Enriching The National Map Database for Multi-Scale Use: Introducing the VisibilityFilter Attribution

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ABSTRACT: The US Geological Survey's (USGS) National Geospatial Technical Operations Center is prototyping and evaluating the ability to filter data through a range of scales using 1:24,000-scale The National Map (TNM) datasets as the source. A "VisibilityFilter" attribute is under evaluation that can be added to all TNM vector data themes and will permit filtering of data to eight target scales between 1:24,000 and 1:5,000,000, thus defining each feature's smallest applicable scale-of-use. For a prototype implementation, map specifications for 1:100,000- and 1:250,000-scale USGS Topographic Map Series are being utilized to define feature content appropriate at fixed mapping scales to guide generalization decisions that are documented in a ScaleMaster diagram. This paper defines the VisibilityFilter attribute, the generalization decisions made for each TNM data theme, and how these decisions are embedded into the data to support efficient data filtering.

KEYWORDS: The National Map, Filtering, ScaleMaster, Multi-Scale

Introduction

In the mid-2000s, the U.S. Geological Survey (USGS) began implementing The National Map (TNM), which transitioned the National Digital Cartographic Database, a collection of compiled cartographic data, into an integrated database of layer-specific geographic information (Kelmelis 2003). TNM is now a seamless, continually updated collection of seven vector data themes: elevation, hydrography, geographic names, structures, transportation, boundaries, and land cover. The USGS uses TNM to make base layers accessible to the public and support 1:24,000-scale mapping through the US Topo program (Carswell 2013).

As The National Map database expands and improves, the USGS National Geospatial Technical Operations Center is exploring strategies to further enhance the data for cartographic and analytical use at various scales. Many other National Mapping Agencies (NMAs) have constructed Level of Detail (LOD) datasets of their own cartographic databases to support such efforts (Stoter 2005). This paper explores research into how the USGS plans to support multi-scale use of its 1:24,000-scale seamless TNM datasets through database enrichment.

The database enrichment is proposed to be implemented through a single attribution change to the current data models. This attribute will be termed "VisibilityFilter" and will define the smallest applicable scale-of-use for each feature within The National Map. The VisibilityFilter values are defined based on extensive generalization procedures derived from previous generalization research conducted at the USGS and information gleaned from historical topographic mapping specifications. The enrichment will enable TNM data to be queried efficiently and return a subset, or level of content, of the data appropriate for use at various scales. The phrase 'level of content' is used because a query will return features appropriate for the specific scale of use, though these features will have the same detail or feature resolution as the 1:24,000-scale base data. The level of content may require additional geometric generalization to meet user requirements; however, geometric simplification is not addressed with the VisibilityFilter.

This paper establishes how this database enrichment fits into current research trends at other NMAs and discusses the transition of The National Map database into a more multi-representation database-like storage repository. The generalization processes applied to various vector data themes are discussed, including how generalization rules are gathered, organized, and applied to each data theme. Initial results of the generalization are covered, including how generalization decisions are encoded within the VisibilityFilter attribution and how the VisibilityFilter attribute can be utilized by end users for smaller-scale mapping and analytical needs.

Background

This work continues to explore and implement activities researched by other NMAs. Stoter (2005) challenged NMAs to research various facets of cartographic generalization to support national mapping production. Several NMAs already have constructed LODs to support a wide breadth of multi-scale mapping initiatives. While the USGS has spent considerable effort to automate its 1:24,000-scale data management and map production system, other NMAs have focused on developing capabilities to support on-the-fly generalization (Torun et al. 2000) and investigating Multi-Representation Databases (MRDBs) (Lecordix and Lemairié 2007) to enhance and automate multi-scale mapping capabilities. All of these techniques emphasize database enrichment (Stoter et al. 2014).

A multiple representation database contains several instances of the same object that differ in resolution or abstraction (Sarjakoski 2007). In essence, the MRDB stores various LOD datasets where features between each LOD link to the same geographic object and support on-the-fly, pre-determined generalization decisions and store them within the LODs. This has been a major driver towards rapid map production at multiple scales as demonstrated by Torun et al. (2000) and Cecconi et al. (2002) where time-consuming generalization processes are stored within the database and simple generalization decisions are performed on the fly, such as data selection or map symbolization.

The importance of on-the-fly generalization through data selection (Frank and Timpf 1994; Cecconi et al. 2002) cannot be overlooked especially when the selection process is based off a small, easily interpreted data hierarchy. Buttenfield (1995) encourages embedding knowledge and rules that define the relationship of an object's cartographic and geographic meaning. This can become especially meaningful if the results of a complex generalization process were captured within the data, developing a feature importance factor or hierarchy within the data.

While the goal of enrichment of TNM datasets is to store the results of a generalization process, careful attention must be paid to the purpose of the generalization operators. The focus must explicitly be on data reduction, or statistical generalization, defined by Brassel and Weibel (1988) as a filtering process. Cartographic generalization, defined as a modification of local structure, can then be performed on a filtered subset of the enriched data. Generalization must focus on content changes (Roth et al. 2011) and lead to operations such as selection and elimination (Robinson and Sale 1969; Slocum et al. 2009) of data through scale.

Methods

Knowledge acquisition and organization

Understanding how generalization decisions are made is an important aspect of the generalization process (Weibel 1995; Kilpeläinen 2000). Ultimately, it saves time and effort from trial and error experimentation and establishes the results in historical processes and expert opinions. In order to focus generalization efforts to specific pieces of data, TNM data models were mined for content. There are 729 feature types within the TNM data models, 241 of which are rigorously maintained. These 241 feature types are the focus of generalization efforts explored in subsequent sections of this paper.

The data model was converted into a ScaleMaster diagram (Brewer and Buttenfield 2007). Nine benchmark scales were included in the diagram (1:24,000; 1:50,000, 1:100,000; 1:150,000; 1:250,000; 1:500,000; 1:1,000,000; 1:2,000,000; and 1:5,000,000), though this paper focuses on scales of 1:250K and larger. These scales have been determined based on the data's ability to be pushed to other scales (Brewer and Buttenfield 2007; 2010), prior USGS research (Stanislawski 2009; Stanislawski et al. 2012), current needs of USGS product services, and user requests.

To begin populating the ScaleMaster diagram, historical USGS topographic mapping standards were explored (USGS 1967; 1991). The focus of mining historical specifications was to target features in the current data model that were represented at smaller scales. The textual map collection criteria (Figure 1) were translated into generalization operations.

a.

1:24,000 and 1:25,000 scale
All airport facilities are mapped. All paved runways, taxiways, and aprons adjoining hangars or terminals are mapped to scale. Hangars, terminals, and other buildings are mapped as buildings.

b.

Selection at 1:100,000 scale
Show all runways associated with airports. Show to scale if they exceed the minimum symbol length and (or) width. Do not show taxiways or aprons.
Do not show hangars, terminals, or other buildings. (Plate 116, symbol no. 16)

c.

a. Civil and military aerodromes - Aerodromes are shown by symbol 213 or 214. Aerodrome elevations, if known, are shown adjacent to the symbol. Use symbol 213 and show the complete runway pattern as found on the 1:100,000-scale source maps if any runway meets a minimum length of 0.096 inch. Use symbol 214 if no runway meets a minimum length of 0.096 inch or if the runway pattern has not been mapped on the 1:100,000-scale source map. The latest 1:500,000 scale Sectional Aeronautical Charts should be used as supplemental source to verify and update aeronautical data.

Figure 1: Map collection criteria for airports for a) 1:24,000 maps; b) 1:100,000 maps; and c) 1:250,000 maps (USGS 1967; 1991).

As in the airport runway example demonstrated in Figure 1, runways less than 800 feet are removed at a scale of 1:100,000. Then at a scale of 1:250,000, existing runways with lengths less than 2000 feet are replaced with point symbols. A similar process continued with the rest of the data model content. Very few instances of generalization operations other than elimination were mentioned in the specifications. However, geometric simplification is likely implied through the horizontal accuracy standards of 1/50th of an inch at scale (USGS 1999). Only changes in data content were documented within the ScaleMaster diagram (Figure 2). The ScaleMaster diagram demonstrates where generalization efforts need to be focused (e.g. when many geometric constraints are being applied to a single feature), when data are completely eliminated from representation (e.g. police stations removed at regional scales), and when ancillary data are added or substituted (e.g. airport points replacing runway outlines).

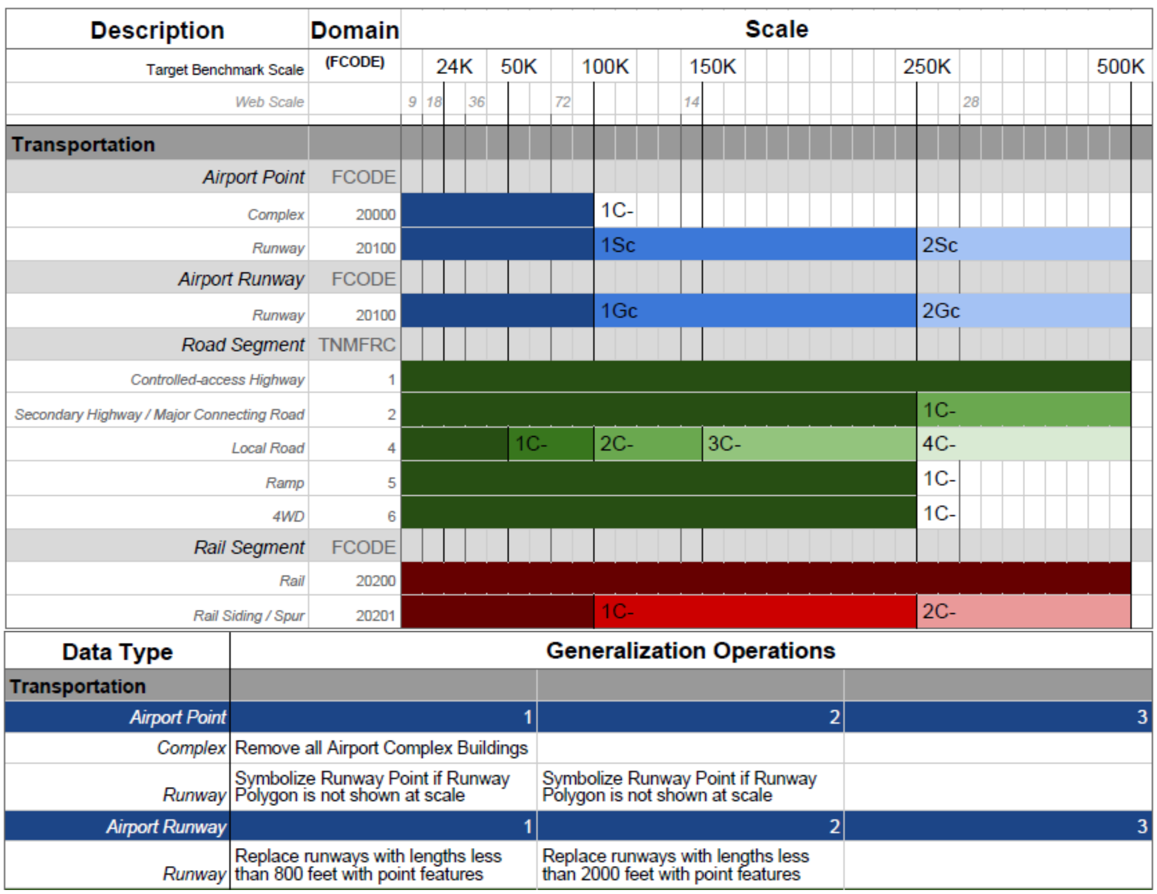


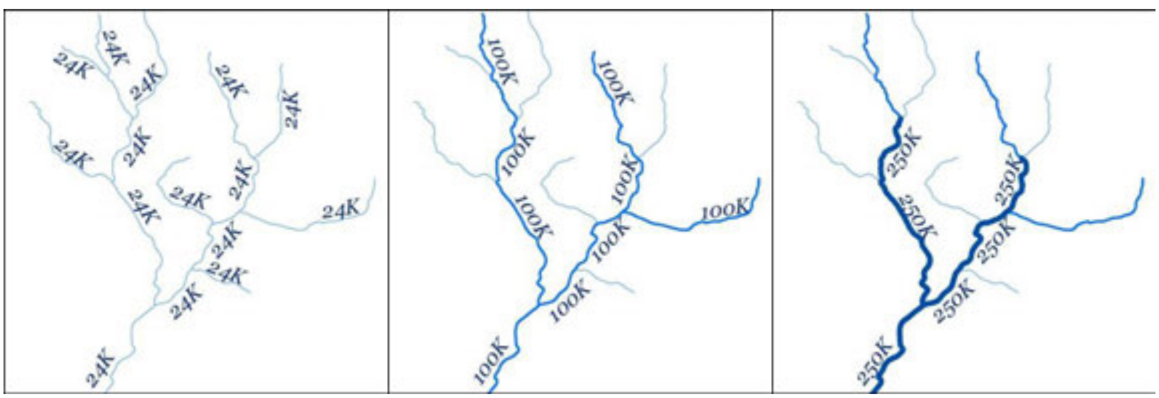
Figure 2: A portion of the ScaleMaster diagram derived from knowledge acquisition activities.

Except for hydrographic, contour, and road data, the effort of building the generalization rules has focused on 1:100,000- and 1:250,000-scale topographic content. In the near future, trends of generalization decisions between these two scales as well as the source scale (1:24,000) will be interpolated to determine the generalization decisions for the 1:50,000 and 1:150,000 scale benchmarks. Generalization decisions and requirements will then be gleaned from USGS cartographers currently working on small-scale (1:50K to 1:5000K) mapping designs, specifically aimed for cached web mapping.

Developing and Implementing the VisibilityFilter Attribute

The VisibilityFilter attribute will store the results of the filtering documentation in the ScaleMaster diagram. In most cases, data are generalized to the eight benchmark scales by gradually reducing content of the data in a ladder-like form of generalization (Stoter 2005). However, other data themes, specifically hydrography, repeat the generalization process from the source scale.

Before generalization, a master table is created. This master table serves as the link between the source dataset and the generalized dataset by performing a 1:1 join with a unique identifier. This master table also contains a VisibilityFilter attribute which is transferred back to the source data when the generalization process is complete. After each filtering iteration, unique identifiers are extracted from the generalization results. These surviving features create the level of content at that scale. The master table is updated, such that the VisibilityFilter value for surviving features is updated to reflect the current benchmark scale (Figure 3). By gradually overwriting the VisibilityFilter values in the master table, a hierarchy is developed that reflects the smallest applicable scale-of-use for each feature.



OBJECTID	Permanent_Identifier	VisibilityFilter
1	{9DC52270-8964-429C-BDBB-EDB4AFBDD6CC}	24000
2	{9A318C8E-E5EE-4CD8-A143-CE9235C3AA8C}	100000
3	{04720E4B-5AEC-497A-88E9-494A3DBE4A24}	24000
4	{71063EC2-FAC3-4F18-AEAF-37891C98CD01}	100000
5	{3D5109CF-2A14-4563-B23D-15752492A901}	250000

Figure 3: Iterative generalization to define scale-appropriate features (top) in hydrographic data through database enrichment (bottom).

Once the entire generalization process has been completed, the VisibilityFilter is transferred back to the source data, enriching those data and explicitly storing the generalization decisions for that dataset across the nine benchmark scales. In order to derive the level of content dataset from the source, 1:24,000-scale dataset, a simple selection must occur:

```
SELECT *
FROM [dataset]
WHERE VisibilityFilter >= [scale denominator]
```

Generalizing Hydrographic Data

Hydrographic generalization is the most complex process applied to TNM data. It is a formalized process discussed by Stanislawski (2009) and Buttenfield et al. (2011) and has been designed to convert the local-resolution enriched National Hydrography Dataset (NHD) to 1:24,000-scale appropriate data for US Topo map production. The process follows several main steps, involving data enrichment, pruning, generalization, and validation. The NHD is enriched with upstream drainage area metrics and groups features in partitions of homogenous line density. NHD features, primarily flowlines, are then gradually pruned, or removed, based on upstream drainage characteristics and other map-related requirements such as being a named feature.

Pruning is conducted until the line density matches that of a target value, which has been pre-computed based on hydrologic modeling to mimic real-world hydrographic features and their relative importance at benchmark scales. To achieve appropriate results, pruning is conducted differently by areas of similar characteristics (e.g. line density), which yield results that mirror natural variations within the data.

NHD waterbodies, areas, and lines are much simpler to filter. Non-network lines and polygonal features that are below National Map Accuracy Standards (USGS 1999) at each benchmark scale are removed. This process focuses simply on feature size and currently ignores other metrics such as axis dimensions (to collapse double line features) or feature clustering (in which aggregation would create a single, large feature out of multiple close features). Figure 4 demonstrates the hydrographic filtering results out to 1:250,000-scale.

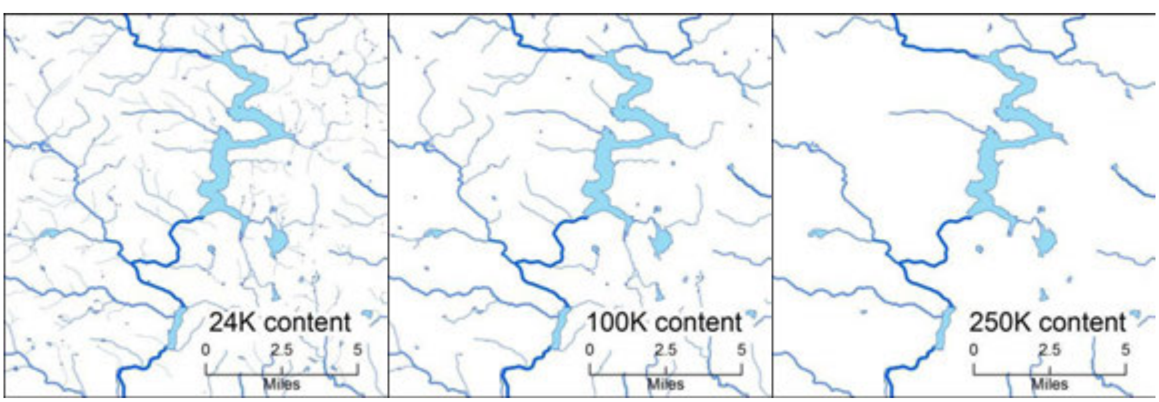


Figure 4: Results of stream pruning from 1:24,000 to 1:250,000.

Generalizing Transportation Data

To derive the VisibilityFilter values, transportation data undergo a ladder-based generalization approach where source data are initially filtered and the resulting filtered data are filtered again to the next successive scale. Similar to hydrographic generalization, road data must be filtered cautiously such that the road network is maintained. Esri's Thin Road Network tool is iteratively run, using thresholds defined by Brewer et al. (2013), shown in Table 1. The Thin Road Network calculates the network length in which each road segment participates. This creates a metric that can then be similarly used as upstream drainage for hydrographic pruning, allowing for gradual filtering within each functional road class. In the same way hydrographic data are pruned based on relative feature density, road data also are pruned based on density that define urban and rural regions. By partitioning the filtering process based on line density (Stanislawski and Buttenfield 2011), filtering results can be enhanced and can preserve localized data characteristics.

Table 1: Minimum road network maintained at benchmark scales

Scale	*Urban Areas (road density > 2.5km/km^2)*	*Rural Areas (road density < 2.5km/km^2)*
1:24,000	All Roads	All Roads
1:50,000	1 KM	7 KM
1:100,000	3 KM	11 KM
1:150,000	5 KM	14 KM
1:250,000	8 KM	18 KM

Interestingly, airports are unique in their ability to hold generalization decisions within the VisibilityFilter attribute since they are contained in two datasets, runway polygons and airport points. Airports are pruned based on longest runway lengths. In Figure 1c, runways that do not meet length thresholds are collapsed to points. Since two geometry types exist for airports, the collapse operation can be represented in the VisibilityFilter when the two datasets are joined:

```
SELECT *
FROM AirportPoint
WHERE AirportPoint.VisibilityFilter >= [scale denominator]
AND AirportRunway.VisibilityFilter <= [scale denominator]
INNER JOIN AirportPoint ON AirportRunway.FAA = AirportPoint.FAA
```

Generalizing Elevation Contour Data

Contours pose another interesting challenge to the filtering process. Contours at 1:24,000-scale are generated specifically to support US Topo map production, and are thus derived according to the 7.5-minute US Topo map extent. This is done to tailor contour intervals to the relief of each map. However, this business logic often causes contour breaks and inconsistencies at map boundaries where contour intervals may differ. Therefore, the process of filtering contours is a two-step process where the edge effects are first remedied and contours that conform to a 'new' contour interval are then maintained.

The filtering process is demonstrated in Figure 5 to render the 1:24,000-scale generated contours at a scale of 1:250,000. A modulo operation is first performed to harmonize the contour interval between maps:

*SELECT **
FROM Elev_Contours
WHERE MOD(Elev_Contours.ContourElevation, [TargetContourInterval]) = 0

Figure 5: Results of contour filtering using the modulo function.

The 1:24,000-scale contours are currently compiled at intervals of 5-, 10-, 20-, 40-, 80-, 100-, and 120-feet, though intervals of 80-feet and larger are only used in special circumstances. Common contour intervals used at the 7.5-minute extent are then majority-selected based on intervals within a 30-x60-minute extent (which define 1:100,000 maps) and within a 60-x120-minute extent (which define 1:250,000 maps). New contour intervals are derived based on terrain type, which is gleaned from the majority selection of contour intervals (Table 2). Again, the modulo function is used to filter the source contour intervals to intervals appropriate at smaller scales.

Table 2: Recommended contour intervals by terrain type (derived from Frye, 2008)

Scale	*Flat*	*Hilly*	*Mountainous*
1:24,000	5, 10 feet	20 feet	40, 80, 100 ,120 feet
1:50,000	20 feet	40 feet	100, 120 feet
1:100,000	20 feet	80 feet	200 feet
1:250,000	40 feet	160 feet	400 feet
1:500,000	50 feet	200 feet	400 feet

Generalizing Geographic Names, Structures, and Land Cover Data

Geographic names, structures, and land cover have a rudimentary generalization process at this time. Geographic name features and structures are eliminated altogether at various scales based on type (e.g. Police Station, Fire Station, etc.). Land cover data are simply filtered and removed based on size characteristics.

It is important to note, however, that contextual and local significance factors are a major driving force in retention of a subset of this content (Kilpeläinen 2000). Currently, geographic names are being filtered and enriched in support of US Topo map production for enhanced labeling. Among the various business rules for geographic names filtering is the retention of 'locally significant' features that otherwise would not be shown on the map; for example, features that share a name with the US Topo map index. The enrichment process involves adding Populated Place populations to points to develop a strong label hierarchy. Additional business rules such as retention of nationally significant features (national cemeteries, veterans' hospitals, etc.) are being explored to further supplement the old selection criteria. Currently, geographic names feature types (e.g. ridges and valleys) are being converted to linear and polygon data to support enhanced labeling. Once this process is complete, filtering rules can be adapted to consume geometric properties that accompany these higher level geometries.

Results and Conclusions

The goal of the VisibilityFilter attribute is to provide a basis from which users may represent 1:24,000-scale TNM data at medium and small scales to meet their needs. As described by McMaster and Shea (1992), the level of generalization depends on application-specific requirements such as map purpose, scale, and clarity. The VisibilityFilter attempts to standardize the second requirement about scale by defining the level of content appropriate at a given scale. Other forms of generalization (e.g. simplification, aggregation, displacement, etc.) are purposefully omitted as these are much more related to map purpose and clarity requirements. The VisibilityFilter attribute allows an end user to efficiently filter data to a target scale and leverage the attribute to proceed with further geometric generalization tasks.

Though the level-of-content concept developed through the VisibilityFilter does not provide an immediate cartographic Level of Detail dataset, it does put the USGS on the correct path. This work allows the USGS to enter the realm of multi-scale data use (cartographic or otherwise) similar to other National Mapping Agencies' initiatives in on-demand mapping, automated generalization, and MRDB development.

The VisibilityFilter attribute will improve current map products by providing a hierarchy of features within the data models that can support improved map symbolization, label priority, and map clarity through an improved visual hierarchy. Some improvements to multi-scale mapping, especially for web services, will also be gained from this hierarchy.

In the future, the USGS will continue to evaluate improvements to generalization decisions defined in the ScaleMaster diagram built around old topographic map specifications. Specifically, datasets such as point features may appear to be simple yet have not received the full attention they deserve. Point feature content has been filtered based on rudimentary metrics (categorical elimination). However, this can be improved by building business rules that take into consideration feature density and local importance (Raposo and Brewer 2013).

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