THE DISPLAY OF BOUNDARY INFORMATION: A CHALLENGE IN MAP DESIGN IN AN AUTOMATED PRODUCTION SYSTEM

Dana Fairchild
Geography Division
U.S. Bureau of the Census
Washington, D.C. 20233

ABSTRACT

Political and statistical boundaries are among the most important elements displayed on maps produced by the Census Bureau. The use of a totally automated system for mapping from TIGER files presents some interesting challenges in the display of these boundaries, the most important of which involves the display of multiple coincident boundaries. This paper explores several alternative methods of displaying boundaries on maps produced in batch mode on a 200 dot-per-inch monochromatic electrostatic raster plotter. Examples of maps generated using the different methods and the results of a survey conducted to solicit user preferences are included.

BACKGROUND

Political and statistical boundaries are among the most important elements displayed on Census Bureau field maps. With the exception of maps used by Census Bureau enumerators to locate housing units in the field, the purpose of most census maps is to accurately depict the boundaries of areas for which data are or will be tabulated. Even on enumerator maps the display of the limits of the enumeration area is of critical importance. For some Census Bureau operations, the boundaries that are displayed are coincident with one another; in other words, they run along lines on the earth's surface defined by the same coordinates. Coincidence of two to four boundaries is very common; on some maps as many as eight boundaries may run along the same line.

There are several criteria involved with the display of boundary information that must be met in either a manual or automated map-making environment:

1. A wide audience of users with widely varied levels of experience in map reading must be able to interpret the types and locations of boundaries on a Census Bureau map.

2. Boundaries that run along earth base features, such as roads and streams, must not obscure these underlying features or the text that identifies them.

3. Boundaries that are coincident with one another must be displayed in such a manner that each individual boundary is identifiable while the coincidence itself is evident.

While meeting the above criteria presents complications regardless of whether manual or automated map production systems are used, there is a definite advantage to a manual system. Simply put, the individual creating the artwork can use his or her judgement in the placement of a boundary or boundaries, so that the correct boundary location can be inferred if plotting the exact locations cannot be achieved without creating visual clutter. For example, if three boundaries follow a road and plotting each of the boundaries over the road causes obliteration of the road and boundary symbology, one or more boundary symbols can be offset from the road just enough to reduce image congestion yet allow for the correct inference of the true boundary locations. This same result can be accomplished in an automated environment if an interactive review and edit of the graphic image occurs before map plotting. Offset boundaries can also be accomplished in a totally automated mode. The plotting program can determine when an offset is needed and perform the necessary changes in symbology locations; however, this is extremely costly in terms of processing time.

When multiple boundary symbols are coincident, solid symbols are more likely to obliterate underlying features and one or more of the boundaries than are screened symbols. Screened symbols are generally more versatile than solid symbols because the reader is able to see solid linework beneath the dot patterns. Still, when several boundaries are overplotted along the same line, the image can quickly darken and the necessary information is difficult to interpret, if it is not lost completely. Traditionally the offset approach discussed above is used, and the same advantages of human intervention apply.

Color is a tool that can be used to help solve this problem because it assists the reader in distinguishing between symbols or groups of symbols, but it is also very expensive and time-consuming to use. Because of these expenses, the Census Bureau will most likely restrict the use of color to publication-quality maps.

The Census Bureau must produce hundreds of thousands of maps for field use within an extremely tight time frame (6-9 months) for use in collection operations for the 1990 decennial census. All maps will be generated by computer in batch mode using TIGER Files*. Although color plotters may be used for some map types, black and white electrostatic raster plotters will be used for the production of field maps for data collection activities. At this time it is expected that 200 dot-per-inch (DPI) technology will be used. Thus, the following constraints are placed on the methodology used for displaying boundaries on Census Bureau field maps:

1. No use of color
2. 200 DPI electrostatic raster plotters for output
3. All maps generated in a totally automated environment (no interactive review and/or edit)

*See papers by Kinnear, Knott, and Meixler in these proceedings for discussions of the TIGER System.

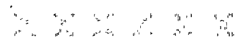
The purpose of this paper is to explore several alternative methods for displaying boundary symbols within the constraints discussed above. Several methodologies are discussed and examples of portions of maps reflecting the different approaches are provided.

Because the ability of the map reader to interpret boundaries is the primary concern, a survey was conducted to learn of the preferences of different groups of users for one method over the others. The results of that survey are included.

AUTOMATED BOUNDARY DISPLAY METHODS

Three approaches to the automated display of boundary symbols are discussed here. Each of the three uses symbols that are screened rather than solid because the plotting programs will place boundaries directly over base features when they follow them, rather than perform the complex and time-consuming calculations need to offset the boundaries.

Method 1 - Overplotted symbols
Each boundary is symbolized by a uniquely shaped screened symbol:



COUNTY AMERICAN INDIAN RESERVATION

When more than one boundary runs along the same line, the symbols are plotted over one another:

Screening is accomplished by a repeating 4 x 4 raster matrix pattern. The raster patterns that make up the individual symbols are unique for each symbol so that when one boundary overprints another, different rasters are turned on and the area of overlap is darkened. This is necessary for symbol shape distinction.

Darker matrix patterns allow for easier distinguishability of individual symbol shapes; however, overplotting several boundaries with dark patterns (for example, four rasters on in a 4 x 4 matrix) causes the area of focus to become too dark to easily identify each of the component boundaries. At the other end of the spectrum, a one-raster pattern is too light to define many shapes. Two rasters in a 4 x 4 matrix appears to work best for the overplotting method; more boundaries can be overlaid before approaching black. Even so, shape definition is not optimal in this format.

Method 2 - Alternating symbols
As with Method 1, each boundary is symbolized by a uniquely shaped screened symbol. Instead of overplotting coincident boundaries, the shapes of the component coincident boundary symbols alternate along the

boundary line. An example of the same coincident boundaries used to illustrate Method 1 would be:

With this method, darker raster patterns can be used for enhanced shape distinction because only base features are overplotted – not other boundary symbols; however, more linear space is needed for alternating the symbols. The symbols themselves cannot be smaller than .10" without losing shape on a 200 DPI device and more complex shapes cannot be acceptably defined at that size. Assuming a .15" size with .10 inch spacing between shapes, four shapes (boundaries) can be shown in one map inch. Sometimes boundaries are coincident for less than one map inch and all component boundaries cannot be symbolized in the allotted space using this method.

This is comparable to the problem encountered with Method 1 when so many boundaries occupy the same line that the area becomes too dark to decipher the component boundaries. With both methods, the map reader will have to infer which boundaries are coincident. These confusing situations should not occur frequently and the map reader should be assisted in his or her inference by locating and identifying the individual boundaries leading into the problem area.

Method 3 - Unique multiple boundary symbol
The same symbol appears on the map whenever two or more boundaries are coincident. A key number appears next to the symbol and also in the map legend, where the component boundaries are identified. This method eliminates the problem of unacceptable dot density and inadequate amount of space for correct boundary display. The drawback is that it causes the map reader to be totally dependent on the map legend since individual symbols are not uniquely symbolized as part of the multiple boundary. Example:

LEGEND

MULTIPLE BOUNDARIES

2 COUNTY AND AMERICAN INDIAN RESERVATION

Boundary Hierarchy
Certain political and statistical areas nest within others. For example, counties (or county equivalents) nest within states – they never cross state boundaries and state boundaries always run along a set of county boundaries. Therefore, a hierarchy exists. Traditionally, only the "highest" boundary in a hierarchy is shown on Census Bureau maps. For example, although state, county, and minor civil division boundaries are coincident along a state line, only the state boundary symbol is plotted, and the map reader infers that the symbol also represents the county and minor civil division boundaries.

While this approach certainly is economical and an implied hierarchy is not a difficult concept for many users of Census Bureau maps, it may be that an explicit display of all boundaries is preferable for some groups of users. Explicitly displayed hierarchies may be quicker to interpret even for experienced users of Census Bureau maps. The drawback is that more symbols are shown along the lines where a boundary hierarchy exists and the problems with dark areas in Method 1 and space restrictions in Method 2 are compounded. More legend space for text is needed for Method 3.

There are advantages and disadvantages to each of the methods discussed above, as well as to implicit and explicit symbol hierarchies. The Geography Division at the Census Bureau, in an effort to learn the feelings of different user groups about boundary display techniques, developed a boundary interpretation and evaluation survey.

SURVEY DESIGN

A survey package was developed that included six maps of the same area with boundaries displayed in six different ways:

Map 1 - Overplotted boundaries with an explicit hierarchy
Map 2 - Overplotted boundaries with an implicit hierarchy
Map 3 - Alternating boundary symbols with an explicit hierarchy
Map 4 - Alternating boundary symbols with an implicit hierarchy
Map 5 - Unique multiple boundary symbol with key numbers and explicitly described hierarchy
Map 6 - Unique multiple boundary symbol with key numbers and implicit boundary hierarchy

The maps displayed combinations of the following boundary types: international, state, county, minor civil division, incorporated place, and American Indian reservation. The maps that used an implicit hierarchy included the following information in the legend:

IMPORTANT NOTES ON BOUNDARY INTERPRETATION

International boundaries are always state, county, minor civil division, and incorporated place boundaries.

State boundaries are always county and minor civil division boundaries.

County boundaries are always minor civil division boundaries.

In each package the maps were arranged in an order different from any other package. Respondents were asked to use the maps in the order received to complete six exercises in boundary interpretation, one exercise for each map. Once the exercises were completed, the participants were asked which methods they thought were best and worst overall, which took the least and most amount of time to interpret, which were the easiest and most difficult to interpret, and which were probably interpreted with the most and least accuracy.

Four groups of approximately thirty people each participated in the survey. Each group was chosen based on average level of experience in interpreting Census Bureau geography and maps in general:

Group 1 - Clerical/computer digitizing operators
This group was expected to have very little experience in interpreting Census Bureau geography although they had a high exposure to interpreting general map base features. This group will be involved with interpreting boundaries for certain TIGER File input operations.

Group 2 - Census Bureau professional skills development training class
This group of new (less than one year) professional employees had just completed a six week course in all aspects of Census Bureau operations, including some training in Census Bureau geography. They were expected to have some understanding of this geography and a small amount of experience with map interpretation. As Census Bureau employees they will be users of a wide array of maps.

Group 3 - Participants in the Census Bureau Boundary and Annexation Survey from randomly selected incorporated places
This group of mayors, town clerks, and city engineers was expected to have good experience with interpreting a limited scope of Census Bureau geography and a good amount of experience in map interpretation. As participants in a survey used to certify current corporate limits, they will be regular users of computer-generated Census Bureau maps.

Group 4 - Professional Census Bureau Regional Office Geographers
This group was expected to have very high levels of experience in both the interpretation of Census Bureau geography and the use of all levels of census maps. As professionals in the Census Bureau's twelve regional offices, they will be users of most computer-generated map products and will be responsible for helping many inexperienced people interpret these maps.

SURVEY RESULTS AND DISCUSSION

Following are portions of each of the six maps showing the same boundary combinations displayed in different ways. An asterisk next to the map type indicates that the notes explaining boundary hierarchy (discussed earlier) were included in the legend.

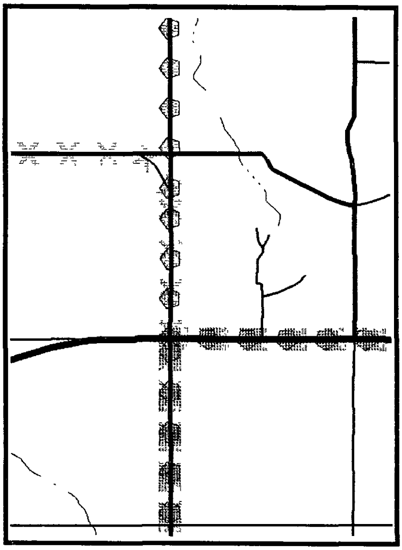
Legend for the first four maps:

STATE

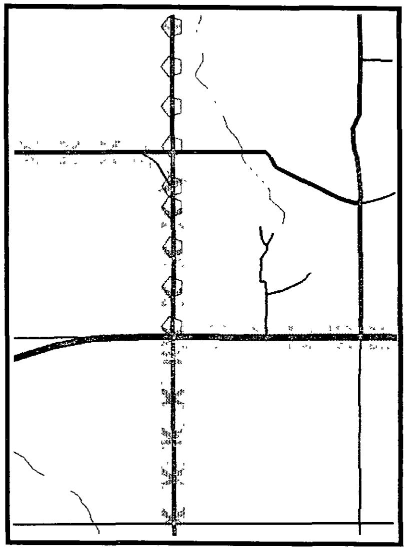
COUNTY

MINOR CIVIL DIVISION

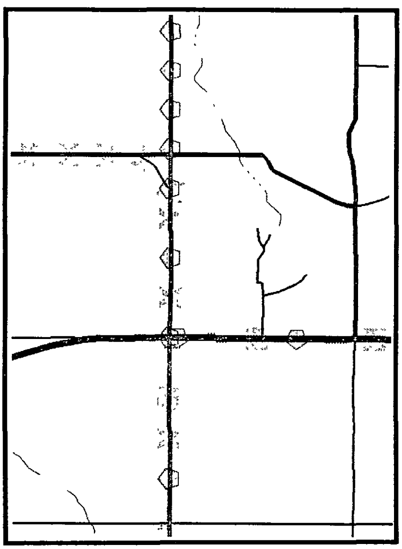
AMERICAN INDIAN RESERVATION



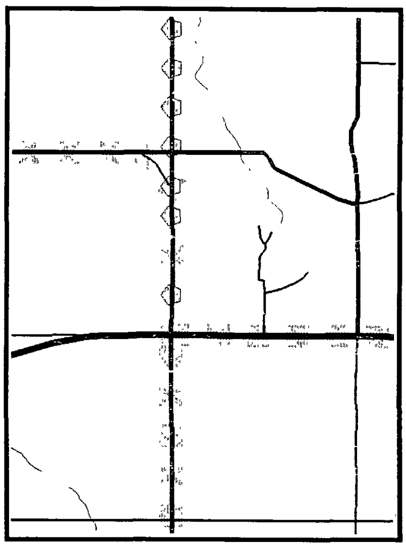
MAP 1: Overplotted Symbols, Explicit Hierarchy



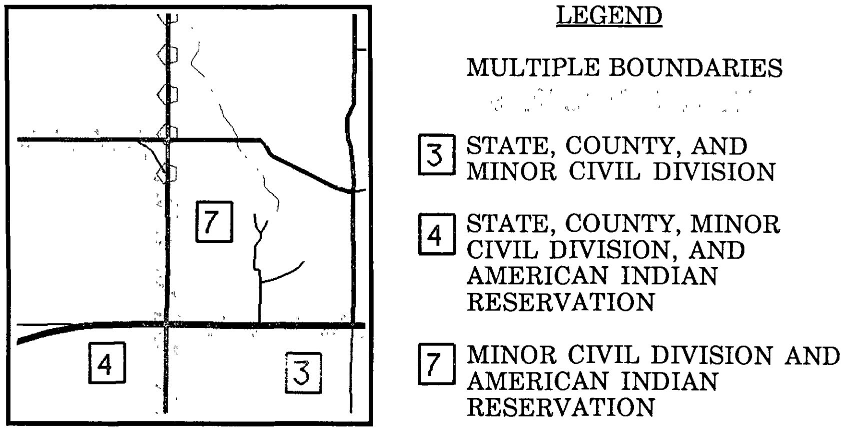
MAP 2*: Overplotted Symbols, Implicit Hierarchy



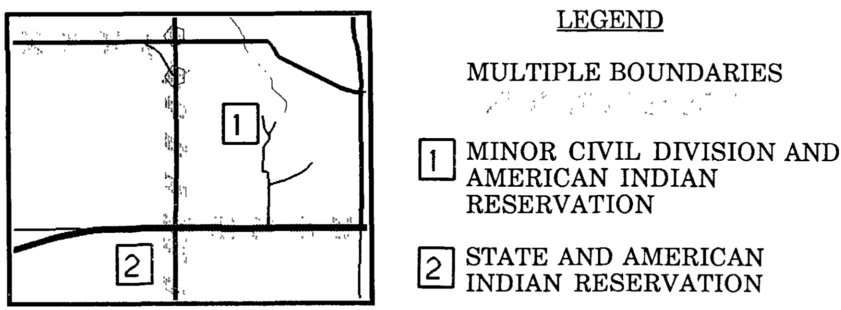
MAP 3: Alternating Symbols, Explicit Hierarchy



MAP 4*: Alternating Symbols, Implicit Hierarchy



MAP 5: Unique Multiple Boundary Symbol, Explicit Hierarchy



MAP 6*: Unique Multiple Boundary Symbol, Implicit Hierarchy

TABLE 1 shows the map type (boundary display method) selected by the majority of each of the four groups in response to the criteria stated at the left. The percentage selecting each map type is indicated in parenthesis next to the map number.

TABLE 1: Map type selected in response to selected criteria, by group

CRITERIA	GROUP 1	GROUP 2	GROUP 3	GROUP 4
Boundaries are easiest to interpret	3 (43%)	3 (50%)	4 (32%)	4 (60%)
Boundaries are most difficult to interpret	1 (35%)	1 (60%)	5 (34%)	1 (79%)
Boundaries take the least time to interpret	3 (32%)	3 (54%)	3 (41%)	4 (63%)
Boundaries take the most time to interpret	1 (32%)	1 (50%)	1 (60%)	1 (63%)
Boundaries probably interpreted with the most accuracy	3 (32%)	3 (42%)	4 (38%)	4 (52%)
Boundaries probably interpreted with the least accuracy	1 (35%)	1 (55%)	1 (51%)	1 (82%)
Best overall boundary design	3 (32%)	3 (50%)	3/4 (29%)	4 (63%)
Worst overall boundary design	1 (37%)	1 (63%)	1 (51%)	1 (67%)

Map #1 is clearly the least preferred in all aspects. This is to be expected since the areas of multiple boundaries are nearly black and indecipherable on portions of the map. If we disregard that particular map, the least preferred was almost always Map 5, which used a unique multiple boundary symbol with key numbers and an explicit hierarchy.

The percentages in favor of Maps 3 and 4 are not overwhelming when considered separately; however, disregarding the method used to treat boundary hierarchy, the alternative symbol approach is clearly the most preferred method. Based on this survey the overall ranking of the six methods by map type is (in order of overall preference):

1 - Map 4 (Alternating, implicit hierarchy)
2 - Map 3 (Alternating, explicit hierarchy)
3 - Map 2 (Overplotting, implicit hierarchy)
4 - Map 6 (Unique symbol, implicit hierarchy)
5 - Map 5 (Unique symbol, explicit hierarchy)
6 - Map 1 (Overplotting, explicit hierarchy)

While the unique multiple boundary symbol did not receive high ratings, many strong comments were made by those who did favor its use. These respondents indicated that although the legend was constantly consulted, one could usually expect to retrieve the correct information regarding boundary coincidence. With regard to the alternating symbol approach, many of those preferring the implicit hierarchy stated that it took up less space than the explicit display, and the notes on hierarchy in the legend gave the necessary information for hierarchy interpretation. Those preferring the explicitly displayed hierarchy argued that users should not have to decipher a hierarchy and that it is much simpler and more consistent to have all boundaries symbolized in their positions on the map.

Regarding the ability of the participants to correctly interpret multiple boundaries, some surprising points came to light. The first is that a rather low percentage of responses were correct. The maps used in the survey had many boundaries on them because multiple boundaries were needed to satisfy the survey purpose. They were not simple maps to begin with, and in addition to the complex geography, many people are simply not accustomed to looking at maps produced on raster plotters. None of the methods used to display boundaries are familiar ones, and differently shaped screened symbols take some getting used to. These ideas may explain the low percentages of correct responses to the interpretation exercises.

TABLE 2: Percentage of each group successfully completing boundary interpretation exercise, by map number

MAP NUMBER	GROUP 1	GROUP 2	GROUP 3	GROUP 4
1	35%	37%	47%	35%
2	9%	48%	21%	58%
3	39%	52%	42%	77%
4	35%	44%	47%	46%
5	17%	48%	5%	62%
6	13%	37%	16%	48%

TABLE 2 shows that more respondents (three out of four of the groups) correctly completed exercises using Map 3 (alternating, explicit hierarchy) than any of the others. One group responded to exercises correctly most often using Map 1 (overprinting, explicit hierarchy - also that group's least favorite) and Map 4 (alternating, implied hierarchy). It was expected that users would correctly interpret the boundaries on the map they most preferred, but the results presented in TABLE 3 show otherwise. In some cases, no exercises were completed successfully by a group of respondents using their most preferred maps. While we wish to provide maps that display boundaries using a method preferred by our users, we also want them to interpret them correctly!

TABLE 3: Percentage of correct responses to exercise performed using the most preferred map

MAP NUMBER	GROUP 1	GROUP 2	GROUP 3	GROUP 4
1	0%	0%	*	*
2	20%	0%	25%	66%
3	50%	67%	50%	80%
4	0%	50%	25%	42%
5	*	50%	0%	50%
6	40%	25%	*	50%

*Not selected as the best overall map by anyone in this group.

In summary, the findings of this survey are:

1) Alternating boundary symbols were the most preferred, with implicit hierarchies slightly preferred over explicit hierarchies
2) Alternating boundary symbols using an explicit hierarchy were correctly interpreted more often than those using an implicit hierarchy.

Maps produced by the Census Bureau on electrostatic raster plotters will be very different from those produced in the past. Although current technology allows us to accomplish in a quick and efficient manner tasks that in the past were cumbersome, some concessions must be made. The advantages of speed and flexibility of electrostatic plotters outweigh the fact that the output is not a highly-polished product. Although not publication quality, the output is entirely sufficient for Census Bureau field operations. Adjustments must be made by Census Bureau employees and outside users alike in learning to use the new products. By including our map users in our map design process, we hope to make the move from traditional, manually drawn maps to computer-generated maps an easier one.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the work of Amy Bishton of Mapping Operations Branch, Geography Division, U.S. Bureau of the Census, who wrote the programs that generated the maps used in this survey, and Lee Ebinger, Mapping Operations Branch, who programmed all of the boundary symbology routines.