Dimensional Collapse and Airports in Multi-Scale Mapping

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ABSTRACT: Recent emphasis in multiple representations research has been placed on linking a progression of feature representations across a continuous range of mapping scales. Modifying geometry that is sensitive to scale changes poses a significant challenge. For some transitions there may be no change, or the change may be limited to symbol redesign. At specific mapping scales, geometry must change by modifying size, shape and other geometric characteristics. For example, the dimensionality of a feature representation may "collapse". This paper reports on dimensional collapse of feature complexes representing international airports in web (raster) multi-scale map treatments from four national mapping agencies: the United States Geological Survey (USGS), the Ordnance Survey (OS) of the United Kingdom, the French Institut Géographique National (IGN), and the National Land Survey of Sweden, (NLS). We explore how map scale change is reflected in map legends (ontology) and cartographic expression (semantics). This research constitutes a pilot study in a longer term project aimed at determining how to link features undergoing dimensional collapse within a multi-scale base mapping cartographic database.

KEYWORDS: automated generalization, multi-scale mapping, dimensional collapse, map ontology

Problem Context

Research about multiple representations of geospatial information has focused heavily on providing a continuous range of feature representation across mapping scales through cartographic generalization. Unfortunately the process of generalization and map composition is science balance between art and science? (Mackanness *et al.* 2007) Communicating meaning about geography through the medium of the map involves a complex interaction between semiotics and semantics. (MacEachren 1995) Semantics can change with scale, requiring simultaneous changes in semiotics. Like the alchemist's search for the mythical "philosopher's stone", the geographic information scientist's search for a "golden feature" from which all necessary representations may be generated. Just as the contributions by alchemists to scientific chemistry cannot be denied, GIScience has realized many useful results from the pursuit of multiple representations. (Buttenfield and Frye 2006)

One area of significant contribution in the pursuit for multiple representations is the plethora of automated algorithms for geometric generalization. Many published reports relating to multiple representations focus on algorithms for generalizing finely detailed representations to less detailed representations. These algorithms have proven their worth in GIS packages for simplifying datasets prior to analysis or cartographic manipulation.

We can see the benefits to algorithm development derived from multiple representations in the example of the Ramer-Douglas-Peucker (RDP) algorithm which was independently developed and reported by several different researchers in the 1970s (Douglas & Peucker 1972; Ramer

1972; Duda and Hart 1973; Baugmart 1974; Turner 1974; Pavlidis 1977). The RDP algorithm was utilized to generate structured multiple representations by Ballard (1981). A correction to speed processing was developed by Herschberger and Snoeyink (1992); and a correction for topological errors was introduced by Alan Saalfeld (1999). Both corrections were subsequently used by Buttenfield (2002) in a multiple representation database first introduced for efficient data transfer and later (Buttenfield and Wolf 2007) to resolve topological constraints between feature classes.

Building on similar work in multiple representations, Garland and Zhou (2005) discuss the multi-dimensional capabilities of the RDP algorithm and introduce an alternative algorithm. Their algorithm calculates the quadric error measure of the line in order to simplify using a tolerance calculated with the ortho-normal distance from the original line. They extended their results to features of any number of dimensions in a space of any number of dimensions. Most interesting is that their method can also handle features of mixed dimension, like a polygon and line combined feature.

Many attempts have been made to formalize rules for utilizing these generalization algorithms. Little effort has been applied toward producing generalized geometry for features beyond the limits of these algorithms. What we mean by "beyond the limits" is that at some points along the scale continuum, a feature representation cannot sustain additional modification without losing visual or geographic validity. For example, a polygonal stream channel cannot be further narrowed without collapsing; a compound of numerous small buildings cannot be further reduced in size without losing explicit footprints, or a road network can no longer incorporate on- and off-ramps without sacrificing clarity of intersections. Further generalization beyond these limits requires building a new feature representation, rather than continuing to modify the current version: a stream centerline must be substituted for the stream channel polygon; a convex hull or other envelope can surround the buildings; and so forth. In some cases, the collapsed representation can be derived from the current version. In others, as in the case of dimensional change for built-up areas or industrial complexes such as university campuses, factories or airports, new representations must be constructed. Creating the representations as well as preserving database links across these scale limits poses a significant challenge for multiple representations. For some transitions there may be no change, or the change may be limited to symbol redesign.

Su *et al.* (1998) applied mathematical morphology to the problem of dimensional collapse. In particular, a model was created to handle collapse of polygonal feature representation to linear or to mixed polygon and linear representations. Their method created a linear skeleton of the polygon feature and then develops rules to combine that skeleton with simplified versions of larger portions of the polygon (Su, Li, and Lodwick 1998). In 2006, Kang *et al*. examined the dimensional collapse operation in generalization and delineated eight topological relationships between 2-dimensional objects and 19 topological relationships between 1-dimensional and 2-dimensional objects.

This paper explores the semantics of dimensional collapse of cartographic symbology to answer the following questions:

- How does change in scale relate to dimensional collapse in feature symbology in map treatments?
- How is dimensional collapse reflected in the map ontology?
- How do map ontologies reflect the missions of mapping agencies? How do the missions impact dimensional collapse?

Methodology

The process of map feature generalization is complex and far reaching. In order to create formalized rules for automated generalization, the behavior of feature representations in response to scale change requires significant and varied types of knowledge. Armstrong (1991) distinguishes between geometrical, structural and procedural knowledge. The first incorporates measures of length, feature density, or instances of spatial conflict; the second refers to domain expertise such as in hydrology or urbanization; and the third informs choice and sequencing of generalization operators. Several different methods may be used to acquire each type of knowledge. Geometric knowledge may be acquired by comparative analysis among multiple algorithms. Interviews of cartographers may shed light on, and validate the decision-making process behind generalization to acquire structural knowledge. Presenting the results of different generalization sequences to map users in a may solicit user views about the quality resulting from various operation treatments or sequences. This paper emphasizes structural knowledge, by systematically comparing the mission statements, map legends and map series; we explore the impact of stated missions of national mapping agencies (NMAs) on the cartographic semantics surrounding generalization and specifically dimensional collapse.

Selection of NMAs and Airports

Because this was a pilot study, time considerations did not allow for the acquisition of paper maps. The choice of national mapping agencies was based primarily on availability and quality of rasterized cartographic treatments at multiple scales via a web-based interface. Four NMAs were selected: the United States Geological Survey (USGS), the United Kingdom Ordnance Survey (OS), the French Institut Géographique National (IGN), and the National Land Survey of Sweden, (NLS). Four international airports were selected in the cartographic products of each NMA: San Francisco International Airport (SFO), London-Heathrow Airport (LHR), Charles de Gaulle Airport (CDG) and Stockholm-Alranda Airport (ARN).

NMA	Airport	Total Area (km^2)	Runways (lengths in km)
USGS	SFO	7	4 (3.6, 3.2, 2.6, 2.3)
OS	LHR	12	2 (3.9, 3.6)
IGN	CDG	32	4 (4.2, 4.2, 2.7, 2.7)
LMS	ARN	33	3 (3.3, 2.5, 2.5)

Table 1. Airport areas and runway lengths

Creation of Graphic Treatments

One aspect of this study is to explore semantic changes in map treatments in response to scale. A series of graphic treatments were scanned at a common scale of 1:50,000 from cartographic compilations available through the websites of the four NMAs. These cartographic compilations were originally compiled at scales ranging from 1:24,000 to 1:250,000.

Graphic treatments such as these are typically created by scanning paper maps while manipulating the resolution of the scanned image to produce consistent graphic scales. A different approach was taken to produce the graphic treatments used in this study. Web mapping interfaces from each NMA were accessed via a web browser. Care was taken to ensure that the layers presented in the interface were rasterized versions of the paper products of the respective NMA. In the IGN *Géoportail* all layers were disabled except for the *carte IGN* which is normally provided as a background basemap. Both the OS Get-a-Map^{tm} and the NLS Mapsearch only provide rasters tiles identical to their paper products. The USGS provides its topographic sheets as Digitial Raster Graphics (DRG) through a number of sources, including direct download of geo-referenced DRGs.

Once the proper layers were selected in the web mapping interfaces, the next step in producing the graphic treatments was to determine the different cartographic compilations available through each web mapping interface. The USGS National Map Viewer provides 7.5 minute, 30x60 minute and 1x2 degree topographic layers originally compiled for scales of 1:24,000, 1:100,000 and 1:250,000 respectively. The OS Get-a-Map^{tm} web mapping service provides rasters of the OS Explorer Map, the OS Landranger Map, and the OS Road Map originally compiled for scales of 1:25,000, 1:50,000 and 1:250,000. The IGN *Géoportail* provides the SCAN25, SCAN50, *cartes départementales*, and *cartes régionales* originally compiled at scales of 1:25,000, 1:50,000, 1:125,000 and 1:250,000. The NLS MapSearch provides the Topographic Map, the Road Map, and the General Map originally compiled at scales of 1:50,000, 1:100,000 and 1:250,000. The web mapping services of each NMA provided other compilations which were not used in this study. Further, some of the NMAs had compilations at other scales and ontologies that were not available via the web interface, such as the OS Tour Map and NLS Mountain Map.

The web mapping interface was explored to determine the best “zoom level” for each compilation. For instance, the IGN *Géoportail* provides the SCAN25 compilation at three different zoom levels and the middle zoom level was used because it provided the largest extent while not losing too much information to resampling. The web interface was used to move around the area of study and multiple rasters were captured at the best zoom level and cropped using raster editing tools. These cropped raster tiles were assembled into a single seamless raster for each study area. Each seamless raster was imported into ArcGIS v9.2 and geo-referenced by co-registering the imagery to road network data. Layouts were created for each seamless raster at 1:50,000 and printed on high-quality paper. In the case of SFO, the USGS digital raster graphics were downloaded from the California Spatial Information Library in MrSID format and printed on similar 1:50,000 layouts.

The process resulted in thirteen 1:50,000 printed graphic treatments centered on four different international airports. The source data came from cartographic compilations across a range of 1:24,000 to 1:250,000. The web interfaces did not provide absolute scales for the 72dpi screen presentation, so the print resolution of each graphic treatment was variable. However, the visual quality of the graphic representations was adequate for this pilot study. Using paper maps would result in greater control over the print resolution of the graphic treatments.

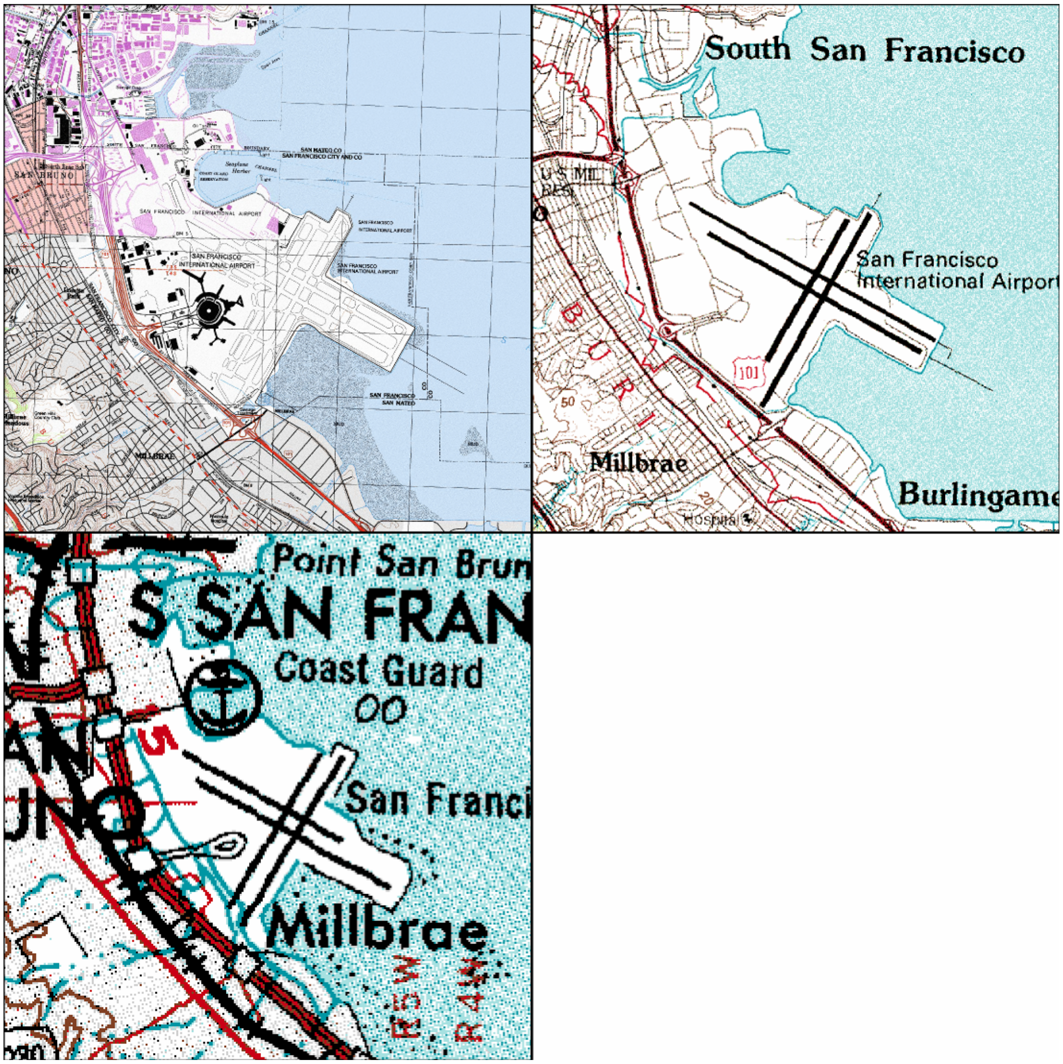

Figure 1. USGS 1:24,000 (upper left), 1:100,000 (upper right), 1:250,000 (lower left), presented as 1:100,000 scale graphics

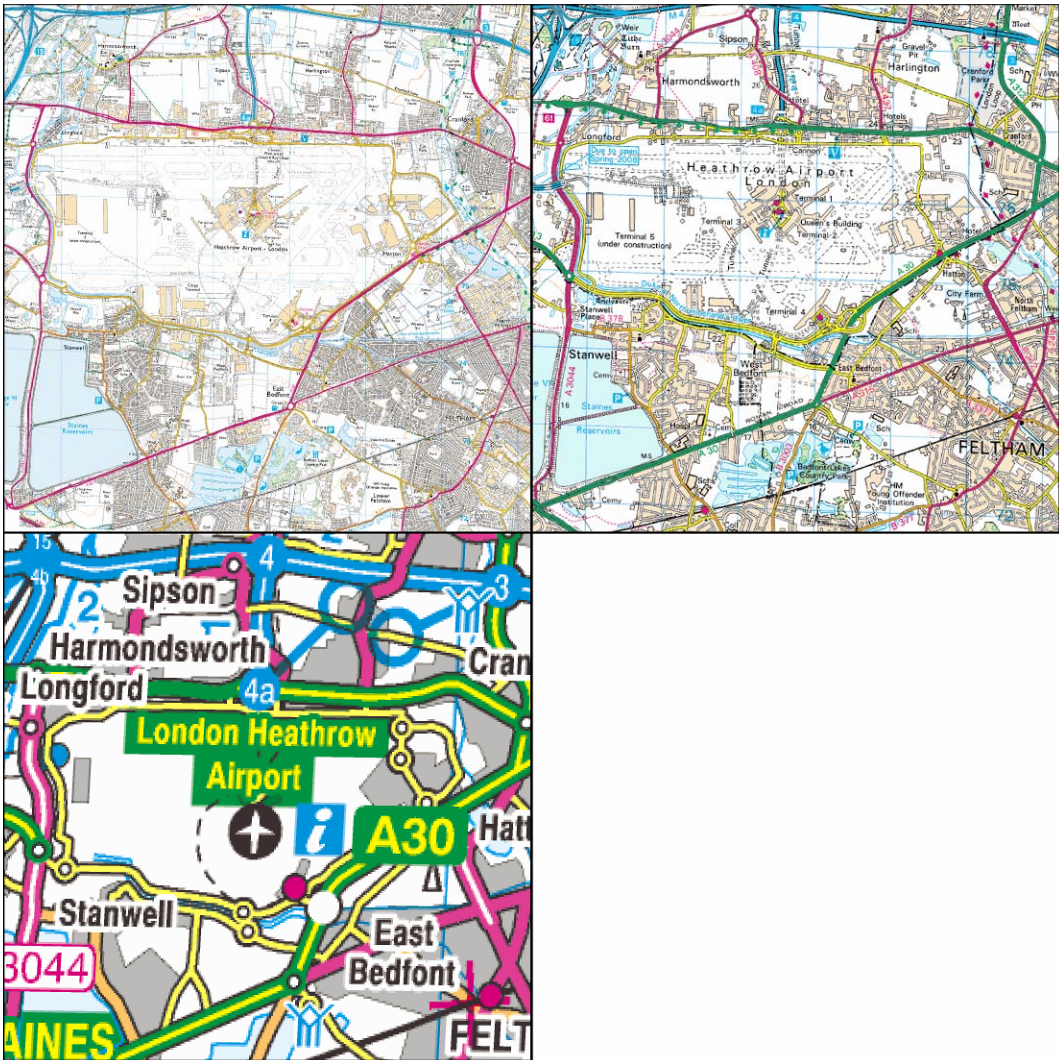

Figure 2. OS Explorer Map (upper left), LandRanger Map (upper right), Road Map (lower left), presented as 1:100,000 scale graphics

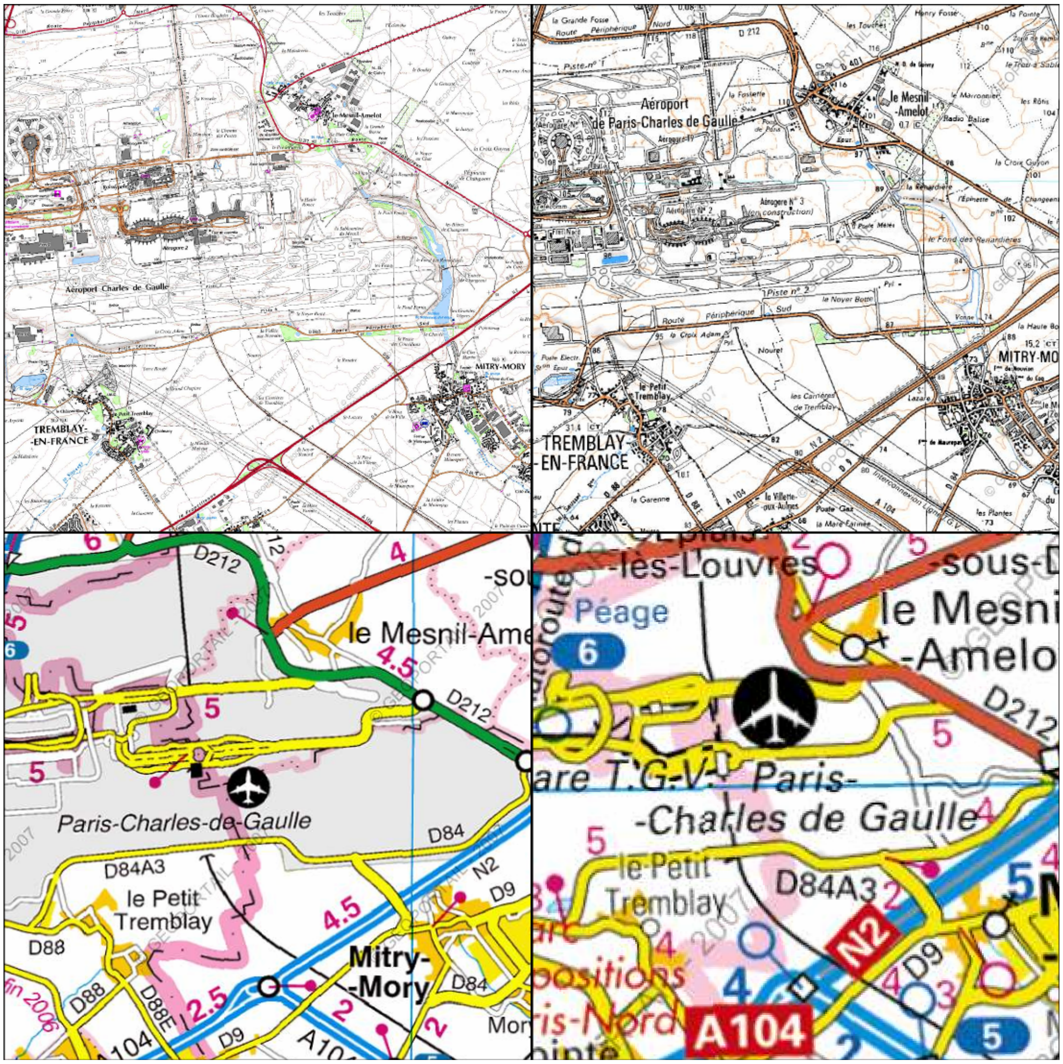

Figure 3. IGN SCAN25 (upper left), SCAN50 (upper right), SCAN Regional (lower left), SCAN Departmental (lower right), presented as 1:100,000 scale graphics

Figure 4. NLS Topographic Map (upper left), Road Map (upper right), General Map (lower left), Map of Sweden (lower right), presented as 1:100,000 scale graphics

Cartographic Semantics in Map Treatments

Cartographic semantics in this paper refers to the meaning derived from one or more of the three types of knowledge (geometric, structural and procedural) discussed above. An inventory of features within and around the major international airport in each study area was created. The cartographic semantics for the inventoried features were compared for changes in geometry, visual variables and visual hierarchy across compilation scale and among the national mapping agencies. Our goal is to identify changes, compare them among NMAs and relate them to agency missions.

USGS Representation of San Francisco International Airport

San Francisco International Airport (SFO) is the thirteenth busiest airport in the United States and the 23rd busiest in the world, in terms of passengers. (ACI 2007; ACI 2008) The USGS archive compiled representations at 1:24,000, 1:100,000 and 1:250,000. USGS uses only a limited palette of colors in the topographic sheets (Figure 1). Compared to the other NMAs, the USGS makes only limited use of line texture, relying instead on the limited levels of hue available in the palette and line width to differentiate features in topographic map treatments (Table 2). In the USGS legend under the feature class "Buildings and Related Features", three symbols are given, two for "Airport" and one for "Landing Strip". According to the legend, the two symbols for Airport are thick solid black lines representing runways and solid black outlines of runways. Landing strips are represented as dashed black outlines of a runway.

USGS SFO	Geometry					Visual Variables				
	Area	Line	Point	Text	Sum	Size	Shape	Value	Hue	Text.
All Scales	34	71	31	1	137	5	7	0	7	15

Table 2. USGS use of visual variables and geometry in map ontologies

The 1:24,000 representation of SFO spans four USGS 7.5 minute topographic sheets. Within the airport area, 123 unique feature symbols were counted: 104 area features, 13 line features, one point feature and five text features. At this compilation scale, the airport terminal is the most obvious feature rendered as solid black area features. The next features, in terms of visual hierarchy, are the other buildings within the airport area which are also symbolized with solid black area features. Following the buildings, US Highway 101 stands out, represented as a solid red line. The runways and taxiways are represented as thin solid lines representing the casings of the impervious surfaces and were counted as area features. The runways are not differentiated from taxiways and the measured length of the runways deviate from actual length by about 10%. Most roads within the airport are not represented in a way to be able to separate them from the taxiway casings or other, more prominent features. The USGS uses a light shade of red to indicate change in topographic sheets and many of the smaller buildings in the airport are colored this way resulting in the representations standing out less. There are four labels for San Francisco International Airport, one on each topographic sheet. All four labels use a slightly different lettering style, reflecting the fact that each USGS topographic sheet was compiled by hand by a different cartographer.

The 1:100,000 representation of SFO is made up of only 37 distinguishable feature symbols. The runways are the highest in the visual hierarchy being represented by thick, solid black areas. The representation for runway 01R/19L was shortened to fit the highway symbol for US Highway 101. Despite this shortening, this runway representation measured length deviates less than 5%

from the actual length and the other three runways deviate less than 3% from their actual length. No buildings or taxiways are represented in the 1:100,000 compilation. Road symbols within the airport area stand out more than in the 1:24,000 representation because the airport representation contains significantly fewer feature symbols.

The 1:250,000 representation of SFO is made up of only 20 distinguishable feature symbols. The visual hierarchy is dominated by the double red line representing US Highway 101 paired with the heavy black railway symbol for the subway line that parallels it. Within the airport, four solid black lines represent the four runways. Except for runway 10L/28R with 25% deviation, the measured length of these lines closely matches the actual length of the runways with a maximum of 6% deviation. The only roads represented are the access roads leading to the terminal. Interestingly, a series of blue lines stand out along the southwest side of the airport representing a network of drainage canals. This canal network is not represented in the small scale compilations.

OS Representation of London Heathrow Airport

London Heathrow Airport (LHR) is the busiest airport in Europe and the third busiest in the world in terms of passengers. (ACI 2008) OS provides scanned raster compilations at 1:25,000, 1:50,000 and 1:250,000 corresponding respectively to the Explorer Map, Landranger Map, and Road Map, via their web mapping service. OS makes use of shape, hue and texture equally to distinguish feature types within feature classes at all three compilation scales (Table 3). Each of the three legend ontologies also show little difference in the total number of feature types with 139, 143, and 103 feature types respectively. Only the 1:250,000 compilation legend provides a specific symbol for airports.

OS LHR	Geometry					Visual Variables				
	Area	Line	Point	Text	Sum	Size	Shape	Value	Hue	Text.
Explorer Map	23	35	65	16	139	1	5	0	9	9
LandRanger Map	23	47	60	13	143	1	8	0	8	8
Road Map	15	29	55	4	103	0	5	1	5	4

Table 3. OS use of visual variables and geometry in map ontologies

In the 1:25,000 compilation, the brightly hued, thick lines used to symbolize the road network stands out in the visual hierarchy (Figure 2). Water features are the next most obvious features represented as light-blue filled areas with dark blue casing. Within the airport itself, the terminal and freight buildings stand out with tan-filled, thin-black-line cased areas showing the footprints discernible at this scale. Labels are used to distinguish large buildings. The fire station is cased in a heavier, solid black line and labeled despite being smaller than many other unlabeled buildings. Runways and taxiways fade into the background and are undistinguished from each other with thin dashed lines marking the casings of the impervious surfaces.

In the 1:50,000 compilation, the road network is most prominent. The hues used to distinguish the road hierarchy are different from the 1:25,000 compilation and dots following the roads are added to denote national cycle and foot trails. Like the 1:25,000 compilation, water features remain the second most visible features largely due to their size relative to other features and lack of other features crossing the symbols. Within the airport, runways are still visible but many taxiways are not symbolized. All runways and taxiways are joined to give the impression of complete symbology. Buildings are still presented as black-cased tan areas but have simpler edges. Terminals and tunnels are labeled but no distinction is made between road and rail tunnels.

The 1:250,000 compilation maintains the road network as the most prominent feature and continues the same system of hues to denote road hierarchy as the 1:50,000 compilation. Within the area of the airport, all symbology has been removed. A point symbol is added for the airport and a yellow text on green backing “London Heathrow Airport” label is applied. A dashed line persists showing the location of the rail tunnel under the airport but is not labeled.

IGN Representation of Charles de Gaulle Airport

Charles de Gaulle Airport (CDG) is the second busiest airport in Europe and the sixth busiest in the world in terms of passengers. IGN provides scanned raster compilations at 1:25,000, 1:50,000, 1:125,000 and 1:250,000 corresponding respectively to the SCAN25, SCAN50, SCAN *Départemental*, and SCAN *Régional* via their web mapping service. The 1:100,000 scale SCAN 100 and 1:1,000,000 scale SCAN 1000 raster datasets were not available via the IGN website at the time the graphic treatments for this study were created. IGN uses a single published legend for both the SCAN25 and SCAN50 compilations (Table 4). Hue and texture followed by size are used to distinguish feature types within feature classes in these two compilations. The legend for the SCAN *Départemental* compilations uses size, shape, hue and texture equally while the SCAN *Régional* compilation relies exclusively on shape and hue to distinguish features. The three legend ontologies exhibit interesting variation in the total number of feature types with 131 in the SCAN25/SCAN50 legend, 41 in the 1:125,000 SCAN *Départemental* compilation and increasing to 65 in the 1:250,000 SCAN *Régional* compilation. It is interesting to note that the variety of feature types increased as scale decreased between 1:125,000 to 1:250,000 while the variety of visual variables decreased in the same interval. The IGN provides point symbols for airports in both the 1:125,000 and 1:250,000 compilation legends.

IGN CDG	Geometry					Visual Variables				
	Area	Line	Point	Text	Sum	Size	Shape	Value	Hue	Text.
SCAN25/SCAN50	17	64	49	1	131	4	2	0	6	7
SCAN Regional	3	18	10	10	41	2	2	1	2	2
SCAN Departmental	2	26	33	5	65	1	4	0	4	3

Table 4. IGN use of visual variables and geometry in map ontologies

Considering the area inside and immediately surrounding CDG in the 1:25,000 SCAN25 compilation, the most prominent features are the road network and structures (Figure 3). CDG has many architecturally unique buildings which are rendered clearly at this scale with black casing and grey-hued fill. Highways are red and orange cased in black, and surface roads are shown as casings. Water features and green land cover are present but not prominent in the urban Parisian environment. The airport is designated with a label “*Aéroport Charles de Gaulle*” and significant structures are similarly labeled but with smaller font sizes. Runways and taxiways are all symbolized using thick black lines showing the casings with labels on the runways. The *Interconnexion Ligne Train à Grande Vitesse* (TGV) rail line is symbolized and labeled inside the boundary of CDG but falls into the background compared to other features. The rail stop at CDG is not labeled.

The 1:50,000 SCAN50 compilation maintains the same visual hierarchy with roads and buildings in the foreground. However, the highway network is now symbolized solely in a single black-cased orange hue with surface roads maintaining the black casings. Building symbology has changed from a grey hue to a diagonal-lined texture with some architectural detail being omitted. The few bodies of water and green land cover areas fade further into the background as their relative size diminishes. Two very interesting changes occur between the 1:25,000 compilation and this one: the airport is now labeled as “*Aéroport de Paris – Charles de Gaulle*” as if to imply that this is the single “airport of Paris, while neglecting the existence of Orly Airport. Additionally, runway four (08R/26L) has been removed entirely from the map while the relatively minor taxiways continue to be represented, essentially retaining a runway network but reducing its prominence in the landscape. The TGV is no longer labeled at 1:50,000 nor is it symbolized through the tunnel under CDG.

In the 1:125,000 SCAN *Départementental* compilation, the highway network is made even more prominent with a variety of hues and sizes used to differentiate highway categories. Some feeder roads remain symbolized with thin black casings. Detail of the airport has been entirely removed except for a light grey area denoting the bounds of CDG. An airport point symbol has been added and the labeled has changed again to “*Paris-Charles-de-Gaulle*”. The TGV is symbolized with a solid black line but not through the tunnel under CDG. However, the TGV stop within CDG is now symbolized with a solid black rectangle.

The 1:250,000 SCAN *Régional* compilation further promotes the highway network, eliminating all feeder roads. The airport, CDG, has lost all detail and is replaced with a single point symbol and similar label to the 1:125,000 compilation. The TGV, however, has been elevated in prominence with the rail line being symbolized continuously through what would be the bounds of CDG. The TGV stop within CDG is now symbolized with a black cased, white rectangle and labeled as prominently as CDG itself: “*Gare T.G.V.*”

NLS Representation of Stockholm-Arlanda Airport

While the Stockholm-Arlanda Airport (ARN) is the largest airport in Sweden, it serves less than half the number of passengers as SFO (17.9 million passengers in 2007) and lies 30 minutes outside of Stockholm. The airport occupies 33 square kilometers making it the largest in the study in terms of land coverage. The Swedish NLS favors hue and texture throughout all three compilations in the legends to differentiate among feature type within feature classes, with the use of size and shape becoming a little more balanced in the legend for the 1:250,000 compilation. Overall, the number of feature types and the complexity of geometric representations decreases almost linearly as scale decreases (Table 5). The legend for the 1:50,000 compilation features 127 feature types. This number decreases to 105 feature types at 1:100,000 and 80 feature types at 1:250,000. Like the OS and IGN, the NLS assigned names to the different scale compilations. The 1:50,000 compilation is the “Topographic Map” while the 1:100,000 compilation is the “Road Map” and the 1:250,000 is the “General Map”.

NLS ARN	Geometry					Visual Variables				
	Area	Line	Point	Text	Sum	Size	Shp.	Val	Hue	Text.
Topographic Map	21	43	62	1	127	3	5	0	7	8
Road Map	17	45	42	2	105	3	4	0	6	8
General Map	9	40	29	2	80	5	5	0	7	7

Table 5. NLS use of visual variables and geometry in map ontologies

What immediately stands out in the graphic treatments acquired from the NLS Mapsearch is the use of hue to designate land cover (Figure 4). In the 1:50,000 “Topographic Map”, as many as nine hues can be seen to differentiate land cover. Hue is also used to bring the road network out of the land cover with highways given elaborate line symbols consisting of thick red casing around a yellow fill with a black centerline. The width of the casing-enclosed area is used to provide cues to the hierarchy in the road network. Smaller roads are represented with black casings. Rail lines are represented with a heavy black-and-white alternating cased line. Within the airport, buildings are detailed but represented only in solid black and remain unlabeled. The runways are black-cased with an orange hued fill. Taxiways are represented with black casings.

In the 1:100,000 scale "Road Map" compilation, much of the green vegetative land cover has been changed to shades of yellow and tan hue, allowing the land cover to fade more to the background. The road network now comes to the foreground with greater use of hue. Primary highways are now blue-filled with secondary highways red-filled both with black casing. The primary highways also maintain a black centerline. Feeder roads become solid black lines and the rail network becomes a solid black with cross hatches. Within the airport, the runways are now black casings around white or colorless fills without representation for taxiways. Many smaller buildings are removed and some architectural features are simplified. Interestingly, small airplane symbols not found in the legend now mark the runways.

The 1:250,000 scale "General Map" compilation returns to the green hue for vegetation. The road network now features red fills for primary highways and orange fills for secondary highways. Only select feeder roads remain symbolized with solid black lines. Almost all buildings within the airport are removed and the runways are black rectangles maintaining the approximate orientation and relative length. The rail line now is symbolized passing under the airport with a dashed line and a circle is provided showing a rail stop within the airport.

Dimensional Collapse in Airport Representations

The anticipated trend toward fewer feature classes and simpler representations is well supported by the data acquired in this study. For instance, as scale changes from fine to coarse, the airport bounding area symbology collapses from polygons to point features and the intricate casing symbology for taxiways and runways generally reduces to solid lines and in some treatments disappears altogether. However, while symbology simplifies for some features, other feature classes become more complex as scale changes. The rail lines and rail stops within the bounds of the airports are shown with richer symbols at smaller scales than at larger scales. For instance, the TGV stop within CDG is not symbolized in the 1:25,000 and 1:50,000 compilations but is present in the 1:125,000 and 1:250,000 compilations. Further, the symbology for the TGV line through CDG is not present until scale is reduced to 1:250,000 (Figure 3). We see the exact same behavior in the symbology for the rail stop and rail line through ARN (Figure 4).

Mission Statements as Epistemology

The mission statements of the four NMAs were found on their respective web sites and compared, to explore the guiding principles of each NMA and ultimately, how these guiding principles are reflected in their cartographic semantics and legend ontologies. English translations were provided for the IGN and NLS mission statements on their respective websites.

Each mission statement was broken down into a list of verbs and direct objects: *describe* Earth, *protect* quality of life, *collect* definitive record, *develop* market, *carry out* research, *direct* activities (of the National School), *promote* placenames, etc. A chart was created from this list noting similarities among the NMAs. List items were simplified and consolidated (Table 6).

This consolidation of items in the chart, however, potentially obscures meaning. The three European NMAs all have checks for "Database" but the purposes of the databases are somewhat different. The OS mission is to "collect, portray, and distribute the definitive record" and "improve and maintain the definitive database". IGN mission limits the scope of the database to "prepare and update…the geographical data bases…whose list is fixed by the Minister…in particular the large scale reference.” And while the NLS simply states that they produce “databases containing geographic information” they uniquely take on the challenge of providing a national cadastral database.

	USGS	**OS**	**IGN**	**NLS**
Database		✓	✓	✓
Geodetic Networks			✓	✓
Research and Development in GIScience			✓	✓
Direct and Advise Government		✓	✓	
Generate Revenue		✓		✓
Develop Market		✓		
Describe and Understand the Earth	✓			
Minimize Loss	✓			
Manage Natural Resources	✓			
Protect Quality of Life	✓			

Table 6. Comparison of Mission Statements

It is significant to note the differences in the mission statements between the USGS and the European NMAs. It is well-known that the USGS fills most of the same roles for the United States that are laid out by the mission statements of the European NMAs. However, the USGS mission statement paints a very different picture. According to the mission statement, the USGS focuses on the natural environment in the abstract: providing scientific information, understanding the Earth, minimizing loss from natural disasters, managing natural resources, enhancing quality of life. This is in stark contrast, for example, to the OS mission which spells out details of their “definitive database” funded by generated revenue. There is no mention of maps or cartography in the USGS mission statement. The European NMAs in this study directly mention maps and cartography as part of their mission statements.

Examination of the mission statements of the four NMAs provides some clues to the epistemological frameworks guiding the selection and classification of features as well as the cartographic semantics applied to the representations of those features in the map treatments of the NMAs. For instance, the USGS publishes a single legend ontology for all compilation scales of its topographic maps whereas the European NMAs generally publish unique legend ontologies for each map scale compilation. The USGS mission focuses on a single, scientific view of the world and this singular viewpoint is reflected in a unified map legend for all represented scales.

Map Legends as Ontologies

Dimensional collapse in response to changes in scale can be observed in map legends as well as in map treatments. The geometric symbols used to represent the same geographic feature may have reduced dimensionality on two different scale map compilations. For instance, the OS legends provide an area symbol for forests in the 1:50,000 scale LandRanger Map versus a point symbol for forests in the 1:250,000 scale Road Map legend. Comparing the symbol types used to represent the same feature types in legends for different scale map compilations. The legends for each of the thirteen map compilations used in this study were found on the respective web sites and printed for examination. Each legend was closely inventoried. Major categories for feature classes were either given or derived: roads, railways, land features, land cover, etc. For each category, the number of feature classes was counted by symbol geometry type: area, line, or point. Examples of area type features would be: tailing ponds on USGS topographic sheets, mud on OS Explorer maps, buildings on IGN Scan25 and Scan 50 maps, or glaciers on the NLS Road Map. Line feature examples include township and range lines on USGS topographic sheets, footpaths on OS Explorer maps, commune boundaries on IGN SCAN *Départemental*, or reindeer fences on the NLS Road Map. Point geometry types include gaging stations on USGS topographic sheets, viewpoints on OS Explorer maps, caves in IGN Scan25/Scan50, and map sheet corner markers in the NLS General Map. A fourth “geometry” type of text was created for legend features absent of any geometric symbology. Examples of this text type include the aerial photograph roll and frame number on USGS topographic sheets, Roman archaeological sites on the OS Explorer map, Chief towns of communes on IGN *cartes départementales*, and depth in meters of water bodies on the NLS Road Map.

Cartographic visual variables were employed by each NMA to differentiate among the symbols within each feature class. Of the seven visual variables recognized by Bertin (1983) only five were used in the map legends: size, shape, value, hue and texture. Value was used sparingly and only for area features at small scales. Texture, specifically the style of line symbols, was the mostly common visual variable employed to differentiate among the features types in each feature class or category.

As one might anticipate, the number of feature classes generally decreases as scale decreases (Figure 5). But note the OS pattern, where the number of feature types increases again and the smallest scale. One might conclude from this that the 1:250,000 scale map series serves a different purpose than the previous series. Further, the cardinality of average symbol dimension decreases as scale decreases (Figure 6). This fits with the fundamental idea that generalization from larger to smaller scales involves simplifying the representation. The number of feature classes in the map ontologies is simpler at smaller scales than at larger scales. And symbols used to represent geographic features are less complex at smaller scales than at larger scales.

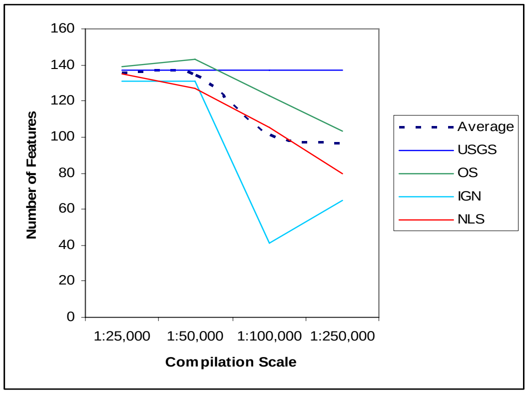

Figure 5. Number of feature types as a function of scale

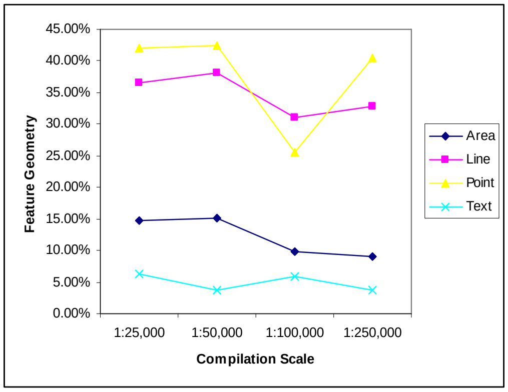

Figure 6. Feature geometry as a function of scale

Summary

This project constitutes a pilot study for a longer term project aimed at determining how to link map treatments of features undergoing dimensional collapse within a multi-scale base mapping cartographic database. We are left with questions relating geometric modification with semantics, as for example in asking: How is dimensional collapse reflected in map ontologies? How do map ontologies reflect the missions of mapping agencies?

In this paper, we have demonstrated that change in map scale from large to small implies simplification in map symbology accomplished through dimensional collapse. Comparison of the cartographic semantics and map ontologies of the three European NMAs demonstrates that feature representation tends away from area and line symbology towards greater use of line and point symbology as map scale is reduced. Map ontologies reflect the guiding mission of the NMA producing the map. The USGS's use of a single map ontology for all mapping scales directly reflects that agency's mission focus on a scientific world view. The OS creates maps relatively close in scale (1:25,000 and 1:50,000) with different map ontologies in order to fulfill their "focus clearly on the needs of customers" rather than just dissemination of scientific information. The mission-focus on end-user needs results in feature behavior that is contrary to the general trend. In the IGN and NLS compilations, as we see the general details of the interior of the airport simplified removed, the importance of the rail network is elevated. These results show that the overall trend in dimensional collapse in response to scale may be formalized in linkages between automated generalization algorithms across points of dimensional collapse. However, these linkages must account for changes in map ontology which reflects the map purpose and guiding missions of the NMA.

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