Smarter Symbols: Smarter Maps

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ABSTRACT

The convenience of database-driven cartography has traditionally been offset by the design limitations of automated symbology. To address this, ArcGIS 9.2 introduces a rule-based way to store cartographic symbology alongside spatial data within a geodatabase. Symbology is applied intelligently to spatial features through powerful representation rules to achieve complex depictions. Geometric effects within rules can dynamically alter spatial geometry before symbology is applied, and values within the feature class table can define symbol properties to customize the appearance of features. The new framework offers geoprocessing tools that can automate aspects of symbolization and detect areas where symbols overlap even when the spatial geometry does not. The intelligent combination of the components of the representation framework can result in intricate and insightful database cartography. This paper investigates the potential of the representation framework by building and describing a set of representation rules and geoprocessing models that experiment with traditional cartographic depictions that have proven difficult to automate in the past.

1 INTRODUCTION

1.1 The cartographic challenge

Maps by their very nature are generalized; they are a reduced portrayal of geographic reality. This is true not just because of the obvious unwieldiness of a equal-scale map, but also because a map should present only certain parts of reality. Showing all of it is impossible and certainly undesirable. Even in topographic mapping there is a need to emphasize certain spatial phenomenon over others to communicate the map's message.

Symbols are the key to this inherent categorical generalization. They can simplify reality by classifying individual features into groups that can be depicted in a common way. Ideally, symbols should clearly convey the reality of the features they depict, while alluding to the depth of variation present among them. Symbology is the avenue through which the reality of the features is communicated to the map reader. Whether symbols are associative or abstract, they help explain to the reader what resides where.

Geographic features do not exist autonomously in reality, but instead can appear differently in response to proximate features; and, they rarely arrange themselves neatly on one horizontal plane as they are forced to do on a map. The challenge in mapping is finding ways to illustrate these relationships while depicting tangible and non-tangible spatial continua, many of which likely overlap. Effective symbology serves to categorize spatial features to organize them to be understandable, but at the same time to describe them thoroughly enough to show their unique characteristics where relevant.

1.2 Historical symbology

Historical maps look the way they do partly from which cartographic style was in fashion at the time, partly from whatever political motives lay behind their making, and largely from the technology available to reproduce them. While maps owe their beginnings to ephemeral scratches in the sand, snow, or on the cave wall—and later to hand colored notations on parchment—the strength of a map is most evident when it is able to communicate geographic reality to a large audience. This requires replication. A map may be beautiful and detailed, but if it cannot be reproduced, it is little more than artwork.

Early printed maps were made by carving around raised areas in woodblocks to hold ink for a single impression. The resulting symbols were somewhat crude, not only from rough cuts but also because the ink had a tendency to bleed out from the sides of the wood and blur the detail. Once maps were made by engraving reverse images into soft copper sheets—filling the grooves with ink and making an impression by pressing paper against the copper—multiple maps could be made in succession before a re-inking was required. But still, features could be rendered only by varying the length and width of engraved strokes—there was no way to create a smooth fill, or any colour other than solid black. And, copper is so soft that it was very difficult to create symbols with much detail. The invention of lithography permitted imageable areas to be made by applying a lampblack grease to void areas on a smooth stone. Varying the amount of grease permitted tonal gradation for the first time in a printed environment. Furthermore, since a tool was no longer required to physically scrape map markings, symbols could be rendered in finer detail. With the advent of color lithography came the ability to use variable tones of hue to further advance symbol design [Rumsey and Punt 2004].

Once reproduction technology was mastered, the way symbols could be composed and applied to features was almost limitless. Out of convenience, cartographers organize features in the world into discrete categories in order to map them, but strictly following a classification structure leaves little opportunity for customizing symbology to portray the inherent diversity in features. The next challenge became how to use symbols in a replicable manner to classify reality.

1.3 Database-driven cartography

As soon as computers were able to efficiently store significant amounts of spatial data, the next logical step was to make maps using values contained in a database. Although geographic information systems (GIS) software was initially created only to process and analyze spatial data, it was soon expected to perform automated cartography as well.

The major benefit of database-driven cartography was that it could produce identical maps, or maps following identical specifications, very quickly. The challenge of replication clearly had been overcome, but with the limitation that natural variation in the data was left unrepresented. The cartographer had all but lost a role in the map-making process: symbols could still be designed in this new medium, but the way they were applied to features was nearly uniform. There existed a need to leverage the power of the database to drive symbology, yet retain enough flexibility to represent features with some diversity. This need is now being addressed with the introduction of rule-based cartographic representations into a commodity GIS.

1.4 Representation symbology

There is recent development in ArcGIS 9.2 that helps bridge this gap between database organization and feature variability [Hardy et al 2005]. Previously, symbol information was applied to features and stored in individual map documents and optionally managed as styles. There was a disconnect between the symbols and the features they depicted. But now, feature classes can support representations which store rule-based symbology information in a geodatabase. Rule-based symbology can leverage the richness of GIS data to fully represent inherent variations in the landscape.

Representation symbology begins with common symbol elements familiar to commercial drawing software users: strokes and fills. Solid strokes of variable width and color illustrate linear features and solid, hatched, or gradient patches fill polygonal features. These elements form the initial structure of a representation rule. Geometric effects can then be added to rules to dynamically alter the geometry—even the geometry type—prior to symbolization. Complex depictions can be achieved by chaining geometric effects together so the result of one becomes the input to the next, creating a depiction of a feature that differs somewhat from the spatial geometry of the feature that is stored in the GIS database. This is the key to allowing expressive cartographic portrayal of the landscape without disrupting the spatial integrity of the geodatabase [ESRI 2004]. Custom geometric effects can be written and easily loaded into the representation framework to solve specific problems.

In addition to strokes and fills, representation marker symbols can be introduced into any representation rule regardless of the input geometry type. Marker placement styles dictate how these symbols will be placed in relation to the geometry. Representation markers themselves are composed of strokes and fills, and can also include chained geometric effects. A comprehensive editor provides a drawing canvas and a construction toolset to create and modify representation markers.

A further degree of refinement can be achieved when geometry includes repeating phases of dashes or markers. The phases can be controlled by representation control points, which are vertices with additional intelligence to manage the specific placement of the repeatable parts of the symbol. Control points are invaluable for synchronization of patterned lines, as well as for ensuring that sharp corners occur in a visible section of the pattern. They can be introduced dynamically at sharp corners by a geometric effect or persisted in the geometry when created with a geoprocessing tool or interactive editing.

All the components that can be added to a representation rule become modifiable properties of that rule. Representation rules become powerful cartographic tools because they can react to the nuances of the feature-classified data they depict when rule properties are mapped to fields in the database. This means that the inherent variability that cartographers could reproduce in the hand-drawn realm is now available in a digital cartography environment.

2 SYMBOLIZING A FICTICIOUS MAP

Sample data was digitized and attributed to form the basis of a fictitious study area. The database was subdivided into three thematic groups. The study area forms a stereotypical topographic map with natural landforms, hydrography and transportation features. This map presented a variety of cartographic challenges common in topographic maps.

At the start of the process, the data was added to the map and symbolized with standard GIS symbols. These symbols were then modified to produce the maximum level of complexity available from GIS symbology. Screen shots were taken at this stage to illustrate the capability of these standard symbols.

Some of the existing symbology was converted into representation rules, while in other cases, entirely new rules were created to demonstrate the functionality of symbol creation in this framework. With the initial structure in place, representation rules were modified with additional geometric effects and the rule properties were adjusted to further refine the portrayal.

The goal was to show that complex rules can be created from existing GIS symbology as well as from scratch. In either case, the rules can be further customized to suit a cartographer's specific needs. With the rules in place and applied to the data, the map was fully realized without the need for any edits to the data. Additional screen shots were taken again at this point to illustrate the enhanced capability of representation symbology.

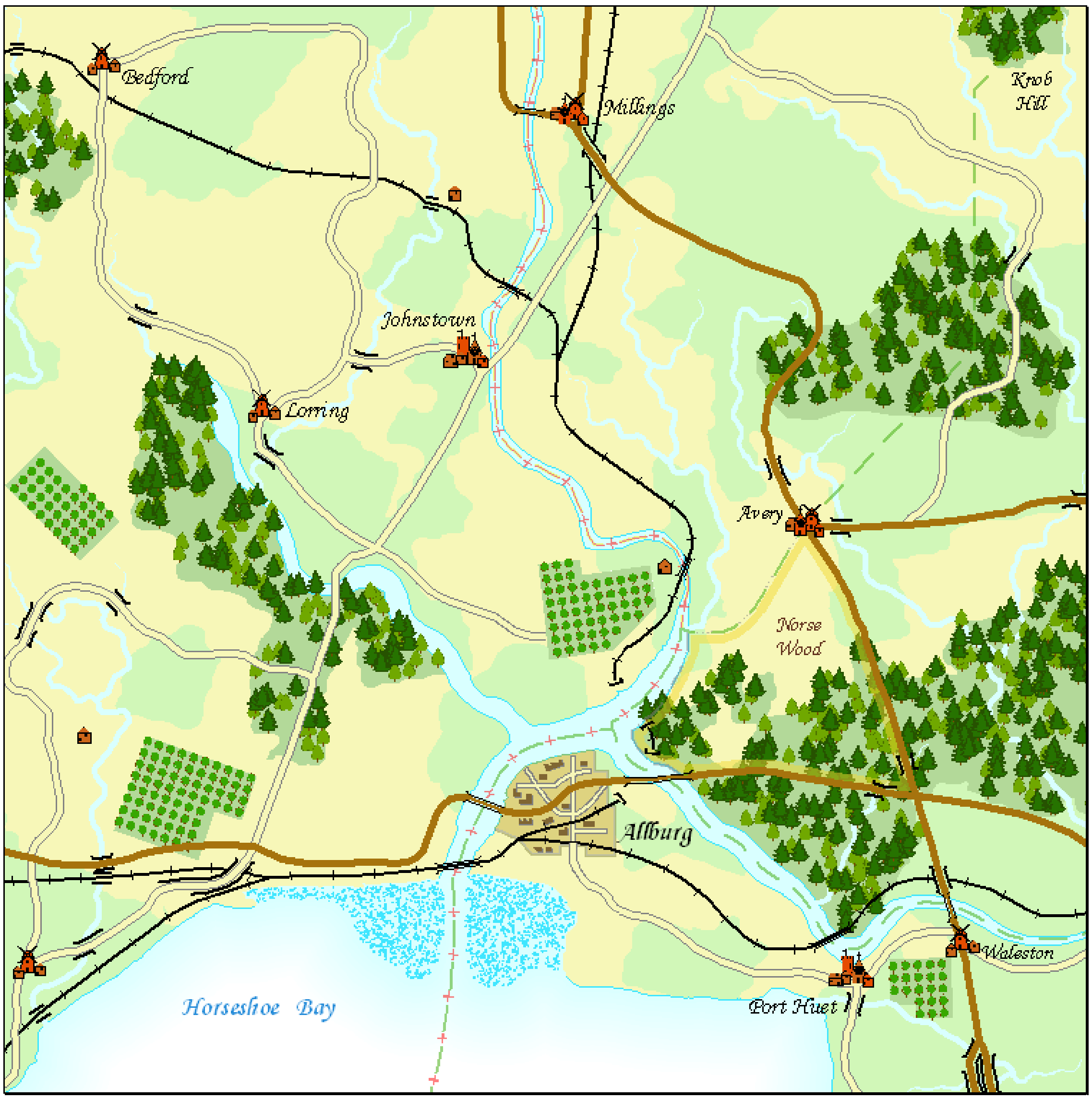

fig 2. The fictitious map symbolized with representations

3 CARTOGRAPHIC SCENARIOS

3.1 Estuary

To model geographic data digitally, features have to be assigned a dominant geometry type to render them as point, line, or polygons as these are, the only vector geometry able to be drawn by most mapping software. Not all features fit these discrete categories at all scales though. For example, a common approach to modeling hydrology is to differentiate between the linear stream features that flow into polygonal estuaries that in turn flow into polygonal open water features. While this is an organizationally sound practice, difficulties arise when rendering these features on a map because discrete boundaries between these features are not visible in reality; water tends to flow imperceptibly from one to the other.

Most digital mapping systems are engineered such that a polygonal feature can be symbolized by a fill symbol and/or a linear outline symbol. To draw only a portion of the outline of a polygon either requires masking by a separate feature, or converting the polygonal outline geometry to line geometry that can be cartographically modified as an independent feature.

To approach this challenge another way, the Suppress geometric effect was created to dynamically suppress linear geometry between specified representation control points. These control points were added to the shoreline where the estuary empties into the ocean, suppressing the outline of the estuary feature in this area. Subsequent updates to the shape of the estuary would not cause discrepancies in the map because a separate linear feature did not need to be created to depict the shoreline, nor were any masking polygons introduced.

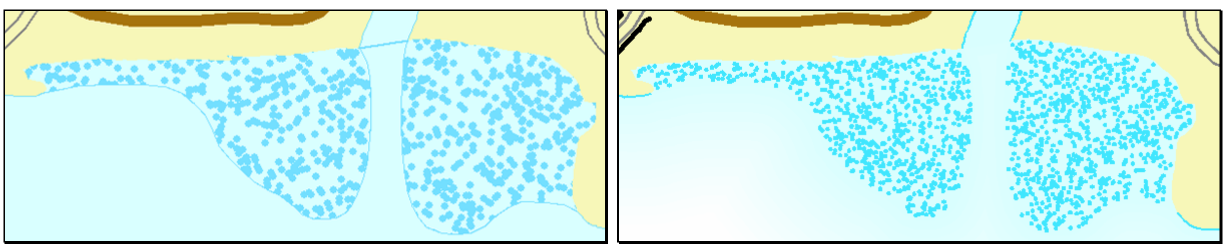

fig 3.1. Standard polygon outlines delineate foreshore flats and cross the mouth of the estuary. Using representations, the shoreline of the open water polygon is suppressed to create a seamless transition from to estuary to ocean, and from land to foreshore flat to ocean.

3.2 Towns and villages

Regional settlements are typically modeled as simple point features in digital cartography. They are then often rendered as uniform dots, or ordinally, using progressively larger symbols to denote population or regional influence.

It was common on hand-drawn historical maps to employ an oblique, birds-eye perspective when depicting towns and villages as small clusters of buildings scattered across the region. This accomplished two things. Firstly, it allowed a loose classification of settlement size to be applied by adjusting the number of buildings that were drawn at each location. Secondly, it enabled some of the unique character of each settlement to be depicted by customizing each cluster to include simplified version of one or more of the town's landmark buildings.

The representation rules that were designed to symbolize the regional towns and villages on this map achieve both these goals. Four separate buildings were drawn and saved as representation markers. Then four representation rules were created—one each for the village, town, major town, and fortified town classifications. The representation rules include multiple marker symbol layers, each referencing one of the building representation markers. Each symbol layer includes the On Point marker placement style, but uses varying x- and y-offsets to cluster the buildings around the spatial point location of the town while allowing them to overlap them slightly. The larger the settlement, the more marker symbol layers the representation rule includes. Some representation rules reference the same building symbol on different layers, but applies slightly different size and offset property values to ensure a sense of variation in the cluster. By including—or not including—distinctive buildings such as a fort, the unique character of the settlements can be portrayed.

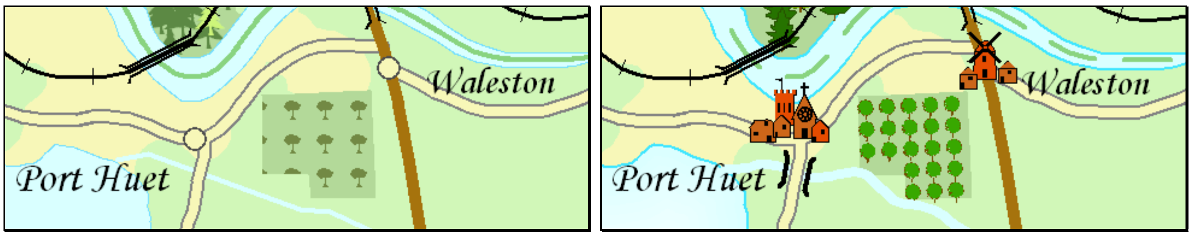

fig 3.2. Simple point symbols depict towns uniformly. Clustering custom-drawn representation markers in different arrangements captures town variations.

3.3 Woodlands

Cartographers often randomly disperse small pictorial symbols throughout polygons to characterize the nature of certain areas. On hand-drawn maps they were often drawn from an oblique perspective to impart a realistic, birds-eye view to the map. To mimic this effect, woodlands are symbolized in this map by oblique, randomly distributed stands of two types of coniferous trees.

The challenge with symbolizing polygons in a digital environment is that marker symbols applied to polygons generally can't be rendered beyond the extent of the polygon geometry. So, dispersing pictorial symbols within a polygon usually meant clipping exactly to the spatial edge of the polygon, effectively ruining any birds-eye perspective.

To avoid unnatural clipping, a representation rule was created that included two marker symbol layers to hold two different tree representation markers. Both marker symbol layers included the Randomly Inside Polygon marker placement style to ensure a naturalistic arrangement. Separate representation properties were set for each symbol layer, allowing a truly random appearance. These two layers then draw above a simple fill symbol layer that covers the polygon with a solid green.

Both marker symbol layers employed a clipping option that allows whole markers to be drawn at the polygon edge, so no partial trees will appear. The drawback to this technique is that some trees near the bottom of the polygons would appear to be growing outside of the woodland area in a different feature, in the grassland, or even in water. To counteract this, the Transform geometric effect was applied to both marker symbol layers to shift both marker symbol layers upwards, ensuring that the bases of all the tree trunks are correctly located inside the woodlands, while still allowing the tree tops to protrude above, enhancing the desired effect of the oblique perspective.

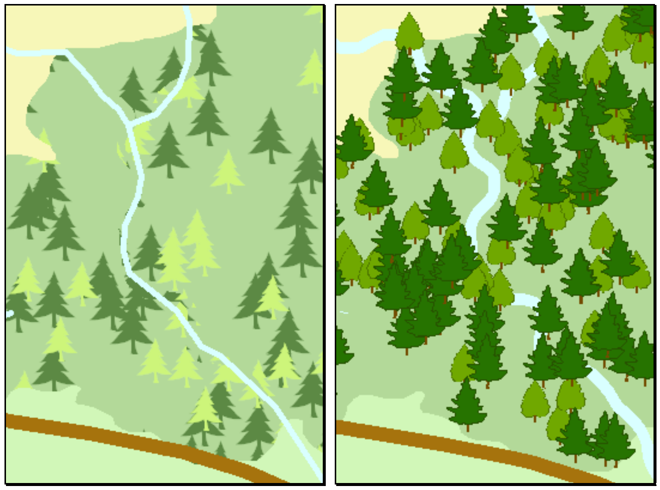

fig 3.3. Standard symbology creates a flat depiction with tree symbols clipped unnaturally at the edges of the feature. Using a representation geometric effect, the polygons dictating where the trees will be drawn have been dynamically shifted to create a natural, birds-eye depiction.

3.4 Tapered streams

The very linear nature of streams dictates rendering them as line features at most scales, but uniform stroke symbols cannot eloquently depict the nuances of stream hierarchy and stream origin. In the landscape, streams begin at a source, join with other streams to become rivers which then join with other rivers to become bigger rivers. Hand drawn maps implied this ascending hierarchy by drawing rivers and streams progressively thicker as they drained toward a coastline, originating from a sharp point at the source of the stream. A common digital approach to depicting stream order is to symbolize progressively larger streams with progressively wider strokes. Although the hierarchy is represented this way, close inspection reveals unnaturally jagged steps mid-stream, uneven transitions at stream confluences, and abrupt stream origins.

Natural streams have a very organic morphology since they react to the surface of the land. Digitally, line features are defined by a series of points. As with all digital cartography, hydrologic data should be modeled and captured with an eye toward the scale that the features will ultimately be displayed at. The challenge with organically shaped lines like those used to model streams is that the meandering character of the stream is determined by how many points are included in the data. There is a compromise to be made, though. Capturing too few points results in an awkwardly geometric appearance, but capturing too many can be cumbersome to store and make the data far too detailed for use at smaller scales.

To better represent the true character of natural streams, the Wave and Streamline geometric effects were added to representation rules to dynamically alter the of lines before a blue stroke was applied to them. The result is similar to the organic, hierarchical, tapered appearance of hand-drawn streams.

The Streamline geometric effect dynamically converts line geometry into narrow, wedge-shaped polygons that taper to a point on one end. A length property is specified to determine the distance over which the tapering will occur. In this example, only the first order streams (those that connect to another hydrologic feature only at one end), have the Streamline geometric effect applied to them.

The Wave geometric effect dynamically converts essentially straight lines to naturally undulating lines by applying a sinusoidal curve to them based on a wave period, a wave height (bend width), and the number of points per period that make up the curve. Although the algorithm generates a very uniform sine wave, the result is an organic curve because it is applied to the irregular geometry of the original data. This allows very generalized data to be rendered with more apparent detail than it actually contains. The main bends in the river are retained, but the undulating character of the streams is enhanced.

fig 3.4. Uniform stroke symbols don't portray the organic hierarchy of streams. Representation rules dynamically create sinuous curves and tapered ends to produce a natural appearance.

3.5 Orchards

Orchards and other plantations are generally planted so that the rows of trees are aligned to the longest axis of the orchard, making them as long as possible to facilitate the harvest. Rarely are these orientations exactly aligned to cardinal directions. In hand-drawn maps, manual sketching allowed a cartographer to orient orchard symbols to reflect the nature of the actual stand, and draw individual tree symbols to look like the species that they represented. In a GIS, the depiction of orchards is usually a uniform, orthogonal view—where even if realistic looking tree symbols are drawn, they appear flat and with rows oriented to the top of the page. Since the dominant axis of polygons is generally stored with geographic data, manual editing is required to align orchard rows to match reality.

To create the orchard symbols on this map, markers were introduced to the representation rule in a stepped grid placement. A geoprocessing tool was then used to determine the angle of the dominant axis of each orchard polygon, and store the value in the feature class. The grid angle property of the marker symbol layer was mapped to this field to draw the rows of trees parallel to the longest axis of each orchard.

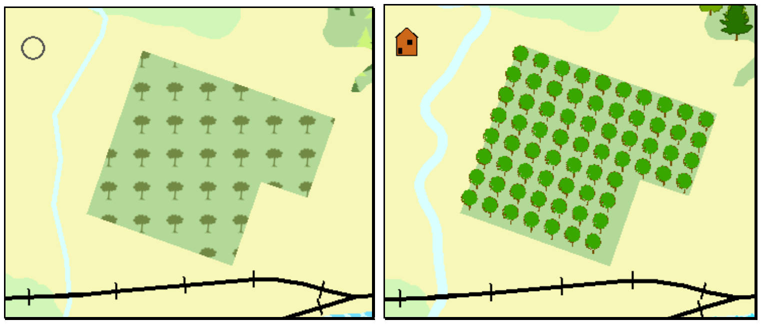

fig 3.5. Standard marker fills do not reflect the orientation of orchard planting. Using geoprocessing tools, the dominant angle of a polygon is determined and used to drive representation symbol orientation.

3.6 Boundaries

Depiction of administrative boundaries has long been problematic in GIS. Administrative areas need to be stored as polygons for analysis, but such boundaries are traditionally depicted using dashed or patterned outlines. Isolated polygons are less of a problem, but many administrational units come as tessellations or nested sets, where districts lie within counties, within states, within nations—all sharing sections of common boundaries. It is easy to adjust repeating patterns, and arrange coincident lines when hand-drawing these outlines, but typically digital mapping systems provide little if any control over the way the outline of a polygon is depicted. The very order that these boundary lines are meant to convey becomes ambiguous when the pattern phases get out of synch, or when multiple lines coincide.

The representation rule capabilities provide control for defining and synchronizing patterned lines. Dashed lines are generated using the Dash geometric effect, which has controls for pattern repeats and lengths, but also controls for phase behaviour at line ends and at control points. Patterned lines can also include markers within their patterns, their placement dictated by marker placement styles within the rules.

When the boundaries of this map are drawn with standard symbols, they merge together, erroneously appearing as a solid stroke, and the pattern goes out of phase at certain points along the line. Once the boundaries are symbolized with representations, control points can be automatically introduced at sharp corners, and additionally at places where boundaries that were shared now depart in separate directions. The result is to ensure that the several depictions sharing the common boundary remain locked in synchrony.

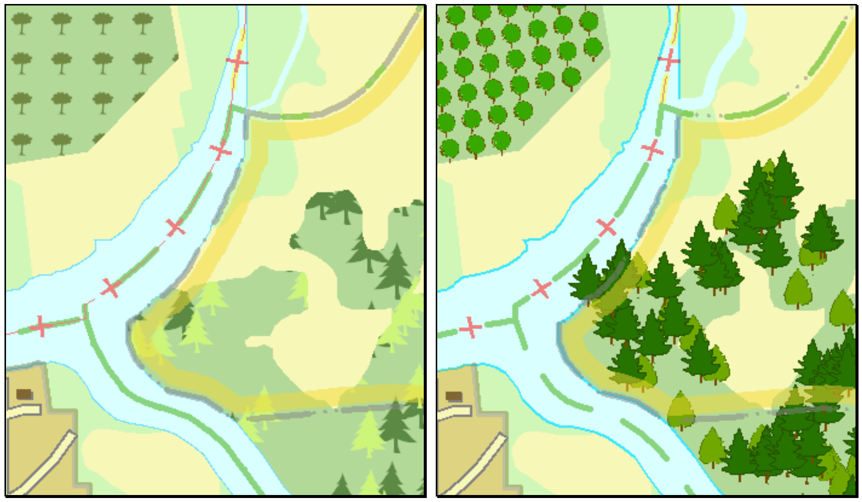

fig 3.6. Standard patterned line symbols can overlap when they symbolize coincident boundaries. Representation control points ensure that the patterns stay synchronized.

3.7 Overpasses

Creating visual hierarchy between intersecting transportation and hydrographic features using an automated method has long been a difficult task. Early digital mapping systems were able to symbolize discrete features, but there was little, if any, consideration of features that interact with one another in reality. Hand-drawn historical maps took these interactions in stride. A bridge symbol wasn't a randomly placed symbol, but one that was placed thoughtfully in relation to a stream and a road, for example. This ascending hierarchy was implied by drawing parapets around primary features and then drawing subsequent features which would abut the parapets, but not continue past. Introducing these 'gaps' into spatial data has proved troublesome however, since digital data tends to require feature connectivity for analysis. Representation rules can solve this inconsistency by creating and symbolizing dynamic geometry that is independent of spatial geometry.

A common approach to mimicking this effect in digital mapping is to split and hide portions of some features but this requires time consuming manual intervention. Drawing the parapets around which to split and hide features is predicated by the possession of point or line geometry specific to bridges and tunnels, or on the notion of the linear data having a populated attribute field which indicated the location of bridges and tunnels. More often than not, these preconditions were not satisfied in the database.

Conceptually, the notion of creating a new feature where two existing features intersect is straight-forward, requiring merely the identification of intersections and the manufacturing of new data. The challenge is to create a feature that will look appropriate when symbology is applied to it. As previously stated, data for all digital cartography should be modeled and captured with an eye toward the scale at which it will ultimately be displayed. A bridge that appears with satisfactory spacing between the parapet and the road at one scale will be unsuitable at another scale.

The Create Overpass and Create Underpass geoprocessing tools can cartographically create this visual hierarchy. They rely on the symbology, the reference scale, and the user-defined designation of which features are 'above' and which are 'below' at an intersection, as well as how far apart to space the linear symbols for bridges (or tunnels). Masking polygons and linear parapet features are then generated. The masking is the key to the solution of this long standing issue. The masks are set at the feature level and use a relationship class to maintain connectivity. The mask will make the 'below' features vanish and form a visually satisfactory result. With the optional parapets features in place, the look is completed.

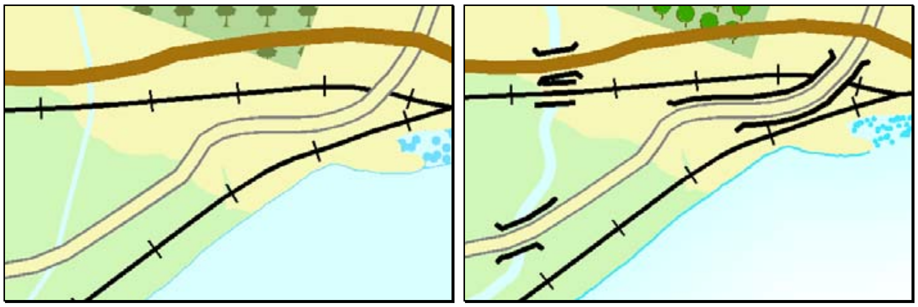

fig 3.7. Geoprocessing tools manage feature hierarchy and masking to portray overpasses.

4 CONCLUSIONS

The representation framework makes these complex depictions possible by creating and symbolizing dynamic geometry at draw time. The power is this approach is that this geometry can be different than the spatially referenced data held in the geodatabase, whose connectivity and spatial integrity generally cannot be altered for the sake of cartography. The representation framework empowers the cartographer to achieve quality cartography, well beyond the constraints of previous GIS symbology. Bringing together the elegance and simplicity of historical symbols with the power and ease of database cartography provides the best of both worlds.

The examples given above, although based on a historical map scenario, highlight the power of the representation framework to present GIS data in clear, cartographically desirable ways. The rich rule-based symbology, high degree of cartographic control, and dynamic generation of representation geometry through geometric effects and marker placement styles all contribute to the clarity of the presentation, much needed by modern mapping. These solutions to common cartographic problems are applicable to the production of a wide range of hardcopy mapping, not just topographic but also thematic. The solutions presented here are not revolutionary, but they are unique in that they are efficient, they leverage the power of database driven automation, and they required no manual editing to achieve.

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