Database Driven Cartography – The ‘swisstopo’ Example

Dieter Neuffer[1], Barbara Schneider[2,] Paul Hardy[3] & Thierry Kressmann[3],
[1]ESRI Geoinformatik GmbH, Kranzberg, Germany, d.neuffer@esri-germany.de
[2]ESRI Geoinformatik AG, Zürich, Switzerland, B.Schneider@esri-suisse.ch
[3]ESRI, Redlands, California, USA, phardy@esri.com,tkressmann@esri.com

ABSTRACT

Commercial GIS software such as ESRI ArcGIS has historic strengths in geography, spatial data modeling, and data analysis, but has traditionally been perceived as less strong in cartographic representation, artistic freedom and map publishing. However, a set of major software advances in cartographic functionality has recently become available, which together with further developments under way, will greatly automate high quality cartographic production, while empowering the human cartographer.

This paper highlights how the advances arising from research and development at ESRI are applied in a production setting at swisstopo, the Swiss national mapping agency. Using a real world case study as an example, the paper explains how the developments at ESRI meet the various requirements of a mapping agency, from the rigor of a master geodatabase to the artistic freedom provided by the representation editing tools.

ABSTRACT (deutsch)

Kommerzielle GIS Software wie ESRIs ArcGIS hat traditionelle Stärken in den Bereichen Geografie, Modellierung raumbezogener Daten und Datenanalyse, wurde aber bisher in den Bereichen kartografische Darstellung, künstlerische Gestaltungsfreiheit und Kartenproduktion als weniger leistungsfähig eingeschätzt. In letzter Zeit sind jedoch eine Reihe von Fortschritten bei der kartografischen Funktionalität verfügbar geworden, die zusammen mit weiteren aktuellen Entwicklungen die weitgehend automatisierte Erstellung von qualitativ hochwertigen Karten ermöglichen und gleichzeitig den Kartographen gezielt unterstützen.

In diesem Paper wird beschrieben, wie die Fortschritte aus Forschung und Entwicklung bei ESRI in der Produktionsumgebung von swisstopo, dem Bundesamt für Landestopografie der Schweiz, angewandt werden. Mit Hilfe dieser realen Fallstudie legt dieser Beitrag dar, wie die Entwicklungen bei ESRI die Anforderungen einer ‘Mapping Agency’ erfüllen, von den harten Anforderungen an eine Geodatenbank bis zu den weichen Anforderungen bezüglich der künstlerischen Gestaltungsfreiheit, die von den Editierwerkzeugen geboten wird.

1 INTRODUCTION

1.1 Context

The majority of commercial cartographic publishing today relies on using file-based graphics software to create the visual product and to carry out cartographic edits. This is typically either a desktop graphics software package (such as Macromedia Freehand or Adobe Illustrator) or a specialist graphic map finishing system (such as Star Mercator or Lorik Dry). Almost always, the source line, point, and area geographic data for this cartographic process comes from a Geographic Information System (GIS), such as ArcGIS [ESRI 2004B], which maintains the data in a spatial relational database (such as Oracle or SQL Server).

While this split workflow has the possible advantage of using best-of-breed tools, there are a number of drawbacks. Having to export then import data to transfer it between packages is time consuming, and duplicating changes and updates in both environments is inefficient and expensive. This approach is further limited by not providing a WYSIWYG connection throughout the process, by making feature attributes unavailable during finishing, and by the need to maintain separate databases to make multiple products at different scales.

1.2 Case study: swisstopo

Recently, swisstopo (the Swiss Federal Office of Topography) has decided to modernize its complete production process from data capture through data validation, generalization, and incremental update to symbolization and map production. The data capture aspects of the new workflow are described in detail in [Schmassmann & Kreiter 2006]. This paper concentrates on incremental update, symbolization and map production.

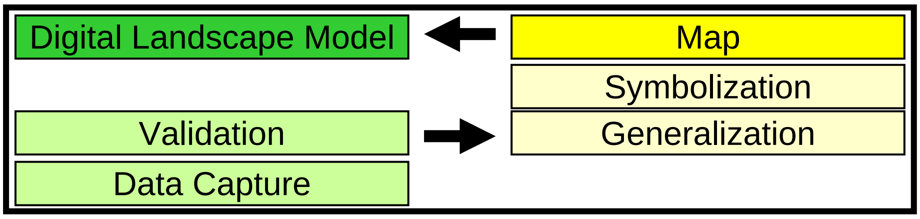

Fig. 1 – Traditional map production workflow at swisstopo.

1.2.1 Traditional workflow

The traditional workflow historically evolved from glass engraving and focuses on updating the national map series (see Fig. 1). While this workflow supports the production of top-quality maps, there are a number of drawbacks:

- The Digital Landscape Model (DLM) is based on the national map 1:25,000. Therefore, it is already cartographically generalized, and is not (strictly speaking) a landscape model.
- Normally, it takes two to two and a half years from data capture to map production, and up to three years from data capture to populating the DLM.
- Considerable effort is needed to keep both maps and DLM up-to-date.
- It is costly to produce topical map products such as hiking maps and skiing maps.
- Map production is mainly based on raster data.

The traditional workflow and the motivation for change are described more detailed in [Kreiter 2005].

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1.2.2 Vision and objectives

For the future, swisstopo plans to implement a new workflow based on vector data that offers several advantages over the existing one:

- The DLM will not be derived from the national map any more but will be the basis for most of the national map series.
- The time to update the DLM as well as the maps will be considerably shortened.
- The data will be more accurate, more up-to-date and will be used in a more flexible way.
- Map production will be entirely based on vector data in most applications.

Vector data workflows can be implemented in many different ways but most national mapping agencies and commercial mapping companies have a strategic goal of using a common database and common environment for all map publishing, and a ‘capture once and use many times’ ethos. Swisstopo is one of the organizations at the forefront of this development. At swisstopo, the dataset at the core of this strategy is the Topographic Landscape Model (TLM). With an accuracy of approximately 1 meter, it represents a comprehensive topographic base dataset in 3D. It will be used for many purposes, one of which is the derivation of analog and digital maps. The development and strategy behind this data model is beyond the scope of this paper. The interested reader is referred to [Schmassmann & Kreiter 2006].

In Section 2, we present how ESRI has designed a solution. In Section 3 we relate the solution to swisstopo, and in Section 4 we look at how ESRI research and future developments could contribute.

2 THE ESRI SOLUTION: COMPONENTS AND INTEGRATION

The strategy is to make the best use of the master landscape model data and to achieve an efficient overall workflow as well as high quality products. The solution to achieve this includes the following features:

- A single software environment from capture to finishing. This minimizes the number of interfaces and the potential for information loss, thereby ensuring the highest possible quality.
- It is centered on an enterprise database. This is paramount for the safety and integrity of the data.
- It supports multiple representations for multiple products, which enables efficient reuse of the data.
- It is capable of generating high-quality cartographic outputs to rival the quality of the existing swisstopo maps.
- It is extensible to handle generalization and incremental update as these advanced facilities mature. The new flowline will be in operation for many years to come and must therefore be future-proof.
- Last but not least to allow sufficient freedom for creating cartographic representations without losing the efficiency and convenience of pre-defined and rule-based representations.

The last point is covered in more detail in the following sections. More information on this subject can also be found in [Eicher & Kressmann 2005].

2.1 The challenge of database versus freedom

The introduction of a GIS and database at the heart of the map production process has many advantages that are covered in more detail below. In particular it facilitates data sharing, process automation, and the handling of updates. Most cartographic production agencies have adopted a GIS database environment because of these strengths. However, in the past, the GIS database approach to cartography was criticized from two fronts:

- **Not being comprehensive enough**: storing only geographic features in the database, with all other associated information such as symbology and map marginalia being kept in files outside the database.
- **Not being flexible enough**: being bound by simplistic symbolization rules based on feature class properties or geographic attributes.

2.2 Concepts

The solution to the above requirements and challenges necessitates the introduction of new concepts and capabilities into the GIS/cartographic software:

- cartographic representations
- overrides and exceptions
- cartographic editing tools
- cartographic data models
- generalization and product derivation
- automation of production, map series and atlas page layout
- graphic control and visual output

For some years ESRI has been researching the marriage of geography with cartography, the extension of the GIS geodatabase [ESRI 2004C] to handle map presentation and cartographic details, and the fusion of database with freedom [ESRI 2004; Hardy & Kressmann 2005]. These concepts are described in detail in later sections, and are being addressed in new releases of ArcGIS, starting with cartographic representations, overrides and tools in ArcGIS 9.2.

2.3 Representations

2.3.1 Cartographic representation

The conceptual basis for cartographic representation has been the subject of extensive academic analysis [MacEachren 1995], [Fairbairn et al 2001], but there has been continued difficulty in resolving the conflicting pressures of automation (rule-driven visualization) with those of cartographic clarity (freedom of expression). Giedre Beconyte in a paper on "Conceptual Models for Cartographic Representation" states "*Other than in the simplest cases, it is impossible to limit cartographic design to a single set of rules at all; hence thematic mapping can hardly be subject to automated processing functions*" [Beconyte 2004]. The Representations and Overrides system which is summarized in this paper and described more fully in [Hardy, Eicher, Briat, and Kressmann 2005] unifies automation and freedom capabilities, and hence contradicts aspects of the above analysis. Its fundamental advance is to add minimal information to geographic feature classes in a GIS database to store representation rules and graphical overrides to individual features.

2.3.2 Line example

Representing linear features unambiguously with patterned or dashed lines has traditionally been a challenging problem for cartographers. A database-centered mapping system provides a new solution to this and similar problems, by supporting high-quality automatic representation of GIS features, while at the same time providing the flexibility to override the automated rules. Clear and attractive maps can be efficiently produced.

Fig. 2 below shows five stages of symbolization for linear road or 'track' features from a vector topographic GIS dataset (data copyright swisstopo). Traditional GIS-based mapping systems support only the first two stages.

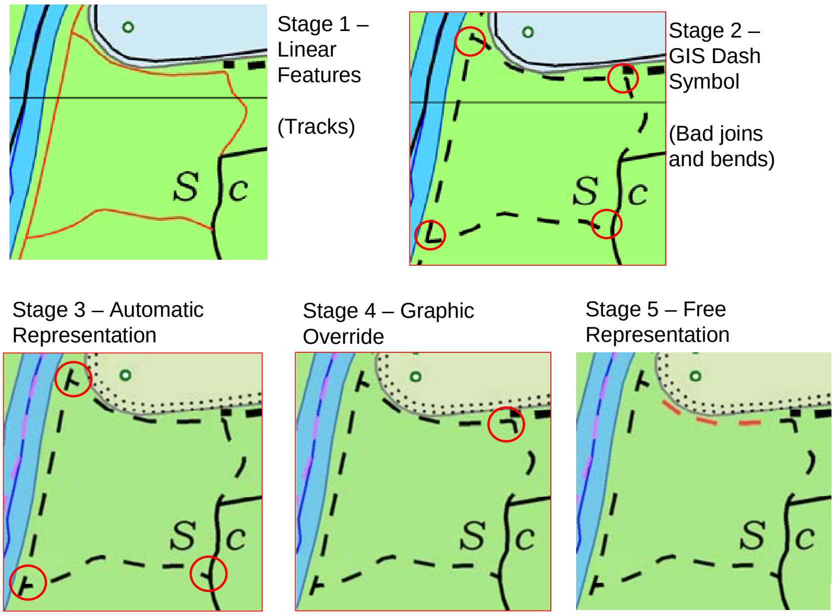


Fig. 2 - Five stages in symbolization.

In stage 1, default GIS symbology (a red line) is assigned to the linear features, and in stage 2 a dashed line symbol is applied, as this is the typical line pattern used in cartographic products for tracks. This GIS symbolization falls short of many cartographic requirements because the poorly symbolized line intersections and bends (highlighted by the red circles), lead to ambiguity as to where the tracks start and end.

Stage 3 shows how the new representation capabilities can automatically produce better symbology at line intersections by adjusting the line dash pattern to ensure intentional (half-dash) connections at the ends of all such line features. Stage 4 shows how using this improved representation as a starting point, the cartographer can further perfect it by forcing the centre of a dash to be placed at the sharp bend in the track in the northeast corner. This modification is stored in the database as an override to the representation geometry.

Stage 5 shows the ultimate graphical freedom and escape from the rules, where the cartographer has decided to change the color of some of the dashes, and to delete one dash from the other track. However, this ‘Free Representation’ is still closely associated with the original feature.

2.3.3 Representation Storage

Physically, a cartographic representation adds additional columns to a standard ArcGIS feature class table within the spatial database. As in any vector GIS, the source feature class stores point, line, or polygon geometries, as well as a set of additional attribute columns used for mapping, analysis, and data management. The added representation columns store data that defines the representation rule used to symbolize a feature. They also store cartographic overrides, which are exceptions to the representation rule for a given feature.

A representation system design premise was to avoid unnecessary duplication of data. Therefore, the extra columns that hold cartographic representations and overrides are minimal in size, and wherever possible the representation information is derived dynamically from the existing GIS feature as it is needed. The structures used to hold overrides are flexible enough not to require separate columns for individual overrides.

2.3.4 Representation Rules

Each cartographic representation added to a feature class can refer to different rules for subsets of features within the feature class. For example a roads feature class will typically have different rules for streets, first, second and third class highways, and for freeways. It may also have variant rules for highways on bridges, in tunnels, or for unique circumstances not normally part of the standard data model (such as a highway temporarily interrupted by a fair).

Rules are made up of one or more visual layers, each of which start from the feature shape geometry and have an optional chain of ‘geometric effects’ and ‘placement styles’ that are applied dynamically prior to rendering with a basic symbol (marker, stroke, or fill).

Fig. 3 shows the data flows during symbolization of a cartographic representation added to a GIS line feature. The shape field of the feature has a representation rule applied, which generates two visual layers, the first of which goes through two geometric effects (an offset to one side, then a dash pattern) before having a basic symbol (stroke) applied. The second layer has one effect applied (a marker placement pattern) before the basic symbol (marker) is applied. Fig. 4 shows a typical visual result of such a rule.

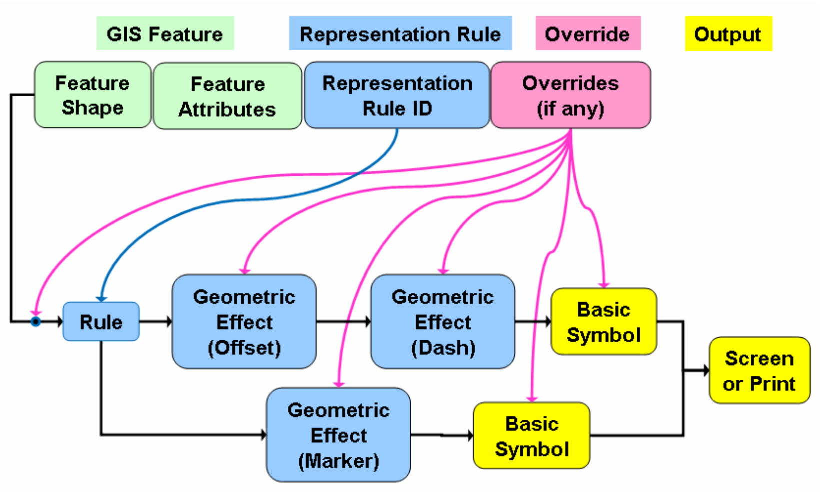


Fig. 3 - Drawing pipeline for representations with overrides.

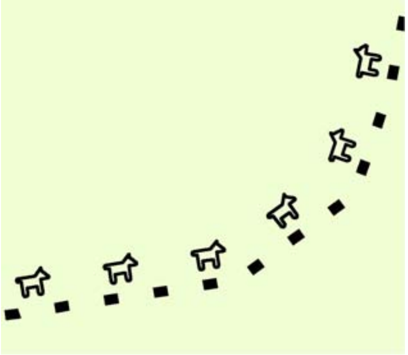


Fig. 4 - Result of Representation Rule.

Rules can also be set up to use any existing field in the database as an ‘Explicit Representation Field’ to control the feature representation appearance. Such field values can be set by geoprocessing processes, which can use the full power of the GIS toolkit to determine the need and calculate the required result. A typical and powerful example is the use of the topology engine from within a geoprocessing tool to find all the cul-de-sac roads, and set a database field which is then used to control their line end style to be square rather than round ended (Fig. 5).

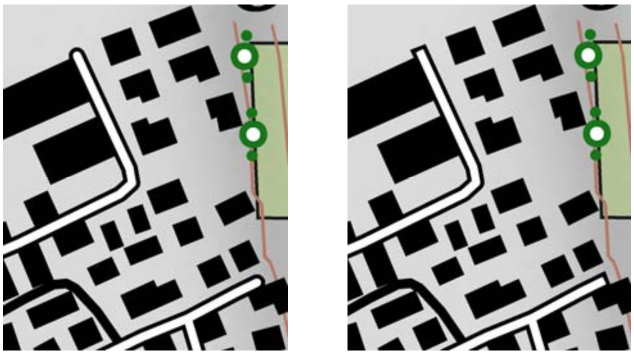


Fig. 5 - Before and after Cul-de-sac processing.

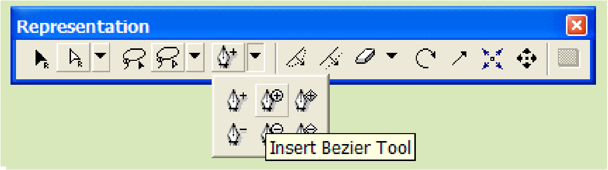


Fig. 6 - Cartographic Editing Tools.

2.3.5 Exceptions to Rules

Overrides

Overrides allow the user to make exceptions to the rules, while remaining within the data model. In Fig. 3, the override field can modify the input shape, the properties of the geometric effects, or any of the graphic properties of the symbols. A set of intuitive geometric and representation property editing tools are provided for defining and modifying overrides, based on tools familiar to a user of desktop graphics packages such as Adobe Illustrator or Freehand (Fig. 6).

Free Representations

A further level of exception is provided by the ability to convert any representation into a ‘Free Representation’. This makes an in-line copy of the rules affecting the particular representation, so that the rules can be changed for this one feature. This can include change of geometry type (area to point), adding new rules or symbol layers, or introduction of arbitrary new graphics. Being able to liberate a particular representation from the data model in this way gives freedom to successfully represent features with appearance too rich to model otherwise, such as a railway siding area where the representation should just show a typified subset of lines indicating ‘there are lots of railway lines here’. It also allows repositioning or suppression of individual graphic elements of the symbolization, such as individual dashes of a road tunnel to avoid important features at ground level, as in Fig. 7 & 8.

Fig. 7 - Rule-based Representation of Tunnel.

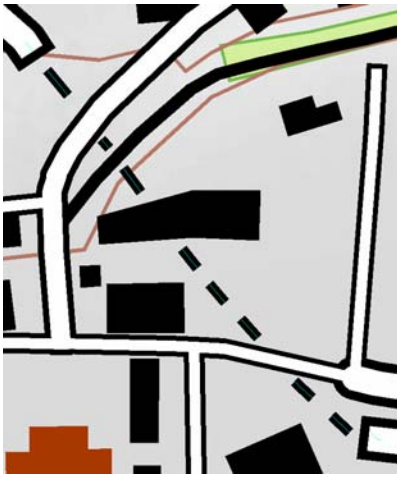


Fig. 8 - Free Representation of Tunnel, with edited dashes.

2.4 Cartographic Editing Tools

The introduction of focused cartographic representation editing tools (Fig. 6) allows cartographers who currently prefer to graphic software to work even more efficiently in a GIS-based system. Representation editing tools that work similarly to tools found in graphic packages such as Illustrator or Freehand are introduced to ArcGIS. Furthermore, many of the newly introduced tools are particularly efficient because they are designed with specific cartographic tasks in mind. Editing of representations takes place within the same versioned editing environment supported by ArcGIS for editing vector feature classes. See [Eicher & Briat 2005] "Supporting Interactive, Manual Editing of Cartographic Representations in GIS Software" for a detailed exploration of the cartographic editing tools and their applicability.

2.5 Cartographic Data Models and Workflows

2.5.1 Simple workflow case

In the simplest case, an organization has existing GIS data in a feature class, and wants to use it to produce a high-quality cartographic product. In this case, they add a cartographic representation to the feature class (see Fig 8).

2.5.2 Multi-product Case

In the next case, an organization has existing GIS data in a feature class, and wants to use it to produce more than one high-quality cartographic product at similar scales. In this case, they add a cartographic representation for each product to the one feature class (see Fig. 9).

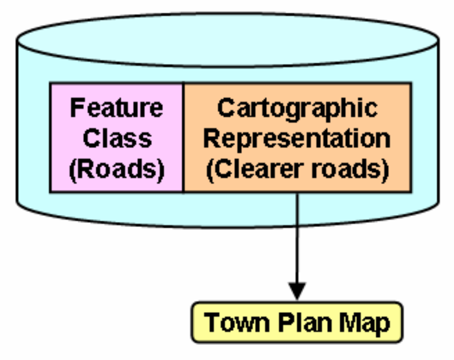


Fig. 9 - Simple case – Existing Feature Class.

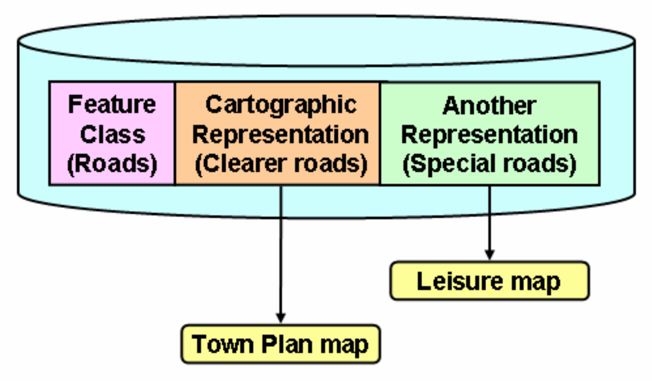
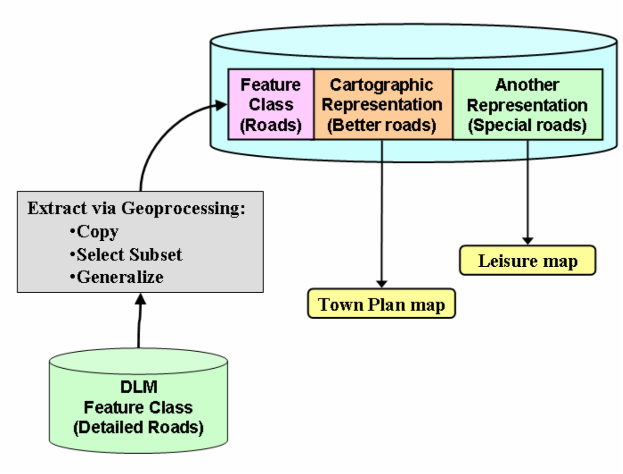


Fig. 10 - Multiple Cartographic Representations.

2.5.3 DLM/DCM Case

In the third case, an organization has a master landscape model data (DLM), and wants to use it to produce more than one high-quality cartographic product at different scales, as well as non-cartographic products (such as navigation routes for an in-car voice guidance system). In this case, they require the extraction of requisite data from the DLM by selection and generalization into a Digital Cartographic Model (DCM), which can then be enhanced with multiple representation capabilities as in the multi-product case (see Fig. 10). See also [Buckley & Frye 2005] "An Information

Model for Maps: Towards Cartographic Production from GIS Databases” for background on DLM/DCM models and the model transformations involved in their use.



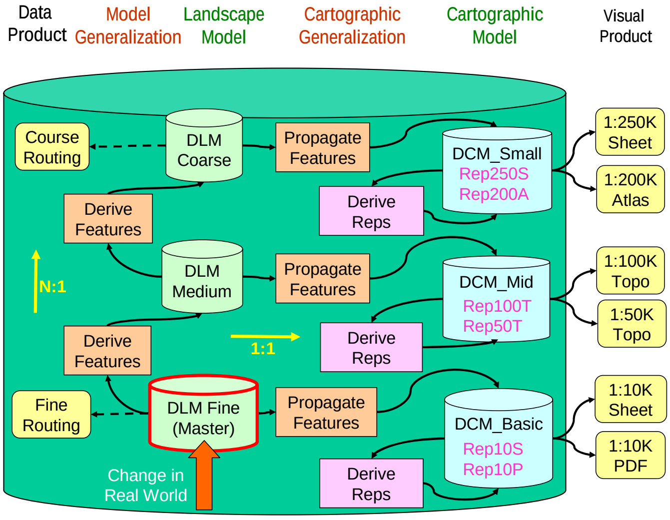


Fig. 11 - Enterprise case with DLM/DCM.

Fig. 12 - Multi-scale DLM/DCM Data Flows.

3 THE SWISSTOPO SOLUTION

3.1 TLM/DCM Model

The generic approach as described in the previous section is mirrored by the swisstopo approach. The role of the master data model is adopted by the Topographic Landscape Model (TLM). Because this is a 3D data model, its uses go beyond what is described below, but it has been designed to fulfill that role as well. The overall workflow is shown in Fig. 13 below.

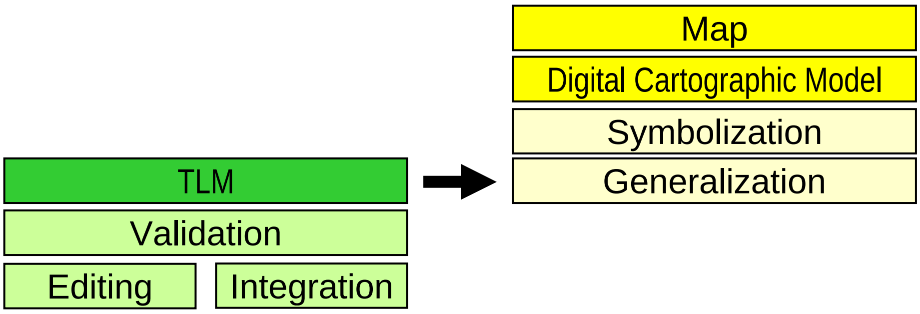


Fig. 13 – New map production workflow at swisstopo.

Fig. 14 gives the swisstopo data flow. The DKM25 is the basic DCM, the DKM50 is a medium DCM and the DKM100 is a small scale DCM. The DLMs are not required here as they are not intended for export. It is interesting to note that swisstopo intends to derive the DKM100 from the DKM50 and not from the TLM, this is shown in Fig. 14. This is considered to be more efficient as some of the results of the derivation of the DKM50 can be reused in this way.

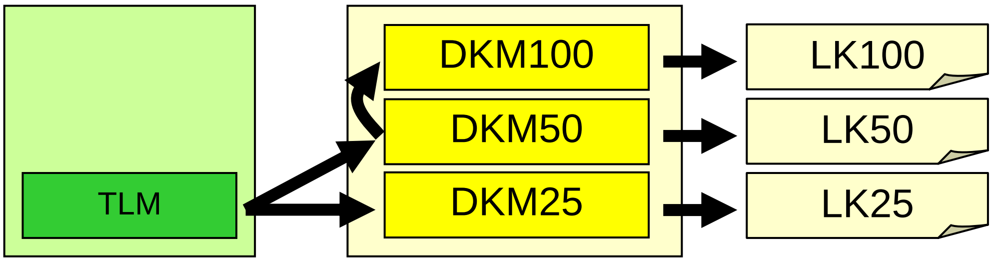


Fig. 14 – Derivation of DKMs

Another variation of the DLM/DCM model is the swisstopo solution for small scales <1:100,000. The respective DKMs, i.e. the DKM200 and the DKM300 are derived from a small scale base data model, the VECTOR200. This is not unusual and other mapping agencies pursue a similar approach. The advantage of having two base data models is that each can be tailored for the particular requirements of the respective scale range. The drawback of this approach, namely that two dataset must be maintained independently, can be overcome by closer integration of the two base datasets within one database. This allows linking the data models for incremental updates.

3.2 Incremental updates

One of the main objectives of swisstopo was that the new workflow should allow more efficient and faster updates of the map series. This requires a degree of automation when it comes to propagating updates of the master dataset (TLM) to the DKMs. This is achieved by determining the changes in TLM and passing these on to DKMs. The relevant processing is performed by the system, involving a number of steps:

- Relevance checking: only those changes of the TLM that are relevant for a particular DKM are passed on to downstream processes.
- Automatic representation and conflict detection
- Automatic resolution of conflicts, where possible
- Interactive resolution of conflicts

A large potential for efficiency improvements is offered by a system that preserves the interactive edits wherever possible. These edits are carried out by highly trained cartographers and hence present a large proportion of the effort and therefore cost of the update process.

3.3 Text Placement

Another important aspect of map high quality map production is the placement of labels and annotations. For swisstopo, the following workflow was selected to achieve high quality text placement. In a first step, text is formatted and dynamically placed as labels using the Maplex Label Engine. This engine requires the ArcGIS Maplex extension and has numerous rules that can be set to create and facilitate better name placement on maps [Murad 2005B]. For example, it allows you to control which label classes are placed first by setting the label priority, and to control whether labels can overlap particular features or other labels by setting the label and feature weights. This massively reduces the previously labor-intensive task of generating and positioning text for cartographic clarity (see Fig. 15).

In a second step, after these automatic rules have been applied, the dynamic labels are converted into static annotation. With annotation, each piece of text stores its own position, text string, and display properties in the geodatabase. This allows the cartographer to manually finalize the placement of individual text annotation. Annotation can be freestanding for feature linked. Feature linked annotations are tied back to the GIS features from which they were created so that they can be automatically updated as change happens in the real world.

Fig. 15 - Text placed by Maplex Engine.

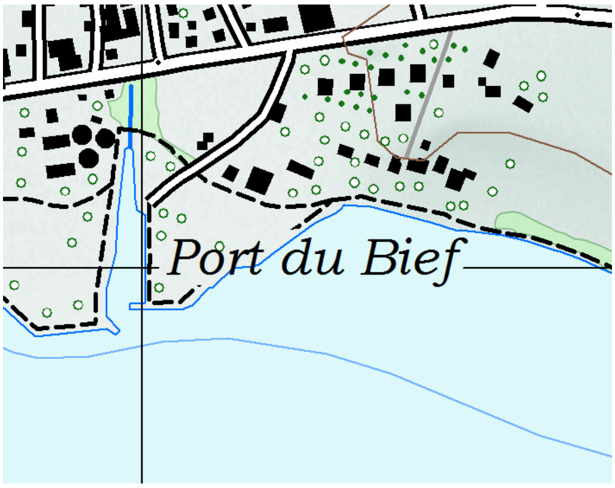


Fig. 16 - Selective Masking of Black behind Text.

4 FUTURE ESRI DEVELOPMENT

4.1 Graphic Control and Visual Output

Underpinning the visualization capabilities of ArcGIS is a powerful graphics output pipeline that handles stroking, filling, patterning, color, priority, transparency, visibility, masking, and much more. It drives screen output, plotting, and graphic export formats.

The graphics pipeline supports powerful visualization capabilities that were previously only available in specialized graphics applications, such as selective masking, which allows the user to specify a set of target layers to be masked or erased for each source polygon layer (see Fig. 16). This can greatly increase cartographic clarity, for example, by suppressing road casings where crossed by text without suppressing the road infill.

Work continues at ESRI to revise the graphics pipeline for greater performance, new functions, and platform portability. It will improve handling of complex graphics primitives, such as the clipping and merging of patterned fill areas, and hence reduce plot file sizes, particularly on output to intelligent plotting devices. Support is also planned for new document color models to provide a better framework for CMYK and spot colors, and to facilitate the use of gradients and textures.

4.2 Generalization

Fig. 12 extended the generic enterprise DLM/DCM case to where multiple products at different scales are to be produced. Here, the data flow encompasses both 'model generalization' (deriving landscape model features at coarser resolution by selection, aggregation and simplification), and 'cartographic generalization' (deriving visually appropriate features by applying displacement, exaggeration and typification), taking into account symbolization widths and sizes.

Model generalization is applied first, to derive a set of reduced-resolution landscape models. Starting from each DLM, cartographic generalization is applied, to produce a digital cartographic model for a particular 'scale band'. Once cartographic data appropriate to the scale band has been derived, then the multiple representation and override capabilities can be applied. These handle the symbology requirements and geometric differences for the product specifications and sheet/page limits needed to produce the various different products.

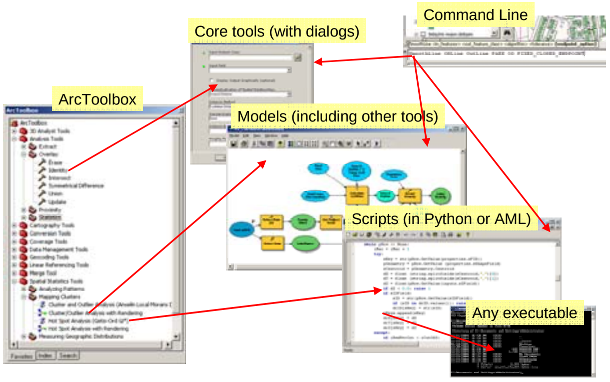


Fig. 17 - Geoprocessing framework, models and tools.

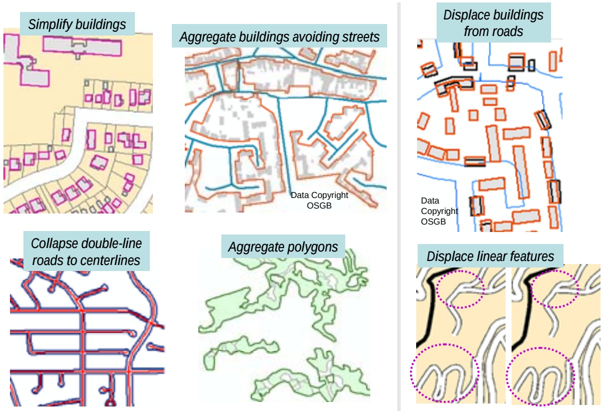


Fig. 18 - Generalization Algorithms.

4.3 Generalization Framework

Both model and cartographic generalization in the ESRI products are executed using the geoprocessing environment. This environment has a large and increasing range of algorithms for manipulation of geospatial data, including ones specifically aimed at generalization for product derivation [Fig. 18]. Algorithms can be combined into sequences, either by scripting languages such as Python, or using a visual ModelBuilder [Fig. 17]. The system is extensible, and user-written tools can easily be added as scripts or executables. See [Lee & Hardy 2005] for more details on database-driven generalization.

5 CONCLUSIONS

Advanced cartographic representation mechanisms and cartographic editing tools will soon become available in a commodity GIS. In conjunction with production automation and graphics capabilities described above, they will dramatically change the scope of automated cartography, facilitating the generation of multiple products from a central database. The human freedom enabled by the override system, combined with the symbolization rule pipeline, will permit high-quality attractive cartography within a database-centered environment.

It has been shown in this paper that the new ESRI cartography technology can be used to re-engineer traditional workflows to provide real benefits for the customer. The swisstopo solution is a prime example of how new technology and existing standards and requirements can be combined to improve the quality of the workflow in aspects such as data currency, accuracy and flexibility. At the same time swisstopo can look forward to efficiency improvements and cost savings through a streamlined update process.

6 NOTES

1. The sample data used in Fig. 2, 5, 7, 8 & 16 is swisstopo VECTOR25, copyright Swiss Federal Office of Topography. Samples in Fig. 18 are courtesy of OSGB, Crown Copyright. Data for Fig. 15 is copyright HarperCollins.

2. Some contextual matter in this paper is revised and updated from other documents jointly authored by members of the ESRI team working on representations and DLM/DCM work flows. In particular Cory Eicher, Marc-Olivier Briat, Dan Lee and Edie Punt are thanked for their contributions. Further contextual material is updated from [Hardy & Kressmann 2005].

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