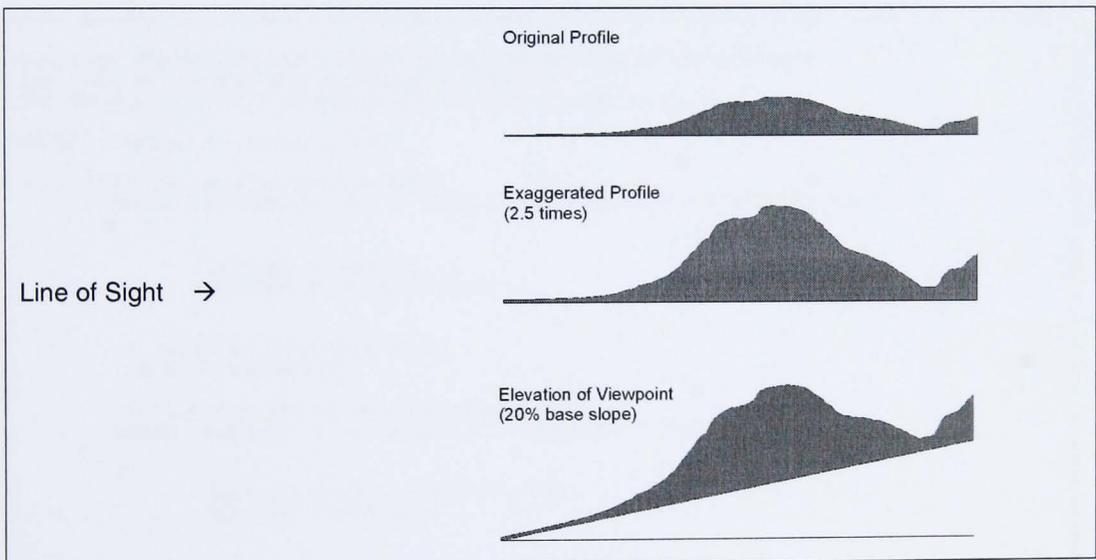


Figure 4.2: Vertical exaggeration and raising of the viewpoint.

4.1.2.2 Calculation of Occlusion

After transformation, the system holds a matrix containing the transformed DEM. This consists of a description of the terrain in world coordinates, transformed with respect to the viewing function. Through adapting a basic hidden area removal technique, detection of occlusion is simple. In the context of this system, the definition of an occluding contour is a line marking out

locations where the surface becomes hidden. This definition is conceptually the same as the sign change in the dot product of the surface normal and viewing vector used in the 3D systems, discussed in Section 3.3, and Marr's (1982) definition of occlusion (Section 2.2.2, p. 16). Although it is computationally expensive, the experimental system tests every model edge in the detection of occlusion. Section 3.3 reviewed some novel approaches to reducing this problem.

The transformed DEM consists of a two-dimensional grid, with each cell containing an x, y and z value plus various flags for the attachment of other derived information. The algorithm extracts profiles (cross-sections), parallel to the line of sight, and traverses them from the front (closest to the viewer) to the rear (furthest from the viewer) to determine those cells which are hidden in the projected view. The algorithm flags hidden cells as falling within occluded zones and the cell immediately in front of a zone is marked as contributing to an occluding contour. This cell is then copied to a structure termed the occlusion matrix, along with the length of the hidden zone that follows the occlusion cell. Figure 4.3 (from Visvalingam and Whelan 1998) illustrates the detection of occluded zones in a transformed profile. The following pseudo-code describes the simple detection algorithm used within the experimental system. This could be varied for use within a 3D system (Chapter 3, Section 3.1, p. 26).

```

Let y be the height and curProf the cross-section being processed
Let Info be a means for classifying a point
Let OccMtx [][] be a 2D array for storing occluding cells

WHILE (next_pt <= end_of_line)
{ /* find the next occluding point
  WHILE (current_pt (y) <= next_pt (y) & next_pt <= end_of_line)
  {
    next_pt = next_pt + 1
    current_pt = current_pt + 1
  }

  /* found an occluding point
  occ_pt = current_pt

  /* find the end of the occluding zone
  WHILE (next_pt (y) < occ_pt (y) & next_pt <= end_of_line)
  {
    next_pt (Info) = CellOccluded
    next_pt = next_pt + 1
  }

  Set OccMtx [curProf][occ_pt] to be occluded and store
  z-difference as next_pt - occ_pt

  current_pt = next_pt
  next_pt = next_pt + 1
}

```

Adapted from Visvalingam and Whelan 1998.

Line of Sight →

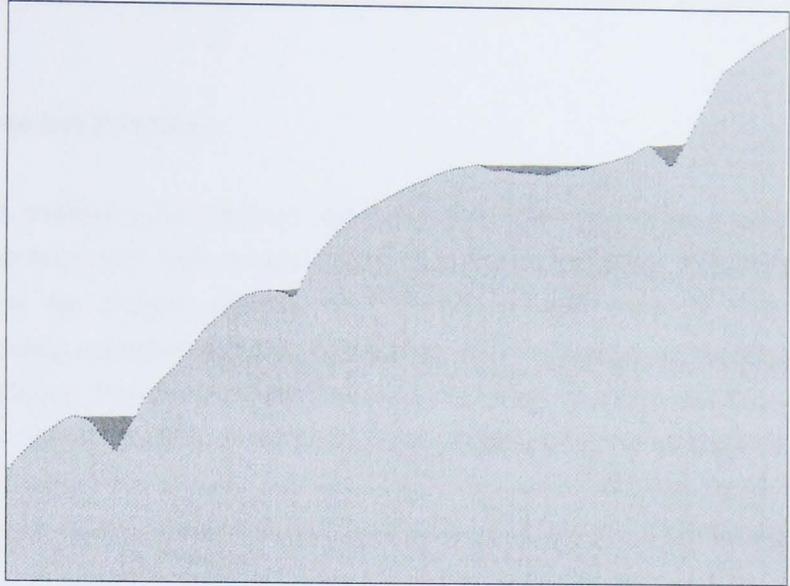


Figure 4.3: Occlusion zones (dark grey areas) when viewed from left to right.

Profile with a vertical offset equivalent to the addition of a 50% base slope

Points of occlusion occur at leftmost end of each shaded area

Source: Visvalingam and Whelan 1998, p. 286

It should be noted that the limit of the occlusion zone is not calculated to a sub-cell level. The next visible point after the hidden zone is therefore classed as the end. Due to the possibility of a small visible area, in-between DEM cells, being flagged as hidden, a slight 'halo' effect can occur in the rendered image, just after an occluding contour. This could be resolved through determining intersections at a scale finer than that of the DEM resolution. However, for the purposes of this project, this is not necessary since cartographers often leave halos to aid clarity.

The occlusion matrix contains unlinked cells marking the start of a hidden area, not primitives representing occluding contours. Consequently, several problems can occur. Firstly, the lack of a linear primitive prevents the attachment of attributes to strokes. This information could be useful in the choice of stylised strokes or for the application of visual weighting. These rendering issues are outside the scope of this thesis but are of concern to the cartographic designer. Secondly, and more importantly, the use of small P-strokes (Dowson 1994; Visvalingam and Dowson 1998; and Visvalingam and Whelan 1998) to render each cell can result in problems such as a lack of contour closure (Figure 4.4(a)(1)) or drawing into areas which are not causing an occlusion (Figure 4.4(a)(3)). These problems cause some disparity between the unchained (Figure 4.4(a)) and the chained (Figure 4.4(b)).

The chaining of cells into vector strokes often occurs at the same time as the detection (Markosian et al. 1997; and Wiebel and Herzog 1989), especially within real-time sketching systems. However, in the experimental system, a modular, pipeline environment was adopted

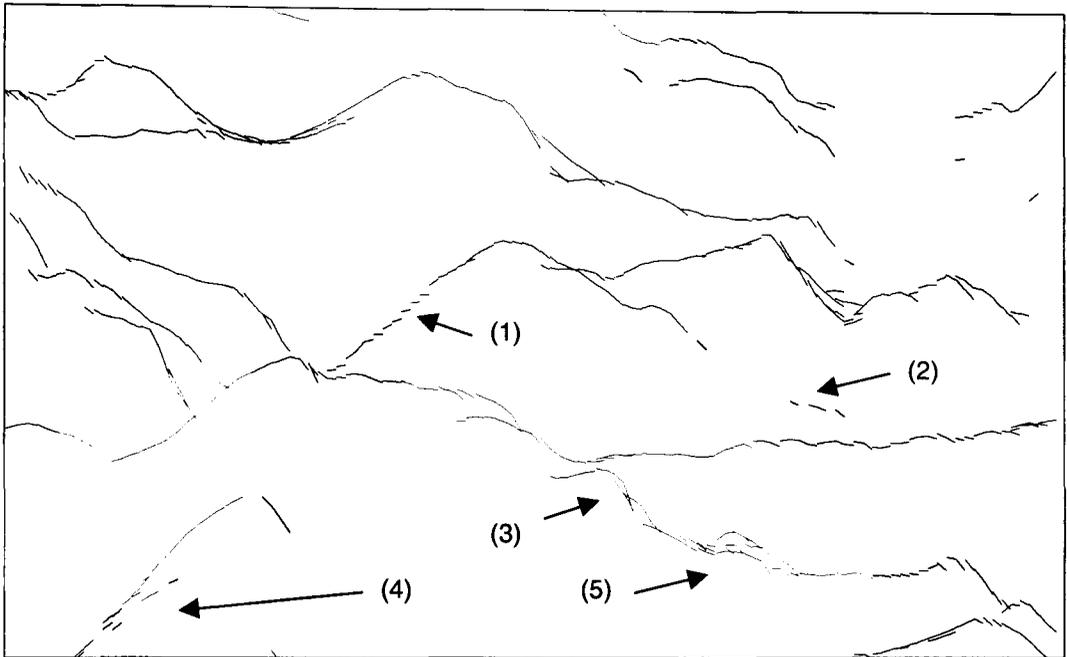
and the various functions are deliberately de-coupled to facilitate a detailed analysis of all intermediate results.

4.1.2.3 Chaining Points into Primitives

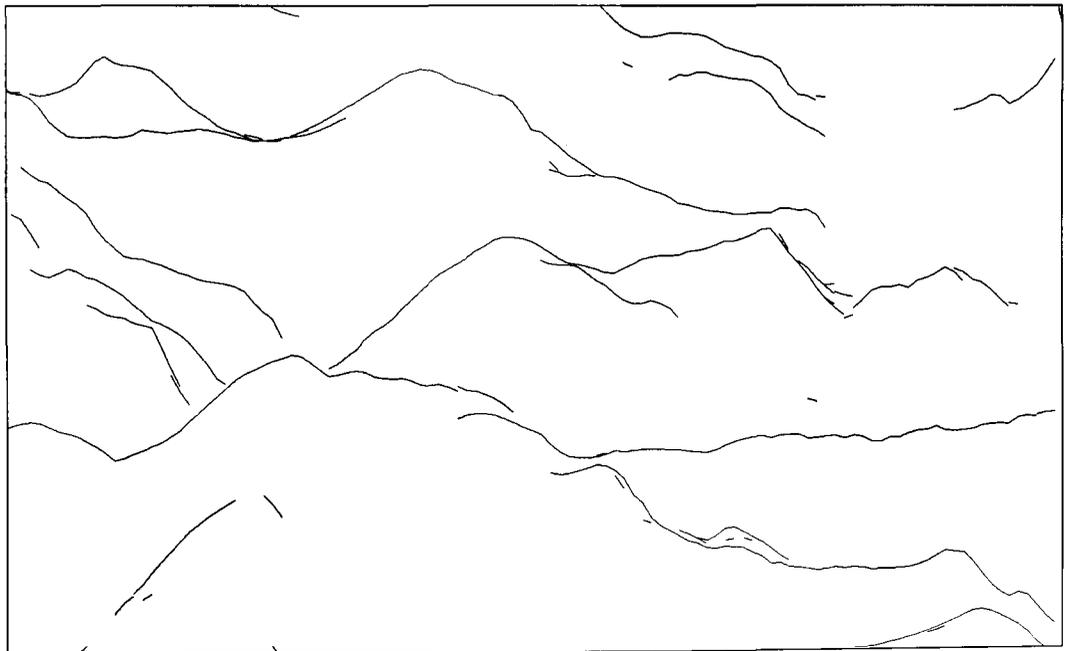
As the objective of this research is not efficiency, the chaining algorithm checks each cell in the occlusion matrix sequentially, from front to back beginning at the left-hand side. The following pseudo-code describes the chaining process. The structure termed `ContourStack []` provides a means of storing occluding contours as primitives. These primitives can be rendered in any order, as by definition, they are all visible. The case of a single occluding cell having no connection points is a special situation. In the experimental system it is not rendered as it is often the result of a digitising error or noise and no cells exist to connect it to. Due to this fact, additional inconsistencies occur between the two sub-figures in Figure 4.4 (Figure 4.4(a)(2), 4.4(a)(4)).

The contours in Figure 4.4(b) present a much more aesthetically pleasing output with confusing situations such as location (5) (Figure 4.4(a)) being easier to perceive. Figure 4.5 shows the map view for the test location. The grey areas are occluding zones and the black cells indicate occluding cells. The red lines show the chained occluding contours. The map backdrop is a shaded slope map. In addition to the visual improvement, the chained contours have added metrics through the attachment of global attributes such as length or average depth of hidden zone.

The following pseudo code describes the chaining process.



(a) No Chaining



(b) After Chaining

Figure 4.4: Illustration of problems related to unlinked occluding contours.

Data: Area around Ullswater, Lake District National Park

© Crown Copyright, Ordnance Survey

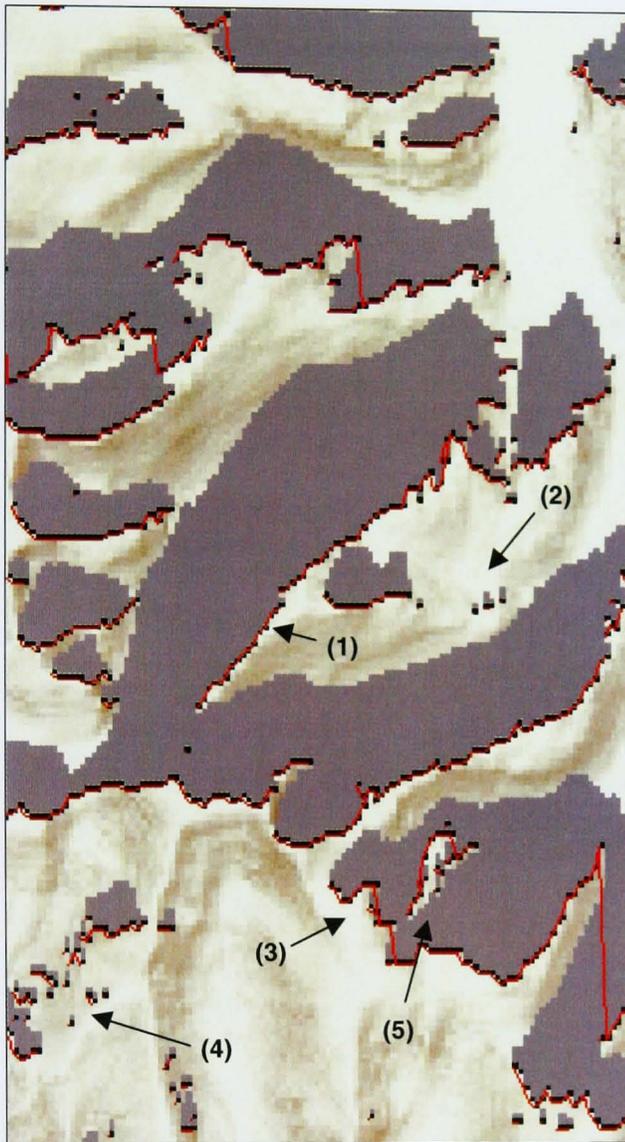


Figure 4.5: Visualization of detected occlusion and chained contours for the area depicted in Figure 4.4.
Data: Area around Ullswater, Lake District National Park
© Crown Copyright, Ordnance Survey

```

Contour_index = 0
col_count = 0
row_count = 0

WHILE col_count < width_of_matrix
{
  WHILE row_count < depth_of_matrix
  {

    current_point = OccMtx [col_count][row_count]

    IF (current_point.Occluding = TRUE & current_point.Found= FALSE)
    {
      ContourStack [contour_index]= new contour()
      ContourStack [contour_index].addpoint(current_point)
      result_point = FindConnectionToRight(current_point)

      IF (result_point = NO_CONNECTION)
      { // One Point occlusion
        ContourStack [contour_index].terminate
      }

      ELSE
      {
        current_point.Found = TRUE
        result_point.Found = TRUE
        ContourStack [contour_index].addpoint(result_point)
        result_point = FindConnectionToRight(result_point)

        WHILE valid(result_point)

        {
          result_point.Found = TRUE
          Contour.addpoint(result_point)
          result_point = FindConnectionToRight(result_point)
        }
        ContourStack [contour_index].terminate
      }
    }
    contour_index++
    row_count++
  }
  col_count++
}

Valid(point)
{
  Takes a point, returning FALSE if the point is not within the sketch matrix or is a
  contour termination, otherwise TRUE is returned.
}

```

Occlusion chaining pseudo code.

```

FindConnectionToRight (test_point)
{
    IF (valid(Profile_To_Right [test_point]) = FALSE)
        RETURN NO_CONNECTION;

    IF (Profile_To_Right [test_point].Occluding = TRUE) &
        (Profile_To_Right [test_point].Found = FALSE)

        RETURN test_point;

    ELSE IF (Profile_To_Right [test_point].In_Hidden_Zone = TRUE)
    {
        WHILE (Profile_To_Right [test_point].In_Hidden_Zone = TRUE)
            //Track Forward to find front end of Hidden_Zone
            test_point--

            IF (Profile_To_Right [test_point].Occluding = TRUE) &
                (Profile_To_Right [test_point].Found = FALSE)
                return test_point;
            ELSE
                RETURN NO_CONNECTION;
        }

    WHILE valid(Profile_To_Right [test_point]) &
        (Previous_Profile [test_point].In_Hidden_Zone = TRUE)
    {
        if (Profile_To_Right [test_point].Occluding = TRUE &
            Profile_To_Right [test_point].Found = FALSE)
            RETURN test_point;
        ELSE
            //Track backwards
            test_point++
    }

    RETURN NO_CONNECTION
}

```

Occlusion chaining pseudo code (cont.)

4.2 Preliminary Explorations

4.2.1 Test Data

The dataset used to test the ideas presented in this thesis comprises of the halves of two DEM tiles supplied by the Ordnance Survey of Great Britain. The data represents an area of terrain in South Wales, UK, digitized from 1:50,000 scale maps. The composite tile measures 20 km sq. and has a UK National Grid bounding window of SS78 (Southwest) to SS90 (Northeast), the terrain is composed of dissected plateau and coastal plain. For a detailed description of the area's geological history, reference should be made to Woodland and Evans (1964, p. 2). This area was chosen as the primary test dataset due to its complex and varied terrain which has had many phases of development, from the uplifting of the plateau, the superimposition of deep-cut valleys to the modification by local glacial ice and subsequent melt-water channels. Woodland and Evans (1964) present a detailed description, with an accompanying map, relating to the area's glaciation (Woodland and Evans, 196. p. 275 - 278).

As stated previously, the data has undergone conversion from NTF (Ordnance Survey proprietary format) to ASCII using a tool provided by Geomatics (Geomatics Online). Figure 4.6 shows the full dataset visualized as a profile plot. It shows the DEM viewed from the west with the Vale of Neath to the left of the foreground and Port Talbot in the centre of the foreground. Here, the rendering of cross-sections from the transformed DEM, orthogonal to the line of sight, as 'hair-width' polylines creates a visualization of all of the data in the DEM. In the case of Figure 4.6, the addition of a 40% base slope to the model gives the impression of viewing the terrain from a reasonably high elevation. All visualizations of this dataset use a vertical exaggeration of 2.5. Figure 4.7 shows the occluding contours extracted from this transformed DEM.

The occluding contours, shown in Figure 4.7, successfully mark out the hidden areas of the plot. However, if an artist were sketching the view-dependent structuring cues discussed in Chapter 2, many locations that would be included in a similar fashion to occlusion are missing. The occlusion definition appears to select only a subset of the view-dependent cues, resulting in the omission of important sketch elements. The annotations on the figure illustrate some particularly important omissions. At location (A), there is a lack of definition of the two gullies running down into the main valley, whereas at (B) there is no indication of a cirque-like form that is prominent in the profile plot. The area highlighted at (C) is unconnected and confusing. Holistically the figure looks unconnected with many lines being difficult to link visually.

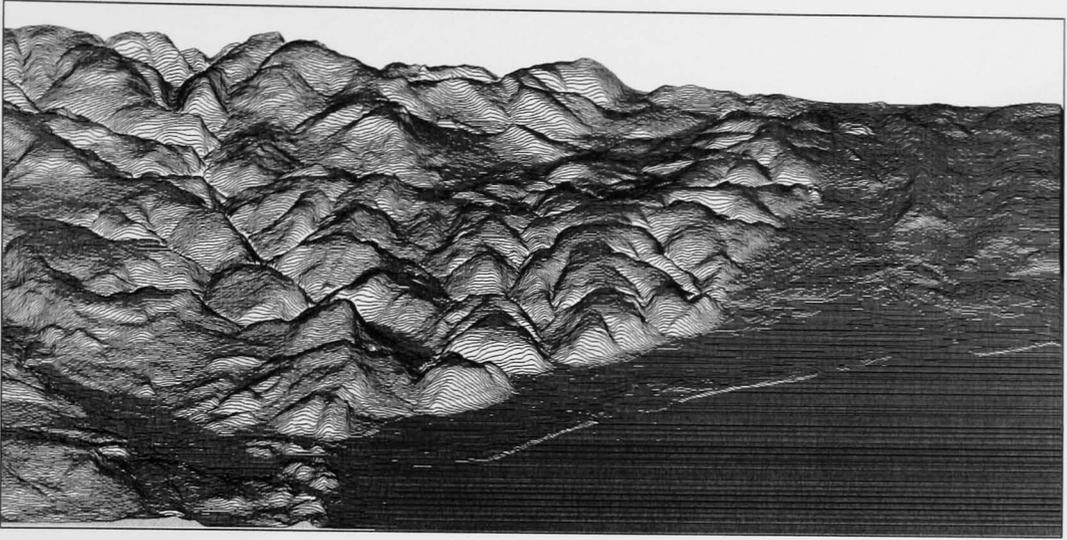


Figure 4.6: Full profile plot viewed from the west.

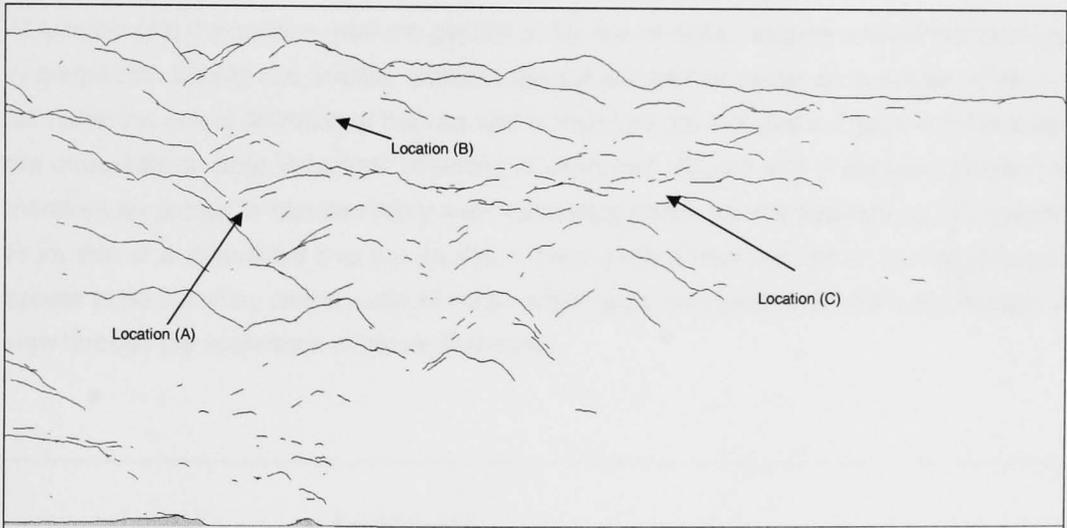


Figure 4.7: Occluding contours calculated from Figure 4.6.

4.2.2 Investigation of Omissions

Cross-sections of the terrain, parallel to the line of sight and passing through the omitted areas, were used to check the results visually. Figure 4.8 shows one of these cross-sections viewed from left to right. The vertical black lines indicate locations where oclusions occur. The annotation corresponds with location (A) in Figure 4.7.

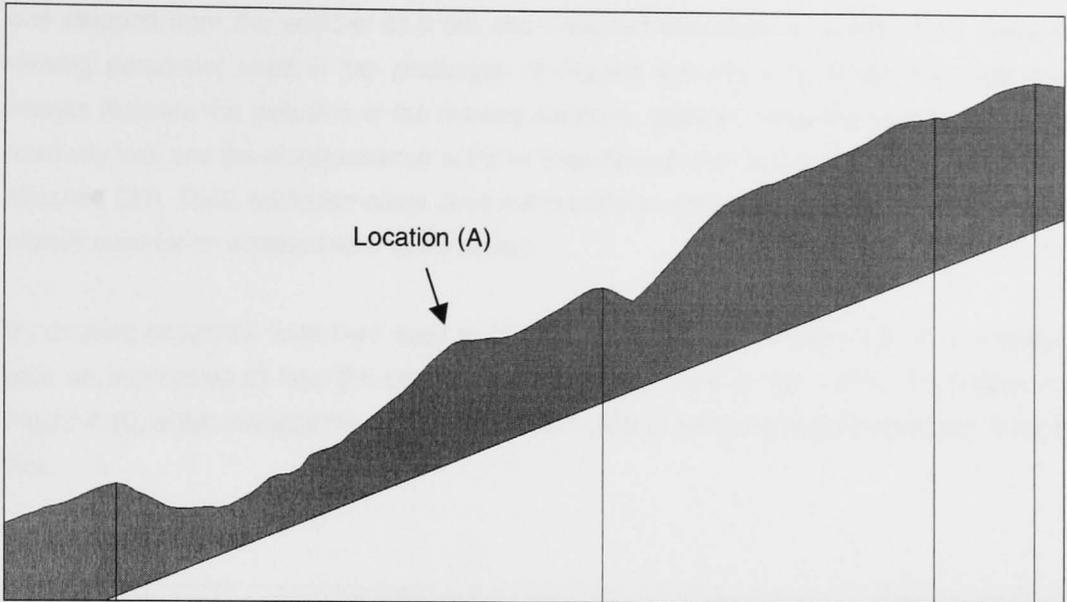


Figure 4.8: Detail of cross-section through Transformed DEM viewed from left to right.

At location (A), the surface gradient, parallel to the line of sight, remains positive but decreases in magnitude. Due to this positive gradient, the surface cannot cause an occlusion. It does not fall within the actual definition of this cue and is therefore not included in Figure 4.7. However, if the cross-section prior to vertical offsetting is examined, (Figure 4.9) a negative gradient and therefore an occlusion can be clearly seen (occluding points are not depicted on this diagram). From this, it is postulated that the important lines omitted from the set of occluding contours appear to be occurring where areas of terrain which were occluding have now been brought into view through the application of the vertical offset.

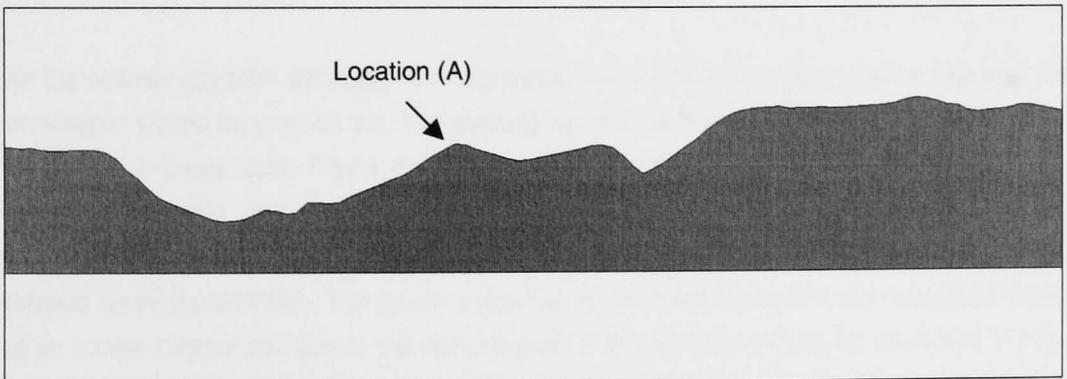


Figure 4.9: Detail of cross-section through Transformed DEM viewed from left to right, prior to vertical offsetting.

The creation of several images of the terrain viewed from the same direction but with increasing vertical offset provides a means of testing the assumption stated previously. The offset value

was stepped from the addition of a 0% (no viewpoint elevation) to a 40% base slope (the viewing parameter used in the production of Figures 4.6 and 4.7). When animated, these images illustrate the inclusion of the missing contours, detected while the viewing elevation is relatively low, and the disappearance of these lines through the raising of the viewpoint (refer to attached CD). Thus, occlusion alone does not provide a complete description of the silhouette-related cues for an elevated view of the terrain.

By drawing horizontal lines from each point on the cross-section (Figure 4.8), it is possible to gain an impression of how the projected surface would look in the profile plot (Figure 4.6). Figure 4.10, which includes the cross-section both prior to and post vertical offsetting, illustrates this.

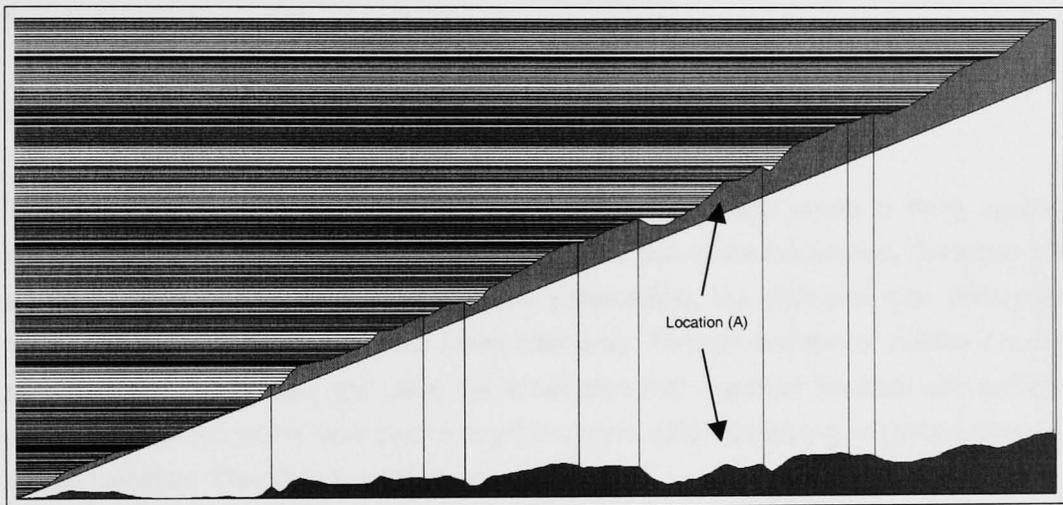


Figure 4.10: Addition of projected profiles to cross-section visualization.

As the surface gradient decreases in magnitude, the profile lines begin to pack together while on steeper slopes they space out. The packing together of profiles, which in turn creates darker areas in the image (see Figure 4.6) provides the observer with clues to perceiving surface shape. The profiles, termed surface contours by Marr (1982) and Stevens (1981), as they lie on the object's surface, can be considered as a regular texture, similar to the regularity noted in furrows on ploughed fields. The packing together of the profile lines and the resulting inference of an image contour are due to the compression of this surface texture, as illustrated in Figure 2.9 (Chapter 2, Section 2.2.3, p. 18). The cue that this gives the viewer is consistent and reliable due to the assumption of the texture's regularity in the artificial case of the profiles or in the natural case of a ploughed field. The perceptual issues involved here are discussed in Horn (1975) where a good description of "determining shape from the depth-cue of texture gradients", (Horn 1975, p. 154), is given.

The occurrence of the darker areas, indicating where the surface is turning away from view but remaining visible, has a direct correspondence to the use of a headlight in a lambertian-shaded model. Pearson and Robinson (1985) and Lesage (2000) exploit these situations in their systems for sketching and Watts' MIRAGE system (Watt 1988) gives a detailed description of their detection. Also in image space, a visible curvature of the z-buffer, as used by Saito and Takahashi (1990) and Chang (1998), occurs at these locations. (Refer to Chapter 3 for the background to these techniques).

Image-based techniques, whose input is primarily a function of surface orientation, do recover the omitted locations. However, as discussed in Chapter 3, they are not suited to the vector-based sketching style under investigation in this thesis. Most model-based sketching systems equate silhouettes to actual occlusions, and those that include additional curvature-related information (Markosian et al. 1997; Bremer and Hughes 1998; Girshick et al. 2000; and Herzmann and Zorin 2000) do so in a largely indiscriminate manner.

4.3 A Proposal to Resolve the Problem

To achieve a vectorised description of the silhouette-related cues, similar to those used by a cartographic artist, the extraction process needs to remain at the model-level. Occlusion forms an important subset of these cues (**Factual Silhouettes**), but additional lines (**Formulated Silhouettes**) are required to portray forms effectively. Through analysis of surface curvature, parallel to the line of sight and using the assumption that important locations are defined by areas of the terrain which have been brought into view, cells contributing to these omitted cues can be identified. Therefore, the objectives are to:

- find a suitable method for selecting cells for incorporation into Formulated Silhouettes.
- form appropriate rules for creating primitives or contour structures corresponding to these Formulated Silhouettes.
- Investigate the attributes that could be attached to sketch contours to add useful metrics.
- Assess the impact of the addition of the Formulated Silhouettes to the Factual Silhouettes or occluding contours.

Chapter 5 presents an original model-based technique for extending the set of silhouette-related cues to include both Factual and Formulated Silhouettes.

CHAPTER 5

The Formulation of Silhouettes

This chapter explores an original technique proposed by my supervisor (Mahes Visvalingam, personal communication) for the identification and extraction of Formulated Silhouettes. This was based on her hypothesis that silhouettes were mental concepts, which subsumed occluding contours, and that they could be found using a slope-based filter.

The previous chapter demonstrated that the silhouette-related cues missing from the set of occluding contours occurred at locations where the surface was likely to cause an occlusion if it were to be viewed from a lower angle. As the viewpoint is raised to produce more map-like sketches, occlusion contributes less and less to the definition of the outline forms or silhouettes. In these situations the cartographic artist relies less and less on what he sees and draws more and more on his **knowledge** of the shape of the forms he is portraying. Given that an automated sketching system does not have such knowledge, the challenge for this thesis was to seek out the key **information** and the **computational methods** which would yield visually acceptable silhouette profiles.

Since the P-strokes (Chapter 2, Section 2.1.1, p. 10) were picking out many of the desired cues, albeit inelegantly, most of the experimental work in the first year of research was directed at using the cues provided by Visvalingam's algorithm for line generalisation (Visvalingam and Whyatt 1993); this algorithm forms the basis of the P-stroke sketching technique. However, as the aim of this chapter is to abstract a shape contour, which tracks the surface in a similar fashion to the occluding contour, the approach reported in this thesis uses a local, point-based algorithm.

The model-based technique proposed in this chapter extends the set of occluding contours through the informed inclusion of additional view-dependent cues or Formulated Silhouettes. Cell selection and stroke creation processes are presented and discussed. Although many of the processes may be applied simultaneously, they are presented in their logical sequence so that the implications of their outcomes may be scrutinised and assessed. To maintain comparable results, the dataset in the previous chapter is also used here, with the same viewing parameters.

The presented method is based on the premise of selecting all of the possible candidate points to start with, and then filtering this to form appropriate cues. This set of cells is termed the **candidate set** or **c-set**, because although it contains errors of commission, it provides a starting

point for recovering the Formulated Silhouettes. The selected zone represents the sweep of the occluding contours, or Factual Silhouettes, across the surface, as the viewing angle is raised.

A filter based upon geographical observation selects from the c-set those cells that are likely to contribute to Formulated Silhouettes and creates what is termed the filtered set (**f-set**). When rendered, this set still comprises of zones of flagged DEM cells and does not have the airy quality of a cartographic sketch composed of shape contours. To relieve these problems and facilitate the ensuing vectorization routine, these zones are thinned, in accordance with some simple observations, to create the thinned set (**t-set**). Once the t-set is chained, post-selection-generalisation can be performed to create what is termed the generalised set (**g-set**).

5.1 Selection of Cells Contributing to Formulated Silhouettes

5.1.1 Location of Process

Formulated Silhouettes, like Factual Silhouettes are view-dependent cues, therefore the extraction process needs to be located after the orientation of the model. However, as we are interested in what was occluded prior to the raising of the viewing elevation, the view-transformation stage needs to be broken up as follows.

There are three phases to the view-transformation function in the experimental system (Section 4.1.2.1, p. 49), namely, model orientation, vertical exaggeration and vertical offsetting. As real-world information from the model can give clues as to which cues to select, it is undesirable to lose or change any model information. Therefore, the cell selection process is best located as near to the unchanged data as possible. Through positioning the process just after model orientation, the height-grid matches the correct viewing direction, but has not undergone vertical exaggeration or deformation of any kind.

The aim of the selection process is to extract those cells that will become visible through the raising of the viewpoint; therefore, knowledge of the intended model transformation is required. This is not a problem since the process is located within the transformation stage, and has access to all of the viewing parameters. Figure 5.1 is an adaptation of the view transformation stage from the occlusion-rendering pipeline (Figure 4.1, p. 49) and includes the new selection and filtering process. Viewing parameters are shown in *italic*.

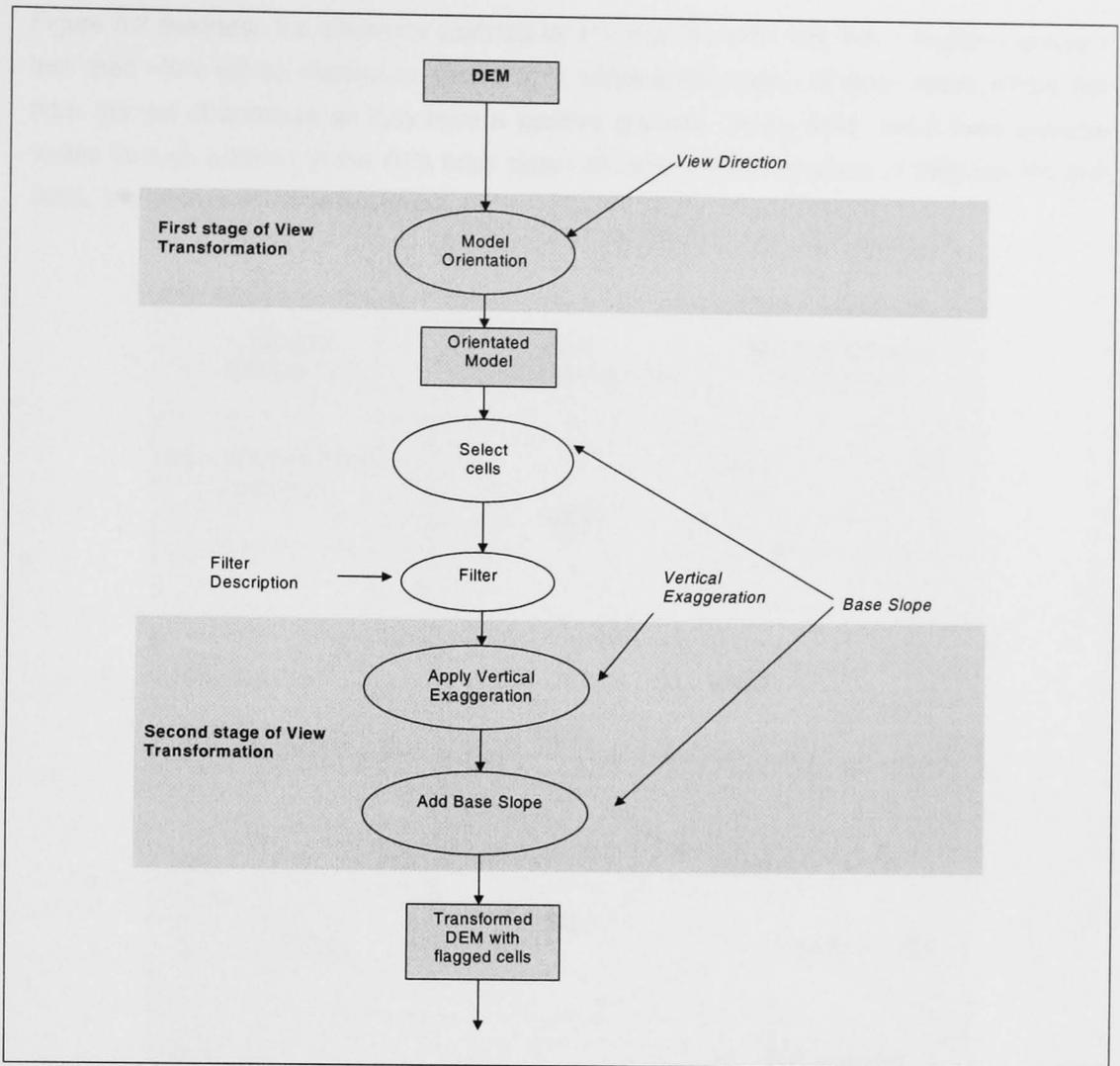


Figure 5.1: Adapted View Transformation Stage including cell selection and filtering processes.

5.1.2 Selection Rule

In the previous chapter, a cell was defined to be occluded if its surface gradient was less than zero. The transformation function used (same as in Chapter 4, Section 4.1.2.1, p. 49) adds a base slope of 40% to the model; therefore, an occluded cell in the transformed model must have had a gradient of -40% or less prior to transformation. Given the definition of the candidate set cells, the following rule may be used for the purposes of selection:

Selection Rule::

```
{(-1*Added Base Slope) < Cell.Col_Slope < 0 }
```

where Cell.Col_Slope is the gradient, parallel to the line of sight.

Figure 5.2 illustrates the situations captured by this rule. A model cell with a negative gradient less than -40% will be classed as occluding in transformed model. All other cases will be lost from the set of contours as they have a positive gradient. These cells (which have become visible through addition of the 40% base slope) all have a model gradient of between 0% and -40%, the bounds of the selection set.

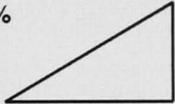
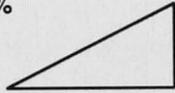
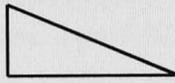
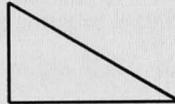
MODEL GEOMETRY	VIEW TRANSFORMATION	TRANSFORMED GEOMETRY
0% - Approaching occlusion 	+40%	+40% 
-10% 	+40%	+30% 
-26% 	+40%	+14% 
-40% 	+40%	0% - Approaching occlusion 

Figure 5.2: Illustration of bounds of selection, viewed from left to right.

NB: Measurements are indicative and gradients are expressed as percentages.

As its input, the selection algorithm takes cross-sections, parallel to the line-of-sight, from the oriented model. These are traversed from front to back in the same fashion as the occlusion detection algorithm. The attributes of cells that fulfill the definition of the c-set are updated accordingly. This is not altered by the rest of the view-transformation and is used further down the pipeline for the creation of vector strokes. The following pseudo code describes the process.

Selection Pseudo Code

Let Base_Slope be the gradient of the base slope to be added to the DEM in the second stage of transformation

```
first_pt = 0
```

```
While not end of cross-section
```

```
{
```

```
    second_pt = first_pt + 1
```

```
    test = gradient(first_pt, second_pt)
```

```
    if ((test > -1*Base_Slope) & (test < 0))
```

```
        Class first_pt as a member of the c-set
```

```
}
```

5.1.3 Visual Analysis of the c-set

After the candidate cells have been flagged, the remaining stage of the view-transformation is performed on the DEM, namely vertical exaggeration and the addition of the base slope. Figure 5.3 shows the c-set and occluding contours for the view of the same dataset used in the previous chapter. The c-set cells have been rendered as extracted P-strokes (see Chapter 2, Sections 2.1.1, p. 10). A plan view of the cells that produced this plot is shown in Figure 5.4. Here, cells that contribute to the occluding contours are shown in red and the c-set cells in grey; a contour map with a vertical interval of 40 meters is used for the backdrop. This contour plot was extracted using a simple raster contour routine similar to those described by Eyton (1984). For this view of the DEM, the c-set cells form 19.7% of the DEM. Although Figures 5.3 and 5.4 contain many large zones, as opposed to shape contours, the omissions from the set of occluding contours (Figure 4.7, p. 59) have been recovered. Location (A), highlighted as an omission in the last chapter is depicted much more successfully in Figure 5.3. Through analysis of the plan view, (Figure 5.4), the incomplete occlusion definition at Location (A) can be seen to be supplemented by the c-set cells. In the projected plot, the cirque (Location (B)) is clearly visible. Location (C) however, is still confusing and difficult to perceive. As the definition of the c-set includes all areas that were hidden, but are now visible, the errors of commission present were expected. These problems occur at locations where a cartographer would not include this form cue, such as flat areas in the valleys or at the tops of hills.

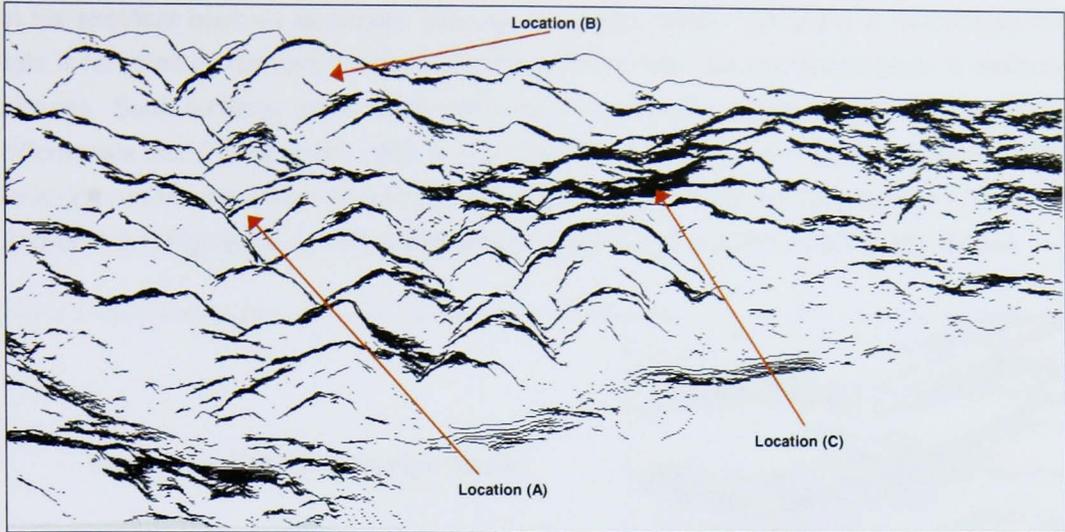


Figure 5.3: Plot showing projected c-set.

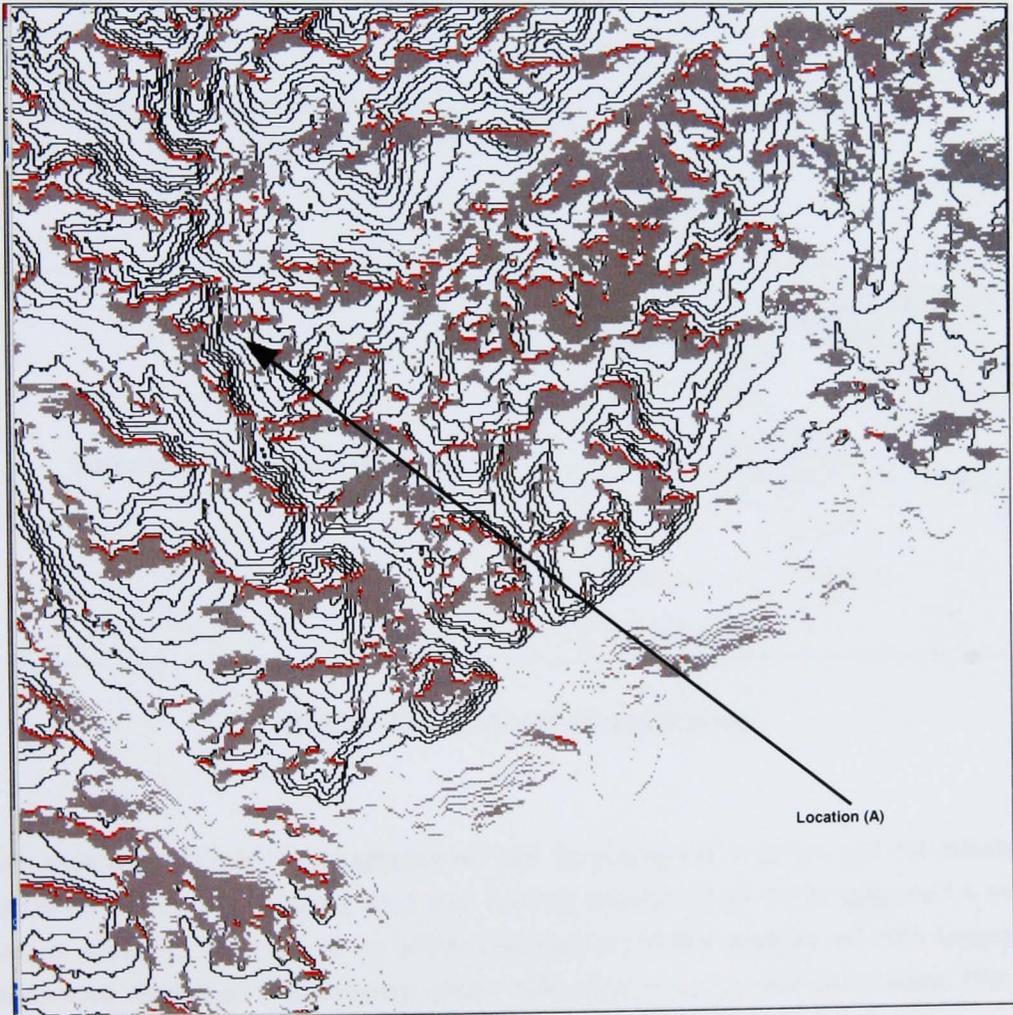


Figure 5.4: Map view of study area.

Red cells = Occlusion

Grey cells = c-set

In his excellent book on landscape drawing, Hutchings states, "Generally in landscapes most light is reflected by horizontal surfaces, so these in the main are the lightest parts of landscape pictures. Such surfaces (level fields etc.) need no shading, except where it is required to differentiate them" (Hutchings, 1960, p. 59). Table 5.1 highlights some types of problem. These locations provide inaccurate visual cues (which are also present in the full profile plot (Chapter 4, Section 4.2.1, Figure 4.6, p. 59)) and produce situations that are difficult to visually resolve.

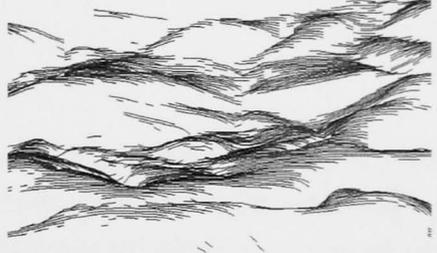
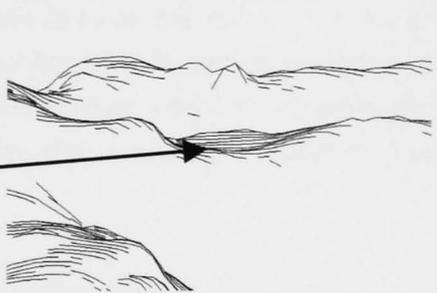
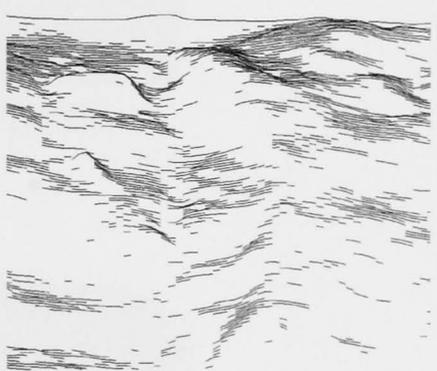
<p>Confusion - Difficult to visually resolve.</p>	
<p>Merging of cue on both sides of occluding contour</p>	
<p>Inappropriate shading in flat areas.</p>	

Table 5.1: Errors of commission in c-set.

When sketching a scene, a cartographer will use the principle of selection and not include all physical definitions of a particular form cue. A visual analysis of the scene may yield a set of locations similar to the c-set, but a further interpretation of this analysis will omit illogical or misinforming situations. The following section describes a novel information-based filter for removing from the c-set, the cells that contribute to the previously described problems.

5.2 Slope Based Filtering of the c-set

Cells are included in the c-set if their gradient, parallel to the line-of-sight, is within certain bounds. In addition to this gradient, there is also the slope running orthogonal to the line-of-sight. In the context of the oriented model, these two attributes (row and column gradient) provide a means of classifying the cells in the c-set and reasoning about the cells which should be filtered (Visvalingam, personal communication).

5.2.1 Filter Inputs

Surface gradient, the first order derivative of a cross-section through the model, is often used to drive various edge detection routines. However, the common practice in image processing is to calculate the absolute difference or magnitude of the directional derivatives e.g. Prewit operator (Bassmann & Besslich, p. 62, 1995). This combination discards the real world information relating to terrain slopes that is available at this stage in the pipeline. In the filter described here, both row and column slopes are used, thus maintaining attribute independence and allowing geographical knowledge to be applied to the model information. Figure 5.5 illustrates the inputs to the filter.

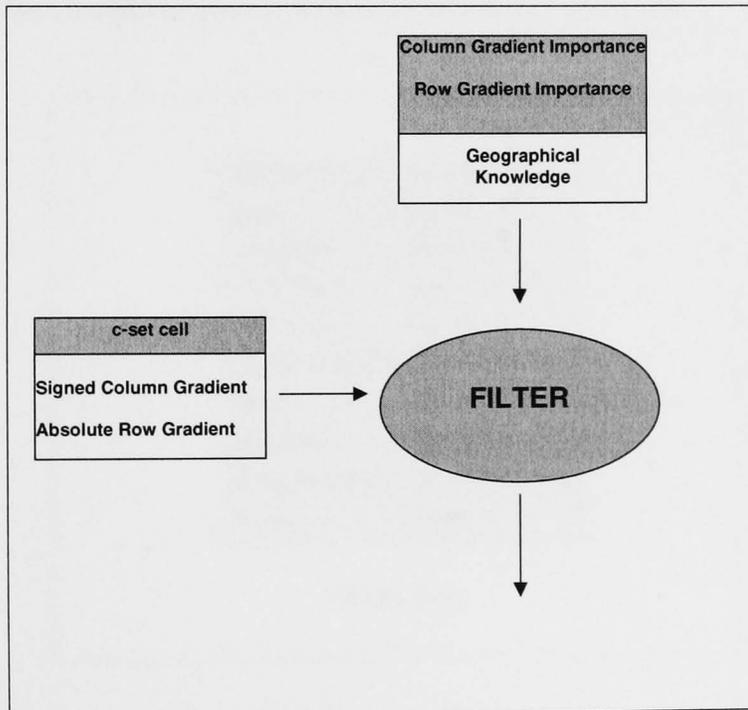


Figure 5.5: Inputs to filter.

From the field of landscape drawing, it has already been noted that areas of a low gradient should not receive much line work. The same text (Hutchings, 1960) also states that "In general, slopes receive and reflect less light the steeper they are, and are shaded accordingly."

(Hutchings, 1960, p. 59). These statements correspond to the assumption of illumination from above, the application of them being evident in the example cartographic sketches in Chapter 2. Slopes also have specific meanings to geographers. Macgregor (1957) states that a slope of 20% is of “crucial importance”, and “careful note should be made of this angle of slope” (Macgregor 1957, p. 170). He justified this through noting that it is “about the limit for ground that is to be ploughed and cut annually” (Macgregor 1957, p. 170). Other categories such as 10% are classed as “clearly noticeable” (Macgregor 1957, p. 170). The cartographer’s art is based on such experience, tutoring and knowledge, and these factors guide their selection of sketch elements. With practice, this selection is most likely performed at a subconscious level. Many of the errors of commission within the c-set can be attributed to the lack of appreciation of such guidelines.

5.2.2 Filter Design

Figure 5.6 gives a general classification of locations within the c-set. These classes apply to the situation of the cells prior to deformation. If an increasing row-slope cut-off is used to filter the c-set, those cells that lie on weak row slopes will be omitted. This will remove some of the problem cases where there is too much line work in flat areas. However, as can be seen from the matrix classification, cells that were causing a strong occlusion but which occur on a weak row slope will be lost. These situations provide important cues and should be retained.

Row Slope	(a) Causing a weak occlusion on a strong row slope	(b) Causing a strong occlusion on a strong row slope
	(c) Causing a weak occlusion on a weak row slope	(d) Causing a strong occlusion on a weak row slope
	Column Slope	

Figure 5.6: Classification of c-set.

If a filter is applied in a similar fashion using column-slope, any weak column cells will be omitted and the candidate set will only consist of steep back-facing slopes. This removal of gentle creases helps solve some problems such as line work on slopes that appear to be front facing. However, those weak creases that lie on strong row slopes (Figure 5.6, cell (a)) can contribute important shape defining lines, such as the orthogonal gullies noted previously (Location (A),

Figure 5.3). It is therefore logical to omit only the weak/weak quarter of the c-set (Figure 5.6, cell (c)).

By omitting the weak/weak area of the c-set, an assumption is being made that all features of interest lie orthogonal or parallel to the line of sight. However, many terrain features also run at a diagonal to the viewpoint. This fact needs to be covered by the filter. As stated previously, it is not desirable to combine the cut-offs as this sacrifices context specific information. The filter needs to be more sensitive to slopes parallel with the line-of-sight (column slope) as it is these which define the silhouette cue.

Figure 5.7 shows a scatter plot of cells from the orientated model showing how slope magnitude relates to the c-set. The plot shows the column slope (horizontal axis) versus absolute row slope (vertical axis). The row slope is taken as an absolute value as the filter is only concerned with its magnitude. The c-set cells, for a base slope of 40%, are shown in red.

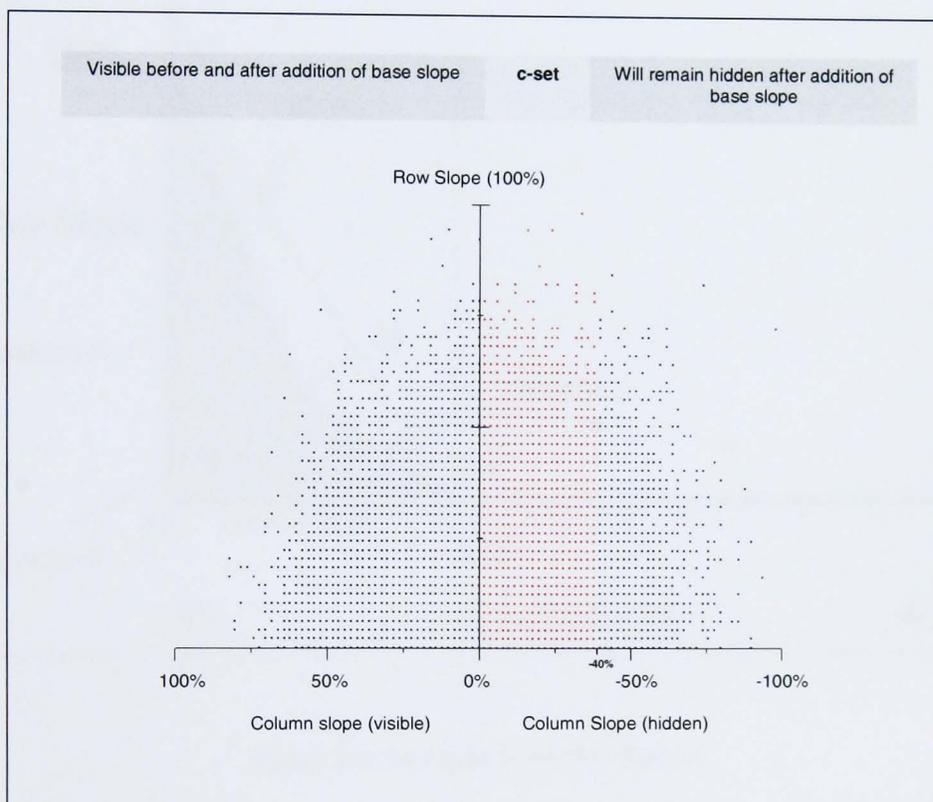


Figure 5.7: Scatter plot of model gradients showing c-set in red.

A logical approach, that would include important diagonals but omit the weaker responses, would be to fit a curve between the chosen cut-off values. This concept was tested but discounted as, due to the nature of a curve, its path runs too close to the axis, not respecting the differing cut-offs. A simple and more appropriate linear approximation of this curve can be

achieved through joining filter lines from the cut-offs through a control point. This approach, illustrated in Figure 5.8, maintains the directional biasing of the derivatives.

The row slope cut-off is based on Macgregors' identification of 20% as "a critical slope" (Macgregor 1957, p. 170), and a more sensitive value of 12% used for the column-slope. Diagonals are allowed for, through using a control point that lies upon the line perpendicular (a,b) to the line connecting the two cut-off values (c,d). The use of a constrained control point maintains correct weighting for the two derivatives. The area shaded in grey indicates the cells removed from the c-set. All cells, with a column slope less than zero, that do not occur in the grey area are retained and form the f-set. The equations marked on this figure are explained in the following section, which describes the implementation of the filter.

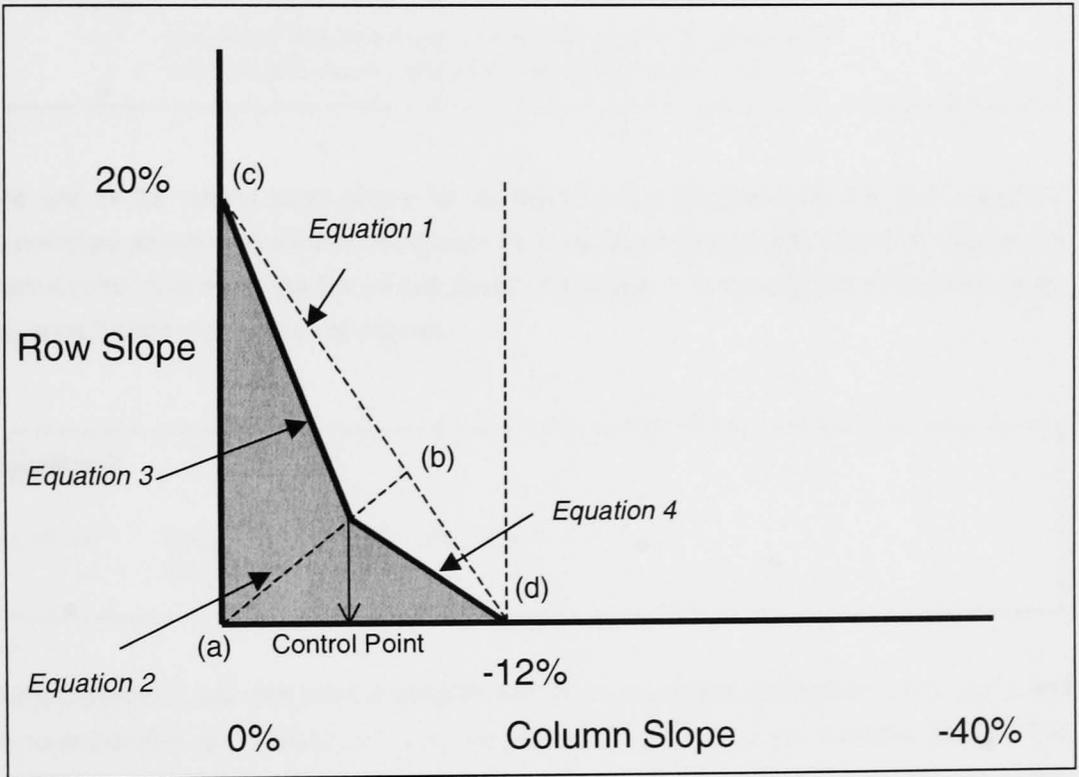


Figure 5.8: Illustration of filter design.

5.2.3 Filter Implementation

The filter operates on the output from the c-set selection routine. To retain cells which lie on diagonals, but still omit the weak/weak cells (see Figure 5.7, cell (c)), the equation of the line passing through the chosen row and column cut-off values can be used as a basis for the filter. This line has the following equation:

Equation 1

$$\text{Row_Slope} = -\left(\frac{\text{Row_Slope_Cut_Off}}{\text{Col_Slope_Cut_Off}}\right) * \text{Col_Slope} + \text{Row_Slope_Cut_Off}$$

Where

Row_Slope and Col_Slope are the directional derivatives

The Cut_Off values are those described previously

The use of the control point allows for an element of interaction with the filter, making it increasingly sensitive to weaker responses. To maintain an appropriate derivative biasing, the control point must lie on the line perpendicular to Equation 1, which passes through the origin. Equation 2 gives the equation of this line.

Equation 2

$$\text{Row_Slope} = \frac{\text{Col_Slope_Cut_Off}}{\text{Row_Slope_Cut_Off}} * \text{Col_Slope}$$

Using Equation 2, a control point is specified with its column slope component (*ctrl_col*), and its corresponding row slope (*ctrl_row*) calculated with respect to the derivative biasing. The two lines that join the control point to each of the derivative cut-off values can be simply calculated and are shown in Equations 3 and Equation 4.

Equation 3

$$\text{Row_Slope} = -\left(\frac{\text{Row_Slope_Cut_Off} - \text{ctrl_row}}{\text{ctrl_col}}\right) * \text{Col_Slope} + \text{Row_Slope_Cut_Off}$$

Equation 4

$$\text{Row_Slope} = -\left(\frac{\text{ctrl_row}}{\text{Col_Slope_Cut_Off} - \text{ctrl_col}}\right) * \text{Col_Slope} \\ + \left(\frac{\text{ctrl_row}}{\text{Col_Slope_Cut_Off} - \text{ctrl_col}}\right) * \text{Col_Slope_Cut_Off}$$

The following pseudo code describes the implementation of the filter.

Filter Pseudo Code

```
If (Current_Cell.Row_Slope > Eq3(Current_Cell.Col_Slope)) &  
    (Current_Cell.Row_Slope > Eq4(Current_Cell.Col_Slope))  
    Then Accept point into filtered set
```

5.2.4 Filter Results

Figures 5.9 and 5.10 use the same techniques as were used for depicting the c-set and show the results of the filtering, both in plan and in projected form. A control point with a column slope value 8.75% is used in these and all of the remaining figures in this chapter. This value was chosen interactively as it appeared to give the most balanced results for this dataset. The projected filtered set, Figure 5.9 depicts the silhouette-related cues in a much clearer fashion than the c-set (Figure 5.3). The omissions from the set of occluding contours, noted in the previous chapter, are retained, and most of the clutter present in the c-set has been removed. The area behind location (C), which was confusing and difficult to interpret, is much clearer. The small river valley running parallel to the line of sight can be clearly seen. The cirque at (B) is retained. Although it is a weak silhouette, its occurrence on a steep row slope results in its retention. The adjustment for diagonals helps retain the two tributary gullies at location (A). The filtered cells form 8.6% of the DEM, a reduction of 11.1% from the c-set. However, at this stage, the results still take the form of shading the retained cells using line work. The presence of these zones as opposed to shape contours is illustrated in the plan view of the filtered set shown in Figure 5.10.

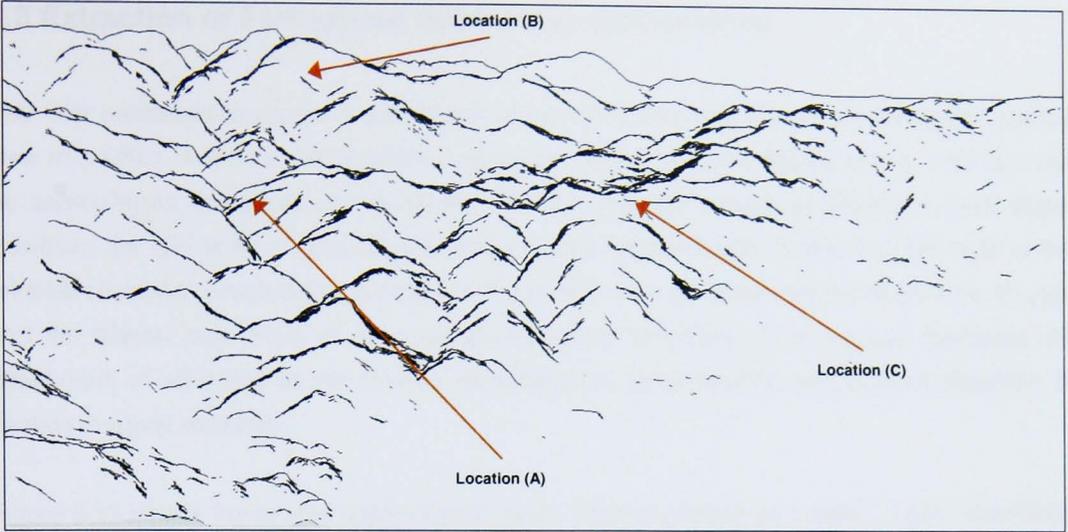


Figure 5.9: Plot showing projected and filtered c-set.



Figure 5.10: Map view of filtered c-set.
 Red cells = Occlusion
 Grey cells = f-set

5.3 Extraction of Formulated Silhouettes as Contours

The filter presented produces a description of the silhouette-related cues for any given oblique view of a DEM. However, the locations are not in contour form but filtered zones. This fact can be camouflaged using coloured poylines, with the intensity varying according to local slope. However, the aim of this research is to derive vector based sketch contours in the style of the minimal sketches presented in Section 2.4. To achieve this, selected regions need to be thinned and the filtered cells have to be chained into vector primitives. This process facilitates the attachment of attributes to the strokes, permitting the generalisation and stylised depiction of strokes in future research.

Figure 5.11 shows the simple observations, taken from line drawings (Lobeck 1924; Murchison 1839; and Holmes 1860), which are applied to achieve thinning.

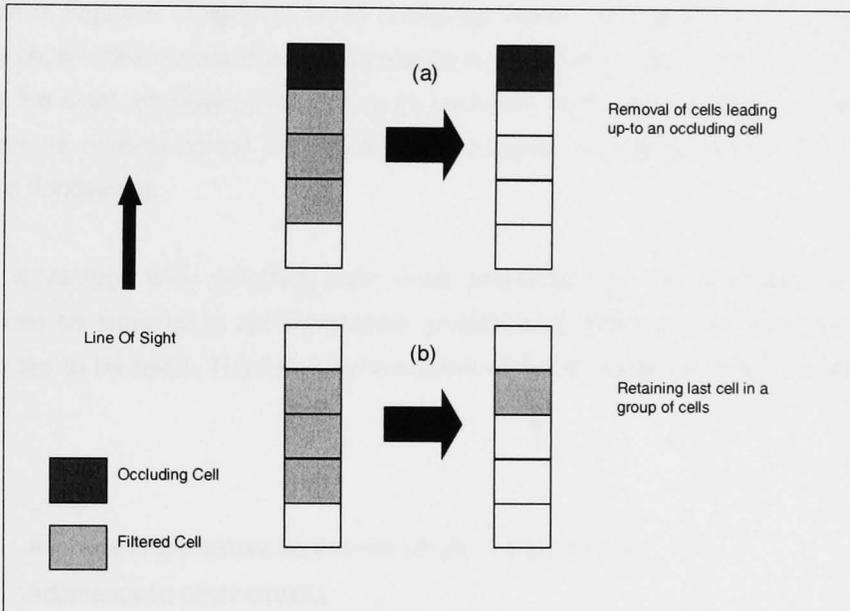


Figure 5.11: Thinning rules.

If a selected zone is in front of and touching an occluding contour, it is classed as a redundant silhouette-related cue, since its location is already being depicted through actual occlusion. The cells that make up this zone are removed from the filtered set (see Figure 5.11(a)). Where a selected zone does not touch an occluding contour, the point furthest from the viewer is retained (see Figure 5.11(b)). This assumption was formed through experimentation and the fact that the Formulated Silhouettes tend to be perceived in the same fashion as occluding contours, which occur at the furthest visible point on a surface.

Through applying the thinning rules to the set of filtered cells, a further reduction of 5.1% is achieved from the filtered set. The input to the chaining algorithm being just 3.5% of the original data.

As with occlusion, the linking of selected cells into a contour primitive is essential. The chaining operation is similar to that used for occlusion (Section 4.1.2.3, p. 53), however, Formulated Silhouettes have no hidden zones. When testing for the connection to a contour cell the algorithm checks forwards and backwards in the matrix within a set search area, consisting of three cells in either direction. If an appropriate cell is found within the bounds, a connection is formed. If two candidates are found, a connection is formed with the cell closest to the last contour point. Figure 5.12 shows a plan view depicting the chained silhouette-related cues. Occluding contours, or Factual silhouettes, are depicted in red and the supplementary, Formulated Silhouettes, in grey. To avoid confusion with the contour lines, a shaded map, with intensity determined by row slope, is used as the backdrop. Although the red lines (Factual Silhouettes) dominate the map, the grey lines (Formulated Silhouettes) provide essential cues. A comparison of Figure 5.13 with the set of occluding contours for the same view (Figure 4.7, p. 59) clearly shows their contribution to the perception of the form of the land. The heavy line work present in the c-set, particularly leading up to occluding contours, has been removed and the shape contours running across the profiles form polylines consisting of both the Factual and Formulated Silhouettes.

The main advantage with extracting such linear primitives from the orientated model is that attributes can be attached to aid subsequent generalisation/filtering or to provide cues for the style of stroke to be used. The following are some of the attributes that can be attached to a contour:

- Length
- Average slope values across the length of the contour
- Adjacency to other strokes

In addition to line attributes, the contour structure can also record local cell attributes such as height, aspect and gradient. These are of particular interest if the line weight or colour is to be varied across the contour. Figure 5.14 illustrates a simple use of contour attributes to aid post selection generalisation. Here, strokes are only rendered if they have a length greater than two cells. This simple generalisation creates what is termed the g-set. Overall, this gives a clearer sketch (for observations on how fragmentation effects form perception time, reference should be made to Elder and Zucker (p. 28, 1994)). However, the lack of intelligent filtering can result in the omission of small strokes that are not physically linked, but which visually connect to portray the form of a larger feature.



Figure 5.12: Map view of filtered c-set.
Red strokes = Occluding contours or Factual Silhouettes
Grey strokes = Formulated Silhouettes

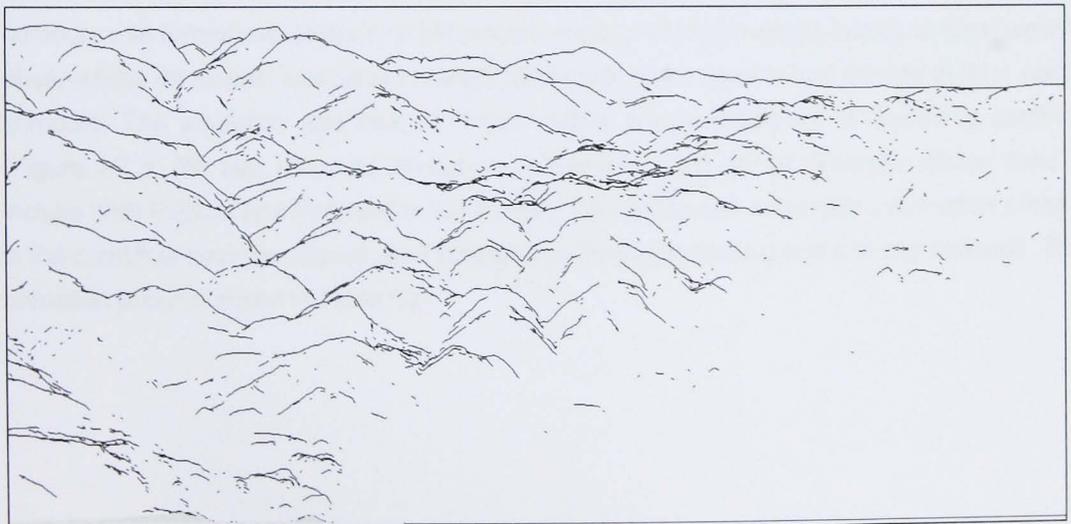


Figure 5.13: Plot showing chained strokes.

These locations are examples of where the perceptual system is interpreting features which are greater than the sum of their parts. To account for this Gestalt grouping, more detailed study of attributes such as stroke adjacency and projected position needs to be undertaken (an interesting hierarchic coding method is described by Watt (1992)). Such aesthetic refinement is outside the scope of this thesis and presents a challenge for future research.

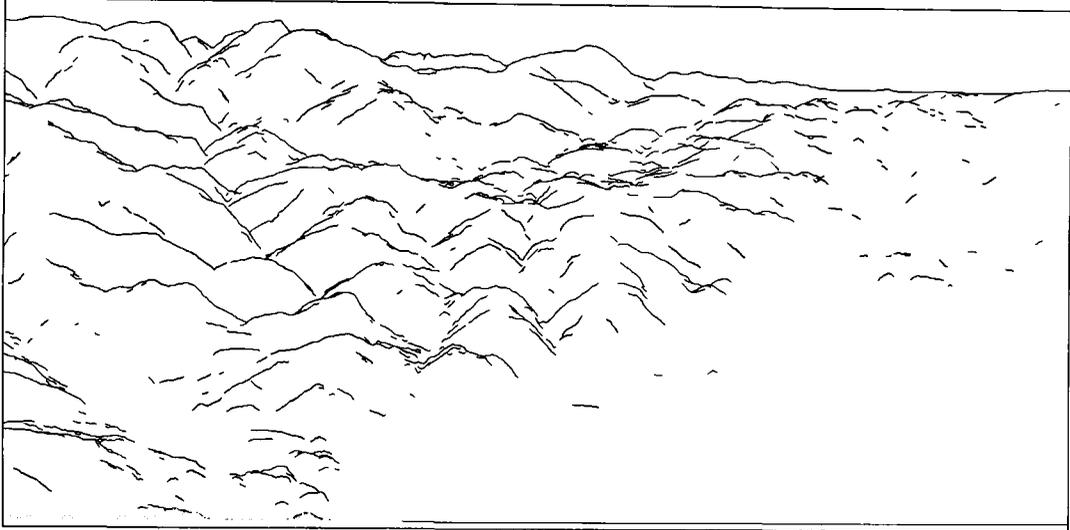


Figure 5.14: Plot showing chained strokes that have a length greater than 1 cell.

5.4 Summary

This chapter has described the investigation into an original method for supplementing occluding contours with formulated sections of silhouettes. A novel filtering method, based on geographical observations on slopes, was used to select DEM cells, which were in turn thinned to form vector contours. The ambiguity and lack of closure within the projected set of occluding contours (Figure 4.7 p. 59) was removed through the extension of the set of silhouette-related cues to include both Factual and Formulated Silhouettes. The clutter and redundant information present in the c-set has been greatly reduced through the presented filtering and thinning methods. This reduction is summarised in Table 5.2.

Stage	Percentage of Model Cells
Candidate set (c-set)	19.7%
Filtered set (f-set)	8.6%
Thinned set (t-set)	3.5%
Generalised Set (g-set)	2.9%

Table 5.2: Statistics for stages of extraction of silhouette-related cues.

The ability to reason about what is being drawn can only be achieved through processing the model and the real-world knowledge that informs this process could not be applied within the image-based approaches described in Chapter 3.

To achieve a comparison of the increased form perception offered by the extended silhouette-related cues an animated sequence, using the same view parameters as in the occlusion animation (Chapter 4, Section 4.2.2, p. 61) was created. If this is compared with the previous animation, the benefits can be clearly seen (refer to attached CD).

This project has proved that it is possible to produce the type of airy sketches which cartographers draw and that the entire process can be driven by slope information. The need to supplement fact with interpretation has been demonstrated through the importance of notional shape contours termed Formulated Silhouettes, which like maps and manual sketches, are interpretations of reality.

More detailed evaluations are presented in Chapter 6 and external verification of ideas is provided by cartographers in Chapter 7.

It must be remembered that silhouettes are only used on their own for portraying distant terrain. They provide a framework for organising other breaks of slope. Visvalingam and Dowson (1998) demonstrated via the P-stroke style of sketching that Visvalingam's algorithm does identify the important breaks of slope. One of the motivations for this project was to inform the omission of some of the P-strokes within small-scale synoptic sketches of terrain. This application of the Factual and Formulated Silhouettes is illustrated in Chapter 8.

CHAPTER 6

Testing and Evaluation

The results presented in Chapter 5 extended the idea of Factual Silhouettes or occluding contours to include what were termed Formulated Silhouettes. This chapter provides a description of the implementation of the proposed method. Computation times and scope for optimisation are discussed and the results are double-checked using a slope map, illustrating how the strokes lie across the surface. In addition, the filter presented in Chapter 5 is tested using several alternative case studies; each composed of terrain of varying character and scale.

This chapter, therefore, aims to address the following questions:

- How was the system implemented and was this good enough?
- Is the filter appropriate?
- Can the results be repeated with differing input data?

The chapter closes with a summary of the pros and cons of the proposed method.

6.1 Description of System Implementation

The approach adopted in the experimental system was not designed for optimal speed or resource usage, but to allow access to data attributes at all stages of the rendering pipeline. This section offers an analysis of the implementation and presents compute times for the various processes. Scope for optimisation is discussed, however, this lies outside the remit of this thesis and is therefore only briefly covered. For more details of the conceptual pipeline, refer to Chapter 4, Section 4.1.2, and Chapter 5, Section 5.1.1.

The system was implemented in an object-oriented style using Java, with Java2D providing the graphics API. As the research only required 2.5D vector graphics concepts and was not concerned with real-time issues, this environment was sufficient. The main objects created in the system are summarised in Table 6.1.

Object	Purpose
Study Area	Holds a copy of the source elevation model.
Transformed DEM	Holds a copy of the elevation model after view-transformation.
Processed DEM	Holds a copy of the transformed elevation model with all cells classed according to their role in the final sketch.
Visible Shape Contours	Collections of Factual and Formulated Silhouettes with associated attributes.
Renderer	Provides the functionality to output contour paths to screen or printer with appropriate line style, weight and colour.

Table 6.1: Main objects in the experimental system.

The objects in Table 6.1 illustrate the large amount of data duplication present in the system. Although putting high demands on memory resources, this allows interactions with rendered contours to refer back to data in the early stages of the pipeline, updating visualizations of the stored data. (Examples of these visualizations include the cross-sections in Chapter 4 (Figure 4.10, p. 61) and the scatter plot in Chapter 5 (Figure 5.7, p. 72)). This modular approach was suited to the research nature of the project. The ability to visualize the data at different pipeline stages proved beneficial in gaining an insight into the inputs to the various objects.

6.1.1 Computation Times

This section details the time taken to perform the processes involved in creating the results shown in Chapter 5 (Figure 5.14, see page 80). The same DEM is used (400 by 400 points). Table 6.2 lists the main operations performed. Stage (a) is only performed when initialising the system. The timing results follow a brief walk-through of the systems operations.

Stage	Description
(a)	Load DEM into Study Area
(b)	Orientate DEM to cardinal direction
(c)	Selection (c-set) and Filtering (f-set)
(d)	Deform to match viewing elevation
(e)	Copy Transformed DEM to Processed Buffer
(f)	Calculate Occlusion and remove hidden areas
(g)	Thin f-set
(h)	Chain Factual Silhouettes (Occlusion)
(i)	Chain Formulated Silhouettes
(j)	Render Contours

Table 6.2: Main operations involved in creating a sketch.

The first operation is to load the chosen DEM into the Study Area object (Stage (a)). Next, the Transformed DEM object creates an oriented copy of the Study Area. This is achieved by flipping and mirroring the source DEM.

Working from the oriented DEM, the system identifies the cells that contribute to the Formulated Silhouettes (see Chapter 5). The selection (c-set) and filtering (f-set) are performed in the same process (Stage (c)). Each cell in the oriented DEM is checked to see if it is a member of the c-set for the given viewing elevation, its row and column slope are then tested to see if it belongs to the f-set. The cell is flagged accordingly. The orientated DEM is then deformed (Stage (d)) through the addition of a base slope, parallel to the line of sight, to raise the viewing angle (See Figure 4.2, Section 4.1.2.1, p. 50).

The following step (Stage (e)) copies the transformed and classified DEM to a buffer termed the Processed Buffer, stored within the Processed DEM object. The occlusion detection performed on this buffer removes hidden areas (Stage (f)) and creates a separate Occlusion Buffer, recording the location of occluding contours (Factual Silhouettes). As noted previously (Section 4.1.2.2, p. 51), the detection algorithm visits every cell in the DEM.

These two buffers (Processed and Occlusion) form the input to the thinning and chaining routines located within the Visible Shape Contours object. Before chaining, the cells previously flagged as belonging to the f-set (Formulated Silhouettes) are thinned (Stage (g)) (see Section 5.3, p. 77), creating what is termed the t-set. The chaining routines, described in Section 4.1.2.3 (p. 53), and Section 5.3 (p. 77), work independently of each other, but in the implementation of the system, they are executed sequentially (Stage (h) and Stage (i)).

The outputs from the chaining routines are two queue structures, containing the Factual and Formulated Silhouettes respectively. Although these store the contour paths in the sequence in which they were found, this is of little consequence as they can be outputted by the Renderer object (Stage (j)) in any order, as they are all visible.

The following tables (Table 6.3 and Table 6.4) give compute times for the various processing stages executed on the system environment described in Table 6.5. Two sets of results have been given, as during the first run (Table 6.3), the execution time is slowed down as Java allocates memory space. The subsequent executions (Table 6.4) are much quicker (~67%). However, fluctuations do occur, possibly due to Java garbage collection (re-allocation of memory). The average time is calculated using the median to remove the erroneous values created when the garbage collection takes place.

The timings show that although the system includes a large amount of data redundancy and makes numerous full, sequential traversals of the elevation model, the operating speed is acceptable for non-real-time interaction. This was demonstrated with a reasonably large (400 by 400) elevation model.

If Table 6.4 is considered, the processing stage using the most resources (copying the transformed DEM to the Processed Buffer) is actually not necessary if an optimised approach is to be taken. Through removing the transformed DEM object and filling the processed buffer whilst orientating the DEM, a large memory and time overhead can be removed.

						Median
(a)	12.68	13.13	13.45	13.79	12.74	13.14
(b)	1.98	1.49	1.48	1.49	1.37	1.49
(c)	0.11	0.11	0.11	0.11	0.11	0.11
(d)	0.05	0.05	0.06	0.05	0.11	0.05
(e)	3.29	2.69	2.85	2.69	2.59	2.69
(f)	0.16	1.15	2.15	1.15	1.09	1.15
(g)	0.05	0.11	0.11	0.11	0.11	0.11
(h)	0.11	0.11	0.11	0.11	0.11	0.11
(i)	0.16	0.16	0.17	0.16	0.16	0.16
(j)	0.27	0.22	0.22	0.22	0.17	0.22

All times are in seconds

Average load time (median) = 13.14 seconds

Average time to create sketch after load (median) = 6.09 seconds

Table 6.3: Time to create sketch from load on environment detailed in Table 6.5.

						Median
(a)						
(b)	0.93	0.27	0.22	0.22	0.22	0.22
(c)	0.11	0.11	0.11	0.11	0.11	0.11
(d)	0.05	0.06	0.05	0.06	0.06	0.06
(e)	0.99	0.94	0.93	0.93	0.93	0.93
(f)	1.49	0.22	0.82	0.28	0.22	0.28
(g)	0.05	0.05	0.06	0.05	0.05	0.05
(h)	0.11	0.05	0.06	0.06	0.05	0.06
(i)	0.16	0.16	0.16	0.16	0.17	0.16
(j)	0.11	0.11	0.17	0.17	0.11	0.11

All times are in seconds

Average time to create sketch from memory = 1.98 seconds

Table 6.4: Time to create sketch from memory on environment detailed in Table 6.5.

Component	Specification
Processor	Intel PII 400Mhz
Memory	128 MB
Operating System	Windows 98 (Stand-alone)
Java Interpreter	JDK-1.2.2-W

Table 6.5: Environment specification.

6.2 Investigation of Problem Cases using Slope Maps

In Chapter 5, the presented results were not combined with any other surface information. It is therefore difficult to evaluate whether or not the extracted contours start and end at the correct locations. In addition, the silhouette contours often tend to 'hang' when they are not supplemented with other cues (as observed by Visvalingam and Dowson (2001)). Figure 6.1 illustrates some areas of concern, identified through a visual analysis of the results. In this section, the extracted contours are overlaid onto a projected slope map. The results used are the same as those shown in Chapter 5, (Figure 5.14 p. 80). The slope map is created as a texture covering the whole of the DEM. As it is purely object-based, it only needs to be calculated once.

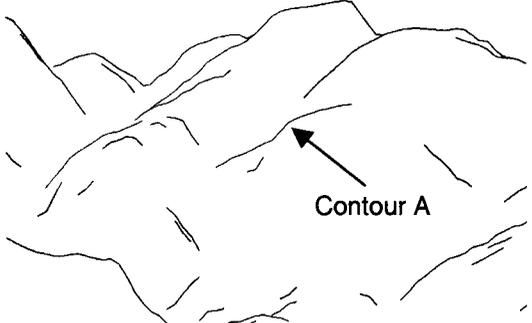
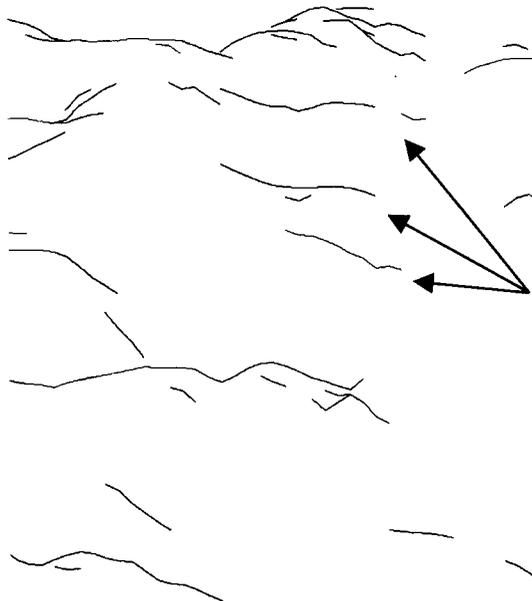
Case	Notes
	<p>CASE 1:</p> <p>The left-hand-side of Contour (A) appears to 'hang'.</p>
	<p>CASE 2:</p> <p>These three small valleys appear to end abruptly.</p>

Figure 6.1: Problems in evaluating locations of extracted contours.

When evaluating the position of extracted contours against the surface of the DEM, it is inappropriate to interpolate or smooth the texture as this changes the representation of the model from which the contours are extracted. The most suitable approach is to use absolute row slope as the attribute for the creation of the texture map. Taking the average magnitude of row and column or diagonals is not appropriate as it introduces an element of smoothing. The use of column slope as the attribute is also not a suitable choice as the overlaid contours are providing silhouette-related cues, which are primarily based upon column slope information.

The next factor to consider is how to map the slope magnitude to an appropriate colour range. Although various scaling techniques exist, this section uses a simple linear mapping between flat areas (Light) and steep areas (Dark). Gooch et al. (1998) note that when overlaying shading

with contours, care should be taken so that dark shading does not obscure contour information. With this in mind, the darker shades were only applied to very steep row slopes (80%). If the scatter plot of model slopes (Figure 5.7, p. 72) is referred to, it can be seen that very few slopes have an absolute row magnitude greater than 75%. The resulting effect produces a light wash-style backdrop onto which the vector contours are drawn. Figure 6.2 shows the projected slope map on its own (a), with the occluding contours (Factual Silhouettes) (b) and with the addition of the Formulated Silhouettes (c). The addition of the slope map compliments the contours very well and, as can be seen by a comparison between Figure 6.2(a) and 6.2(c), the converse is equally true.

Figure 6.3 shows enlarged areas from Figure 6.2 approximately corresponding with the problem cases noted in Figure 6.1. In Case 1, the addition of the slope map has resolved the ambiguity of Contour (A) (Figure 6.1, Case 1). The contour clearly does not hang since the surface information shows that it terminates at a valley. This does not indicate a problem with the identification method as the cues provided by the slope map are not silhouette-related. The abrupt termination of the three small valleys noted in Case 2 (Figure 6.1) was verified against the slope map. A study of a topographical map of this location indicated the presence of open-cast workings in this area (Ordnance Survey, Vale of Glamorgan & Rhondda area, Landranger 170, SS8684), a likely cause of the rather unnaturally sharp break of slope. The addition of the slope map in Figure 6.3 (Case 2) however, focuses attention on two other ambiguities. The first of these is the contour in the bottom left (Contour A), which initially appears to be over-extended. However, if the full profile plot is examined (Chapter 4, Section 4.2.1, Figure 4.6, p. 59) the length of the contour can be seen to be valid as it is running across a small shelf (perhaps a raised beach) before reaching the coastal plane. The perception of this as an ambiguity in the slope map plot (Case 2, Figure 6.3) is most likely due to the simple colour mapping applied which emphasises the second break of slope and creates a weak depiction of the minor feature in front.



(a)



(b)



(c)

Figure 6.2: Row slope map as backdrop for silhouette-related cues.

The second ambiguity is the over-extension of the first of the three valleys (Contour B) noted in Case 2 (Figure 6.3). This however is due to an anomaly in the data, perhaps due to corrupt contours near the open-cast site.

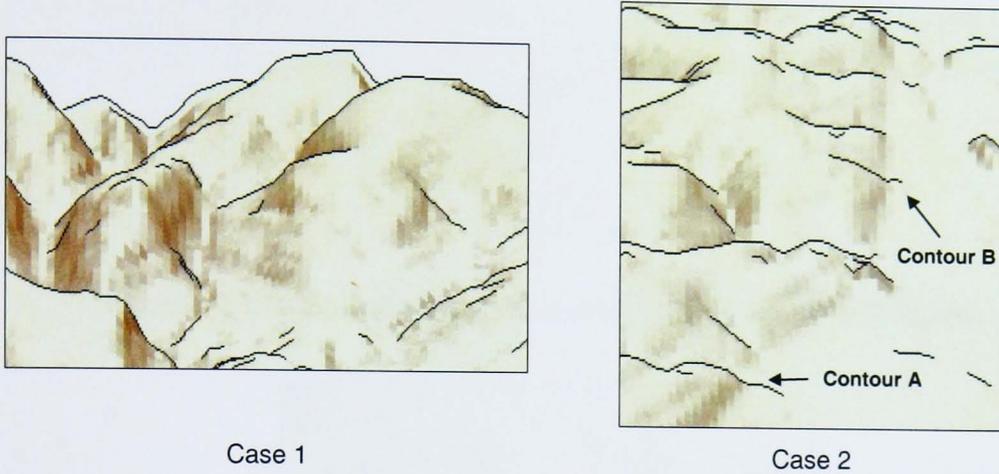


Figure 6.3: Problem cases from Figure 6.1 overlaid onto row slope map.

Another problem brought to light by the addition of the slope map is shown in Figure 6.4. This location, a low ridge of millstone grit close to Bridgend (upper right-hand corner of the dataset) proves hard to sketch when using cut-off values which are applied 'blanket-fashion' to the whole model. If, to produce a more appropriate depiction, more detail were included by lowering the threshold, the remainder of the figure would become cluttered. This case highlights the problems that arise when using a none-adaptive algorithm. In addition to this problem, Figure 6.4 also demonstrates the potential problems created through the post-selection filtering described in Section 5.3. If the contour labelled X (Figure 6.4) is considered, the slope map gives the impression that when sketching this location, a longer contour should be used. However, if the full set of extracted contours (Figure 5.13, p. 79) is studied, the short, unconnected strokes, which were filtered before rendering, can be seen to extend this contour. A similar problem is illustrated in Figure 6.5. Here, the removal of small strokes has caused noticeable gaps in the contours (Figure 6.5, Location (a)). Again, if the full set of extracted contours (Figure 5.13, p. 79) is referred to, these gaps are not as evident.

However, the benefits of filtering the small, unconnected lines outweigh the problems and the case studies presented in the next section only include strokes with a length greater than one (those which connect more than two DEM cells).

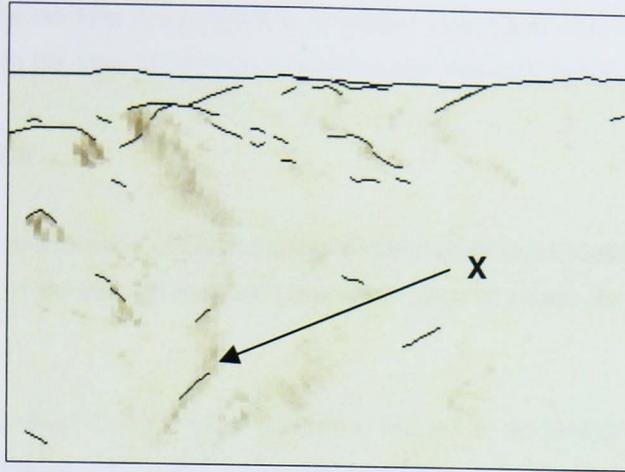


Figure 6.4: Unsuccessful depiction of millstone grit ridge near Bridgend.

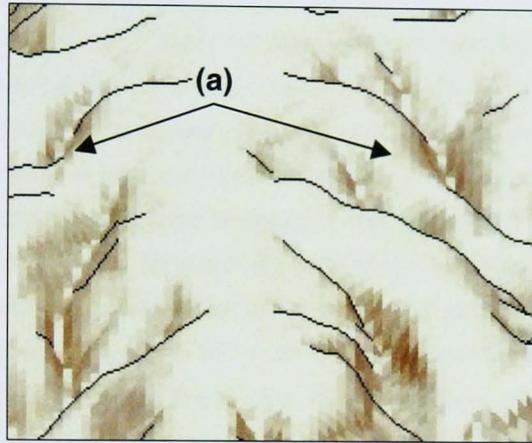


Figure 6.5: Problems with filtering small lines.

6.3 Case Studies

This section uses four contrasting datasets to investigate if the filter presented in Chapter 5 is applicable to any elevation model, or if it is only successful on the primary test dataset. This is achieved through assessing the success attained when using elevation models of varying character and scale as the input. For each dataset, the full profile plot is presented, followed by the extracted Factual Silhouettes and then the combination of both the Factual and Formulated Silhouettes.

The filter presented in this thesis is based on the geographical significance of slopes. This information-based filtering attempts to select those Formulated Silhouettes that a cartographic artist would include in a sketch. Ideally, as the cut-off values are based upon real-world observations (Macgregor, 1957), the filter should be generally applicable across various situations. However, as discussed in Chapter 5, Section 5.2.3, the use of the control point offers

an easy way to make the filter more sensitive to weaker responses. This element of interaction allows for a 'human in the loop' to address complexity and aesthetic issues.

6.3.1 Test Datasets

Table 6.6 presents a summary of the elevation models used to evaluate the filter, recording information relating to the dataset and the parameters used to create the results presented in Figures 6.6 to 6.9.

The first study area (Port Talbot), is an extracted quarter of an Ordnance Survey 1:10,000 Landform Profile dataset. This DEM represents the high ground, Mynydd Brombil, behind Margam, near Port Talbot, South Wales. This area can be seen in the centre of the dataset used in Chapter 5. Here, however, the DEM is derived from large-scale contours in comparison to the 1:50,000 set used in the construction of the smaller scale model. The terrain therefore is of the same class as the test study area, but is of a higher resolution. Figure 6.6 shows this model viewed from a lower elevation than the small scale DEM in Chapter 5. The following DEM (Figure 6.7), again from Ordnance Survey, but at 1:50,000 (Landform Panorama), covers the central area of the Lake District National Park, England. This model reaches from the southern end of Derwent Water (large flat area left-of-centre in the top of the Figure 6.7) to the northern tip of Lake Windermere (flat area in the lower right-hand-side of Figure 6.7). The model displays a glaciated geology resulting in rugged mountain scenery. This landscape is good to sketch as it presents many distinct breaks of slope. The main contrast between this area and the primary test case is the general magnitude of the slopes, hence the lower vertical exaggeration used. The following two datasets (Figure 6.8 and 6.9), acquired as part of a consultancy contact with Visual Insights Inc., are both USGS data. The first covers the area around Pittsburgh, PA, USA with the Point State Park located in the centre, right-hand-side of Figure 6.8, at the confluence of the Allegheny and Monongahela rivers. The DEM is at 1:30K and consists of "erosional remains of a large sediment-filled basin which was formed and, finally, uplifted as a result of the plate tectonic interactions which created the Appalachian Mountains" (Tagg Online). Assistance in conversion of this data was provided by a current PhD student at The University of Hull (Mathers 2001). The second USGS DEM (1:10K) covers the majority of the Battlefield of Gettysburgh, PA, USA. The terrain consists of relatively low relief with incised river valleys and outcrops of volcanic intrusions (diabase sil) such as the Round Tops (Big and Little) (lower left-hand-side of Figure 6.9) and Culp's Hill (location (a) in Figure 6.9) (White Online). This DEM was converted using a utility developed by the late Sol Katz of the Bureau of Land Management, US Government (Katz Online).

Study Area	Scale	Source	Deformation Base-Slope	Vertical Exaggeration	View Direction	Change to Filter	Comments
(A) - Port Talbot: 250 by 250 points 2.5 by 2.5 Km	1:10,000	OS	20%	2.5 times	From the West	None	Same geology but different scale.
(B) Lake District: 400 by 400 points 20 by 20 Km	1:50,000	OS	40%	1.8 times	From the South	None	Similar terrain (Glaciated) but greater magnitude of slopes. Easy to sketch due to sharp breaks of slope.
(C) - Pittsburgh: 400 by 400 points 12 by 12 Km	1:30,000	USGS	66.67%	2.5 times	From the South	None	Differing geology, scale and source.
(D) - Gettysburgh: 500 by 500 5 by 5 Km	1:10,000	USGS	40%	1.75 times	From the South	Control point moved to 6	Very low relief.

Table 6.6: Details of case studies

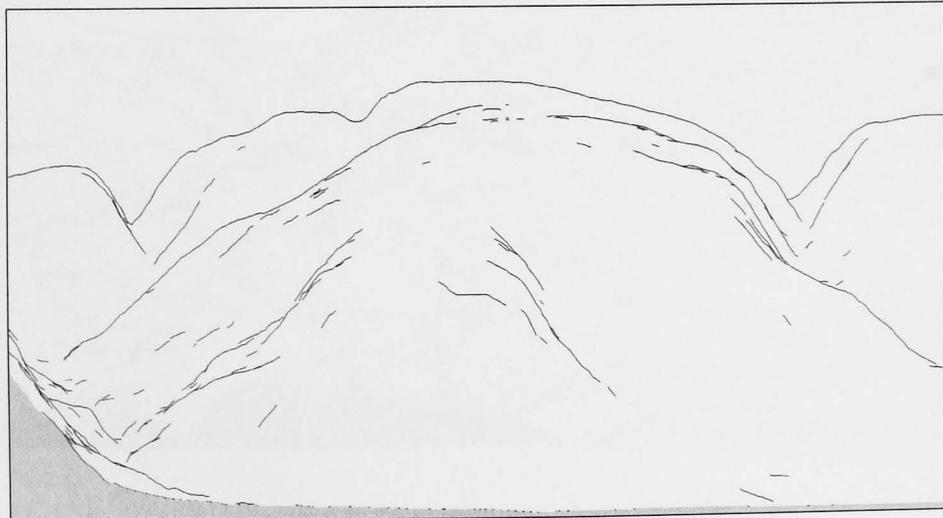
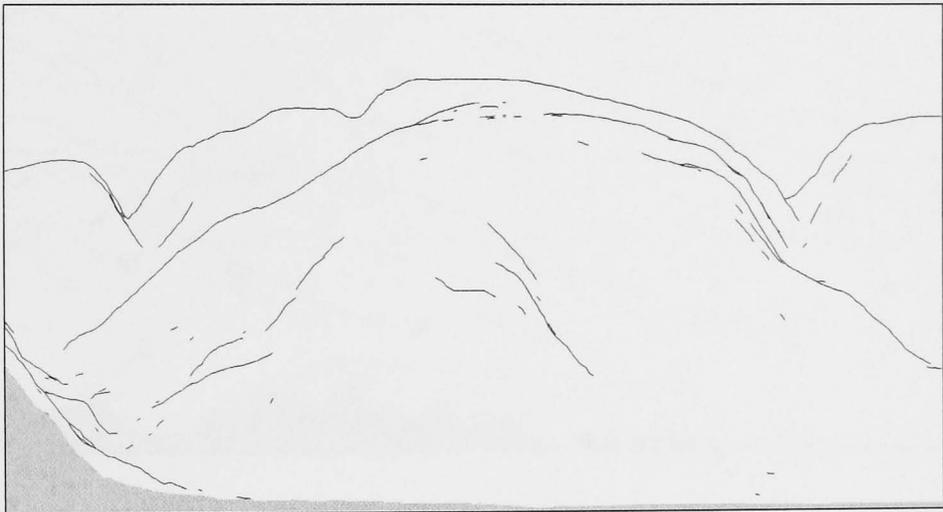
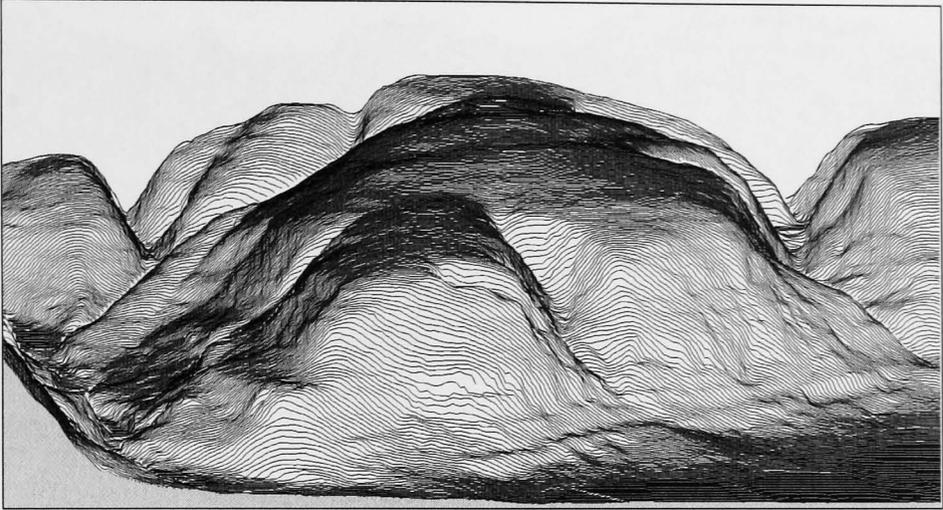


Figure 6.6: Case study (A) - Port Talbot.

Data: © Crown Copyright Ordnance Survey

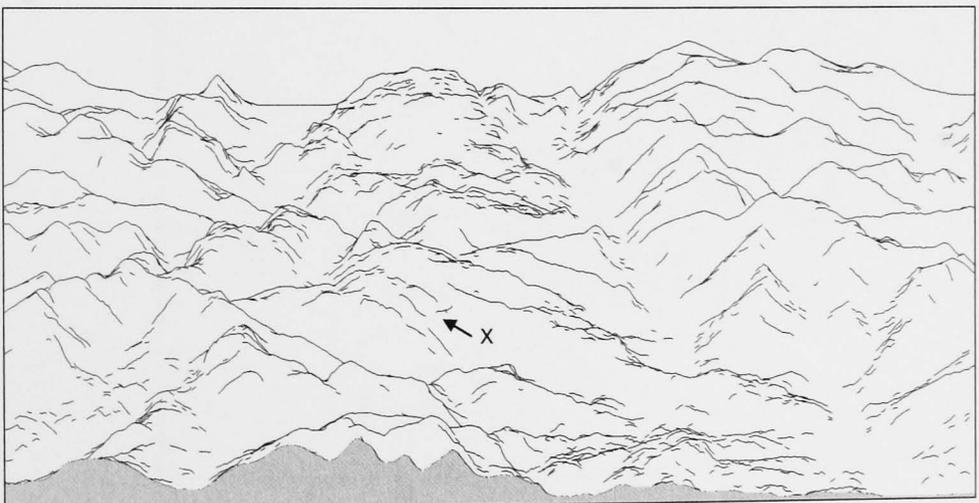
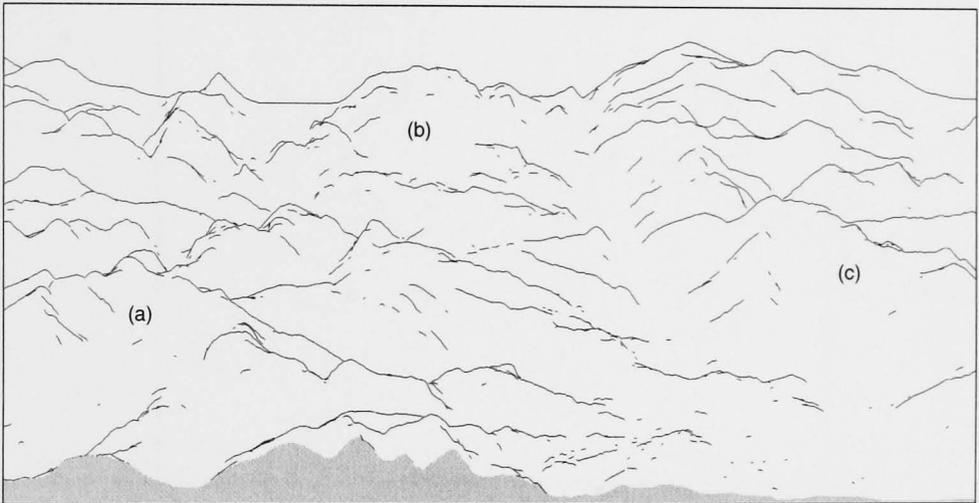
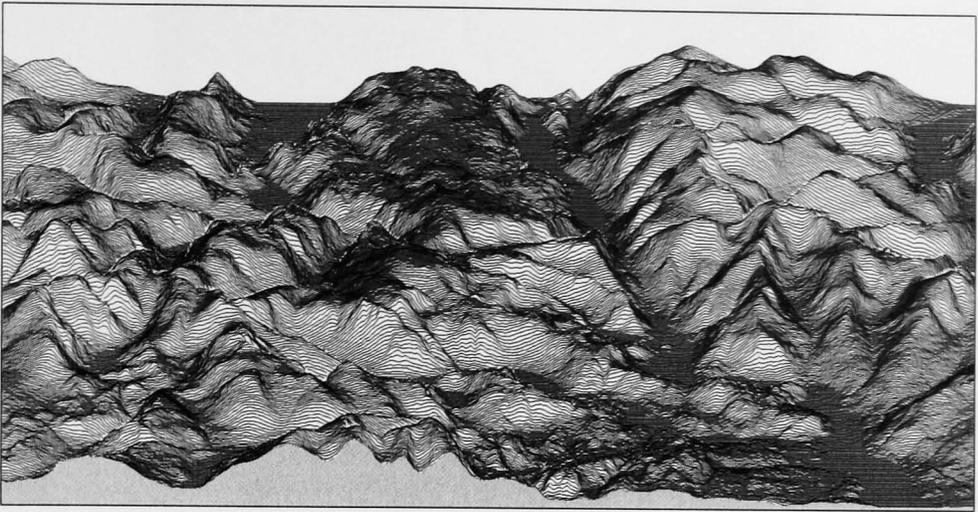


Figure 6.7: Case study (B) - Lake District.
Data: © Crown Copyright Ordnance Survey

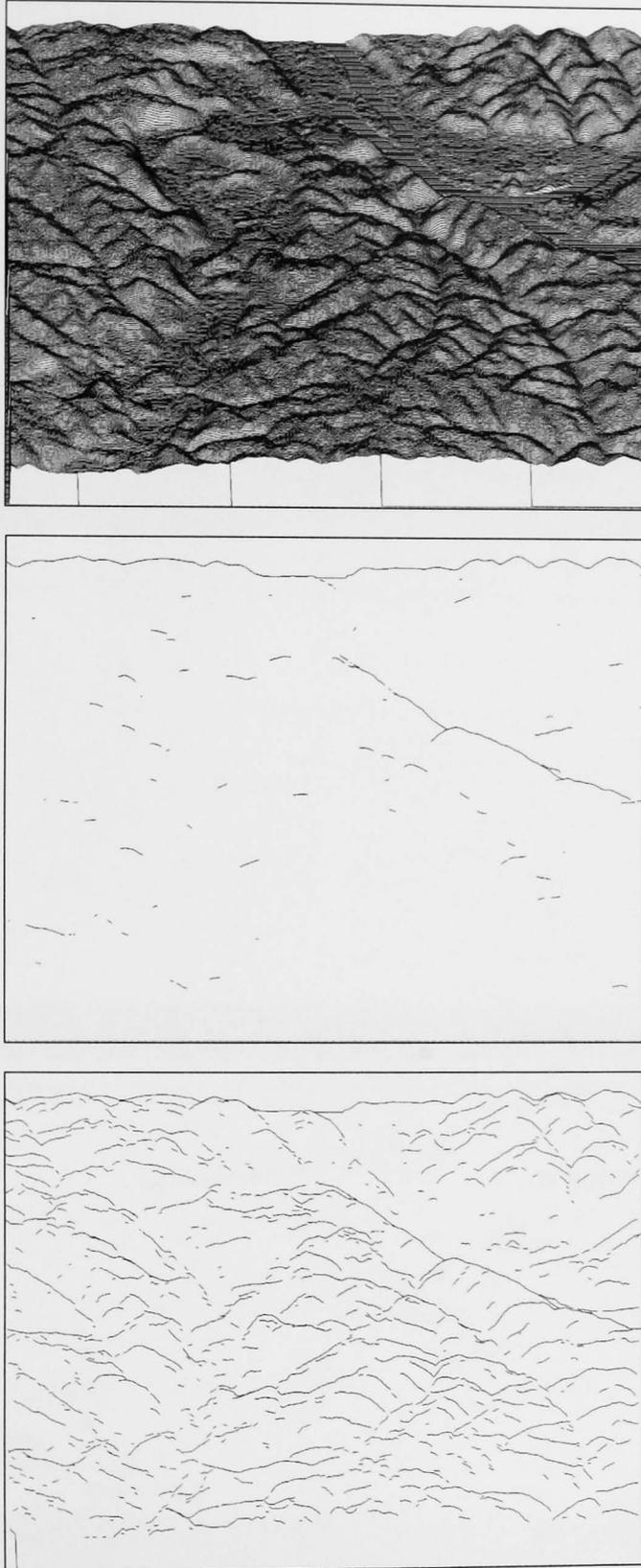


Figure 6.8: Case study (C) - Pittsburgh.
Data: © USGS

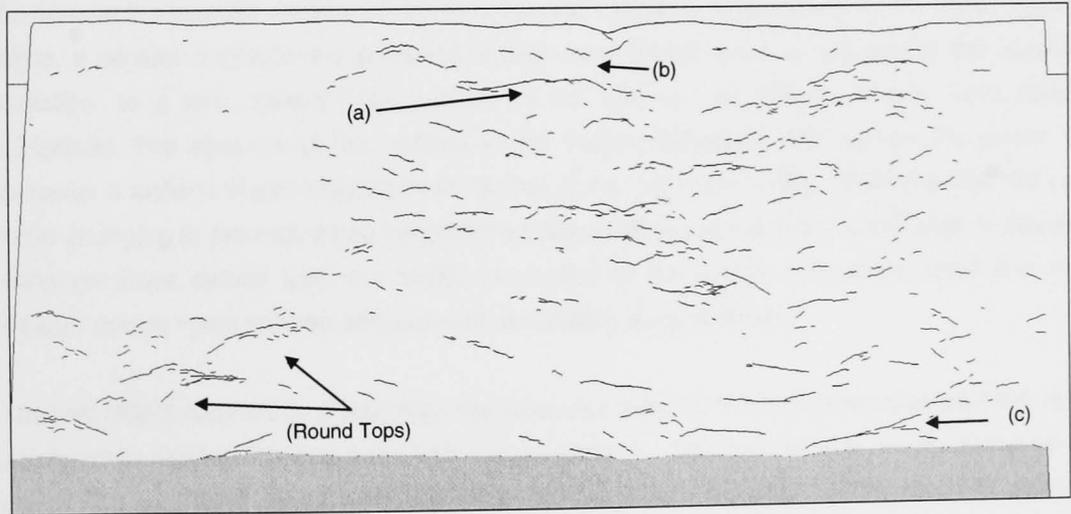
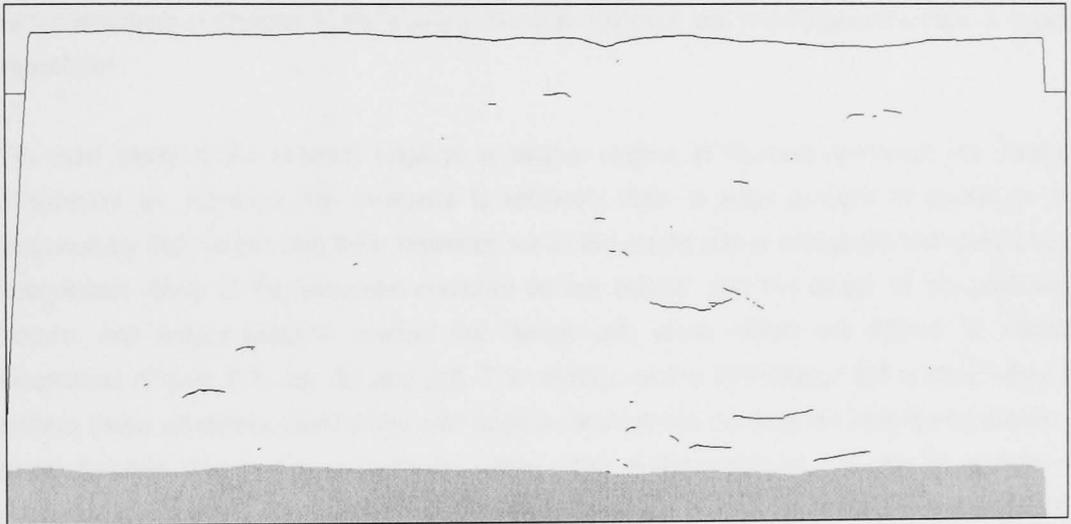
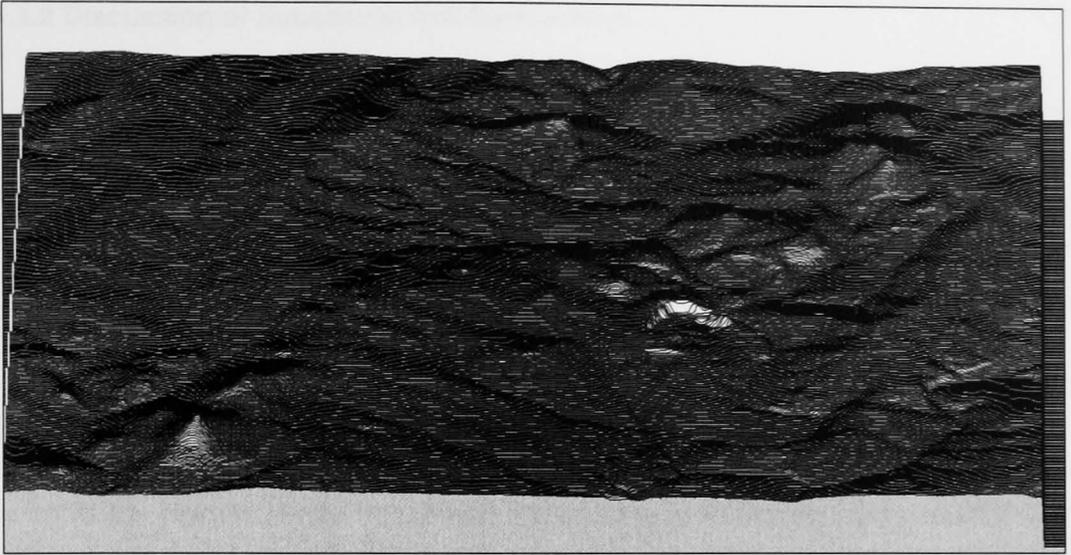


Figure 6.9: Case study (D) - Gettysburgh.

Data: © USGS

6.3.2 Discussion of Successes and Deficiencies

The first three case studies did not require any change to the filter to produce impressive improvements on the figures where only the Factual Silhouettes were rendered. The last study however, demonstrates that even after interaction with the filter, the result is not a completed sketch. This also illustrates that where silhouette-related cues are sparse, additional sketch cues are essential even if an approximate perception of the scene is to be gained. The following text takes each study in turn and comments on the particular successes or deficiencies present.

In the Port Talbot case study (Figure 6.6), the Factual Silhouettes perform reasonably well due to the relatively low viewing elevation. However, some features that are perceived as connected in the profile plot are depicted as broken by the Factual Silhouettes. These situations are rectified when the Formulated Silhouette lines are added. As this is the same character terrain as the test area in Chapter 5, the success the filter displays with this large-scale data is largely expected.

The next study (Lake District) displays a similar degree of success with just the Factual Silhouettes as, although the viewpoint is relatively high, a large amount of terrain is still obscured by high ridges and fells. However, when the profile plot is compared with the Factual Silhouettes, many of the extracted contours do not extend over the length of the perceived feature, and empty patches present the viewer with areas which are difficult to visually reconstruct (Figure 6.7, (a), (b) and (c)). The addition of the Formulated Silhouettes helps to resolve these situations, particularly with addition of contours marking the orthogonal gullies in Upper Eskdale (Figure 6.7, (a)) and the valley sides of Rydal (Figure 6.7, (c)). In addition to extending some of the shortened contours noted previously, a minor but important addition can be seen at the location marked (X) in the combined silhouette-related cues for the Lake District. Here, a contour indicates the presence of high land, dropping down, away from the viewing direction, to a tarn, locked three-quarters of the way up the fellside (Stickle Tarn, Great Langdale). The absence of this contour in the Factual Silhouette plot causes the viewer to perceive a uniform slope dropping from the top of the fell to the valley. While the filter did not need changing to produce these beneficial additions, there are too many small lines in places. Although these detract from the overall perception of the scene, it must be noted that the dataset covers many features and presents a complex, rugged terrain.

The first USGS case study (Pittsburgh) demonstrates how the Factual Silhouettes perform very poorly when viewing the landscape from a high elevation. This type of view is very useful as it presents a map-style sketch with very little 'dead ground', i.e. most of the terrain is visible. Through the addition of the Formulated Silhouettes, a very useful sketch of the silhouette-related cues is presented. As there is no change in the filter, this case study demonstrates the portability of the method to datasets of different character, scale and source.

As with the Pittsburgh data, when viewing the second USGS case study (Gettysburgh) from a high elevation, the form cues which the Factual Silhouettes provide are very poor (Figure 6.9). Due to the low relief present in this dataset, the filter control point was pulled towards the origin of the filter (see Figure 5.8, p. 73). This interaction with the filter allows weaker responses to be included in the f-set whilst still maintaining the cut-off bias. The results do correspond to the perceived silhouette-related cues in the profile plot, however they are difficult to visually structure and stand poorly on their own. The addition of Culp's Hill (a), the incised meander (b) and the river valley at (c) are all crucial as they provide strong form cues in a flattish area. The difficulty presented by this case study is primarily because there are not a great number of silhouette-related cues present in the view. This situation presents the viewer's perceptual system with large areas of white space that, as already noted, are difficult to interpolate into a surface, hence the form of the land is difficult to grasp. This highlights the fact that silhouette-related cues cannot stand on their own and must be supplemented with other, differing classes of form cues.

Figure 6.10 presents the extracted results from the last three case studies overlaid with their respective slope maps (as in Figures 6.2 to 6.5). The vertical striations present in the slope textures for the USGS data (Pittsburgh and Gettysburgh) appear to be interpolation errors in the source data. As these occur at regular intervals in the Gettysburgh figure and once only on the right-hand-side of the Pittsburgh figure they could be caused by the 'stitching together' of digitized areas; this opinion is purely speculative and they could equally be an artifact of data conversion utilities. Their presence is not of concern to the method presented in this thesis. Table 6.7 lists the slope range across which the colours are mapped for particular case studies. The variation in ranges is due to the differing slope magnitudes in the datasets.

Case Study	Slope Range	
	Light	Dark
The Lake District	0%	110%
Pittsburgh	0%	80%
Gettysburgh	0%	30%

Table 6.7: Slope mapping used in Figure 6.10.

Again, the slope maps complement the extracted contours, most noticeably in the Gettysburgh dataset where the inclusion of additional form cues helps to clarify the previous ambiguities.

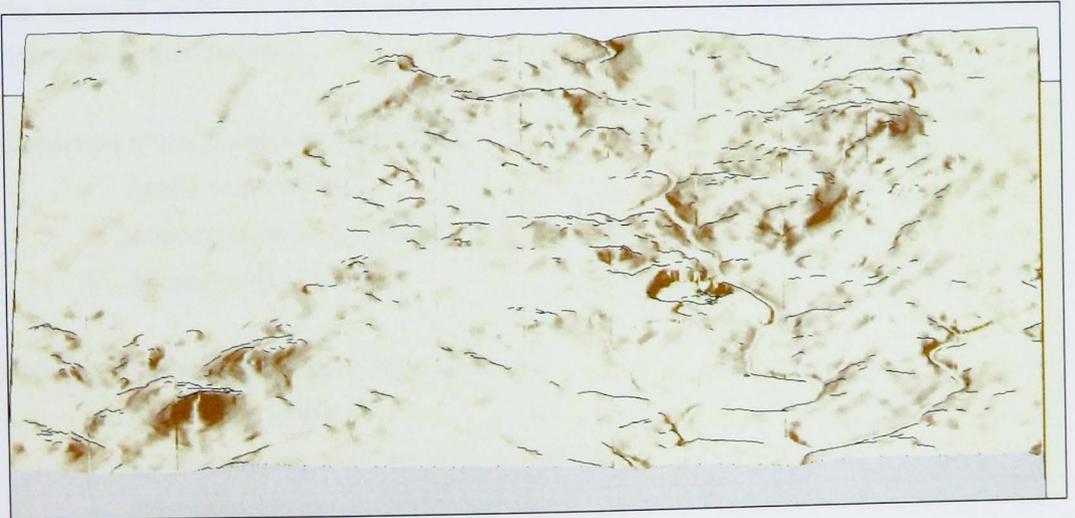
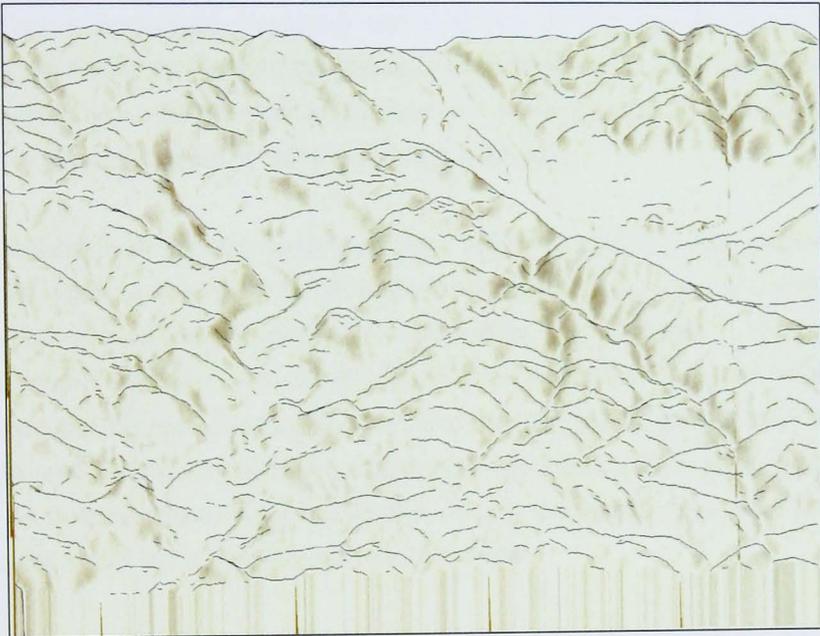


Figure 6.10: Row slope map added to the case studies presented in Figures 6.7 to 6.9.

6.4 Summary of Evaluation

This section summarises the major observations arising from this chapter, and closes with an overview of the successes and drawbacks of the presented technique.

In terms of the success of the implementation, the flexibility offered by the modular approach outweighs the processing and memory overheads at this stage. The system was not designed to operate in real-time, but to prove and test the concept of Formulated Silhouettes.

The second evaluation stage used slope maps to add a means of double-checking the otherwise subjective nature of visual evaluation. This section highlighted the omissions within the set of Factual Silhouettes (occluding contours) and gave a convincing portrayal of the successes of the filter (see Figure 6.2). The use of the slope map to convey the nature of the underlying surface also drew attention to problems in the filtering of small unconnected contours and the lack of balance created by using a none-adaptive filter.

In order to evaluate how the filter performed under different conditions, four case studies were selected to be used as the inputs to the system. This again was a purely visual evaluation. Overall, the filter worked well with terrain of varying scale and character. In one extreme case (Figure 6.9) where the relief was predominantly low, a degree of human interaction was required to increase the sensitivity of the filter. This case study also gave a clear example that the silhouette-related cues cannot stand on their own and need to be supplemented with other form cues. As in the previous visual evaluation, simple row slope maps were provided as a backdrop so the nature of the surface could be discerned.

The following bullet points summarise the outcome of the investigations and evaluations undertaken in this chapter:

Successes of the presented technique:

- Stable and portable.
- Adds clear benefits to other visualization styles.
- Scope for optimisation.

Drawbacks with the presented technique:

- Filter is not adaptive.
- Other cues play vital role in some landscapes.
- Post selection generalisation too naïve.

The next chapter reports on the use of a forum of cartographers to gain external verification of the conceptual filter design decisions such as choice of cut-offs and thinning rules.

CHAPTER 7

External Verification of Thesis Research

The case studies presented in the previous chapter demonstrate that Factual Silhouettes are not enough, especially when viewing the scene from a high angle. Manual sketches tend to include more silhouette-related lines. Having checked the formulated approach and tested it with different datasets, exercises were devised to gauge the preferences of cartographers, study their output and seek external verification of certain research decisions.

The stages up to filtering the c-set (back-facing slopes on the model) are deterministic and do not need testing. Two exercises were designed to extract opinions on decisions taken after this stage of the processing pipeline (see Table 7.1).

The main reason for undertaking Exercise 1 was to ascertain if the cartographers had a preference for levels of filtering. The filter values control cue selection. Since the filters are non-adaptive, there will be noise if the values are too low, and missing cues if the values are set too high.

Exercise 2 was designed to give cartographers the opportunity to draw silhouettes for a given view on the DEM thereby indicating the types of cues they choose. The hand-drawn sketches also indicate whether there is a preference for lines (thinning) as opposed to shading, for connecting parts into lines or leaving them, and for preferred styles of rendering. Exercise 2 also aimed to extract ideas for future work.

The forum chosen for carrying out these exercises was the annual meeting of the British Cartographic Society Design Group, held at the joint conference of the British Cartography Society and the Society of Cartographers at Oxford Brooks University in September 2000. The members of this focus group, from a mixed background of freelance, commercial and academic cartographers; all shared interests in map design issues.

To inform subjects of the research background, a brief poster presentation opened the workshop. The exercises were then introduced and distributed among the subjects, who were encouraged to write comments supporting their responses. The subjects had approximately 20 minutes to complete both exercises.

Stage	Depends on..	Where tested?
Filtered Set (f-set)	Slope based cut-off values	Ex1 Ex2 - Cue Selection
Thinned Set (t-set)	Thinning approach	Ex2
Chained Strokes	Chaining approach	Ex2
Rendered Strokes	Cue representation	Ex2

Table 7.1: Testing of phases of the processing pipeline.

The two exercises were presented in a handout (Appendix A) which was designed to be stand-alone, so, if required, it could be distributed to other interested parties. Introductory text provided the background to the exercises and a cover sheet recorded information regarding the subject's occupation and training. A traditional cartographic sketch (Figure 2.14, p. 23) illustrated the important role played by silhouette-related cues. This was followed by the full profile plot for the test study area, which could be compared with the inadequate set of occluding contours or Factual Silhouettes for the same view. Following the two exercises, a summary was presented and the subjects were asked to comment on deficiency and application issues.

This chapter presents some general comments relating to the value of this work, shows the results from the workshop, discusses them with respect to the processing stages outlined in Table 7.1 and closes with a thesis specific summary.

7.1 Workshop Exercises

7.1.1 Subject Details

As noted in the introduction, the subjects who undertook this exercise were from a mixed background of freelance, commercial and academic cartographers. Out of the 22 people present, 18 returned a completed exercise. The major variable that influenced the subjects was if they had had training in cartographic sketching. Out of the 18 completed exercises, only 6 were returned by subjects who said they had such training.

7.1.2 General Comments

Most subjects (77%) saw the need for complementing existing photorealistic style visualization tools with more abstract alternatives. Of primary interest to the cartographers was the fact that this research is trying to incorporate “intelligent abstraction” into terrain visualization, which is what “cartography is all about”. The sketch was also noted as having the advantage when it came to reproduction costs.

Application suggestions included adding aesthetic value to walker’s maps through the inclusion of sketched views and using the cues to provide cartographers, including those who are skilled, with a base map on which to produce rapid sketches of terrain (also noted in Weibel and Herzog 1989, p. 96).

More technical comments stated that the research offered an “easily interpreted method of representation of landform”, a situation which was “more useful for skewing certain features” and a representation which “offers a very clear impression of the ‘actual terrain’ that does not depend on the eyes interpolation from a photo which may be distorted (atmosphere)”.

In addition to the presented exercise, a number of informal poster presentations in the main conference exhibition facilitated discussions with a wide variety of cartographic professionals. The anecdotal comments that were gained from these interactions provided useful application feedback. One freelance cartographer expressed interest in the possibility of a commercial terrain sketching system that would produce a sketch of publishable quality for importing into a vector drawing package. A military terrain analyst, who was speaking at the conference, was keen on the availability of visual bandwidth allowing for annotations, the perceptual clarity of the sketch and the possibility of rapid transmission to mobile devices.

7.1.3 Exercise 1

The aim of this exercise was to investigate which slope cut-off values, in the opinion on the cartographers, gave the most successful depiction of the silhouette-related cues. Four differing cut-off values were chosen to produce images to test:

- if subjects noted the need for different cut off values for different directional derivatives.
- the importance of allowing for cues lying on diagonals.

Figures 7.1.1 - 7.1.4 show the four images that the subjects were asked to rank according to their success in portraying the set of silhouette-related cues. The captions, detailing the filter choices, were not included in the exercise. Table 7.2 shows the filter values used to produce the images and the reasons for choosing them. Since the focus of this exercise was on the evaluation of the filter, the post selection filtering used in the case studies presented in the previous chapter was not performed.

Figure	Row Slope cut-off (%)	Column Slope cut-off (%)	Allow Diagonals	Reason for choice of Filter cut-offs
7.1.1	20	20	NO	Minimal Illustrates the need for separate weightings for each direction derivatives
7.1.2	1	1	NO	Cluttered Create comments regarding the need to filter i.e. to remove clutter
7.1.3	12	20	NO	Inappropriate Biasing Show how the column slope cut-off should be less than the row
7.1.4	20	12	YES	Information Based Cut-offs Including Diagonals Show how with corrected bias and diagonals included, the optimal description of the cues is achieved

Table 7.2: Design of test filters.

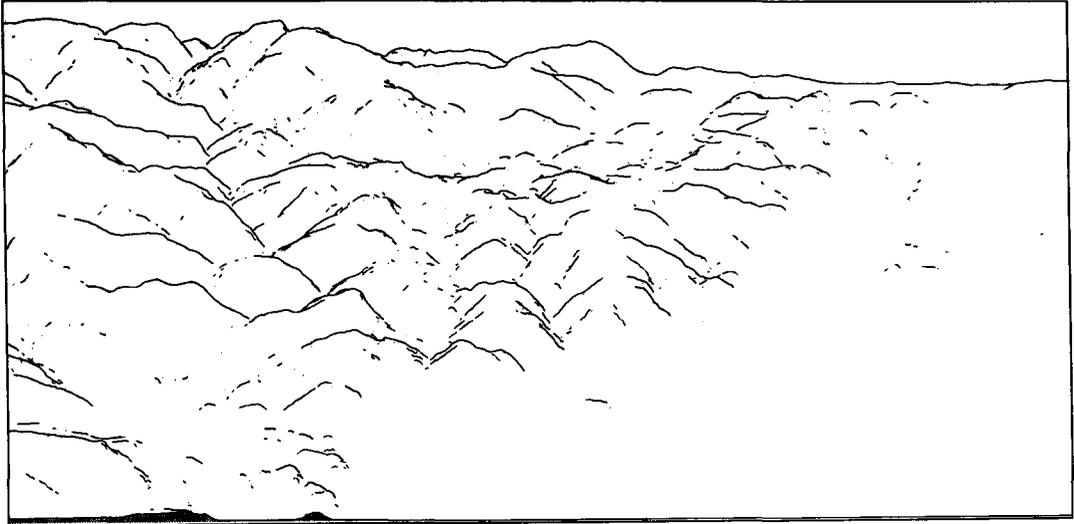


Figure 7.1.1: Minimal filter.

Row Slope cut-off (%) = 20

Column Slope cut-off (%) = 20

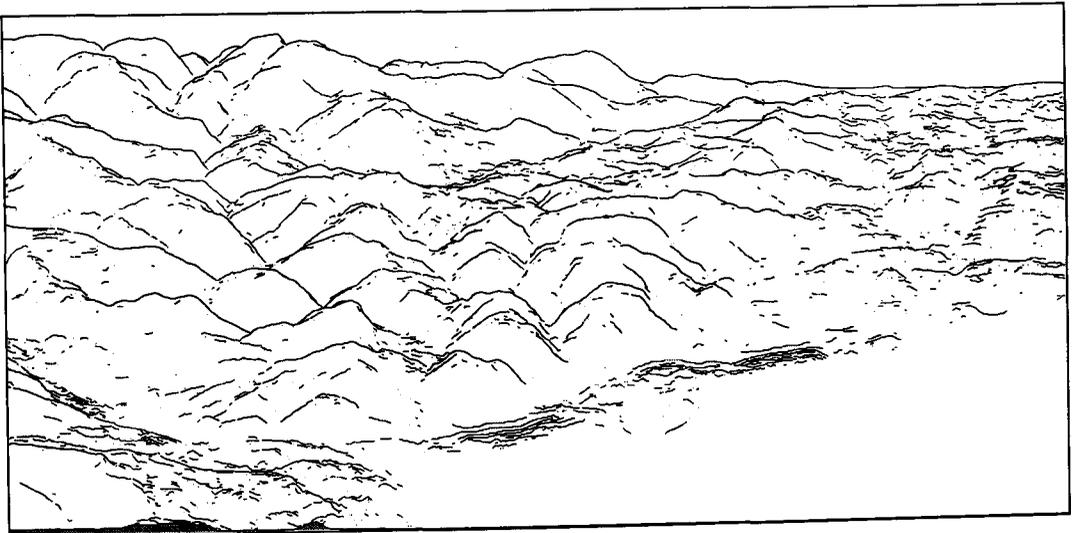


Figure 7.1.2: Cluttered filter.

Row Slope cut-off (%) = 1

Column Slope cut-off (%) = 1

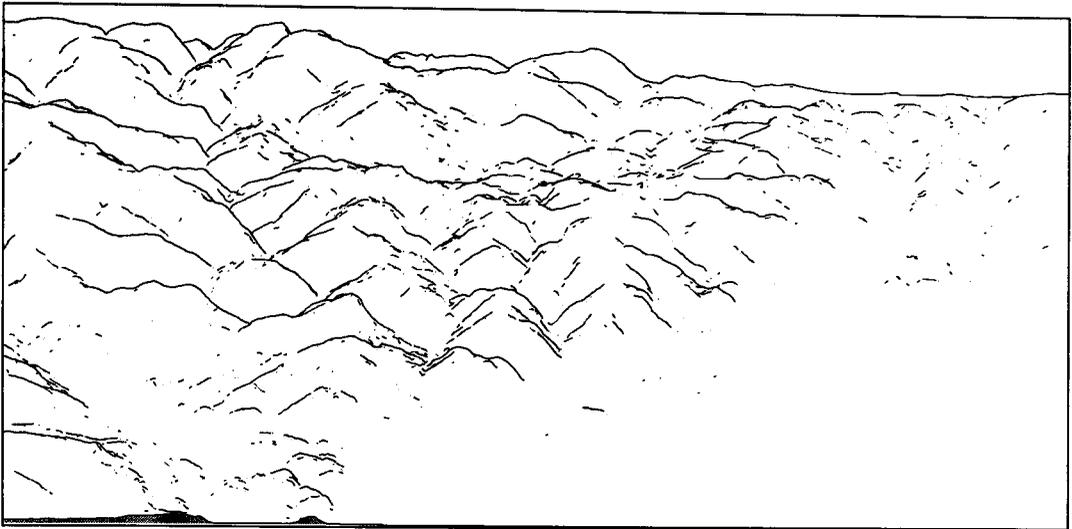


Figure 7.1.3: Inappropriate biasing.

Row Slope cut-off (%) = 12

Column Slope cut-off (%) = 20

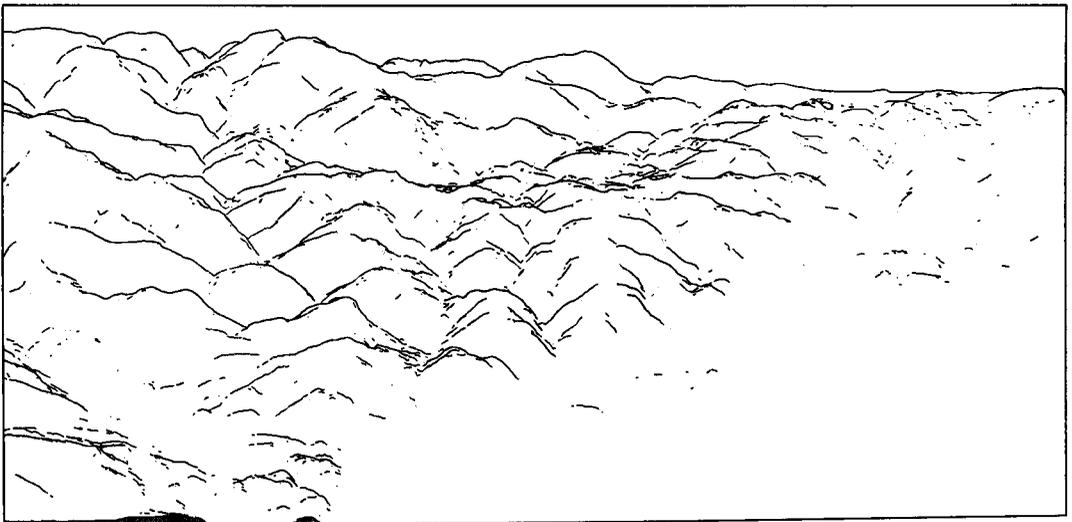


Figure 7.1.4: Information based cut-offs including diagonals.

Row Slope cut-off (%) = 20

Column Slope cut-off (%) = 12

Control Point (Row Slope%) = 8.75

7.1.3.1 Results

Table 7.3 shows the results of the ranking exercise. The frequency, expressed as a percentage, shows the proportion of the subjects who placed a particular figure in a particular position. The tone applied to each cell of the grid indicates the numerical percentage as a grey-scale density. The subjects are split into those who stated that they had training in cartographic sketching, and those that said they did not. The figures on the sub-captions quantify the number of subjects in each set.

Figure 7.1.1 Figure 7.1.2 Figure 7.1.3 Figure 7.1.4

Rank	1 st	0%	33%	33%	33%
	2 nd	0%	0%	33%	67%
	3 rd	67%	17%	17%	0%
	4 th	33%	50%	17%	0%

(a) Ranking of Figures by Trained Subjects (6/18)

Figure 7.1.1 Figure 7.1.2 Figure 7.1.3 Figure 7.1.4

Rank	1 st	0%	83%	8%	8%
	2 nd	0%	17%	42%	42%
	3 rd	8%	0%	50%	42%
	4 th	92%	0%	0%	8%

(b) Ranking of Figures by Untrained Subjects (12/18)

Table 7.3: Responses provided by trained and untrained subjects.

The most obvious difference between the two tables is the positioning of the cluttered plot (Figure 7.1.2). Out of the subjects who stated that they had a degree of training, 50% placed it last; no untrained subjects felt this way, with 83% placing it first.

Within the trained subjects, Figure 7.1.4 had a strong bias to being the most preferred plot, which was actually a tiebreaker between 7.1.2, 7.1.3 and 7.1.4. No subjects placed this image below their second choice. This was not the case in the untrained set, where it was equally distributed through the positions. The minimal plot, Figure 7.1.1, was ranked above the cluttered plot within the trained subjects. This relationship is strongly inverted with the untrained subjects.

To gain an insight into why certain choices had been made, the comments accompanying the returned rankings needed to be studied. Several subjects from the untrained set chose the cluttered image as their favourite as it picked out features such as the shore line, frontal breaks of slope and other foreground information. This gives an indication that the question had been misunderstood and that the subjects were evaluating the plot as a finished sketch rather than the set of silhouette-related cues. Although negative comments were made about the clutter, some untrained subjects still placed Figure 7.1.2 first, perhaps for this reason.

One subject who placed the cluttered image first did so as there was felt to be “more feeling of depth”. This was presumably due to parts of terrain that would fit the description of another type of cue, being filled in by the inclusion of many minor, silhouette-related cues. Also the ability to depict macro features was noted as a positive point for 7.1.2. Again, the primary purpose of this research is to provide structuring cues, not to depict macro features. A commercial cartographer who placed the cluttered image first justified his choice by stating that he would “prefer as much detail as possible and then proactively adjust my level of filtering of data as I view the image”. This point suggests that the subject is experienced in the interactive filtering/generalisation offered by many digital cartographic products. Comments were also made regarding the need to show “main structures without overkill” and that Figure 7.1.2 which had “too many little short lines on the right hand side” (an area of flatish terrain (Figure 6.4, Chapter 6, Section 6.2, p. 91)) could prove problematic if many annotations were to be used.

A trained subject who placed Figure 7.1.4 in first place commented that it showed “a good balance between exaggeration and lack of detail”. The same person placed the cluttered sketch last as “detail was exaggerated” and the plot had “too much black on it”. The same ranking was chosen by another trained subject who noted that the cluttered plot, although complete, disrupts the eye with too much foreground information “drawing my eye away from the middleground and horizon”. The same subject noted that Figure 1.3, the figure with inappropriate biasing, lacked the balance provided by Figure 1.4.

Interestingly, if the whole set of sample subjects is considered (Table 7.4) then the cluttered plot is shown as the clear favourite, with the information based cut-offs coming a solid second. This illustrates how training and knowledge influence what is seen.

Figure 7.1.1 Figure 7.1.2 Figure 7.1.3 Figure 7.1.4

Rank	Figure 7.1.1	Figure 7.1.2	Figure 7.1.3	Figure 7.1.4
1 st	0%	67%	17%	17%
2 nd	0%	11%	39%	50%
3 rd	28%	5%	39%	28%
4 th	72%	17%	5%	5%

Table 7.4: Aggregation of trained and un-trained subjects rankings.

7.1.4 Exercise 2

This exercise aimed to gain an insight into how subjects would sketch the silhouette-related cues observed through studying the profile plot. Due to time restrictions, asking a subject to draw the cues for the full study area was clearly out of the question. To produce results of any worth, their attention was focused onto a more manageable area. Three locations were selected and enlarged and the subjects were prompted to choose which one they were prepared to tackle.

The three areas selected, Figure 7.2, were chosen on the grounds that they provided interesting situations to draw. All included many locations where occlusion was not picking out all of the silhouette-related cues (as noted in Chapter 4, Section 4.2.1, p. 59). The area shown in Figure 2(b) was chosen as a difficult situation to draw with the other two areas offering easier alternatives. Subjects were asked to add to and extend the occluding contours to complete the set of silhouette-related cues. They were instructed to only use cues relating to areas of terrain turning away from view and not to fill out the sketch with other form cues. As with the first exercise, the noting of comments relating to how the task was tackled was encouraged. (NB. Location A in Figure 7.2(c) is referred to later in this chapter)

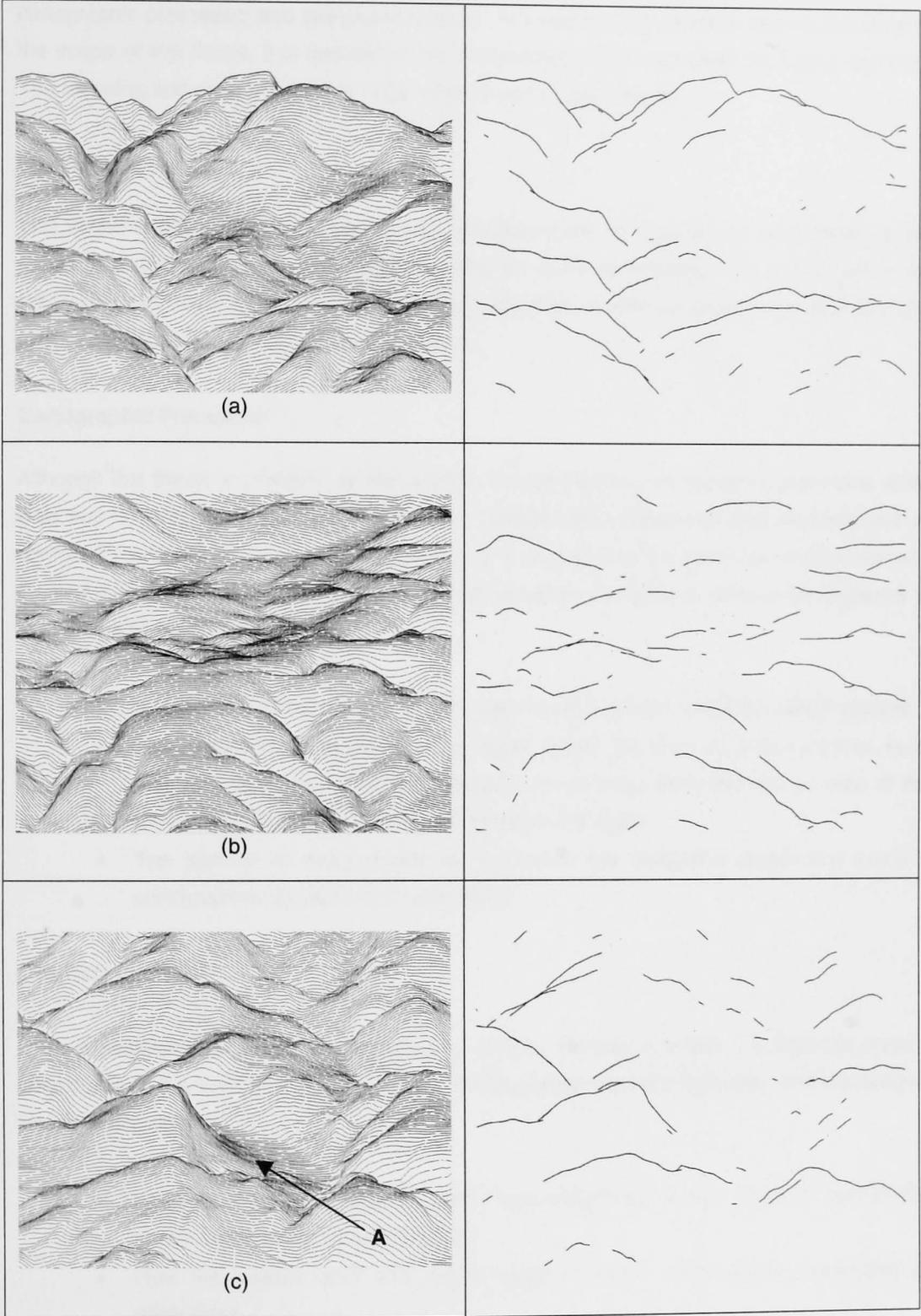


Figure 7.2: The test areas, showing the full-data plot (left) and occluding contours (right).

Three main themes were chosen to categorise the observations, namely: cue selection; cartographic processes; and cue representation. Although the last of these themes lies outside the scope of this thesis, it is included in the observations to extract ideas for future research. The following text details the points under observation in each theme.

Cue Selection

This theme is concerned with which silhouette-related cues the subjects felt were critical to the structure of the scene and which were deemed not to be contributing. The way in which the subjects filtered all of the observed occurrences into their chosen set allows a comparison with their preference of automatic filter in Exercise 1.

Cartographic Processes

Although this thesis is primarily concerned with cue abstraction, cartographic processes other than that of selection, such as generalisation, exaggeration/suppression and displacement all contribute to the final hand-sketched scene. If a comparison between the automated and manual is to be performed, the operations which underpin cartography need to be observed in the context of this exercise.

- Generalisation can be observed through how the subject forms the sketch strokes.
- Exaggeration/suppression can be noted where the form of a feature has been changed, or a small silhouette-related cue has been extended into an area of the terrain not physically matching the selection definition.
- The process of displacement contributes to the qualitative processing which a cartographer performs whilst sketching.

Cue Representation

Once a decision has been made to include a feature, the way in which it is depicted plays a critical part in the sketching process. The following points illustrate important representational issues to be observed.

- Whether a subject chose to apply visual weightings to the whole or part of the stroke to enforce a visual hierarchy.
- How the subject dealt with larger areas of terrain which were contributing to silhouettes.
- If strokes were over extended for effect.

7.1.4.1 Results

All subjects who returned the exercises attempted to complete the occluding contour framework, albeit some better than others. Although many expressed concern and hesitation regarding their ability to sketch, a good proportion of the returned exercises were interesting. Figure 7.3.1 - 7.3.12 shows a selection of the returned sketches. Unlike Exercise 1, no split has been made between the subjects with training and those without.

Only two subjects deviated from the cue constraints, one attempting to add concavities to the sketch, along the base of the main valley (7.3.12) and two adding stream and/or ridge lines to the silhouettes (7.3.1, 7.3.11); both being unsuccessful. Out of the three areas shown in Figure 7.2, (a) was the most popular, with 50% choosing it, closely followed by (c) at 44%, with the difficult area coming a distinct last with 6%. This last case is not included, as it did not contribute anything worth noting.

A factor to be taken into consideration when studying the sketch is that there is no way of determining if the subject had fully finished or just stopped. This is evident in 7.3.4, where it is hard to say if the subject feels that no more detail is necessary or if they simply decided not to continue with the exercise.

7.1.4.2 Observations

The returned sketches can be evaluated in two ways. Firstly, comparisons between the manual sketch and the profile plot, to investigate how the subjects have formed their results, and secondly, between the manual and automated, to evaluate the results presented in this thesis.

To analyse the second comparison, degrees of similarity and difference between the two results under observation need to be investigated. This analysis could be achieved through scanning the images and performing a bit-wise similarity check. However, this approach is not suited to the results due to their inherent 'sketch' nature and the subjects not tracing over the profile data. Of more benefit is to use tools such as the 'MapSheets Express' (ERDAS, Online) which allows different ways of switching between two images of the same scale to facilitate comparison. Techniques such as fading and swiping between the images under observation allow for overlay-style comparisons.

The three themes described in Section 7.1.4 provide the basis for the following interpretation. The text notes observations from the comparisons under their appropriate theme.

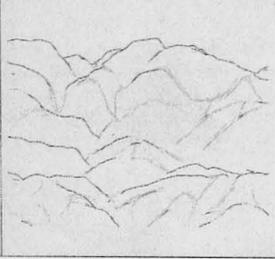
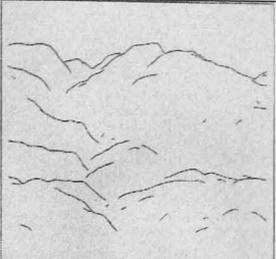
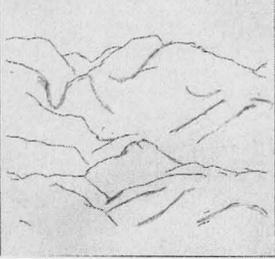
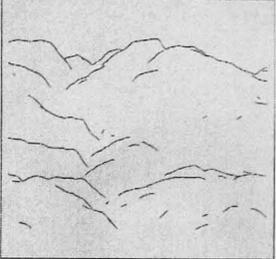
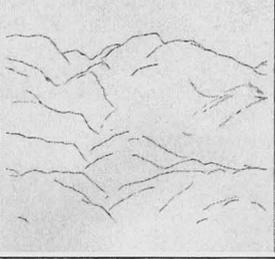
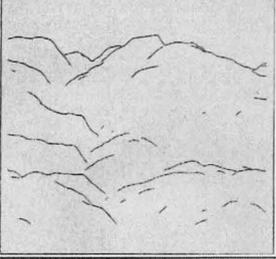
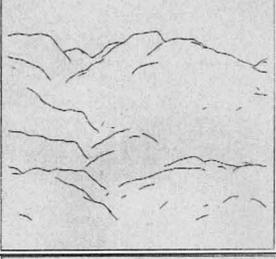
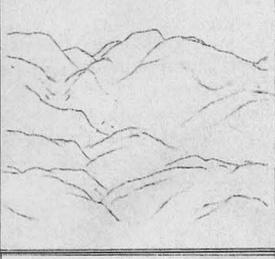
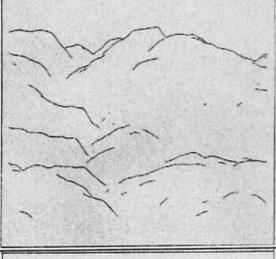
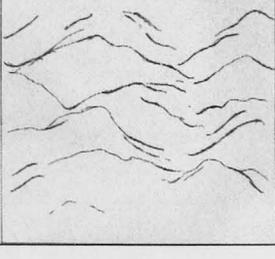
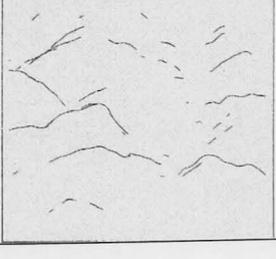
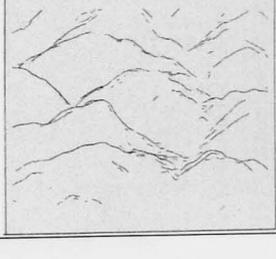
	Hand-Sketched Silhouettes	Set of Occluding Contours	Automatically Extracted Silhouettes
7.3.1			
7.3.2			
7.3.3			
7.3.4			
7.3.5			
7.3.6			

Figure 7.3: Results from Exercise 2 compared with thesis results.

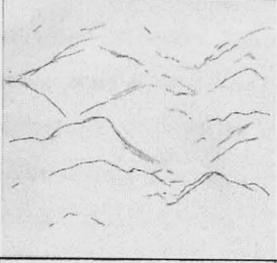
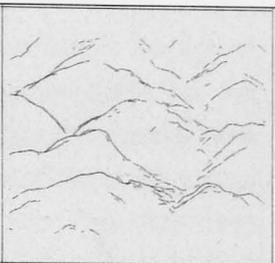
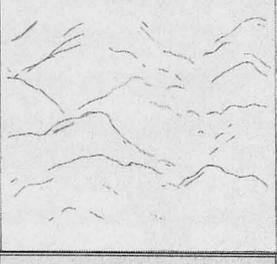
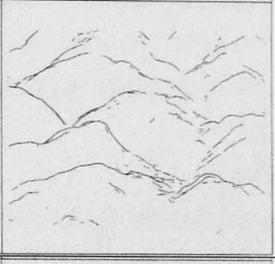
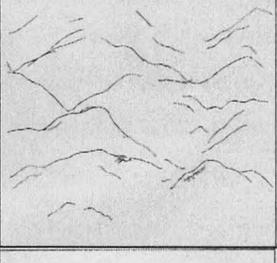
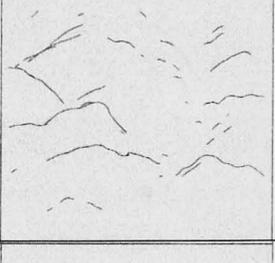
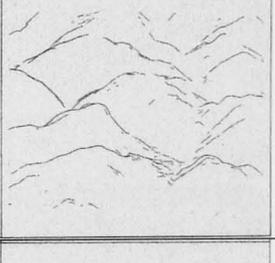
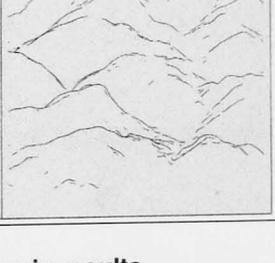
	Hand-Sketched Silhouettes	Set of Occluding Contours	Automatically Extracted Silhouettes
7.3.7			
7.3.8			
7.3.9			
7.3.10			
7.3.11			
7.3.12			

Figure 7.3 (cont.): Results from Exercise 2 compared with thesis results.

Cue Selection

One of the most clear selection differences between the manual and automatic is the lack of small unconnected lines in the hand-drawn sketches. However, it should be noted that the automated results have undergone no post-selection filtering. Interestingly the subjects who chose the cluttered image (Figure 7.1.2) in Exercise 1, sketched a succinct set of silhouettes which presented a much clearer picture than their preferred automatic filter. This shows that when subjects thought about what they wanted to represent, they produced a sketch that had selected only the features they felt were important. The only time small unconnected strokes were included in the manual results was when they seemed to run into larger features. This Gestalt grouping is noted by one of the subjects.

When gaps were observed in the occluding contours, which would not be there in a sketch, the joining performed across the break was, in most cases, very similar to the automated results. However, when a contour did not exist in the occluding set, its manual insertion was often slightly out of place. This can be attributed to placement error, as the profile plot was not being traced. The subjects have often retained some gentle features such as the cirque in the upper right of Figure 2(a).

Cartographic Processes

Generalisation

The main point that can be observed regarding generalisation is that although the manually sketched lines occur in very similar locations to the automated results, the character of them is very different. The hand-drawn lines have an altogether smoother, more natural look. When sketching, the path of a stroke is determined through the mind's interpolation across the extent of a feature – very different to following the DEMs discrete grid. This process is different to selection as it is operating after the feature has been identified, applying a generalisation across the stroke. In this case, the smoothing of the strokes can be likened to a post-processing modification of what has been identified.

Exaggeration / Suppression

In the returned results, exaggeration was mainly discernible in the form of over-extension of strokes, which is discussed under cue representation.

The use of suppression is evident in Figure 7.3.6, where the perception of height has been dampened. Suppression of minor silhouette-related cues has occurred in most cases to enable the clarity of the main framework to come through.

Displacement

A minor occlusion given the same visual weight as major occlusion located close by has been crossed out in Figure 7.3.9 (lower right). This dislike for a contour in close proximity to another contour has prompted the subject to displace the offending line and amalgamate it. This, in the subject's eyes, creates a clearer impression of the terrain.

Cue Representation

Most subjects did not experiment with alternative cue symbologies, sticking to strokes of equal weight. One notable difference was in Figure 7.3.5, where a tapering has been applied to the strokes. The subject, a proficient cartographic artist, notes that in the profile plot the eye sees the silhouette-related cues fade into the rest of the terrain and not just stop. The effect created through the use of stylistic strokes could be easily achieved in the automated system. Only one subject, Figure 7.3.4, attempted to produce a shaded representation. This sketch was clearly submitted unfinished. Of most interest out of the points noted in the representation theme was how subjects treated large patches of terrain which were contributing to the silhouettes. The most significant example of this situation occurs in Figure 7.2(c). Here, a sharp, but gradually flattening, right-facing slope enters the main valley (Figure 7.2(c), Location A). Occlusion only captures the sharp part of this slope, causing the loss of an important form cue. Due to the nature of this feature one subject used a shaded in-fill between its start, nearest to the viewer, and end, furthest from the viewer (Figure 7.3.7) whereas some preferred to indicate the start and end with separate strokes (Figure 7.3.6). The automated results retain only the end - although the start is recorded internally. Several hand-drawn sketches displayed the approach adopted in this thesis and just depicted the end of the feature (furthest from view) with a single stroke, Figures 7.3.8, 7.3.9, 7.3.11 and 7.3.12.

Over extension of the strokes can be seen in Figure 7.3.6. It appears that in some cases the added length has been used to bed down the sketch lines. In the automated system, this would be provided by other cues such as concavities. In some cases, the over-extension can lead to a misinterpretation. For example, in Figures 7.3.2 and 7.3.9, strokes have been extended across valleys, giving the impression that there is a slope tilting away from view across the base of a valley running towards the viewer. The following of lines from the full profile plot provided has probably caused this. Other situations where this occurs can be seen in Figures 7.3.3 and 7.3.5. Here, the cirque is represented as if the terrain is dropping off within it - this maybe so if the cirque contained a tarn with no outlet, i.e. had a deep scour. However, if a map of the study area (Ordnance Survey, Vale of Glamorgan & Rhondda area, Landranger 170, SS8894) is investigated, it can be seen that there is an eroded outlet indicating that there should be a break in the stroke describing the feature. The automated system provides this representation.

7.2 Discussion

This section links the observations from the two experiments with the processing stages listed in Table 7.1 and offers thesis specific interpretations. This is followed by a summary of deficiency issues provided by the subjects.

7.2.1 The Filtered Set

The main specification of the filtered set was that it had to remove the errors of commission in the candidate set whilst retaining most of the required features. The filter designed to achieve this is described in detail in Chapter 5. The images presented in Exercise 1 enabled the collection of feedback regarding different filter designs; and the manual sketches in Exercise 2 allowed for an investigation into the cartographer's selection process.

Those subjects who had training in cartographic sketching were very positive towards the thesis filter and negative towards the cluttered plot (Table 7.2(a)). One trained subject placed the thesis filter first as it "accurately represented the profile detail" and was "easy to re-construct visually", the cluttered image was placed last as it had "too much foreground detail". Key assumptions made in the design of the filter (Chapter 5) were mirrored in some subject's comments stating, for example, that it was important not to include "too much detail in flat areas". Interestingly, those subjects who chose the cluttered plot in Exercise 1 sketched a clear and concise set of lines in Exercise 2.

The rankings provided by the full sample set (trained and untrained) showed a different trend and placed the information based filter joint second (Table 7.3). The filter that produced the cluttered image, assumed to be the worst, was the overall favourite. However, the majority of those who chose this were found to be evaluating the figure on the wrong criteria. This was confirmed through supplied comments and by the way in which they manually sketched the cues in Exercise 2 with far less clutter. Comments noted as deficiencies such as "valleys not coming through clearly" and "break of slope in front of mountains not picked out" all suggest that subjects were evaluating the silhouettes as a finished sketch despite the clear instructions.

The problem of selection is not an easy one. A subject familiar with the area noted that "Where the 'dissected plateau' exists, selecting particular contours for inclusion or exclusion is more awkward." However, the results from Exercise 2, especially from the trained set, give credence to the information-based filter that presented a good approximation of the silhouette-related cues that a cartographer would select. The filtered set retains features such as the cirque in the upper section of Figure 7.2(a) and also agrees with the cartographer's principles of omission. The main deficiency is that the filtered set still retains some errors of commission, such as small, insignificant lines. A small number of minor features that the cartographers omitted are

still present within the automated results. This issue is inherent within the nature of the local processing approach adopted.

7.2.2 The Thinned Matrix

As presumed, a great majority (all but one) of the subjects used strokes rather than shading when sketching the silhouettes in Exercise 2. This illustrates the need to thin the areas retained within the filtered set, a process that aids the chaining of the cells into strokes.

The thinning rules that the cartographers applied when sketching were close to those applied in the automated system. For example, the marking out of terrain turning away from view which was leading up to an occlusion was not performed. The main exception to the similarities was the case of the large patch of terrain noted in Figure 7.2(c), which had several different representations in the manual results. As stated previously, several subjects did adopt the rules used in the automated approach and marked only the end of the patch of terrain. Alternative representations included shaded in-fill or delineation of the start and end of the feature. Clearly, there needs to be an element of case dependency in the thinning rules, perhaps offering a user several alternatives for the representation of a particular cue.

7.2.3 The Chained Strokes

The results of Exercise 2 illustrate how the cartographers, using visual connection and amalgamation, have performed much more sophisticated stroke creation processes than those offered by the automated system as it stands. However, the automated chaining has been able to provide a relatively successful, stroke-based description of features, often in very similar locations to the hand-sketched results.

7.2.4 The Rendered Strokes

The strokes rendered by the system differed in three ways to those drawn by the cartographers. Firstly, the path of the hand-drawn stroke is generalised, providing more aesthetically pleasing results. One subject noted, as a deficiency of the system, that the results were like a technical drawing and that they lacked "gestural quality". This could be due the lack of stroke generalisation. It should be noted here, that this generalisation is occurring as a post selection process. Generalising or smoothing the terrain model prior to selection can often distort the character of the land and remove important features. Secondly, subjects indicated a preference for tapering the ends of strokes, as stated previously, this could be easily applied in the automated system through the use of stylistic strokes. Finally, the process of over-extension of the strokes was also common.

These differences between the manual and automated sketches are beyond the scope of this thesis, which is concerned primarily with what and where to draw, and not so much with the stylistic issues. However, the hand-drawn results do give many pointers to future work.

7.2.5 Deficiency Issues

After the exercises were completed, the subjects were asked to comment on problems with the automated system.

The major deficiency that the cartographers expressed was the inclusion of too many short unconnected lines. Simply thresholding lines on their size does offer a visually pleasing plot (see Figure 5.14, p. 80) However, as pointed out by one subject, small lines are often grouped into much larger features in the mind's perceptual system. The omission of these small but visually connected lines decreases the structuring effect of the cues. This problem was also highlighted in the previous chapter (Figures 6.4 and 6.5, p. 91). The ability to distinguish between isolated, small lines that are perceived as clutter, and small lines that visually connect, is an area that clearly needs more work. One cartographer noted the difficulty the system had in describing the back-facing ridge, running across Figure 7.2(b). As stated previously, this was a difficult area, with only one subject attempting to draw it. A comment noting that the plot had "too little depth of field", could possibly be related to the fact that no perspective or depth-cueing, based on visually weighted strokes, had been applied. Equally, this problem could be due to the omission of concavities and frontal breaks of slope.

7.3 Summary

From the results presented, especially those from the cartographers trained in sketching, the assumptions made in Chapter 5 appear to be appropriate. The selected biasing of the directional derivatives was noted and agreed with, as was the need to select carefully from features located in flat areas. The thinning rules were agreed with in part. However, pointers to more intelligent approaches, which still remain research challenges, were made.

The exercise suggested several stylistic and post-processing issues but the main point to be noted was the system's inability to group cues. This perceptual grouping would allow small, visually connected, but spatially disjoint cues to be structured into a larger perceived feature. This would allow the removal of small insignificant lines thereby clarifying the main structures of the terrain.

This research was well received by a profession that is increasingly aware that they play an essential role in the development of digital cartographic products. The following chapter illustrates how the silhouettes extracted in Chapter 5 can be used to enhance and clarify existing terrain visualizations.

CHAPTER 8

Some Applications of Formulated Silhouettes

This chapter presents two applications of the extracted silhouette-related cues. The first uses the f-set and the extracted contours to enhance and simplify P-stroke sketches, an existing abstract, terrain rendering technique, described briefly in Section 2.1.1, (p. 10). A copy of propriety C source code for P-stroke sketching (© M Visvalingam and K Dowson, 1994) was made available for this restricted purpose. The second application uses the extracted contours to clarify projected, remote sensed images without altering the tone of the image in the way of conventional computer graphics. These alternative styles of terrain visualization have been deferred until this stage as they are not of concern to the extraction of Formulated Silhouettes.

8.1 Enhancement of P-stroke Sketches

The crux of the P-stroke sketching technique (Dowson 1994; and Visvalingam and Dowson 1998) is the global identification and case-dependent depiction of four differing classes of form cue. These cues represent significant breaks of slope (convex and concave) either parallel or orthogonal to the line-of-sight. Although their identification is object-based, they are selected and rendered in a view-dependent manner; using different selection tolerances and rendering attributes for each of the four classes of cue. P-strokes (profile strokes) are created by extending the selected locations along orthogonal cross-sections of the DEM.

The process of identification takes place only once in the Study Area Object (refer to Chapter 6 Section 6.1 for system overview) and consists of scoring the cells in the DEM according to their perceptual significance. This is achieved by passing Visvalingam's line generalisation algorithm (reported in Visvalingam and Whyatt (1993)) over each row and column of the model. The view-dependent selection occurs in the Processed DEM object where cells are identified as contributing to a P-stroke if their 'score' is above a user set tolerance level, with each class of P-stroke having a separate level. The cell is then used to generate a P-stroke by applying various extension rules. This stroke is then copied to the Processed Buffer. Chaining into vector strokes is simple as the extended lines are orthogonal to the line-of-sight and do not cross over profiles.

The main deficiency with the P-stroke sketch is that, although it uses different global tolerances for various form cues, it does not treat silhouette-related cues differently to any other surface convexity, parallel to the line of sight. This fact means that there is no special dispensation for view-dependent contours; these are treated in the same way as object-based cues. This poses a problem in that to achieve a relatively closed description of the silhouette-related cues many other convexities parallel to the line of sight need to be included. This clutter proves most

problematic when rendering small-scale plots such as the case studies presented in the previous section. In addition, as the viewing elevation is raised, the lack of connectivity in the sketch renders it difficult to interpret. Figure 8.1 presents a P-stroke sketch of the study area used in Chapter 5. The tolerances in this figure have been purposefully kept low to attempt to depict the silhouette-related cues in a closed manner, the result is, as can be seen, far too cluttered and there are still breaks in view-dependent cues. Figure 8.2 shows a more appropriate tolerance selection for this scale of sketch; however, the perception of the silhouette-related cues has been greatly reduced. Table 8.1 details the two tolerance sets used in the production of these figures and the number of cells used by each class of cue.

Simply overlaying the extracted silhouette-related contours over the sparse P-stroke sketch (Figure 8.2) would improve the form perception. However, as the extracted contours are replacing a subset of the parallel convexities, some removal needs to be performed to prevent excessive strokes describing the same form cue. Two simple rules are used to achieve this, namely:

- Do not seed a P-stroke if it starts in a cell belonging to the f-set
- Do not extend a P-stroke seeded outside the f-set into the f-set

Through applying these rules, a reduction in the amount of data needed to describe a view of a study area can be achieved and the rendered sketch simplified. Figure 8.3 and 8.4 show visualizations of the Processed Buffer with and without the application of the stroke removal rules respectively, convexities are shown in black and concavities in green. The tolerances used are the same as for the sparse sketch in Figure 8.2. Note that hidden area removal has already been performed on this buffer and is depicted through grey shaded zones, with the red zones in Figure 8.4 indicating the location of cells belonging to the f-set. Table 8.2 presents the cell count difference achieved through applying the removal rules and Figure 8.5 combines the sparse sketch shown in Figure 8.2 with the extracted Factual and Formulated Silhouettes.

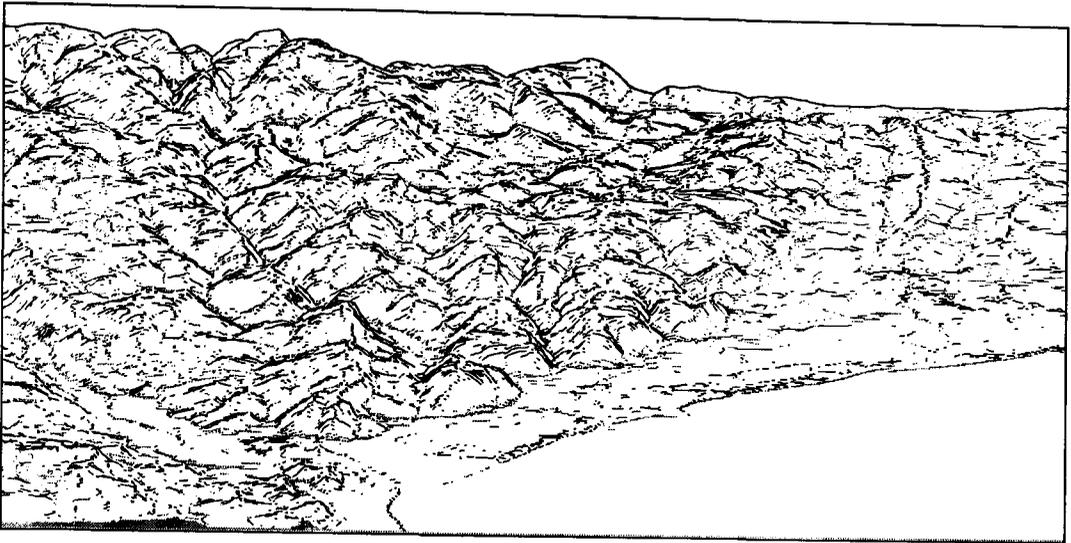


Figure 8.1: Dense P-stroke sketch.

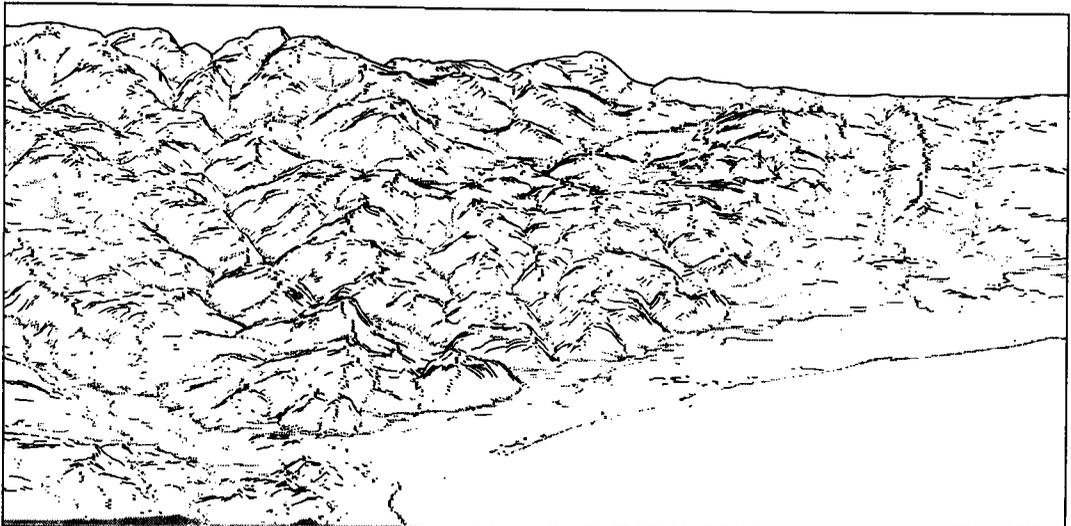


Figure 8.2: Sparse P-stroke sketch.

Class of Stroke	Figure 8.1		Figure 8.2	
	Tolerance	Cell Count	Tolerance	Cell Count
Convex Column	5,000	14279	15,000	9054
Concave Column	20,000	5784	60,000	3485
Convex Row	10,000	3082	30,000	1922
Concave Row	5,000	6561	15,000	4668

Table 8.1: Tolerances and cell counts for P-stroke sketches.

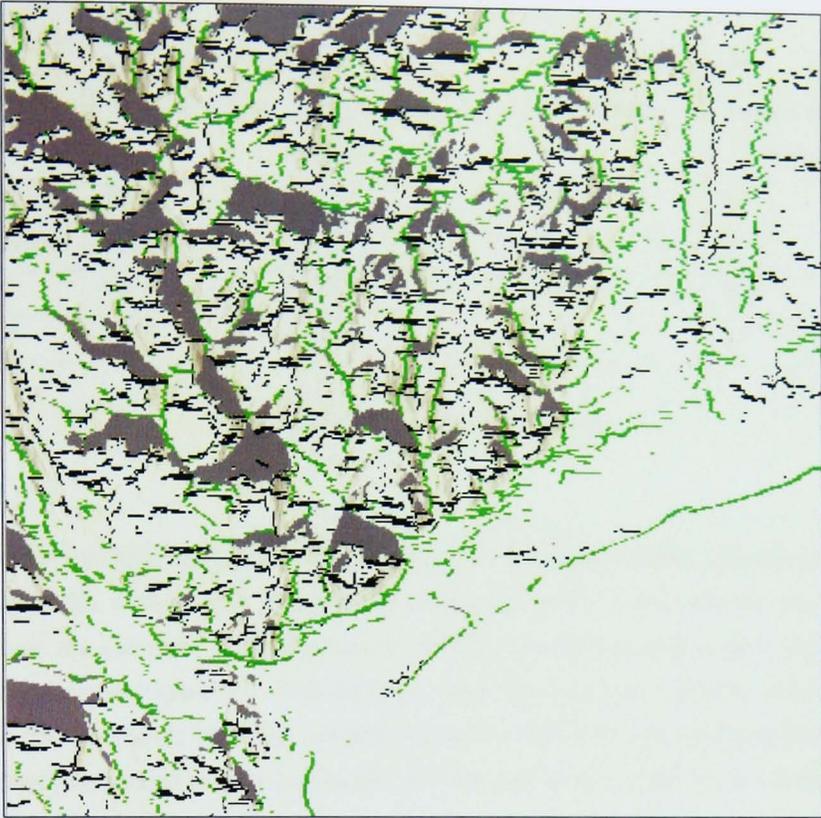


Figure 8.3: Visualization of Processed Buffer of Figure 8.2.

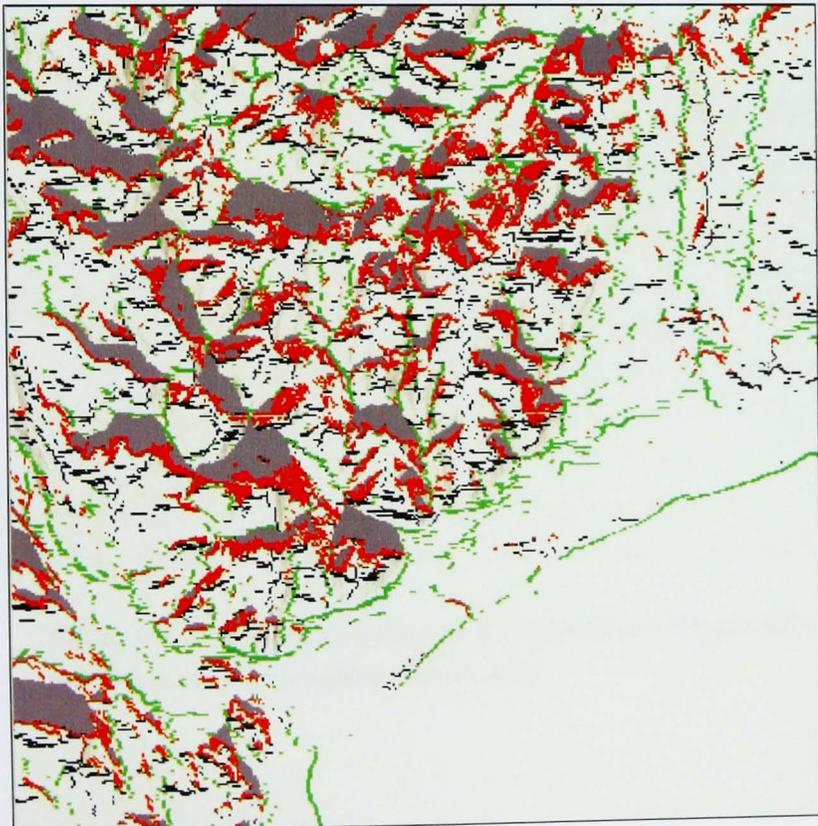


Figure 8.4: Visualization of Processed Buffer of Figure 8.2 with addition of f-set.

Class of Stroke	Figure 8.3		Figure 8.4	
	Cell Count	Percentage of DEM cells	Cell Count	Percentage of DEM cells
Convex Column	9054	5.6	6046	3.7
Concave Column	3485	2.1	3225	2.0
Convex Row	1922	1.2	1514	0.9
Concave Row	4668	2.9	4207	2.6

Table 8.2: Cell removal statistics.

The total number of DEM cells used in Figure 8.3 (the Processed Buffer used to create Figure 8.2) make up 11.8% of the DEM. The application of the removal rules reduces this by 2.6% to 9.2%. However, the inclusion of the Factual and Formulated Silhouettes adds a further 2.9% to the total cell count for Figure 8.4. This addition takes the cell count slightly over the original count for the sparse sketch. However, Figure 8.5 shows that although a similar amount of data has been added, compared to what has been removed, the sketch is far more successful.

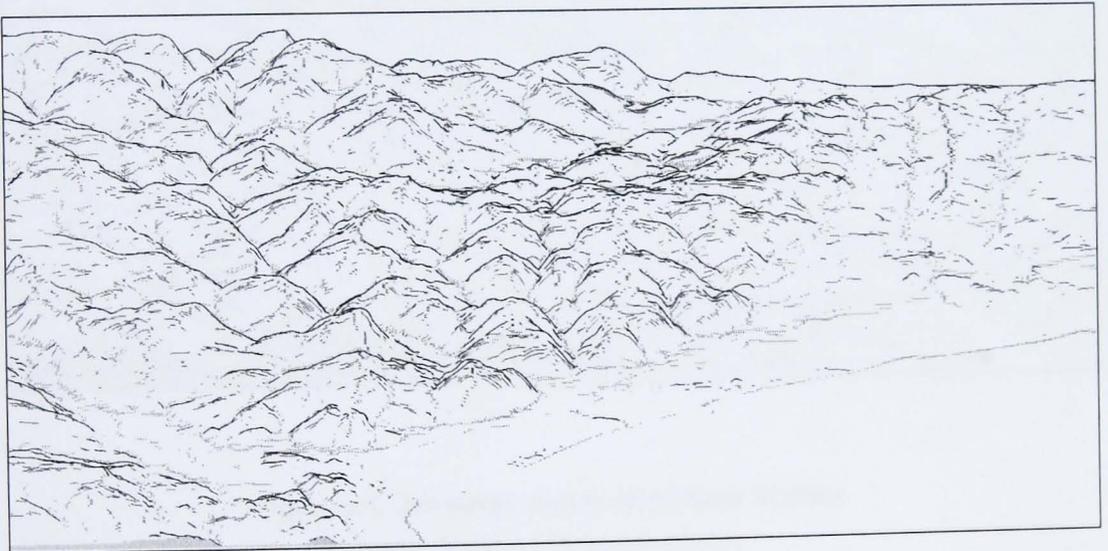


Figure 8.5: Combination of sparse P-stroke sketch (Figure 8.3) with Factual and Formulated Silhouettes.

The addition of the silhouette-related cues greatly enhances the sparse P-stroke sketch, providing a bonding framework of connected lines. Equally, the suggestive description of the frontal breaks of slope and concavities, provided by the P-strokes, place the Factual and Formulated Silhouettes into a visual context. The result is a relatively minimal generalisation (12.1%) of the original DEM, which retains important features at model resolution. Dowson (1994) stated that P-stroke sketches could be enhanced with depth-cueing by only depicting major features towards the rear of the plot. However, without explicit identification and depiction of silhouettes, both Factual and Formulated, the visual structure would be lost. Aesthetic refinements could also be applied to the P-strokes such as varying the line weight according to local slope magnitude or other attributes. The visual-framework created by the silhouettes (both Factual and Formulated) provides a good starting point for future enhancements of the P-stroke sketching technique. Figure 8.6 - 8.8 present three of the case studies from Chapter 6 (Figure 6.7, 6.8, 6.9) sketched using the combination rules outlined in this section.

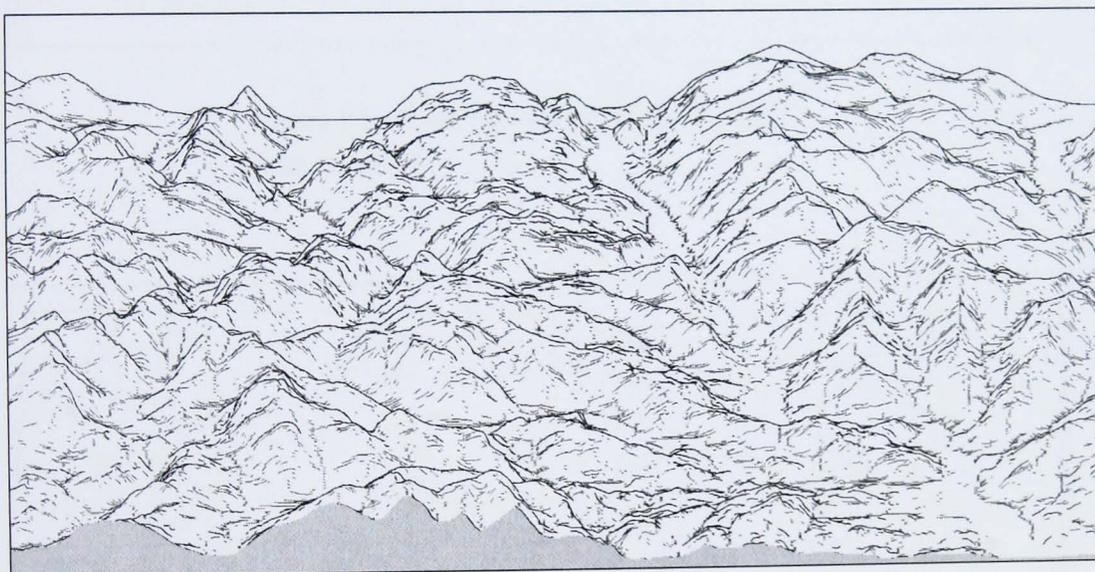


Figure 8.6: Combined sketch of the Lake District.

Data: © Crown Copyright Ordnance Survey

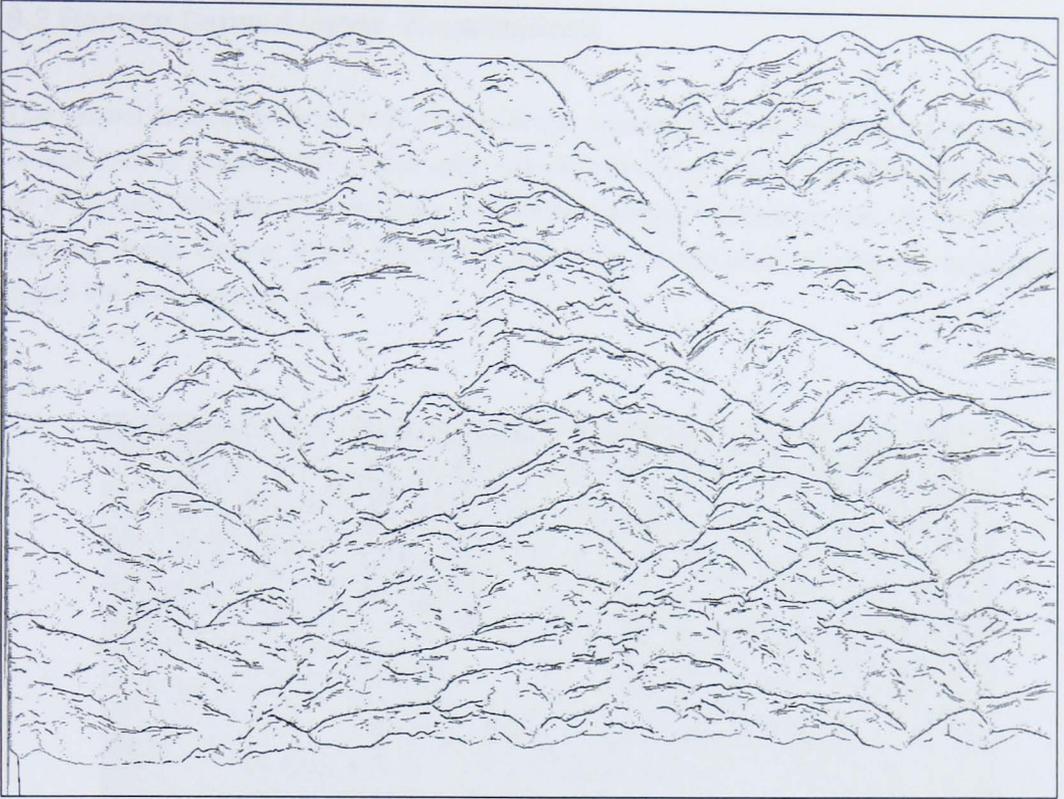


Figure 8.7: Combined sketch of Pittsburgh.

Data: © USGS

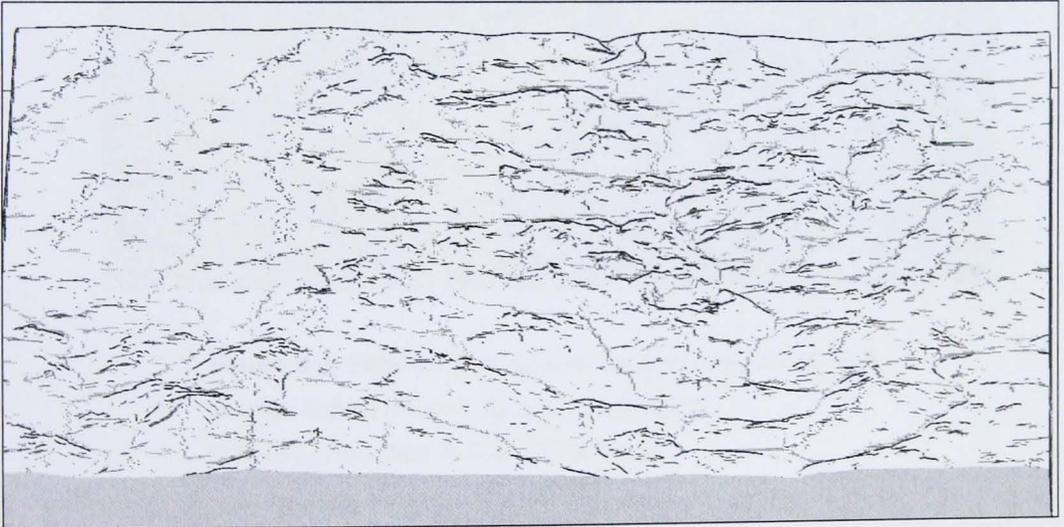


Figure 8.8: Combined sketch of Gettysburg.

Data: © USGS

8.2 Remote Sensed Image Visualizations

The second application case study uses a simple texturing to render thematic information from remote sensed images. The source data was extracted from a 30m resolution bitmap created by a Landsat Thematic Mapper from a CD-ROM entitled "Window on the UK 2000" (British National Space Centre, 2000). Figure 8.9 shows the bitmap after cropping and re-scaling to match the primary study area.

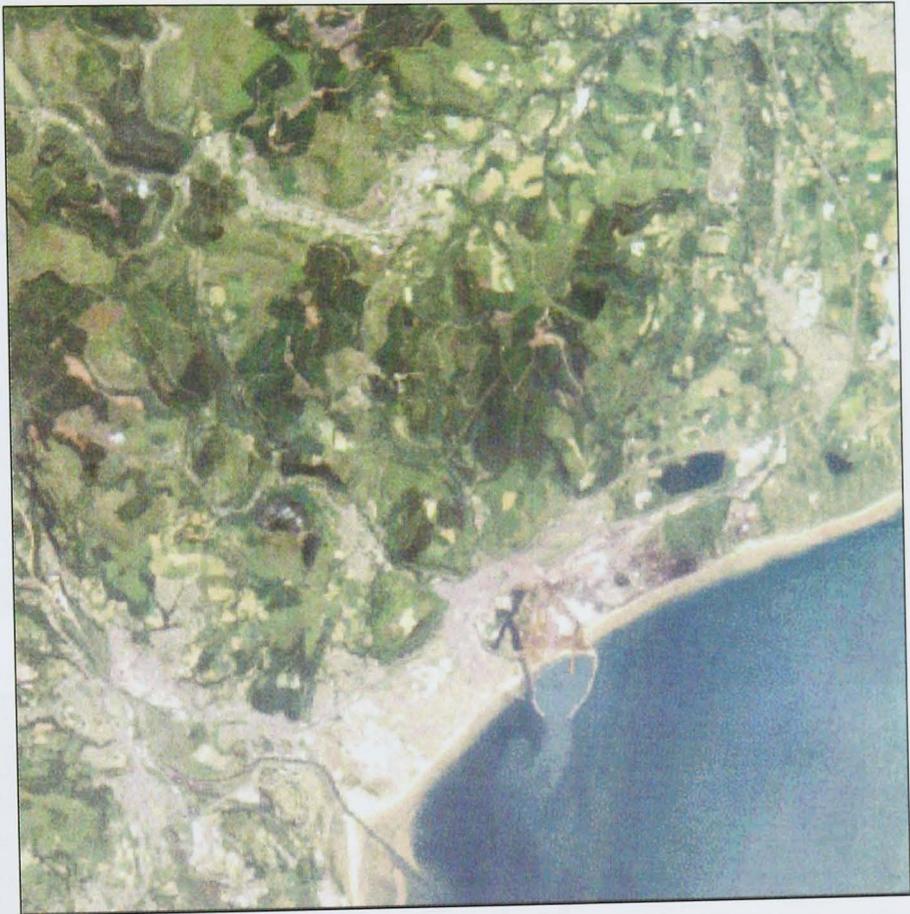
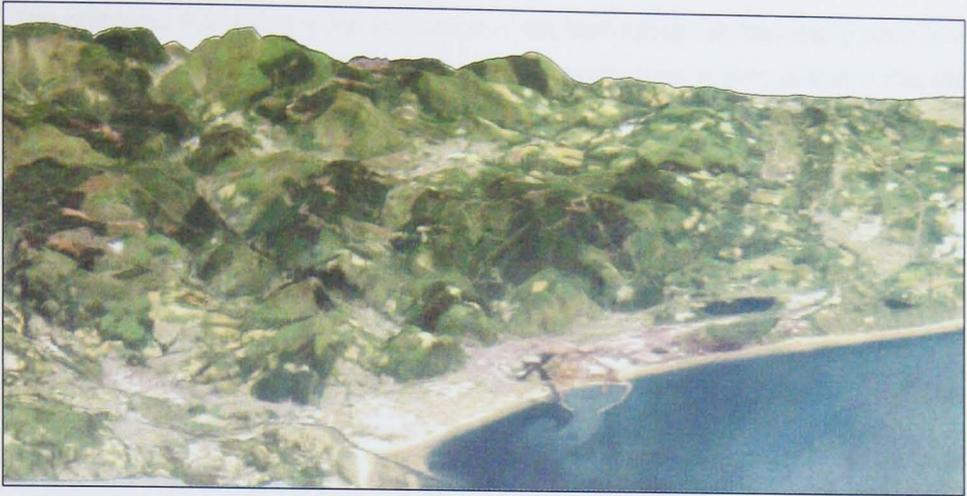


Figure 8.9: Satellite picture covering primary study area.

Source: British National Space Centre, 2000

© NRSC (Raw data © ESA / Eurimage)

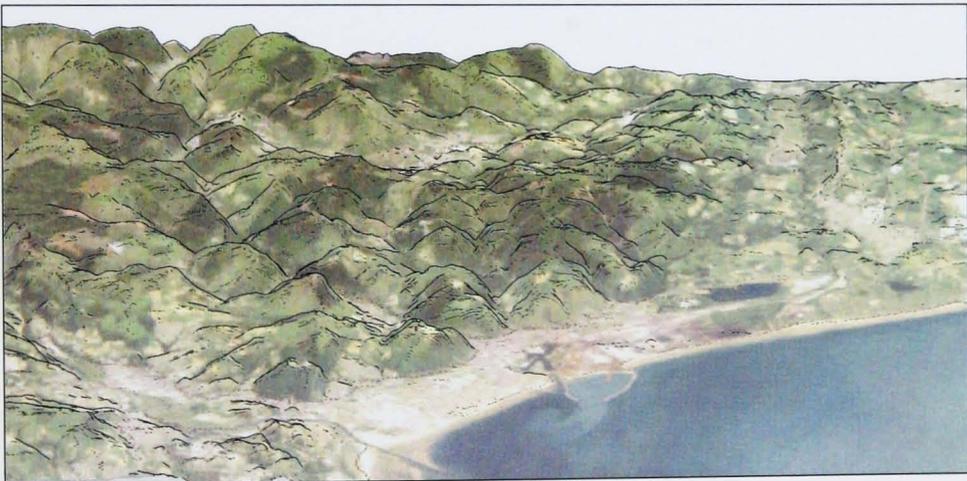
After loading into the Study Area object, the bitmap is attached as a texture to the DEM in the same fashion as the slope map. Figure 8.10 shows the projected texture (a) on its own, (b) with the silhouette-related cues overlaid and (c) combined with Figure 8.5. When visualizing remote sensed images in traditional computer graphics, the usual approach is to illuminate the projected texture, simply draping the bitmap over an elevation model provides poor form



(a) Remote Sensed Image



(b) Inclusion of Factual and Formulated Silhouettes



(c) Remote Sensed Image overlaid with Figure 6.15

Figure 8.10: Enhancement of projected remote sensed image with sketch cues.

Source: British National Space Centre, 2000

© NRSC (Raw data © ESA / Eurimage)

cues. The problems that occur when the scene is not illuminated can be clearly seen in Figure 8.10(a). The enhancement offered by overlaying the sketch cues is very useful in this situation as it does not alter the tone of the projected texture in the way that shading would yet adds very clear form information. This is important where the texture colour conveys thematic meaning such as land-use. The sketch cues would also be useful to enhance a projected geological map, indicating underlying rock type. This approach would be similar to the use of colour washes on topographic sketches accompanying early geological texts (Murchison 1839).

8.3 Summary

This chapter has investigated how this research can be applied to existing terrain visualization techniques. The intelligent integration with the P-stroke sketching technique demonstrated both the benefits of working at the model-level, allowing the two techniques to interact with each other, and the low-data/high-information content provided by the silhouette-related cues. Equally, in the remote sensed image example, the inclusion of sparse, information-rich line-work provided strong form cues without the need to illuminate the thematic texture.

The following chapter discusses the ideas presented in this thesis with respect to the existing background in automatic silhouette extraction. The specific contributions of this thesis are presented, along with future work and conclusions.

CHAPTER 9

Discussion, Future Work and Conclusion

This thesis adds to a growing body of research indicating how the field of computer graphics is rapidly breaking free from the confines of photorealism (see Chapters 2 and 3) and now offers a broad spectrum of graphical communication possibilities. Building on the work into automatic terrain sketching, started by the Cartographic Information Systems Research Group (CISRG) in 1994 (Dowson, 1994) and through an awareness of ideas from perceptual psychology and cartography, this thesis adds important concepts to this stimulating, multidisciplinary strand of research.

9.1 The Research in context

The aim set out in the introduction to this project, to extract a vector description of the silhouette-related cues for a view of a DEM, has been achieved. This was shown in the previous two chapters. This section discusses the original contributions with respect to the background ideas and techniques that have been presented in this thesis.

Chapter 2 highlighted two classes of form cue used within cartographic sketches of terrain, namely object-based and view-dependent cues. This thesis is primarily concerned with the latter. The main purpose of view-dependent contours is to structure the scene through the delineation of silhouette-related cues, the perceptual importance of which was also discussed in Chapter 2. This thesis, however, has demonstrated the problems associated with equating silhouettes to the occluding contour (Stevens 1981; Marr 1982; Koenderink 1984; Watt 1992). Furthermore, it has been shown that when a cartographer sketches a scene, actual occlusions form only a subset of the silhouette contours used to structure the sketch. This statement is especially true when sketching from a high angle to create a 'bird's eye' style sketch (see Figure 6.8 (Pittsburgh), p. 96). The proposed method recovers the remainder of the set of silhouette-related cues through novel information-based filtering and thinning of model-level, back-facing slopes.

The results extend the set of occluding contours (Factual Silhouettes) to include situations which are perceived to be causing an occlusion, and would be sketched in a similar manner; these cues were termed Formulated Silhouettes.

During the inception of this project (1997), it was known that occlusion alone did not provide a successful depiction of the silhouette-related cues (Visvalingam and Whelan 1998). It was also known that image-based approaches did offer techniques for recovering additional silhouette-related cues (Pearson and Robinson 1985; Saito and Takahashi 1990). However, as the

requirement of this project was to extract scaleable vector-based descriptions, directly from the model, it was decided not to adopt the image-based approach.

At the time of starting the project, one model-based piece of work (Markosian et al. 1997) was using additional silhouette-related cues to enhance line sketches (Section 3.2.2, p. 38). However, the set of silhouettes was still equated to the properties of occlusion i.e. the edge between a front-facing and back-facing polygon. The additional cues employed did not resemble silhouettes as such, but are more comparable with the c-set, identified in Chapter 5 (Figure 5.3, p. 68). This method would clearly produce too many lines when sketching terrain and not resemble the elegant contours of the traditional sketches presented in Chapter 2 (Figure 2.13, p. 22).

During the course of this project other researchers perusing model-based approaches, have supplemented occlusion with additional cues in a similar fashion to Markosian et al. (1997). Firstly, Bremer and Hughes (1998) drew several copies of an identified silhouette, in parallel and in front of it, giving the effect of shading leading up-to the occluding contour. Surface curvature parallel to the line of sight was indicated in a similar fashion to Markosian et al. (1997). Where parallel silhouettes occur in the approach described in this thesis, they are removed by the thinning rules, which were externally verified by cartographic designers in Chapter 7 (Section 7.2.2, p. 119). Bremer and Hughes (1998) also note problems when their approach renders cusps (Figure 3.11, p. 41). The results shown in the previous three chapters do not suffer from this issue and bare more resemblance to the hand-drawn cusp presented in Bremer and Hughes (1998, p. 159); also shown in Chapter 3, Figure 3.11 (Section 3.3.3, p. 41). Following this work, Girshick et al. (2000) used the principle direction of surface curvature to supplement the extremal (figure/ground) silhouette of a surface, but as shown in Chapter 3, Figure 3.8 (Section 3.3.1, p. 38), this was error-prone. In addition, this did not seek to extend the perceived silhouettes that are omitted from the set of occluding contours. Finally and most recently, Hertzmann and Zorin (2000) proposed a silhouette extraction method which supplemented occluding contours with extensive cross-hatching. Again, although occlusion was supplemented with other line-work, they were not concerned with extending the set of occluding contours.

In summary, although several researchers have noted that occlusion is not enough, this deficiency has not been addressed from the perspective of a person sketching. The incomplete set of silhouettes provided by occlusion is not supplemented with a similar style of contour, but with the addition of surface curvature information often without thought for what it is trying to depict. This can result in the inclusion of other surface features within the silhouette-related cues.

This thesis has treated the omissions as if they were occluding, and depicted them in an appropriate manner. The Formulated Silhouettes are view-dependent structuring cues, like Factual Silhouettes. They do not require the depiction of other cues.

9.2 Specific Contributions

This multidisciplinary project, which has primarily been a study into information extraction and communication, has provided both conceptual and application-based contributions to several research fields.

Primarily, the most important conceptual addition has been to the area of Perceptual Psychology. It has been shown that when considering the perceived silhouettes present in a scene, it is incorrect to define them as being wholly based on occlusion (Stevens 1981; Marr 1982; Koenderink 1984; Watt 1992). The application-based contribution of this thesis is an information-based filter, designed in accordance with the geographical significance of slopes (Macgregor 1957). This filter selects, from an oriented model, those additional cues that extend the incomplete set of occluding contours, as a cartographer will tend to (verified in Chapter 7). The following bulleted list summarises the approach adopted:

- Determine the model back-facing slopes that will become visible after deformation (c-set).
- Select from the c-set, those locations that bear geographical significance (Macgregor 1957) on the slope magnitudes, parallel and orthogonal to the line-of-sight (f-set).
- Thin the selected locations and chain into vector strokes (t-set).
- Perform optional post selection generalisation based upon primitive level attributes (g-set).

The results presented in this thesis are also of interest to the non-photorealistic rendering community as they add a high-information content to sparse visualizations without adding high-data overheads. This was demonstrated through intelligent integration with an existing abstract, terrain visualization technique, namely the P-stroke sketch (Section 8.1, p. 121). Also of interest to the computer graphics and visualization communities is the ability to substantially enhance other styles of visualization such as slope maps (Section 6.2, p. 86) and remote sensed image drapes (Section 8.2, p. 128).

However, the main drive behind this research was the cartographic aspect of visual abstraction. This thesis has demonstrated that the combination of Factual and Formulated Silhouettes can be used to emphasise important terrain features whilst removing visually redundant information. These sketch-style visualizations provide excellent base-maps either for manual 'touching-up' by cartographic artists or overlaying with additional thematic information.

9.3 Assessing the approach

Although the implemented approach (described in Section 6.1, p. 82) was primarily concerned with proof of concept, the resulting system was quick enough (less than 2 seconds) to allow for non-real-time interaction when sketching a large (400 by 400) DEM. This section differs from the implementation evaluation in Chapter 6 (Section 6.1) and discusses the conceptual approaches adopted.

The reasons for choosing the model-based over the image-based approach have been addressed throughout this thesis. These were covered in detail in the summary of Chapter 3. The P-stroke application study (Section 8.1, p. 121) also provided substantial evidence backing up this choice. However, other aspects of the adopted approach which have not been addressed are the choice of projection system, why the system is in two-and-a-half dimensions and why was terrain the only test data.

The choice of the oblique, parallel projection system was briefly discussed in Chapter 4 (Section 4.1.2.1, p. 49) where its cartographic validity was noted. Also, attention was drawn to commentators on visual perception and art who have questioned the need for linear perspective. In addition to providing a map-like output, which maintains correct spatial dimensions across the sketch, the use of a simple projection permitted the problem to be studied and evaluated in depth, without confusing the situation with multiple viewing parameters. Equally, the choice to operate in two-and-a-half dimensions was preferable since Factual and Formulated Silhouettes are primarily projected two-dimensional entities. In his interesting and early paper proposing '*A new direction for computer graphics*', Parslow (1987) noted that "3-D makes life difficult" and that "even top professionals have produced faulty algorithms based on a false 3-D view." (Parslow 1987, p. 25). Moving into the three-dimensional domain is considered more of an application of the concepts presented in this thesis.

With the concepts now established, interesting future work could investigate the projections demonstrated in Macaire (1998) and Wainwright (1992) to enhance the communicative possibilities of the sketch.

Although the title of this thesis corresponds to the conceptual issues rather than application, the main example of this concept has been concerned with sketching the silhouette-related cues for a view of terrain. This choice of input relates primarily to the existing research into terrain sketching (P-stroke technique) within the Cartographic Information Systems Research Group (CISRG); however, it also presents a challenging surface to sketch, when compared with the less complex models often used by the background techniques.

9.4 Merits and Flaws of the Approach

The perceptual benefits of creating sketched visualizations have been addressed several times in this thesis. This research has shown that if a perceptually successful sketch is to be created, the silhouette-related (both Factual and Formulated) cues need to be rendered in a complete manner. Although the method presented is a simple one, it should not be viewed as simplistic. The value of this strand of work has already been noted when a preliminary study with Visual Insights Inc. was extended into a consultancy contract (as already noted, p. 92). The cartographic community was also very interested in the development of the project and suggested numerous application areas (Section 7.1.2, p. 104), some of which have already been noted in Visvalingam and Dowson (1998). The following text summarises the various merits and flaws of the approach.

Merits of the approach

The sketch paradigm, due to its scaleable, vector nature, provides a relatively quick render time for high-resolution output. The output is high in information, but low in data (Factual and Formulated Silhouettes formed only 2.9% of the source data for a view on the primary test DEM). In addition, the use of vector strokes produces publish-quality output that can be imported into a graphic art package for editing. This provides a much more draftsman-style output compared to image-based techniques. In a similar vein to Northrup and Markosian (2000), only visible lines are rendered. This approach takes away the need for hidden-area-removal, which in turn simplifies the use of stylistic strokes, as clipping is not an issue. Finally, approaching the problem from the model-level facilitates the intelligent integration of the silhouette-related cues with other visualization techniques.

Flaws of the approach

As it stands, the filter is not sensitive to local or relative conditions. This lack of adaptivity can produce an unbalanced sketch (as noted in Chapter 6, p. 90). In addition, the inability to retain small lines, which were omitted during the post-selection-filtering but which visually link into larger features, can cause problems (see Figure 6.4 - 6.5, p. 91).

9.5 Future Work

The primary direction for taking this research further, lies within the aesthetics of post-selection-filtering and the use of primitive-level attributes to control stylistic strokes. These are both outside the scope of this project, which was concerned with what to draw, rather than how to draw it. This area would benefit from further multidisciplinary research, from fields such as

perceptual psychology, cartography and art. Northrup and Markosian (2000) do attempt a degree of post-selection generalisation, merging silhouettes that lie in close proximity to each other and Hertzmann and Zorin (2000) use interpolation to create a smooth surface, reducing the problems which occur when using a discrete mesh.

The issue of adaptivity, noted as a flaw in the method, is still a research challenge. The ability to balance a visual abstraction remains an art which cartographers find hard to quantify (Visvalingam, Personal Communication). The other major flaw noted, is the inability to group strokes that are not physically, but visually connected. This 'unseen' link would allow for the retention of small but important strokes and the 'safe' removal of those that do not visually connect.

9.6 Conclusion

This thesis has demonstrated that occluding contours form only a subset of the perceived silhouette-related cues; this is especially true when viewing a scene from a relatively high elevation. The remainder of this set of cues has been shown to occur at locations where the surface turns away from the viewing direction, but remains visible. This observation illustrates how silhouette contours relate to perceived entities, based upon some knowledge of surface features, rather than actual occlusions. In addition, this work highlights that when creating abstract visualizations, with realistic depth cues such as aerial perspective, texture compression and lighting removed, both perceived (Formulated) and actual (Factual) silhouettes must be depicted in a complete manner.

A filter has been presented which supplements the Factual Silhouettes (occlusion) with Formulated Silhouettes. Several case studies were used to evaluate this filter, each composed of terrain of varying character and scale; the results were largely successful. However, where relief is relatively low, some human interaction was required to increase the sensitivity of the filter. The extraction of the contours as chained vector strokes allowed for the attachment of primitive-level attributes (e.g. length) to aid post-selection-filtering and permit the use of stylistic strokes in future research projects. In addition, external validation of the ideas presented in this thesis was achieved through consulting and interacting with cartographic designers.

The combination of Factual and Formulated silhouettes provides a means for visually structuring the sparse suggestive cues, used to describe other important breaks of slope. This application was demonstrated by intelligently integrating the silhouette sketching system developed for this project with the P-stroke sketching system (Dowson 1994; Visvalingam and Dowson 1998). In addition, the inclusion of stroke-based form cues within conventional terrain visualization styles, such as remote-sensed image drapes, greatly enhanced the perception of form without detracting from the land-cover information. Here, traditional tonal cues, such as shading and aerial perspective, can obscure important form or thematic information.

This thesis has shown how a successful description of the most important view-dependent cue, namely silhouettes, can be abstracted and used to enhance existing visualizations of terrain. Cartographic landscape sketching, as practised by Murchison (1839), Holmes (1876) and Lobeck (1939), is dying out, this is noted in Lesage and Visvalingam (2000) where it is also stated that these techniques are “no longer widely taught by Earth Sciences” (Lesage and Visvalingam 2000, p. 3).

This thesis contributes to a strand of research within the Cartographic Information Systems Research Group (CISRG), which aims to redress the balance, between art and science, within the modern environment of digital cartography.

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Appendix A - Exercise for Cartographers

Cues For Structuring Cartographic Sketches of Terrain

Details

Name :

Training in Cartographic Sketching :

Occupation / Field :

Employer :

INTRODUCTION

Little if any scope is provided for the production of abstract depictions of terrain within modern visualization systems. Contour extraction, layer tinting and shading are often the most advanced abstraction techniques available. This lack of software for abstracting surface contours from the mass of height data prevents the user from being able to produce generalized depictions such as topographic sketches. From these sketches, landform type and structure can be readily perceived. The sketch also provides white space for annotation and inclusion of cultural data.

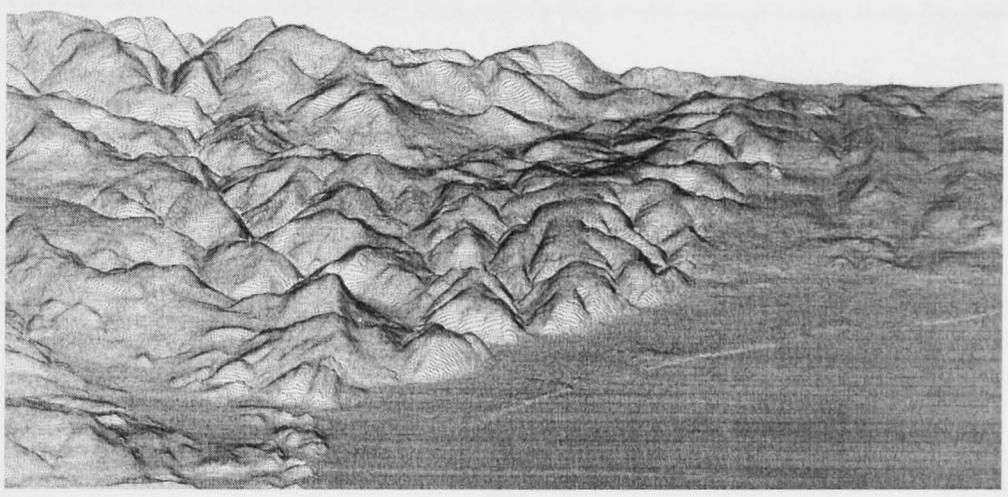
Within the Cartographic Information Systems Research Group, a research strand has developed which aims to investigate how sketches, such as those performed by cartographers, can be automatically produced from views of digital elevation models, (DEMs).

The focus of this exercise is to investigate the use of silhouette-related cues, within small-scale depictions, viewed obliquely from above. As can be seen from the illustration from a classic geology text, shown in Figure 1, silhouettes play a key role in structuring the sketch.

The silhouettes present in a view of a DEM, termed *occlusions*, are the result of depth discontinuities within the projected surface. These can easily be identified and chained into strokes or *occluding contours*. Figure 2 shows the set of occluding contours abstracted from a view of a DEM. As can be seen by comparing the two plots in Figure 2, the framework provided by the occluding contours is far from complete. The eye seems to be classing many locations in (a) as occluding or relating to a projected silhouette, yet they are not captured within the set of occluding contours (b).



**Figure A.1: An illustration from a classic geology textbook.
Source: R. I. Murchison, "The Silurian System", 1839, p. 224**



(a) Full profile plot



(b) Set of occluding contours

**Figure A.2: View of a DEM showing area around Neath and Port Talbot, Wales.
Data: Crown Copyright, Ordnance Survey.**

The aim of this exercise is to investigate how you would extend the sketch of the silhouette framework in different contexts.

Exercise 1:

Figures A.3.1 through to A.3.4 show the results of different techniques for extending the framework provided by the set of occluding contours. These techniques focus only on the areas of the terrain which are turning away from view, but which are still visible.

Please refer back to Figure A.2(a) and assess the extent to which the plots portray the framework of silhouettes, then rank the figures in order of your preference.

It would be helpful if you could explain your preferences in the comment box, or on the back of this page if you need more room.

Position	Figure Number	Comments
1 (Provides best structure)		
2		
3		
4 (Provides worst structure)		

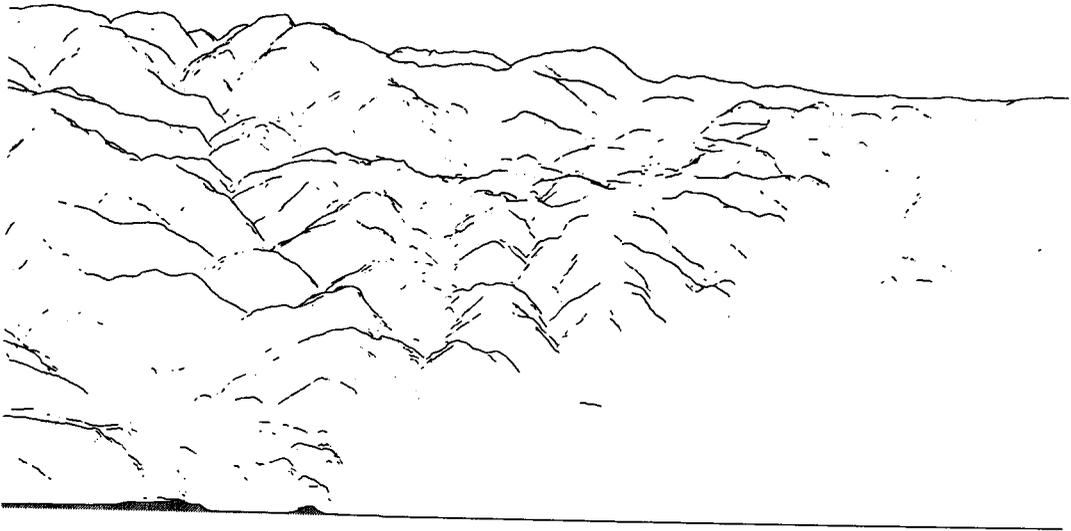


Figure A.3.1

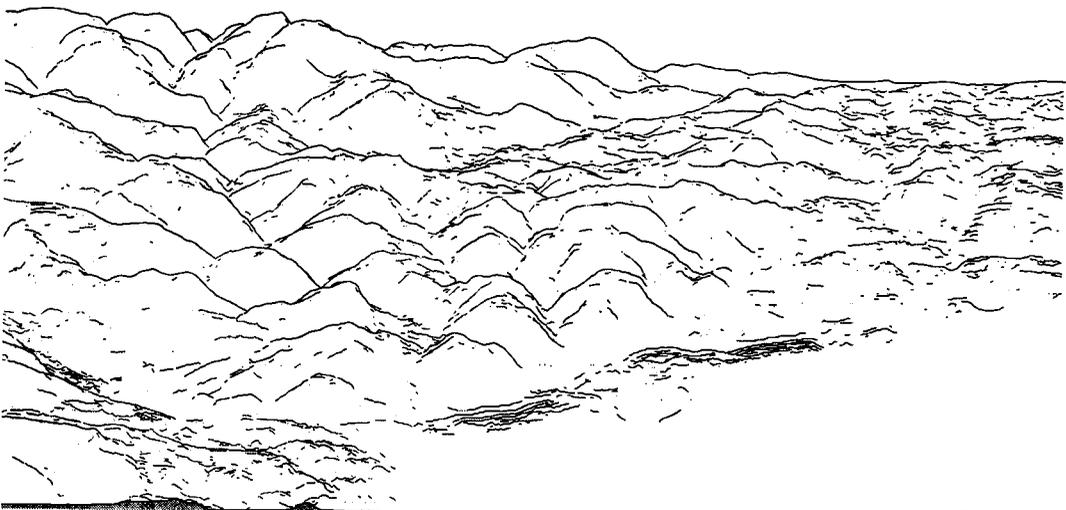


Figure A.3.2

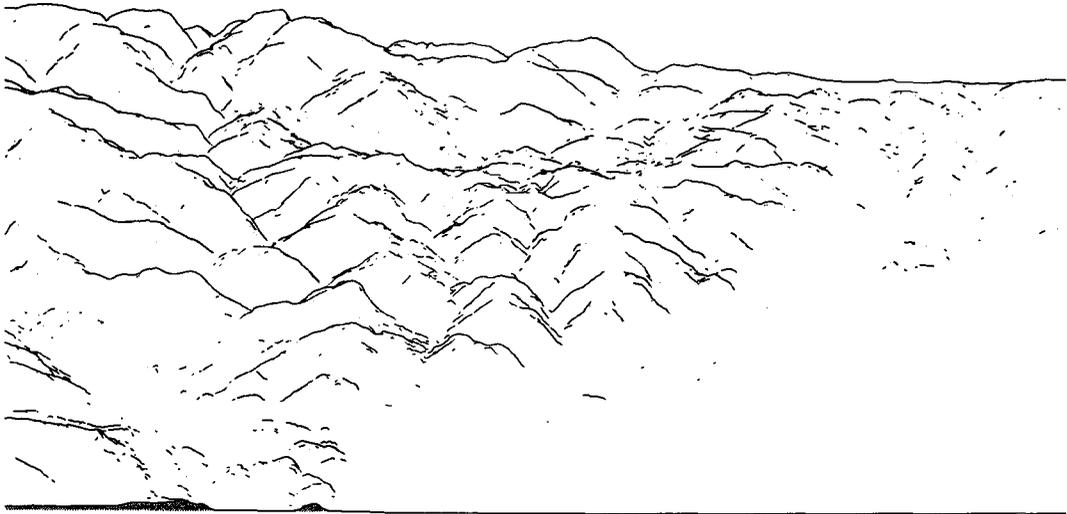


Figure A.3.3

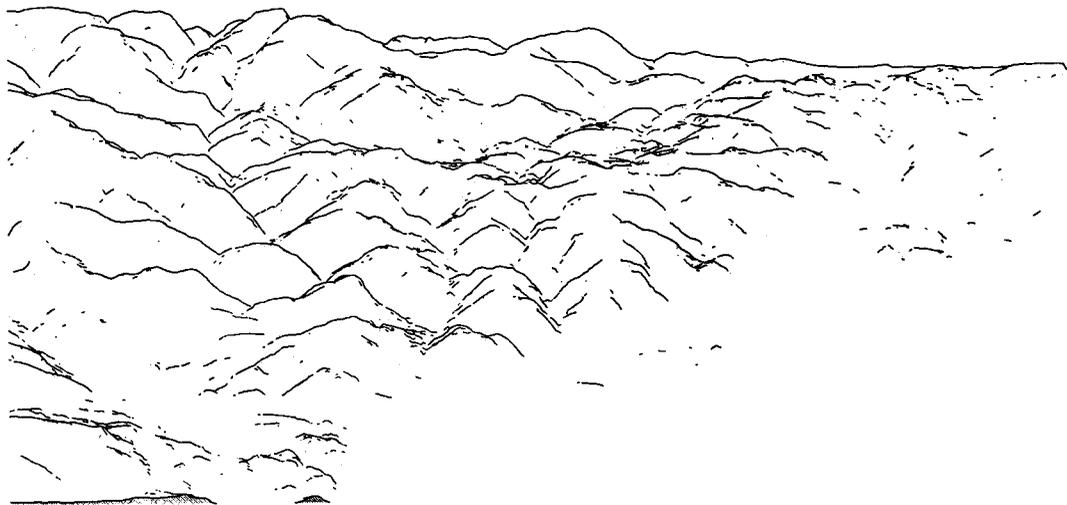


Figure A.3.4

Exercise 2:

This exercise focuses on some parts of Figure A.2, which are enlarged here. The full profile plot and the set of extracted occluding contours are shown. For one row (a, b or c), try to complete the framework by extending the occluding contours. Remember to keep only to cues relating to silhouettes. Please ignore front facing form cues and concavities. It would be helpful if you could explain your drawing in the comment box provided.

Comments:

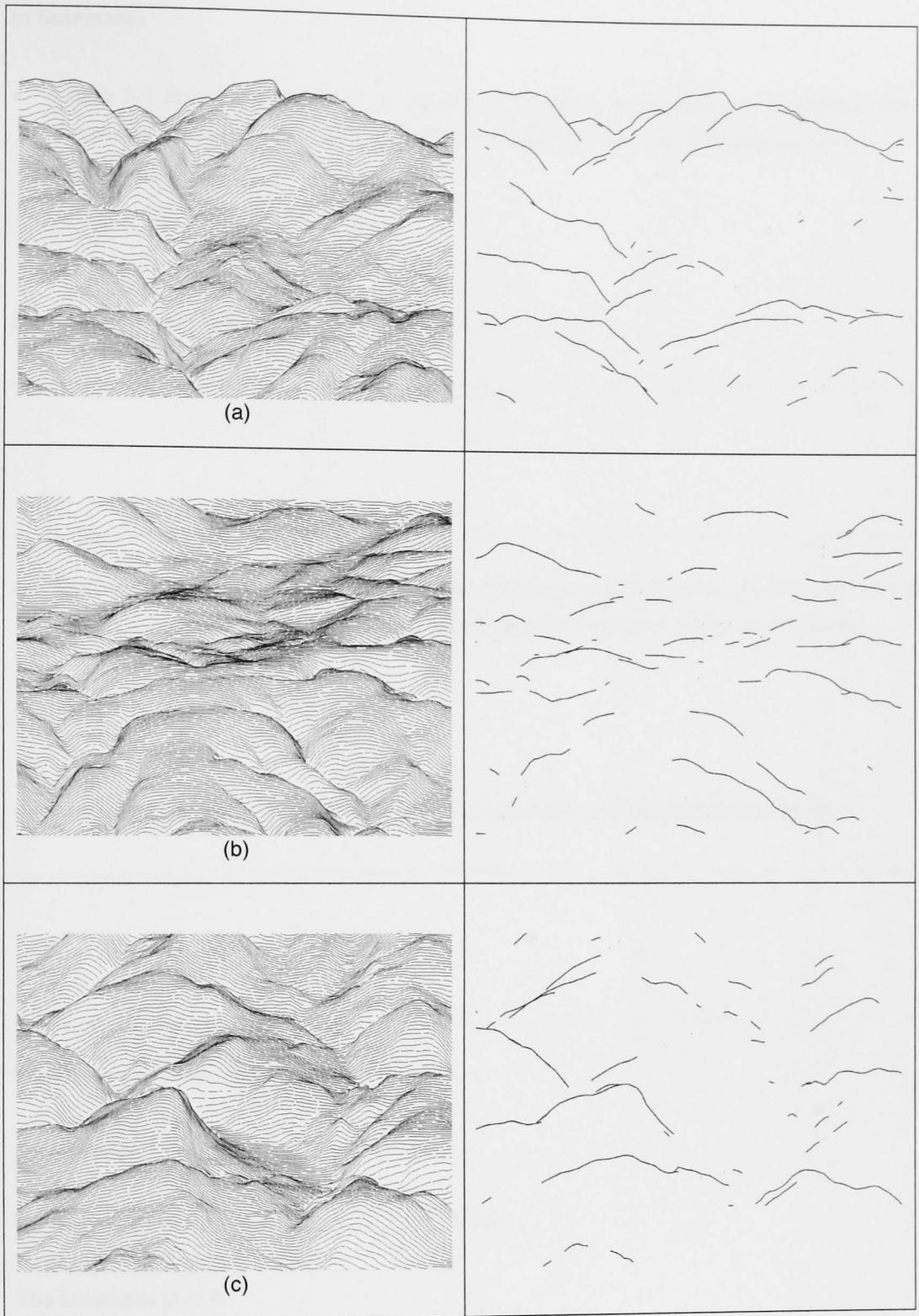


Figure A.4

Choose one case (a, b or c).

Complete the Framework of Occluding Contours (right) using the Full-Data Plot (left).

Take care to only use cues relating to silhouettes.

In Summary:

- Figure A.5 shows the results of an algorithmic approach to extracting a connected, view-dependent framework from a view of a DEM. Do you feel there are deficiencies in this sketch?

Please circle

YES NO

If your answer was YES, please comment.

- From what you have seen, in this document and on the display boards, do you feel that this research complements the photo-realistic approaches offered for terrain visualization?

Please circle

YES NO

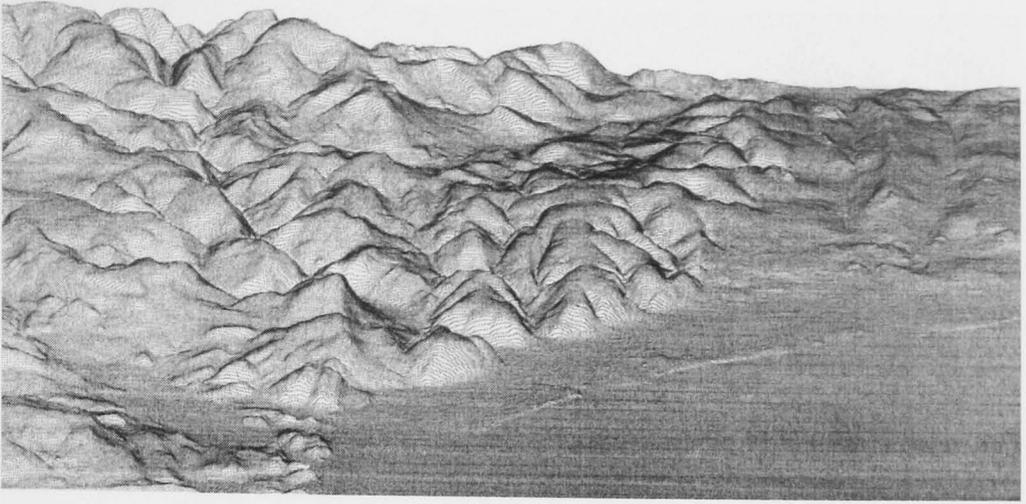
If your answer was YES, please comment on the application and value of this research.

Thankyou very much for your time.

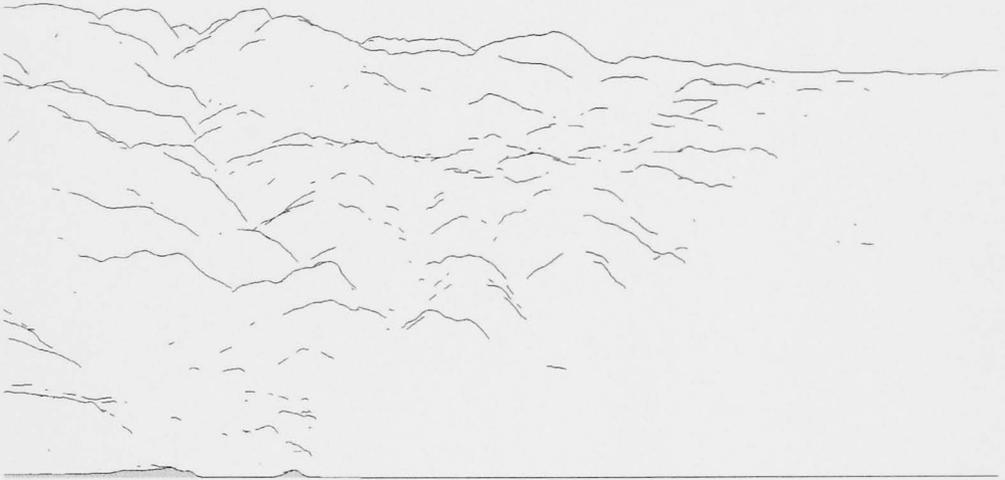
John Whelan

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(a) Full profile plot



(b) Occluding contours



(c) An extended view-dependent framework of silhouettes

Figure A.5: Automatic extension of the occluding contour framework.