Reconstruction of digitized contour lines
by Charles Glen Swenson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Computer Science
Montana State University
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Abstract:
A method is proposed for the understanding and reconstruction of raster images of paper-based topographical maps. Topographical maps of mountainous regions can exhibit certain inherent problems. Among these is the confluence of contour lines when spacing between the contours becomes too confined for the resolution of the map. A method to automatically detect and resolve such junctions in raster images is proposed and tested. In this method, contours are efficiently thinned as they are extracted, without thinning cliff areas or other map symbols. This results in end points in the extracted contour lines at the junction points. The Breakpoint Method is shown to be effective for resolving these end points.

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APPROVAL

of a thesis submitted by

Charles Glen Swenson

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

1/13/92
Date

Chairperson, Graduate Committee

Approved for the Major Department

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Head, Major Department

Approved for the College of Graduate Studies

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This thesis is dedicated to my wife Giselle, who always believed in me.

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ABSTRACT

A method is proposed for the understanding and reconstruction of raster images of paper-based topographical maps. Topographical maps of mountainous regions can exhibit certain inherent problems. Among these is the confluence of contour lines when spacing between the contours becomes too confined for the resolution of the map. A method to automatically detect and resolve such junctions in raster images is proposed and tested. In this method, contours are efficiently thinned as they are extracted, without thinning cliff areas or other map symbols. This results in end points in the extracted contour lines at the junction points. The Breakpoint Method is shown to be effective for resolving these end points.

CHAPTER 1
INTRODUCTION

Motivation

The computer's ability to rapidly retrieve and manipulate large quantities of data has spurred a swift growth in the field of computer aided cartography. But to use computers to store and manipulate geographical data, the data must be in a form the computer can use; that is, digitized. Some modern data acquisition techniques, e.g. remote sensing via satellite, may capture data in a form ready for computer use [18]. However, much of the geographical information currently available is in the form of paper based maps. This has led to growing interest in techniques for digitizing these maps.

Digitization of paper based maps has traditionally been done manually with the aid of a digitization tablet. Maps may store many types of information, such as roads, buildings, property boundaries, population densities, vegetation cover, etc. A map is placed on the digitizing table, and the boundaries of these features are traced by hand using a stylus or a puck. The digitizing hardware and software save the data in a vector format convenient for computer processing.

Topographical maps are a common type of paper-based map. These maps show elevation data in the form of contour lines. Contour maps contain unusually massive amounts of data, making their digitization by traditional means an expensive and time consuming process. Digitizing a typical contour map by manually tracing all of its contour lines may consume from 40 to more than 400 tedious man-hours [5, 24]. Human error in these tracings is also a recurring problem; loops that should close don't, or do so with an over-

lap, leaving a tail on the end; lines may be inaccurately scanned, scanned twice, or omitted.

A need has therefore been recognized for effective ways of automating the process of digitization and vectorization of contour lines from paper-based maps. Three different approaches have been taken toward automating this process.

The first method attempts to mechanically imitate the manual tracing techniques. Special opto-mechanical line following hardware has been used to trace the lines directly from paper-based maps [3]. This method has seen only limited success.

A second approach uses scanning hardware to produce a raster image of the map as an end result [2]. This raster image is little more than a photograph of the map in question, as there is no implied relationship between pixels in the image; i.e. the contours are not extracted as individual entities. Although initially inexpensive, this approach is unpopular because most existing Computer Aided Cartography (CAC) software requires the data to be in vector format, and can make little use of raster images [5, 13, 18]. Another problem with this method is that the storage requirements for a raster image of a map will always be greater than that of its vector representation [5]. Considering the amounts of data involved, a reduction in storage requirements is very desirable.

Most promising are methods involving raster-scanning with subsequent processing to vectorize the image. Many methods have been proposed for extracting various shapes and features, but few can address problems particular to the correct extraction of contour lines.

Problems in Vectorization of Contour Lines

Most techniques for line extraction have concentrated on documents with highly regular lines and structures. Examples of these are algorithms for extracting lines from blueprints and engineering drafts [6, 9, 12], and for extracting buildings, roads, and certain boundaries from map images [2, 6, 10, 11, 14, 16, 19, 22, 23, 24]. Lines in these drawings tend to be straight and uniform, or composed of simple curves or dashed lines. These algorithms generally work by exploiting these known features of such lines. Unfortunately, contour lines exhibit none of these regularities, taking shapes as infinitely varied as the terrain being mapped.

It can further be proved that contour lines must follow certain strict laws not shared by other line structured data [17]. These laws include:

1) ***Contour lines cannot intersect.***

2) ***Contour lines cannot end except on the edges of a map.***

This causes special problems in the processing of topographical data, particularly in regions of mountainous terrain such as Montana. As the steepness of a mountain slope increases, the distance between contour lines on a map decreases. If the distance between contour line centers becomes less than the thickness of the contour lines, then rule 1 above is necessarily violated. Essentially, the contour lines will all run together into one large line. These junctions have been termed *Cliff Lines* [17].

Map makers faced with these problems may take one of 3 options when producing their paper-based maps. They first may increase the contour interval, thereby reducing the amount of data stored on the map (and subsequently its usefulness.) This is a poor solution at best, for in steeper terrain

the map would require a yet larger interval, until finally no contours at all could appear on maps of areas with vertical cliffs.

More often, map makers ignore the above rules, forming cliff lines and/or contours with endpoints on their maps at such problem areas. (Figures 1 & 2). Other problems can also arise later when text, or lines from other map symbols are inserted and overlap the contour lines. These situations are also handled by having the contour lines end before the overlapping symbol and resume on the other side, or by just imprinting the symbol on top of the contour line (Figure 3). Once again the rules for contours are violated on the map.

These violations of basic cartography are most often not a problem for the intended audience of these maps [11]. The human mind has powerful reasoning capabilities and usually (but not always) can correctly interpret

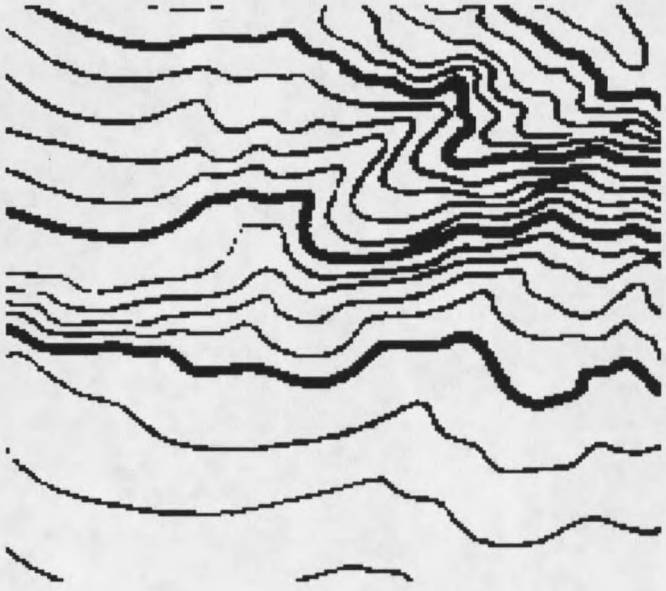

Figure 1. A digitized contour map with intersecting contour lines

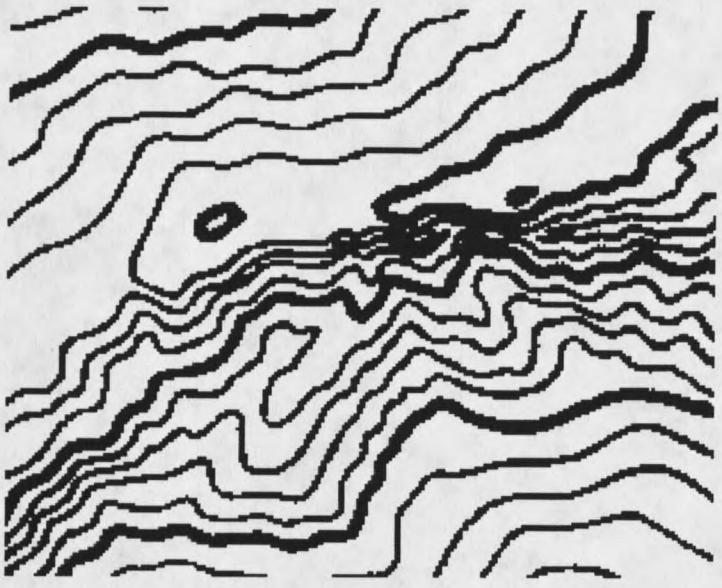

Figure 2. A digitized contour map with intersecting contour lines and contour lines that end in the center of the image.

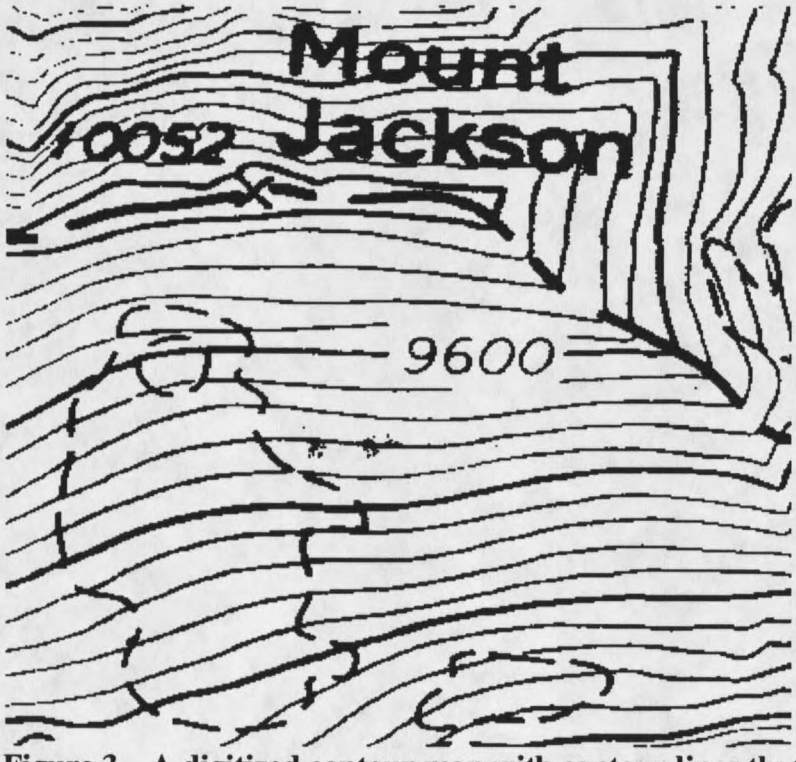

Figure 3. A digitized contour map with contour lines that intersect other map symbols, or end to avoid intersecting them.

these areas. The situation presents a greater challenge for the digital computer.

Figure 4 shows a simulated cliff line composed of intersecting contour lines. Figures 5 - 8 show some of the ways the contours could be reconstructed, none of which can be rejected as violating rules 1 or 2.

Violations of rules 1 and 2 may also result solely from the scanning process itself. The dilemma is that too high a scanning resolution results in

Figure 4. A cliff line formed by intersecting contour lines.

Figure 5. A possible interpretation of the cliff line in Figure 4.

Figure 6. Another possible interpretation of the cliff line in Figure 4.