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Automatic Color Map Digitization by Spectral Classification

A scanner digitizing technique is described and is compared with table digitizing.

ABSTRACT: *A method of converting polygon map information into a digital form which does not require manual tracing of polygon edges is discussed. The maps must be in color-coded format with a unique color for each category in the map. Color scanning using a microdensitometer is employed and a three-channel color separation digital data set is generated. The digital data are then classified by using a Gaussian maximum likelihood classifier, and the resulting digitized map is evaluated. Very good agreement is observed between the classified and original map.*

INTRODUCTION

Machine analysis of remotely sensed data such as Land-sat multispectral scanner data often requires availability of digital ancillary data from other sources generally in map format. In these cases digitization and registration of ancillary and remote sensing data must be carried out before project goals can be pursued. Many systems have been developed which use multiple data types (Bryant, 1977; Anuta, 1977), and transformation of various map type inputs to digital form is a problem common to any such effort. The data conversion requirements vary significantly according to the types of maps, what type of information is required, and the final digital format. However, any such process is essentially analog-to-digital in nature and involves positioning of points on a two-dimensional plane.

This paper is concerned with digitization of one particular type of hand-drawn analog map. This type of map is characterized by lines or boundaries partitioning an area into subareas, called polygons. Each polygon is associated with some particular type of information. An example of this type is the map of land-use patterns of Kansas, as shown in Figure 1. The data conversion process requires the production of a digital image of the map in grid format, with the gray levels representing the type of land-use pattern.

One method of converting this type of map to a digital image is digitization of the x-y coordinates of the boundaries which separate polygons of different land use. This is usually carried out manually with a mechanical table digitizer. The information associated with the polygons is keyed into a computer by means of human interpretation. An algorithm based on line segmentation and sorting* is used to convert the digital boundary description to the grid storage format. Figure 2 contains a flow chart describing the process. As is suggested from the above, two problems exist: (1) the method depends heavily on routine and tedious manual operations which, in complex cases, have a high risk of error in boundary positioning and (2) the complexity

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* LARS-USGS undocumented boundary algorithm, Laboratory for Applications of Remote Sensing, West Lafayette, Indiana

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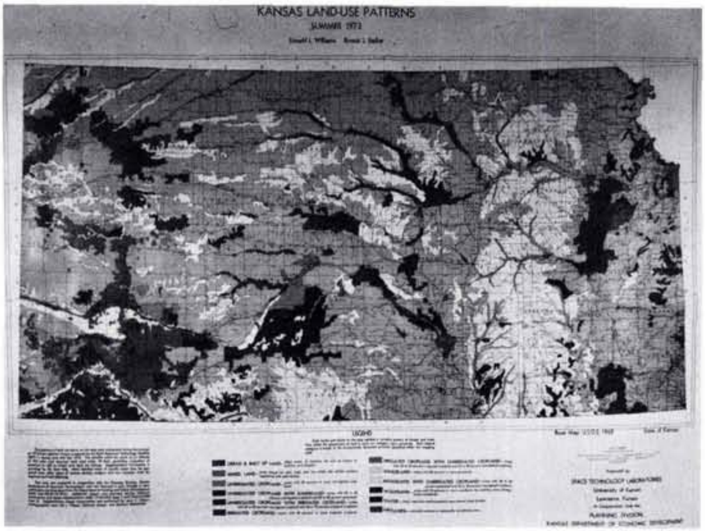

FIG. 1. Kansas land-use map used to test automatic map digitization method.

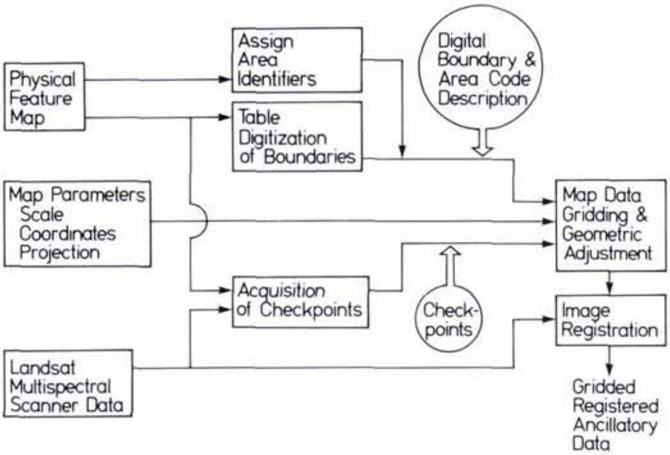

FIG. 2. Flow chart of digitization procedure using a table digitizer.

of line segmentation and sorting increases rapidly with complexity of boundaries. Memory limitations and computer time requirements can become a major problem.

The results of an investigation into the feasibility of an automatic method of digitization are presented here. The method calls for the use of a film scanner to perform the tedious digitization, the use of maximum likelihood classification to extract the information or the features associated with the polygons, and the use of image processing techniques such as derivative-type edge detection to reduce errors that may have been introduced along polygon boundaries. Because scanner digitization is essentially automatic, very little direct human labor is involved, and because all intermediate steps involve only images in grid format, no boundary conversion is required.

The advantages and disadvantages of scanner digitization are discussed and it is pointed out under what circumstances this method is advantageous. An example of cost and resource requirement is also presented by using estimates from an actual experiment. The automatic method originated from the search for an alternative to the table digitization method; therefore, side-by-side comparison is frequently made in this paper.

SCANNER DIGITIZATION METHOD

The basic requirement for this method is that the information or the features on the

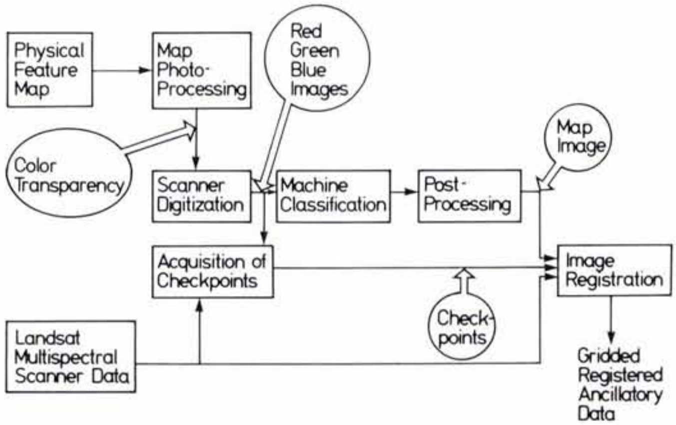

FIG. 3. Flow chart for scanner-classifier method of map digitization.

map must be color-coded so that each class on the map has a distinct color. Many maps such as the map of land-use patterns of Kansas satisfy this requirement. The main idea set forth here is to recover the color-coded polygons by machine classification. The map, if too large, must be photo-reduced to a color transparency, which should be small enough to be mounted on the drum of a film scanning device. Digitization is subsequently performed automatically so as to generate the red, blue, and green digital color separation images of the map; then, a three-feature classification based on these three color images is used to recover the original color-coded polygons. The information associated with each polygon can be easily restored by referencing an internal table stored in the memory of a computer. A block diagram of this method is shown in Figure 3.

How well the color-coded features on the map can be recovered from its color image depends on how well the classification can be performed. Classification performance is strongly influenced by the quality of the color separation images, which are ultimately determined by the photo quality of the transparency. Experimental results show that high photo quality may be achieved by (1) using high resolution fine grain film such as Kodachrome KM-135-20 and (2) photographing the map under sunlight.

It is reasonable to deduce that grain noise may increase the variance of the colors, and poor lighting may reduce the contrast of the colors and hence the dynamic range of the data. All of these ultimately affect the quality of classification. This was experimentally verified and these effects are reflected in the spectral (Phillips, 1973) plots of the colors. Figures 4 and 5 show the color class coincident spectral plots of the land-use map of Kansas photographed under two lighting conditions. It can be seen that the color classes in Figure 4 tend to crowd in a small range of values between 72 and 144, but that the colors in Figure 5 tend to spread out between values of 36 and 216. This is due to the strong illumination which gives excellent color contrast. By comparing the blue channel of both figures, it can be seen that variances of the colors is larger in Figure 4 than in Figure 5.

Another important aspect of map scanner digitization is to retain as much detail on the map as possible. This means that the effective spatial resolution must be sufficiently high. Three factors influencing effective spatial resolution are—

- aperture size of the scanner and sampling rate,
- ratio of photo-reduction,
- size of the printing dots on the map.

Although there is a minimum aperture size of the scanner* used, it is always possible to achieve a desired effective spatial resolution by appropriate change of the photo reduction ratio. However, spatial resolution cannot be increased beyond the dot density of the map (about 100 dots per inch, with respect to the map). Note that the dot printed map represents a worst case and better results will be achieved if solid color maps are used. If this happens, the scanner sees one dot or part of a dot at a time and records only the color of the dot, which is unfortunately not the true color representation of the information on the map. Calculations show that the scanner has

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* An Optronics International Corp. Model P-1000

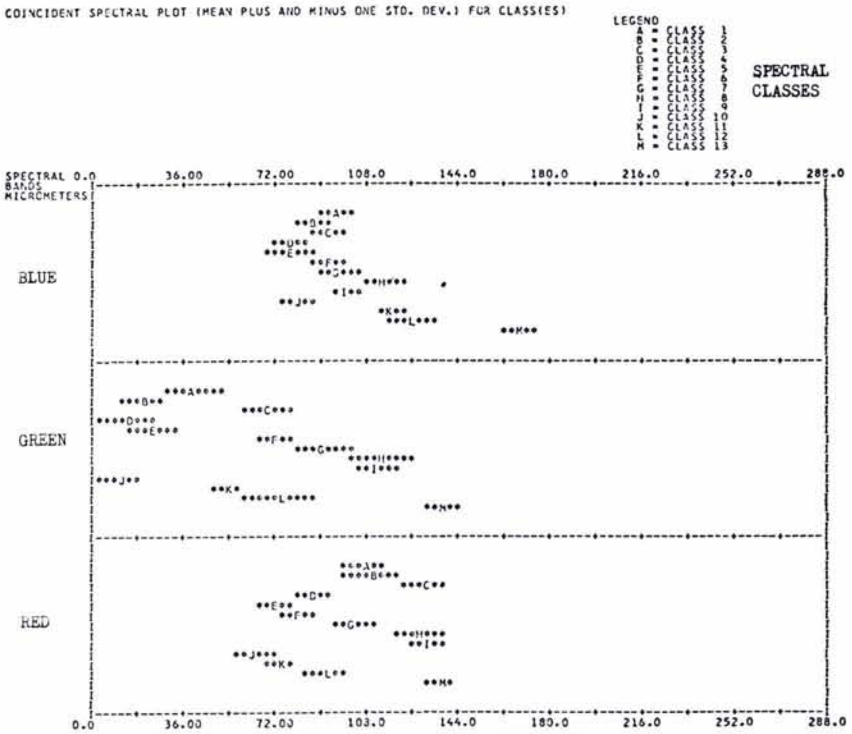

FIG. 4. Coincident spectral plot of color classes from Kansas land-use map photographed under photoflood lamps using coarse grain film.

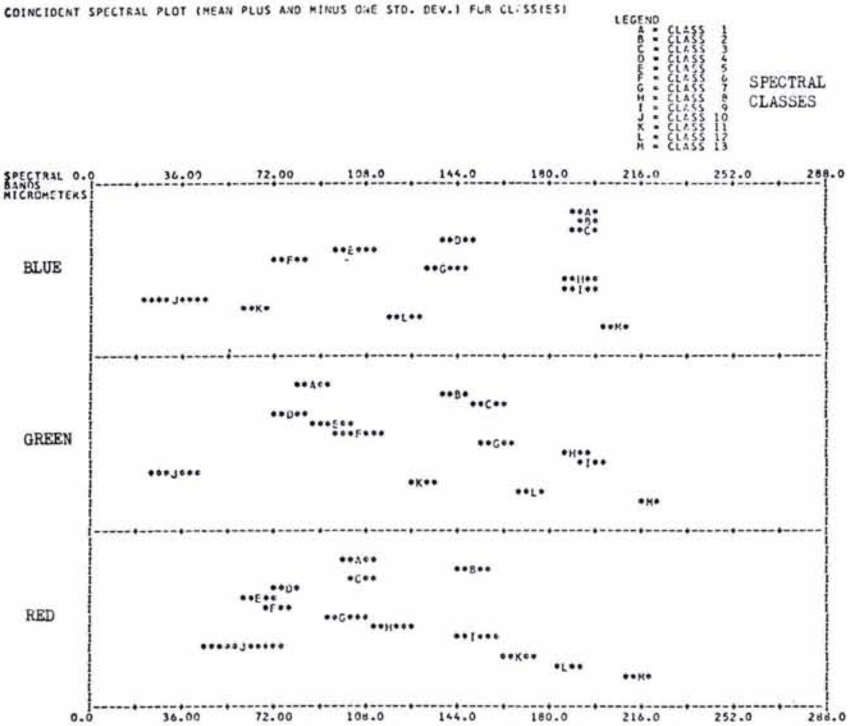

FIG. 5. Coincident spectral plot of color classes from Kansas land-use map photographed under bright sunlight using fine grain film.

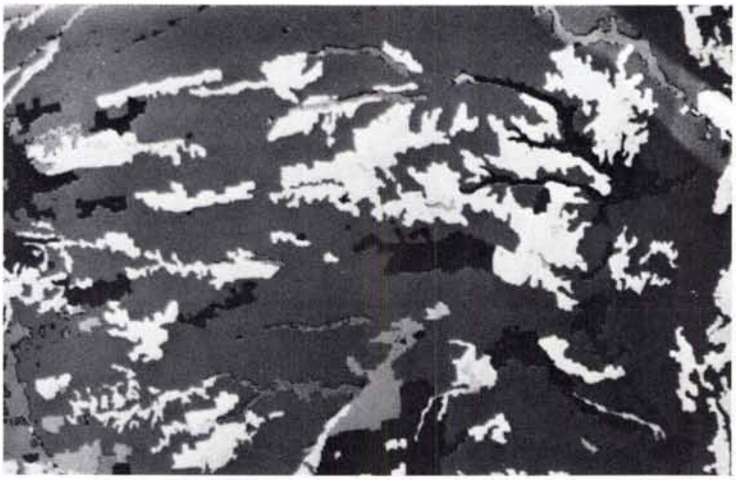

FIG. 6. LARSYS per-point classification of the three band digitized land-use map of Kansas.

to "see" three or more dots in order to record a reasonably true color. The variance of the recorded color depends on the number of dots that are averaged.

A method to improve chances of accurate recovery of the features without sacrificing effective spatial resolution is to increase sampling rate but keep the size of the scanner aperture fixed. This approach essentially provides more data for classification and post-processing.

CLASSIFICATION AND POST-PROCESSING

A small area from the Kansas land-use map was photo-reduced to a 35 mm transparency. Maximum likelihood classification was used to recover the color-coded features. This procedure consists of training the classifier and carrying out maximum likelihood classification using a processor known as LARSYS. The LARSYS system is discussed in detail in the references. The classified image is shown in Figure 6. It appears that the recovery of the color-coded features is excellent, especially in the central portion of the polygons; however, there are numerous misclassifications along the boundaries. Further comparisons with the images show that the error pixels correspond to the lettering and/or marks on the map. These marks are usually "thin" lines. During digitization, the scanner "sees' partially the black lines and partially the true colors, hence creating some intermediate color classes. To reduce misclassifications, one may either correctly classify the intermediate classes or correct them afterwards. The first approach suggests using a more powerful classifier. The second approach suggests post-processing. Experiments showed that post-cleaning is more cost-effective.

A simple but effective post-processing scheme is to estimate the position of a boundary and clean the misclassified pixels, if any, that are in its neighborhood. This method is based on the fact that if no misclassification has occurred at the boundary, there should be a clean stepwise transition of pixel class; thus, the output of an edge-detector should show a jump of one pixel width at the boundary. However, if some pixels are misclassified to some other classes, other than those on both sides of the boundary, the output of the detector should show consecutive jumps of total width longer than one pixel. The objective of cleaning is to make such a "thickened" boundary "thin." To do this, we estimate the position of the boundary by re-assigning the pixels on the thickened boundary to the color classes of the pixels before and after the jumps according to some criterion. For example, a simple half-and-half re-assignment serves this purpose. Figure 7 is an illustration of the one-dimensional cleaning process.

It is obvious that the one-dimensional cleaning process is effective only when the

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                                  1     2
                                  ↓     ↓
           scan line:      AAAAAAABECCCCDDDDD
edge-detector output:      100000011100010000
        cleaned line:      AAAAAAAACCCCCDDDDD
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FIG. 7. Illustration of the one-dimensional cleaning process. A "thickened" boundary occurs at position 1, pixel B is re-assigned as A, pixel E is re-assigned as C. A "thin" boundary occurs at position 2; no re-assignment takes place.

FIG. 8a. Land-use map classification processed by cleaning algorithm with parameter L = 2.

FIG. 8b. Land-use map classification processed by cleaning algorithm with parameter L = 3.

FIG. 8c. Land-use map classification processed by cleaning algorithm with parameter L = 4.

boundary is not parallel to the direction of cleaning. The classification map thus requires a two-dimensional cleaning process. A direct extension of the one-dimensional method to a two-dimensional case is handicapped by some problems, such as detection of parallel edges; thus, a more complex decision scheme is required. A simple but effective method to avoid these difficulties is to apply the one-dimensional cleaning process horizontally and then vertically.

It should be noted that the cleaning process is nothing more than a re-assignment of misclassified pixels based on an estimate of the positions of boundaries. Because the color-coded polygons are well separated by distinct boundaries that can still adequately reappear after maximum likelihood classification, the estimate of boundary position by the edge-detector is very likely to be sufficiently accurate. Based on this, it is subsequently expected that pixel re-assignment of boundaries is reasonably accurate. Even with this, the uncertainty of the position of the cleaned boundaries is not greatly affected; hence, resolution should remain unimproved. As a matter of fact, resolution is expected to be lowered because the re-assignment may move the boundaries slightly. How much a boundary can possibly be moved depends on a parameter L in the one-dimensional cleaning process. This parameter is the minimum length of consecutive pixels of the same class that are regarded as correctly classified. For example, if $L = 2$, then in the direction of cleaning a new class of more than one pixel in length is considered as correctly classified and will not be re-assigned; but a new class of length of only one pixel is regarded as misclassified and will be re-assigned. In this case, maximum shift of boundaries is one pixel. This uncertainty of boundary positions implies some loss of spatial resolution. However, such loss can be compensated for by a higher sampling rate, and not necessarily smaller aperture size. This is because more samples are available to help the estimation of boundary positions and, therefore, reduce the maximum possible uncertainty.

Figure 8a shows the classification map processed by the one-dimensional cleaning process horizontally and then vertically, with the parameter L set to 2. Results show that boundaries are more distinct and many of the misclassifications at the boundaries are removed. Furthermore, it is found that some other misclassified pixels in field centers, especially those corresponding to marks and lettering on the map, are removed. The general classification quality is significantly improved. Better cleaning can be achieved by setting $L = 3$ (Figure 8b) and $L = 4$ (Figure 8c). The misclassifications that still exist in Figure 6 gradually disappear. The price of this is the loss of resolution and details. Loss of resolution which appears to be "stair-like" is observed among some boundaries. Loss of detail is observed among some small polygons which disappear or are broken into several pieces. This implies that the parameter L must be set to some value which compromises between the degree of cleaning, loss of resolution, and detail.

EVALUATION OF SCANNER DIGITIZATION METHOD

Figure 9 shows a portion of the land-use map classification of Kansas. An overlay is provided to enable comparison with the original map polygons. The gray scale image is the cleaned classification map of the scanner-digitized data.* Regarding the table-digitized data as "ground truth," the cleaned classification matches extremely well, especially the boundaries of the areas in the central portion of the figure.

Digitization of physical feature maps using a table digitizer requires close human attention and laborious manual operations assisted slightly by machine. Such heavy dependence on human interaction affects not only the cost, but also quality as well as the time required to make data available to potential users. The scanner digitization method was proposed as an attractive alternative to table digitization primarily in order to reduce the dependence on human interaction, reduce cost of operation, and improve quality of digitization.

However, from the discussion in the previous sections, the quality of scanner digitization is strongly affected by the presence of writing and marks that are usually found on most maps. In fact, misclassification can only be reduced but not completely eliminated; therefore, extremely high quality may not be possible. This is not true for table digitization whose quality can always be raised by intensive human interaction.

Table 1 shows a comparison of the two digitization methods and Figure 10 is a plot of cost (estimate) against map complexity. The major cost of table digitization is editing and plotting. These items depend heavily on

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* Only eight different gray levels can be displayed, so the same gray level has been assigned to more than one color, causing an illusion of losing patches of colors.

FIG. 9. Comparison of land-use map classification and table digitized land-use map boundaries.

TABLE 1. COMPARISON OF TABLE DIGITIZATION AND SCANNER DIGITIZATION

Table Digitizer	Scanner
1) Spatial Resolution: limited by the resolution of the table digitizer.	1) Limited by the size of aperture of the scanner system.
2) Curve Resolution: limited by human eyes. Previous experience shows that curve can be traced by taking short intervals as 0.1 inch.	2) Limited by size of aperture and degree of concaveness of the curve. Since the aperture can be as small as 25 μm, it yields far better resolution.
3) Check point accuracy: limited by table digitizer, same as (1) and (2).	3) Limited by size of aperture, same as (1) and (2).
4) Data Acquisition Preparation: Need to label arcs before digitizing (high risk of error).	4) Need to photo-reduce the physical map to the size of the drum of the scanner system (low risk of error).
5) Editing: Need expensive re-plot and laborious manual checking.	5) Need post-processing or cleaning, but can be highly automated.
6) Job time: Depends on size and complexity of the map	6) Depends on size of the map only.
7) Efficiency of mass production: May not gain significant improvement.	7) May gain significant improvement.

TABLE 2. ADVANTAGES OF THE TWO DIGITIZATION METHODS FOR MAPS OF VARIOUS COMPLEXITY

	simple map	average map	complicated map
1) Cost	TD is lower	about the same	SD is much lower
2) Quality			
a) feature	TD is better	TD is better	TD is better
b) resolution	SD is higher	SD is higher	SD is higher
3) Job time	TD is shorter	SD is shorter	SD is much shorter
4) Efficiency gain by mass production	SD slightly advantageous	SD is advantageous	SD is advantageous
5) Recommended method	TD	TD or SD	SD

TD—table digitization
SD—scanner digitization

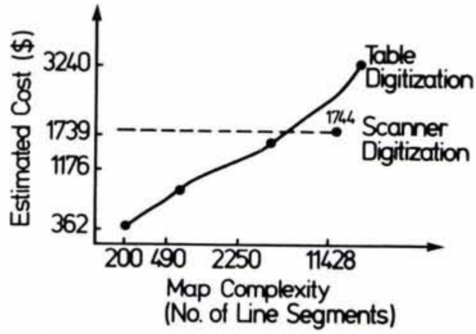

FIG. 10. Estimated cost versus map complexity for table and scanner digitization methods.

total length of all boundaries; therefore, the cost of table digitization increases proportionally to map complexity. On the other hand, the major cost of the scanner digitization method is the cost of computer classification and post-processing. These two items depend on the size of the map rather than the total length of the boundaries; thus, its cost should affect total cost only slightly. From Figure 10 it appears that there is a break-even point for the two methods. This suggests that one method is advantageous over the other for some maps and the reverse for other maps.

When it comes to choosing digitization methods, several factors should be considered; among these are quality, efficiency of mass production, and job time. Quality here is the spatial resolution and accuracy of map information. Because of limitations of the human eye, spatial resolution of table digitization may not be very high, but map information can be extremely accurate. Because of the very small aperture, the scanner method may provide better resolution, but due to classification error and post-cleaning, map information may be distorted.

Table digitization does not gain much in efficiency when several maps are digitized simultaneously because time depends on map complexity. However, the scanner digitization does get more efficient because actual scanning time is relatively small, and most of the cost is for setting up the machines. Finally, job time to table-digitize a map depends on map complexity; but scanner digitization has a relatively fixed time cost. Table 2 contains recommendations for map digitization. As a general rule, use of table digitization is recommended if the map is simple; otherwise, for more complex polygon maps, scanner digitization may be more attractive.

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