Multi-scale Cartography: Maps, Tools and Models

Paul Hardy

Esri, Cambridge UK; phardy@esri.com

ABSTRACT
This paper reviews the multi-scale cartographic capabilities of a desktop, server, and cloud GIS (Esri ArcGIS). It discusses the tiered scale data models and cloud resources used for whole-world maps that show increasing content down to detailed scales. It shows examples of basemaps for various purposes, with content from different countries and communities. It explains contextual generalization tools that can derive abstractions from feature data that is otherwise too detailed, and how they can be used to produce intermediate scale bands, or families of cartographic products. Finally it covers database-driven multiple representation functionality and its application to multi-scale cartography.

1 INTRODUCTION

1.1 Changing Cartography

The art, craft and science of cartography is changing rapidly. No longer is a single map produced on a paper sheet as a result of one cartographer spending weeks of effort. Now:

- Users expect maps of everything, everywhere, for everyone – provided by commodity services like Google Maps, Bing Maps, or ArcGIS.com
- Cloud computing is providing massive scalability of cartographic resources, and data volumes are rising from Megabytes through GB, TB, to Petabytes
- We are in the era of multi-scale web mapping - not just one map but 20 consistent zoom levels, going from the whole world down to individual houses.
- Automated generalization is becoming possible, to derive smaller scale from larger.
- Greater cartographic capabilities are available in GIS, so separate graphical finishing systems no longer needed.
- Data sources are evolving – as well as using authoritative data from National Mapping and Cadastral Agencies (NMCAs), we take from multiple sources, commercial organizations and increasingly from individuals by crowdsourcing (volunteered geographic information).

2 BASEMAPS

2.1 GIS Basemaps

Historically, each map would be compiled from source data and printed for a particular purpose. Now, the trend is for maps to be the result of combining foreground information from GIS analysis, with a background map to give spatial context. Examples of such basemaps are the set from Esri's ArcGIS Online, available through ArcGIS.com. Each of these maps is a multi-scale resource showing increasing detail as you zoom in. The range of basemaps includes:

- Imagery basemap – aerial photography imagery, mosaicked and harmonized
- Streetmap – basemap focused on the man-made environment, particularly roads
- Topographic basemap – more general basemap showing the shape and content of the land
- Canvas basemap – muted color basemap, allows foreground information to stand out
- National Geographic – familiar style, good for larger areas
- Oceans basemap – invaluable for the 70% of the world that is not land, but also for light physical maps on land.

National Geographic *Streetmap* *Topographic* *Light Gray Canvas*

Fig. 1 - Spectrum of cartographic styles

The set of basemaps is designed with a strong-to-mild spectrum of cartography. The intention is that one of these cartographic styles should meet every user's needs given the application and the type of operational data they are using. At the cartographically rich end of the spectrum is the National Geographic Map, which is more likely to be used as a standalone map. At the more subdued end of the spectrum is the Light Gray Canvas Map, which will almost always be used as a backdrop for thematic data. The World Streetmap and World Topo Map fall somewhere in the middle.

2.2 Basemap Samples

Fig. 2 - Imagery

Fig. 3 - Streetmap

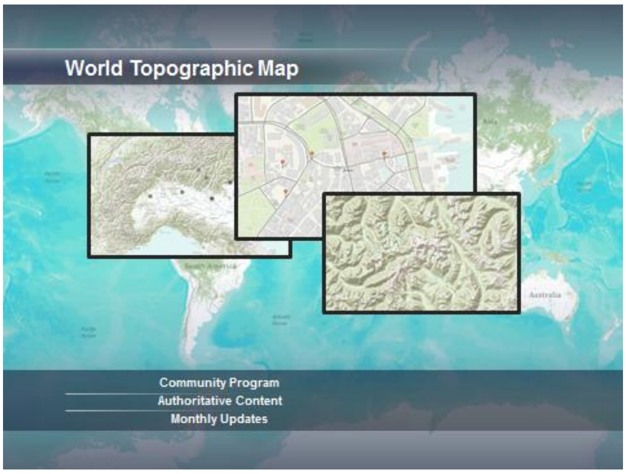

Fig. 4 - Topographic

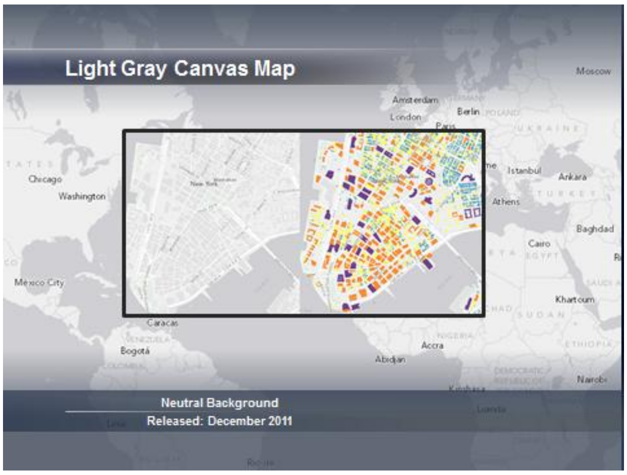

Fig. 5 - Light Gray Canvas

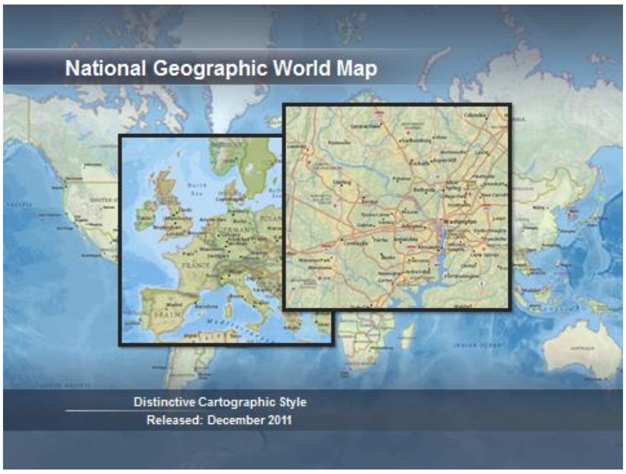

Fig. 6 - National Geographic

Fig. 7 - Oceans

2.3 Community Basemaps

The Topographic basemap has an extra twist because it is the result of a community process. Esri generates the smaller scale bands, but asks its users and international distributors to source appropriate data for the larger scales, and to build the tile cache for these scales.

The cartography and implementation of these basemaps is still evolving. Coming later this year will be a new community topographic map mechanism with new, more consistent but more muted symbology, still further reducing conflict with GIS foreground information. In addition the implementation framework is changing to hold vector data from the community, rather than contributed raster cache tiles, so in the future the data will be rendered for multiple basemap cartographies.

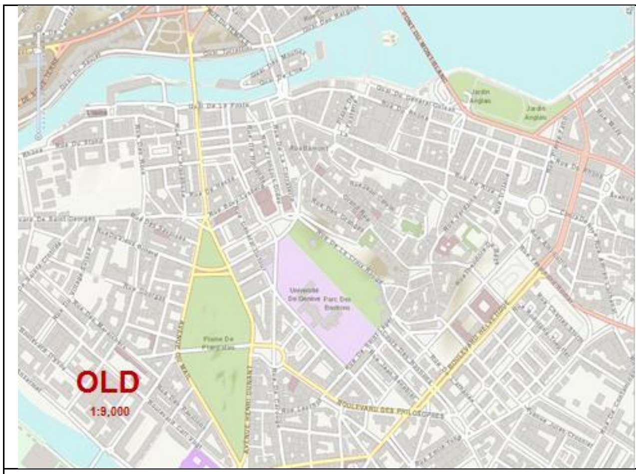

Fig. 8 – Old Cartography - 9K

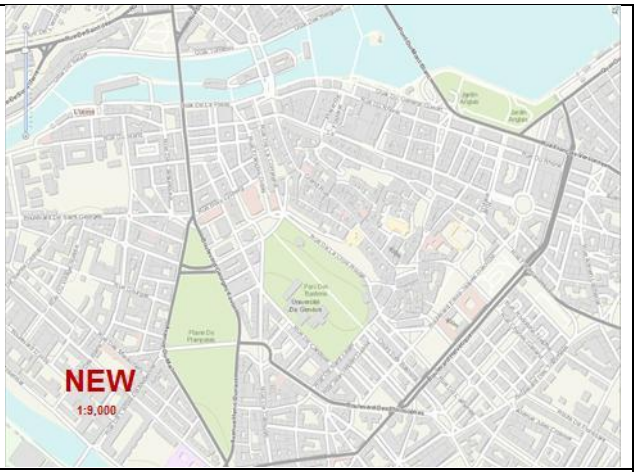

Fig. 9 – New cartography – 9K

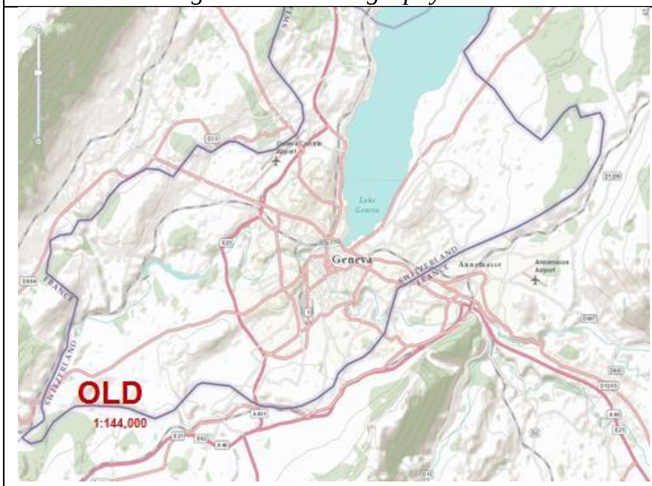

Fig. 10 – Old Cartography - 144K

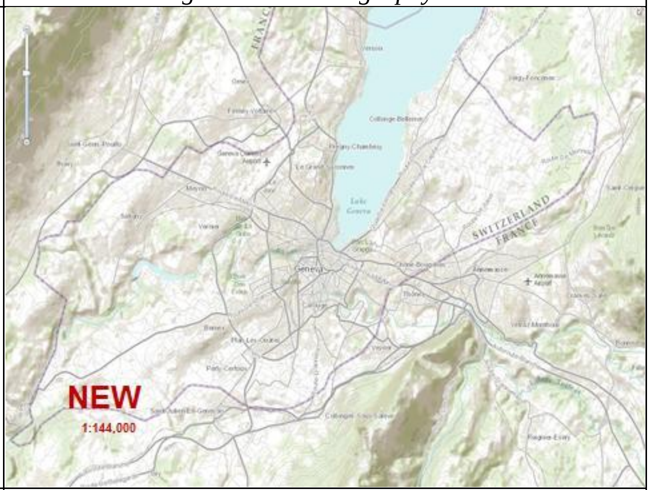

Fig. 11 – New Cartography - 144K

3 GENERALIZATION

3.1 Generalization and Conflict Resolution

Generalization in cartography is the simplification and clarification of features to improve display at smaller scales. Conflict Resolution is the management of the extent and placement of symbolized features on maps. Both processes improve the quality of multi-scale map display, and automation of both is needed to achieve efficient generation of multi-scale basemaps.

3.2 Optimization for generalization

Esri has been working for several years on an optimized, constraint-based approach to solving generalization problems within a commercial GIS [Monnot, Hardy, Lee 2007]. ArcGIS 10 introduced a new generation of generalization tools based on an underlying optimizer kernel, and this set has been enlarged and refined in ArcGIS 10.1. The optimization approach seeks to modify geographic features based on a series of pre-defined constraints designed to clarify the display of that data at smaller scales. Examples of constraint are:

- a building cannot be closer than the specified distance from another building
- a building cannot move too far from its original location
- a building cannot appear smaller than a minimum size

The satisfaction of an individual constraint is improved with one or more corresponding actions. Examples of actions are "move the building away", "move the building back", "enlarge the building" and "suppress the building." Since constraints often conflict, the optimization approach seeks to find the best overall solution, even if the satisfaction of some constraints must be somewhat compromised. This is consistent with the very nature of cartography which has always required making informed compromises about what to display how on a map, at each scale

3.3 Geoprocessing for Generalization

Geoprocessing is fundamental to GIS, and describes the application of a data processing component to modify existing spatial features or to derive new features from them. These steps can be logically chained together or looped in scripts or models to create a complex workflow that can be applied to a range of data to produce multi-scaled databases for print or screen display. By introducing generalization tools into this framework as discrete components, highly customized workflows can be built to address the requirements of a wide variety of map specifications and styles [Lee, Hardy 2005]. Geoprocessing tools released in previous versions of ArcGIS focused on the generalization of features in single themes in isolation, where operations are performed on the geometry of a single layer without regard to symbology or the relationship to other layers. The newer generalization tools in ArcGIS 10 and 10.1 use the underlying optimization-based contextual generalization engine.

The Thin Road Network and the Merge Divided Roads tools simplify road networks while the Resolve Road Conflicts and Resolve Building Conflicts tools redistrib1ute and reshape roads and buildings to avoid symbol conflicts while retaining characteristic pattern and density. To ensure that each tool works with one another to produce a consistent display, the Propagate Displacement tool propagates positional adjustments made during conflict resolution to proximate features.

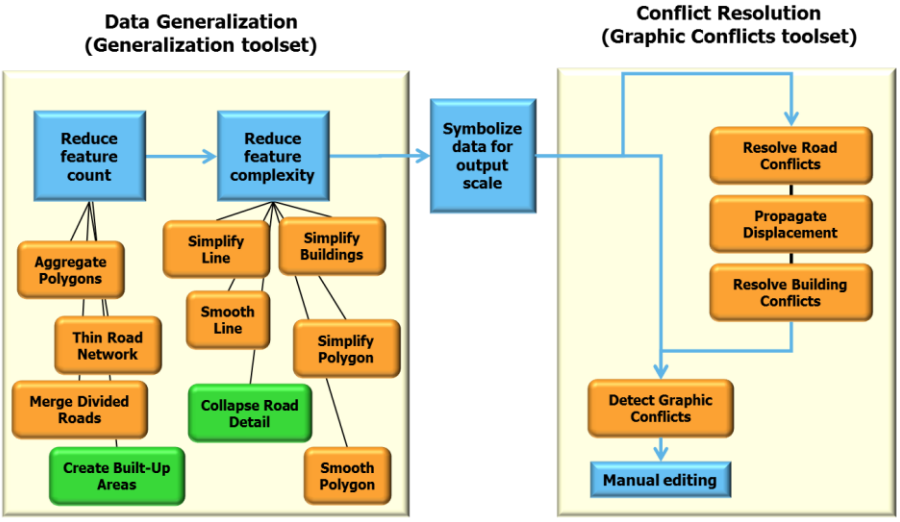

Fig. 12 – Generalization and Conflict Resolution toolsets

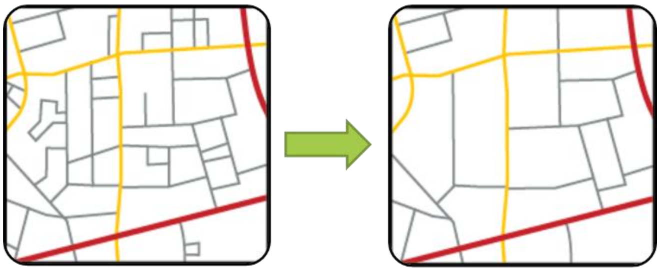

Fig. 13 – Simplify Road Network

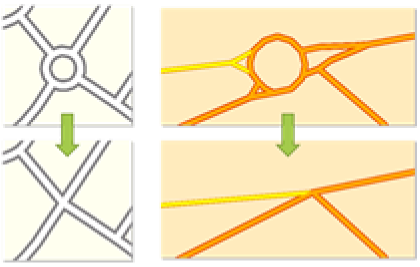

Fig 14. – Collapse Junction

3.4 Generalization Use Case

A practical example of application of these new generalization tools has been shown by a prototyping project at Netherlands Kadaster, involving Esri NL, and research from ITC Enschede [Stoter et al 2011]. This takes 10K topographic data in the Top10NL data model, and derives 50K topographic mapping by use of the Esri optimizer-based contextual generalization tools, built into complex geoprocessing models in combinations with the many basic geoprocessing tools in the ArcGIS framework.

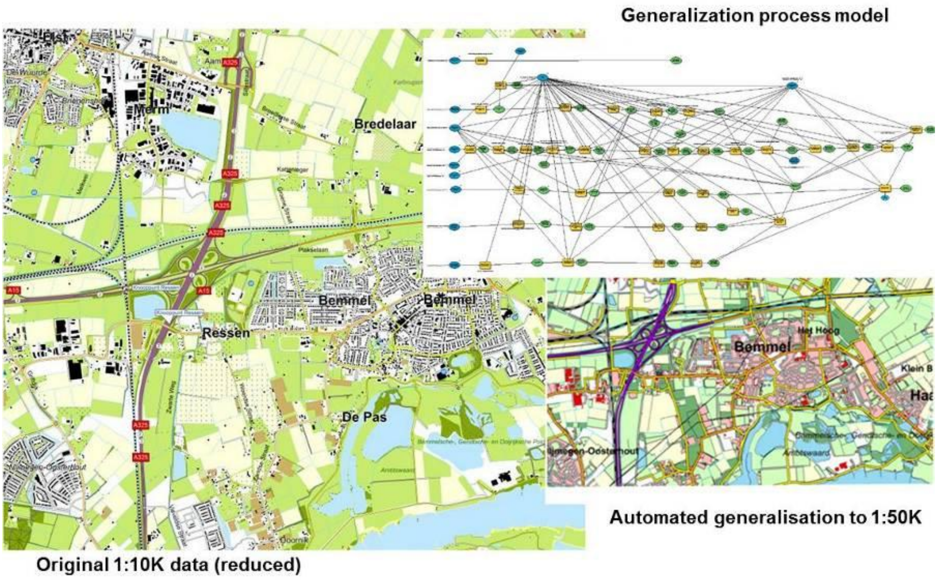

Fig. 15 – NL generalization 10K to 50K

4 MULTIPLE REPRESENTATIONS

A key aspect of ArcGIS cartography is the storing of cartographic representations in the geodatabase, tightly coupled to the feature data of the landscape model. Adding a cartographic representation to an existing feature class adds two more columns to the database table (figure 16). The first field (the Rule ID) is an enumeration, saying for each feature which representation rule to use. The second field (Override) is originally empty and will only get populated if the override mechanism is used. A feature class can hold multiple representations, each with two columns, to allow the generation of different cartographic products using the same feature data, such as different scale bands in a multi-scale basemap. A single representation rule can re-use the feature shape geometry multiple times, passing it through one or more ‘geometric effects’ to cartographically enhance the appearance before invoking stroke, fill, or marker symbols.

Overrides can then affect any of the graphical properties of the symbol – color, width, size, or cap style. They can also affect any of the parameters to geometric effects, such as offset distance, or radial angle. Finally, the override field can store an alternative feature shape (display geometry), to be used just for this representation. The contextual generalization tools described above can set their results into individual override fields dependent on target scale, so as to facilitate the clear representation of multi-scale basemap data.

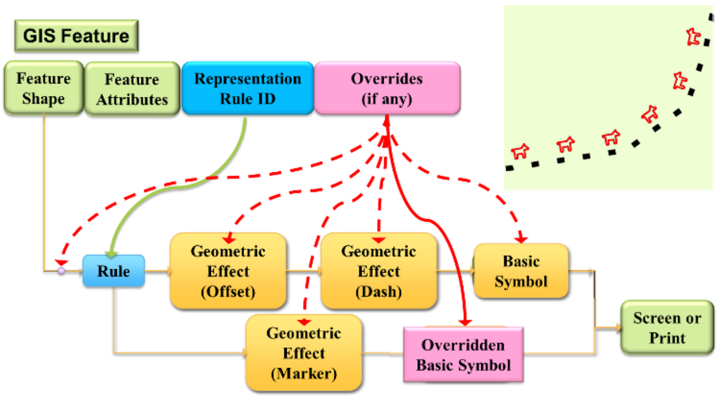

Fig. 16 – Cartographic Representation data flow

5 CONCLUSIONS

The combination of processing tools and visualization capabilities available in a commodity GIS can be applied to efficiently create a range of multi-scale basemaps. In particular, new tools for contextual generalization and conflict resolution make possible automated derivation of intermediate resolutions, to enable smooth transitions between scales.

6 REFERENCES

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Stoter, Nijhuis, Post, van Altena1, Bulder, Bruns, van Smaalen, “Feasibility study on an automated generalisation production line for multiscale topographic products”, ICA Generalisation and Multiple Representation, Paris, June 2011

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8 BIOGRAPHY

HARDY (Paul Geoffrey), M.A. MBCS C.Eng CITP FBCart.S

Born 1953, Paul Hardy graduated in 1975 with a M.A. in Computer Science from Cambridge University in England. He worked for 28 years at Laser-Scan Ltd in Cambridge England, where he held the roles of Chief Programmer, Product Manager, and Principal Consultant. He was Product Manager for Cartography at Esri in Redlands California from 2003 to 2006, and project managed the implementation of advanced cartographic capabilities into ArcGIS. He now is Business Development Consultant for Esri in Europe, focused on national mapping and cadastral agencies.

He is a Chartered Engineer, a Fellow of the British Cartographic Society and a Member of the British Computer Society. His professional interests include digital mapping and charting, automated cartography, map generalization, geospatial data models and data re-engineering techniques. Because of his time in business development and in software development, he bridges the communication gap between business users and technical professionals.