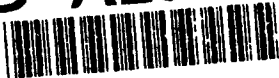


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AN APPROACH TO AUTOMATED TERRAIN CLASSIFICATION
FROM DIGITAL ELEVATION MODEL DATA

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ABSTRACT

Using digital elevation model data, landforms are classified into two broad, generic terrain features -- mounts and non-mounts. Mount represents an aggregation of elevated features including hills, mountains and ranges. All remaining features are classified collectively as non-mount. The results of this work suggest that it may be possible to acceptably replicate the manual classification of certain generic terrain features. However, the general utility of the mount/non-mount classification appears to be limited by the classification algorithms, the nature of the regional terrain and the quality of available digital data. Possible applications for generic terrain feature information, such as mounts and non-mounts, are presented.

INTRODUCTION

Most terrain classification to date has been manually intensive, using aerial photographs or topographic maps as the primary data source. However, with the advent of advanced computer capabilities and mass-produced digital elevation models (DEMs), automated classification of certain terrain features may be possible.

The complex problem of automated terrain classification is simplified by defining two broad, generic terrain features -- mounts and non-mounts (Graff, 1992). Mount refers to terrain features such as hills, mountains and ranges, which are elevated from the surrounding terrain. All remaining features are collectively classified as non-mount.

The developed classification method automatically partitions digital elevation models (DEMs) into mount and non-mount areas. The method has greatest success in high-relief physiographic regions and poor results in low-relief areas, or where the mounts have extensive low-slope tops and/or a long, linear shape.

This paper presents a description of terrain classification, followed by the method developed to automatically classify mount and non-mount areas from digital elevation data and results of the classification method. Possible application areas for generic terrain feature data are discussed including their use as: 1) a terrain data layer in a geographic information system (GIS), 2) a constraint to guide triangulated irregular network (TIN) point selection, and 3) a first step towards a more specific landform classification.

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TERRAIN CLASSIFICATION

This research implements the first stage of a divide-and-conquer approach to the complex problem of automated terrain classification. The approach is based on the premise that it is often easier to classify an area into a few simple generic terrain features rather than, or prior to, classifying many specific geomorphologic landforms.

Guided by this approach, landforms are divided into two broad, generic terrain features -- "mounts" and "non-mounts" (Graff, 1992). Mount is adapted from the U.S. Geological Survey's (USGS) proposed Digital Line Graph-Enhanced (DLG-E) definition of a mount as "a landmass that projects conspicuously above its surroundings" (Guptill et al., 1990, p. A-97).

Mount represents such elevated terrain features as hills, mountains and ranges. The most easily identified mount is considered to be "well-defined." A well-defined mount is an isolated, elevated mass with a distinguishable boundary and a summit or peak. To further simplify the classification problem, all features other than mounts are collectively classified as "non-mount." These features include plains, basins and flats.

The manual classification of terrain frequently depends on isolating and measuring the attributes associated with the feature. For instance, when using aerial photographs, the boundaries between landforms are often apparent at breaks in slope which create apparent tonal and topographic changes (Mintzer and Messmore, 1984). In general, the bases of hills, as well as the tops, are more gentle in slope than the sides (Rinker, 1972). Information such as this can also be used to help delimit mount from non-mount areas in an automated classification scheme.

Analysis techniques employed in this study are adapted from previous work in automated terrain analysis using both general geomorphometry measures and critical points. General geomorphometry is the measurement of landform characteristics over a broad continuous surface (Evans, 1972). Measures used in general geomorphometry often rely on altitude and such derivatives as slope, aspect and curvature (Evans, 1972; Mark, 1975; Pike 1988).

Studies using critical points extract information directly from the elevation data without computing derivatives or other measures. Critical points provide the maximum amount of information about a surface. Although called by different names, these points include: peaks, pits, ridges, ravines, passes, slopes, break points and flats (Peucker and Douglas, 1975).

This research combines information and methods used in manual terrain classification with automated techniques used in geomorphometry and critical point analysis to create various data layers. These layers are combined and

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analyzed to partition the input DEM into mount and non-mount areas.

METHODS

The digital data used are USGS 7.5 minute-based DEMs, which correspond in coverage to 1:24,000 scale topographic maps (U.S. Geological Survey, 1990). These data have a 30-meter spacing between X and Y locations and cover an area comparable to a 7.5 minute topographic quadrangle map.

An automatic mount classification method was developed using ten DEM sites. The sites are scattered across the United States (Figure 1), have a wide range of local relief and contain both well-defined and poorly defined mounts (Graff, 1992). Results of the automatic classification method were compared to manual classifications for the selected DEMs using shaded relief, synthetic stereo images (Batson et al., 1976). The manual classifications were performed by scientists at the U.S. Army Topographic Engineering Center.

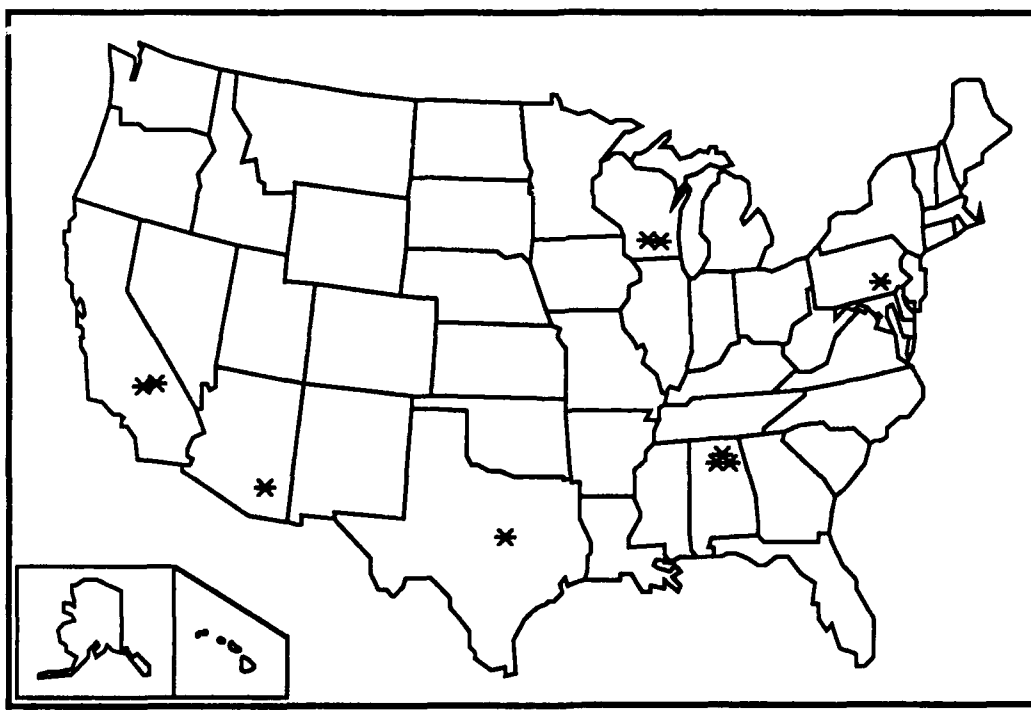


Figure 1. Location of 10 DEMs used to develop automatic classification method.

Preprocessing

Prior to application of the classification algorithm, the elevation data is smoothed twice to minimize the effects of local highs and lows in the elevation values. The smoothed elevation data is used to obtain new data layers that provided information similar to that used in manual terrain classification (Figure 2). This information includes percent slope and ridge points.

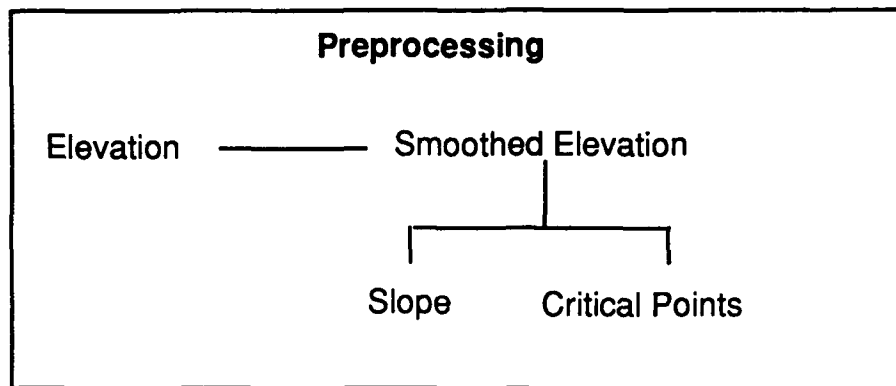


Figure 2. Files created from the original elevation data in the preprocessing step.

Slope is used to provide a boundary between mount and non-mount areas, the value of which is related to the local relief of the site. Final analysis determined a boundary slope between mount and non-mount of 10 percent in areas with local relief greater than or equal 250 m and 6 percent in lower relief areas.

Critical point analysis initially focused on peaks which are defined as a center elevation within a 3 x 3 neighborhood that is greater than all eight neighboring elevations. However, the identification criteria were too strict to extract many peaks. For this reason, ridge points were used as the critical points. A ridge point has a higher elevation than the elevation of its diagonal neighbors in an east-west or north-south direction.

Mount Classification Algorithm

The mount classification algorithm has four steps, each step using the classification of the previous step as input (Figure 3):

1. Reclass Ridges. Assign a boundary slope between mount and non-mount areas based on local relief and classify all ridge point locations with a slope greater than the boundary slope as mounts and all other points as non-mounts.
2. Grow to Boundary. Examine a 3 x 3 window of mounts classified in Step 1 (Result 1) and percent slope to "grow" the mounts from the ridge points to the boundary slope as follows: if the center of the 3 x 3 window is a non-mount **and** its slope is greater than the boundary slope **and** any of its eight neighbors are mount then reclassify the center as mount.
3. Grow Uphill. Continue to "grow" the mounts classified in Step 2 (Result 2), by looking for uphill trends in the data using the original elevation data as follows: if a non-mount is encountered after an uphill trend is established (increasing elevation with mount values), then it is reclassified as mount. The entire area is processed first from left to right then from right to left.

4. Fill-in Flats. Fill in non-mount areas located within mounts by examining the mounts classified in Step 3 (Result 3) and a 3 x 3 window of original elevation data. This algorithm states that if all three neighbors to any side of a center non-mount value are classed as mount **and** the elevation of the central value is greater than its closest mount neighbor, then reclassify the center from non-mount to mount.

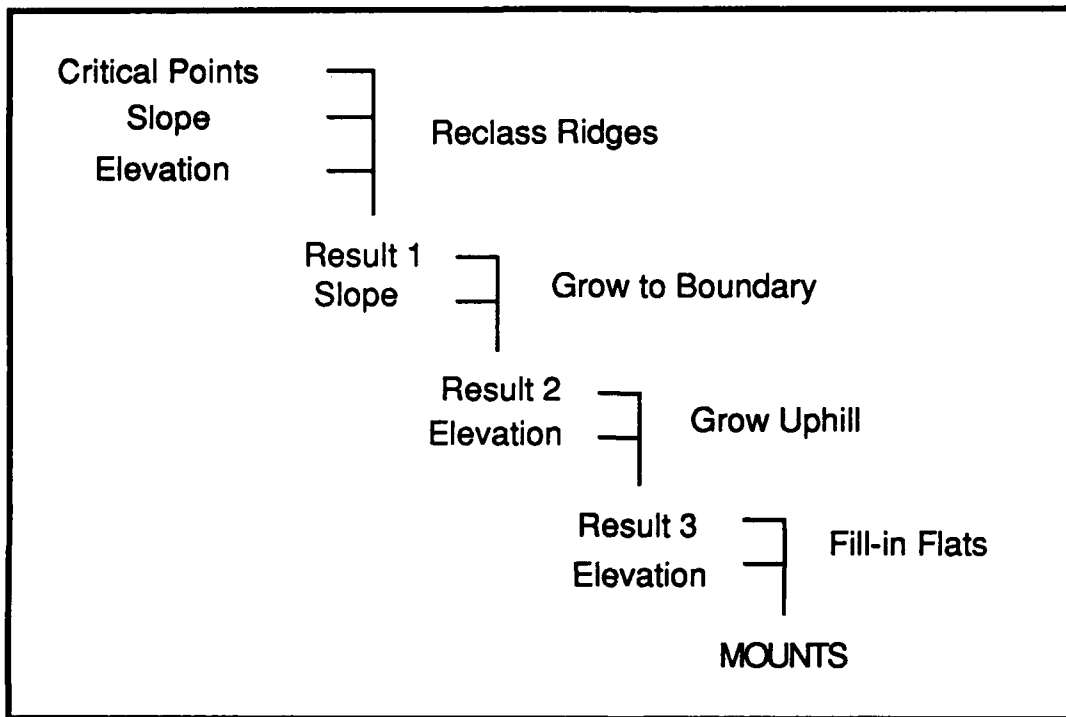


Figure 3. Steps in automated classification method.

Postprocessing

Early analysis of the manually derived boundaries with the automatic classifications showed that the automatic classification resulted in many small isolated clumps where isolated ridge points were located. To eliminate these clumps, all mounts less than 25 cells (150 m x 150 m) are sieved from the final result (Figure 4).

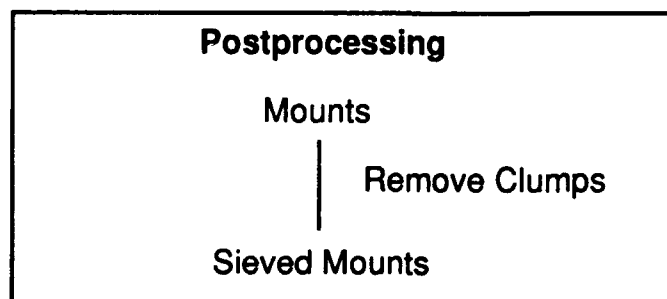


Figure 4. Postprocessing removal of small, isolated clumps.

RESULTS

Initial results suggest that the classification algorithm used in this divide-and-conquer approach to terrain classification is useful in some areas but not in others. The method is most successful in moderate- or high-relief areas where the mounts are well-defined and have ridge points. The classification is less successful in low-relief areas or where the mount has a broad relatively flat summit, or a narrow linear shape.

Figure 5 shows a shaded relief image of Drinkwater Lake, California and the automatic mount/non-mount classification. Drinkwater Lake, California has a local relief of 861 meters and is located in the same geographic area as several of the original 10 DEMs used to develop the classification method. As can be seen in the automatic classification, even in a relatively high relief area, the algorithm has trouble filling in some of the low slope areas within the mounts themselves. It also tends to merge many of the mounts. The mount merging could be minimized by using a higher boundary slope but this also results in more unclassified areas within individual mounts.

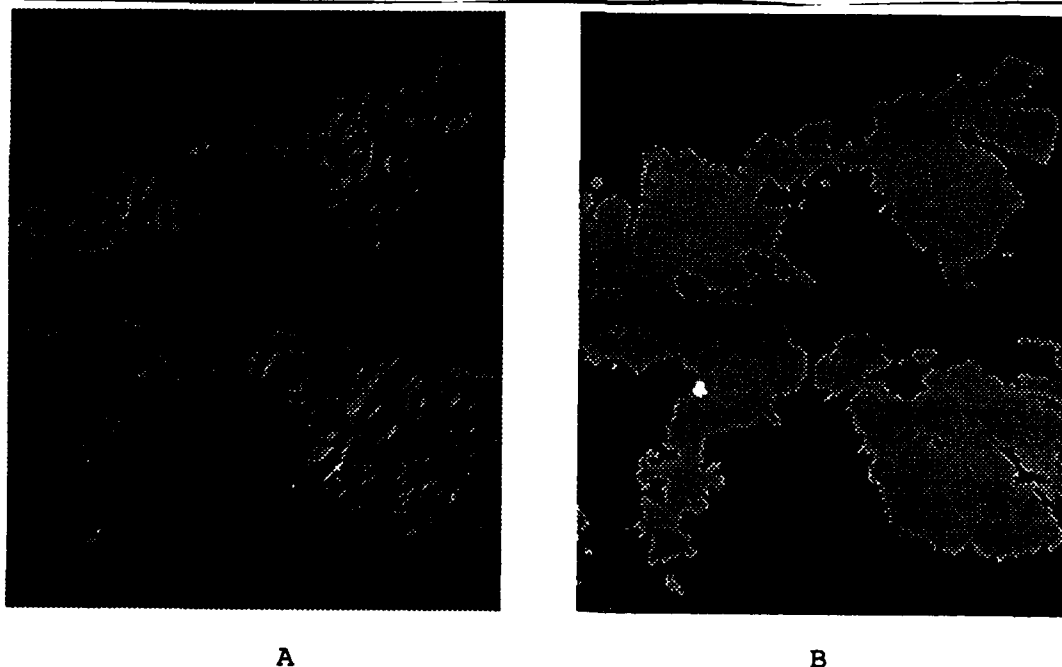


Figure 5. Drinkwater Lake, California. A. Shaded relief image of 7.5 minute-based DEM. B. Automatically classified mounts (gray) and non-mounts (black).

The results of the classification are highly dependant on the developed method. This method heavily relies on a universal approach, local neighborhood operators and "critical values," such as the boundary slope between mount and non-mount. Each of these possible limitations to the current method will be addressed in turn.

First, application of a universal approach that applies the same procedures to each DEM regardless of

geographic location may not be desirable. If the methods of mount identification can be tailored to the area covered by the DEM, it is possible that the mount/non-mount classification would be useful in more areas than suggested by this research. However, it is likely that many areas require a much deeper model of terrain classification than the two-class scheme used in this study.

Second, it appears that local neighborhood operators that examine one small window of information at a time can provide valuable information, as a first look at terrain. However, in many cases a 3 x 3 window, such as that used in this research, may be too small and restrictive for terrain features. Application of more regional operators, that examine the feature as a whole, may be required for accurate classification. This will become especially important if a more specific classification is desired.

Finally, the results of this research suggest that a boundary slope exists between mount and non-mount. As used in this study, this "critical value" is a function of the local relief of the area. Further investigation with additional DEMs is required to determine if there is a unique local relief cut off relating to a slope boundary between mount and non-mount areas or, if this too, is dependant on the area under investigation.

Incorporation of knowledge-based procedures may help constrain and simplify the classification problem, thereby reducing the limitations of the current approach. These procedures can include regional knowledge about the area such as the physiographic region and climate, or local knowledge such as vegetation and landuse. Relationships between knowledge such as this and terrain features have been studied by terrain analysts for many years. This knowledge can be used in a top-down approach to tailor the classification method used in a particular area to the features that are expected to be present.

Additional limitations to the current work may be imposed by the quality and resolution of the data source. Studies have shown that 7.5 minute-based DEMs are sufficient to extract large terrain features such as drainage basins, lakes and, in certain cases, mounts. However, it is insufficient for extracting detailed, local information such as gully shape. This type of information is frequently used by terrain analysts when performing manual feature classification.

It may be possible to extract information, such as gully shape, from higher quality and resolution data. However, until better data becomes readily available, it may be possible to extract similar detailed information, such as hydrography and vegetation, from other digital feature data sources.

APPLICATIONS

The automatic classification of mount and non-mount areas from digital elevation data has several potential

applications. One is the production of a mount/non-mount terrain feature overlay to be used in a GIS. This feature overlay could be used to facilitate queries in conjunction with other GIS information layers. For instance, military systems frequently incorporate the term "hill" into their domain rules as shown in Figure 6. However, automatic interpretation of such rules is not possible if the terrain terms used have no meaning in the system.

"The headquarters will normally take advantage of **a hill to the front** for cover and be on the reverse slope, but on near level terrain."

"Artillery units are located on the **reverse side of a hill** from the forward line of troops, when in **hilly or mountainous** terrain."

Figure 6. Examples of military domain rules.

A second possible application for a terrain feature overlay depicting mount and non-mount areas is in the generation of TIN for simulation modeling. Currently, point selection methods for TINs tend to generate the most points and provide the greatest amount of information in the high relief hilly or mountainous areas (Figure 7a).

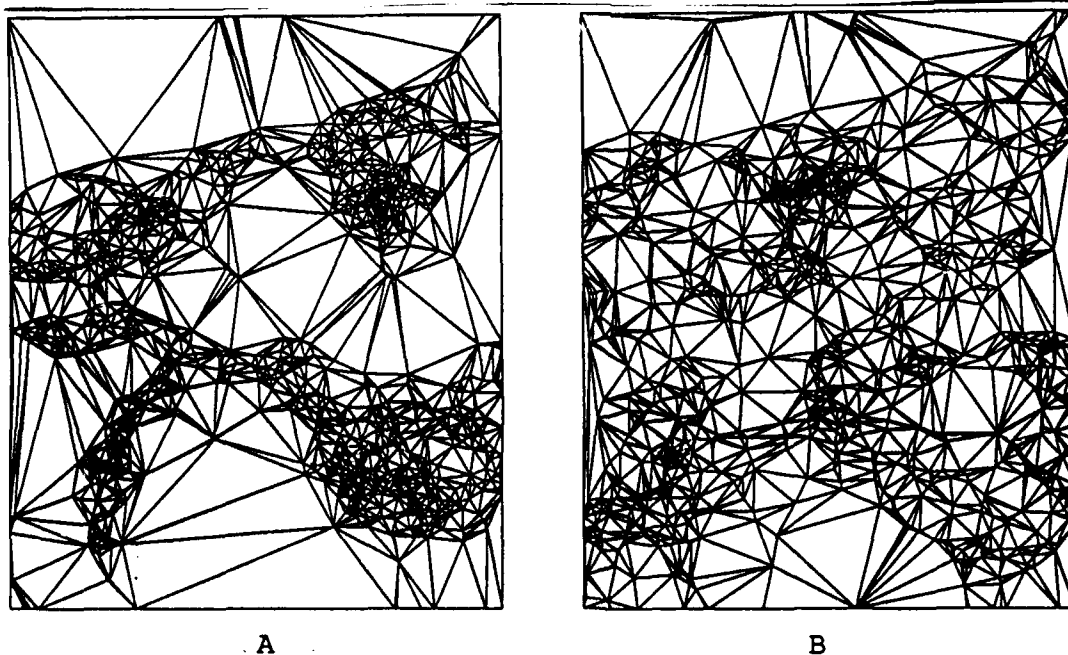


Figure 7. Drinkwater Lake, California. A. TIN generated with all points. B. TIN using mount/non-mount classification as mask for point selection.

However, for some applications, such as simulation modeling and wargaming of maneuver forces, cross country

mobility of ground vehicles is restricted in mountainous areas. In this case, allocation of fewer points in the mounts and more points in non-mount areas may be highly desirable. A mount/non-mount terrain feature overlay could be used as a mask to guide TIN point selection (Figure 7b).

As previously stated the automatic classification of generic terrain features such as mounts could also facilitate the automatic classification of more specific geomorphologic landforms. Evans (1987) states that a form must be isolated from its surroundings prior to a specific classification. By separating individual mounts from each other and from their surroundings it may be possible to apply additional measures to more specifically identify the feature.

CONCLUSIONS

A method was developed to automatically classify certain generic terrain features from digital elevation data. The two-class system differentiates mounts and non-mounts. Mounts are considered to be elevated features, such as hills and mountains. All remaining terrain features are considered to be "non-mount."

The automatic classification method is most successful in high relief areas. Poorer results are obtained in moderate or low relief areas or where the mounts have low-slope tops and/or a long, linear shape.

Although the actual classification method has limitations, this research represents a first step toward automated classification of generic terrain features. Also, by simplifying the classification problem and identifying a few generic terrain features, additional processing may lead to the identification of more specific geomorphologic landforms.

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