Web Map Service Architecture for Topographic Data in Finland

Teemu Sipilä

National Land Survey of Finland

Abstract. Since 2012 National Land Survey of Finland has been renewing its web map services and digital map product pipelines based on Topographic database. A new service architecture utilizing Open Source software like PostGIS, GeoServer and MapCache has been developed.

The core of the system is Visualization Service that provides up-to-date vector based styled map services. Visualization Service has replicated database system based on PostGIS software. Topographic data from production GIS environment is loaded and updated using custom data update process that use GML files extracted from the production environment as a data source.

The main internal service layer of the new system is Web Map Service (WMS) providing dynamic map rendering services for other parts of the system. This implementation is based on a GeoServer cluster with each server having its own replicated PostGIS instance. Styled Layer Descriptor (SLD) files define shared portrayal rules for thematic, topographic and background maps.

Performance for web map services is achieved by populating map tiles on Web Map Tile Service (WMTS) running MapCache software. Also raster map file products are generated by the system. These raster files in PNG format are delivered to customers via online file download service that provides Atom feed letting also customers to keep their file copies up-to-date.

The most important benefit obtained from the new architecture is that same map layers and visualization definitions can be shared for all product pipelines. Also map products are now updated more frequently, performance of web map services has been enhanced and style descriptors are now more consistent. For WMTS services a national recommendation of tile matrix set to be used in Finland is successfully implemented by the new architecture.

Keywords: web map services, software architectures, map visualization

1. Introduction

National Land Survey of Finland maintains national Topographic database and Cadastral register in Finland. In 2012 a new project was started to renew web map services and digital map product pipelines based on data of these databases. A key part of the new solution is *Visualization Service* that provides up-to-date vector based styled map services.

Before the project there existed separate pipelines for web map services, raster map products, printed maps and map printouts. Also there has been some variations how each product pipeline renders same map styling instructions.

Web map service usage loads has exploded also for governmental and public sector services in Finland. This has required more powerful services and adaptation of efficient Web Map Tile Service (WMTS) standards.

This article covers challenges, solutions and best practices learned by NLS of Finland when building its new web map service architecture. Simultaneously there has also been some development on other OGC services like Web Feature Services (WFS) but they are not discussed here. Additionally the focus is on large and small scale topographic maps even if the same system is now used to produce maps also for some other datasets like cadastral data.

2. Renewing the Web Map Service Architecture

2.1. Overview

As described above Visualization Service providing map rendering is the core module of the new architecture presented on *Figure 1*.

Visualization Service is also technically separated from the Smallworld GIS based production environment that is used by NLS of Finland for maintaining Topographic database and Cadastral register. This production environment extracts topographic data as GML files to an online file download service on a daily basis.

Then Visualization Service reads Atom feeds and referenced GML files from the file download service, transforms data accordingly and loads it to a PostgreSQL / PostGIS spatial database.

The internal Web Map Service (WMS) service layer provides dynamic map rendering for other parts of the system. This implementation is based on a GeoServer cluster with each server having its own replicated PostGIS instance with fully populated topographic database.

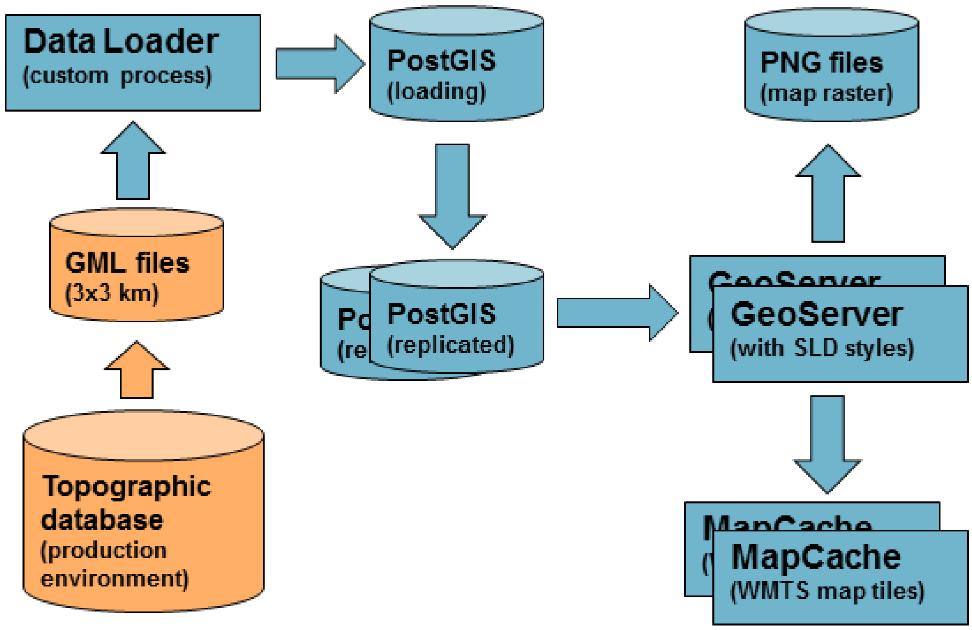

Figure 1. An overview diagram of the new web map service architecture in NLS of Finland. *Visualization Service* is composed of data loader, PostGIS database, GeoServer map service and production pipeline for raster maps. As part of the new architecture MapCache software provides WMTS services.

Performance for online web map clients is achieved by providing cached map tiles implemented as Web Map Tile Service (WMTS) running MapCache software. Digital map products, like raster map products in PNG file format, are processed in batch processes and delivered to customers via Atom based feeds. Updated raster data is also used to update some legacy WMS services based on raster map publishing.

The features described above are now up and running. In 2015 the system is extended to provide map visualization also for on-demand printing.

2.2. Loading Topographic Data to PostGIS

Large scale topographic data daily updates from the Topographic database to the data loader of Visualization Service are transferred as 3x3 km sized GML files with customized schema and map sheet division following national variant of UTM grid (NLS of Finland 2003). Only those map sheet files that contain updated features are transferred.

To ensure data consistency map features in transfer files are not clipped on map sheet borders. Of course this causes multiplication of feature elements like rivers on adjacent map sheets but this has also enabled much simpler data loader logic without complex edge matching processing.

Each topographic feature originated from the Topographic database has unique identifier (however not yet permanent when considering real world features) and also start and end timestamps of feature lifespan. Using these properties loading new and updated features is rather simple. Updating a feature means deleting and replacing it with a new one on a PostGIS instance dedicated only for data loading. As unclipped features may exists on adjacent map sheets a same loader transaction may actually do replacements multiple times but that's just fine because database instance is used only by a loader at this phase. To handle feature removals the production environment outputs also removed features from the last 30 days to GML files. Then a loader can use this data to delete them also from a PostGIS database.

The implementation of the data loader for large scale topographic data is based on custom Java code. The Java program takes GML as input, compares input to already populated rows on PostGIS database and finally produces SQL statements only for new, updated and removed features. Custom implementation has allowed also coding special case manipulations more flexible than it would be possible if a stock ETL tool would have been chosen. Anyway small scale topographic data is handled differently using PostGIS standard SHP loaders as small scale data is updated only once a year in NLS of Finland.

The chosen data loading strategy based on 3x3 km GML files has proved to be a working solution. However as 10-30 % of all map sheets has at least some changed features every week and because of multiplication of unclipped features and verbosity of GML schemas a lot of data transferring is needed. When running the process inside a data center this is not a big issue. Anyway feature-by-feature change streaming from Topographic database to a PostGIS database might be an ideal goal in some distant future.

2.3. Replicated PostGIS Instances on GeoServer Cluster

On the system there is a load balanced cluster of GeoServer instances with each server having its own replicated PostGIS instance. This server architecture is chosen to achieve as fault-tolerant and scalable system as possible.

As described on chapter 2.2 the data loader updates a PostGIS instance on a daily basis. This database instance is however not used by GeoServer map services directly. Once a week PostgreSQL base backup files are exported from the PostGIS instance used for data loading. Then PostGIS instances dedicated for each GeoServer instance are shutdown one by one and base backups are imported. This takes about half an hour for each server. As the system is load balanced no service downtime is experienced by clients.

Also some other techniques were investigated. More fine-grained replication solution could be based on write-ahead-log (WAL) files that would enable only changed rows to be replicated from master to slave databases. However this seemed to be more error-prone on topographic data updates.

2.4. GeoServer as Map Visualization Engine

GeoServer is used to produce visualizations for various digital map products in NLS of Finland like Background map series, Basic map raster (see *Figure 2*) and Topographic and General map raster products on different scales. For Basic map raster there are also multiple theme layers available. See detailed descriptions of these products here:

http://www.maanmittauslaitos.fi/en/digital-products

Figure 2. Example screenshot of Finnish Basic map raster.

GeoServer workspace configurations contain separate layers for each topographic data model feature type and style portrayal rules defined using SLD files and SVG symbols. The actual rendered map products are defined as layer groups by overlaying multiple feature type layers with their styles. There are also scale-independent (or multi-scale) products with layer group definition choosing appropriate styles for each scale. A subset of these configurations is published on GitHub (part of comments in Finnish only):

https://github.com/nlsfi/geoserver-configurations

Mostly SLD features supported by GeoServer has been suitable enough for these topographic map visualizations. However some cartographic elements needed more development efforts to get them rendered right.

For example there is Geographical Names Register in Finland (Leskinen 2009) with certain cartographic rules how map names should be visualized on different scales. Map names may have specific properties on position, direction, spacing, bending and typography. To ensure correct visualizations map names are stored and positioned letter-by-letter on PostGIS with official cartographic rules interpreted partly already on the data loader.

There was some difficulties also to get text labels - being road names, full place names or separate letters of map names - rendered without truncation on borders of WMS request bounding box. First the solution was to force clients to request a buffered box. However this would have required some cutting on the client side to get actual map area and meant wasting of data bandwidth. Finally an improvement published for GeoServer 2.6 version solved the problem by introducing an option whether labels should be truncated on borders or not (GeoServer 2013).

There was many other GeoServer and SLD tricks and issues solved also when implementing Visualization Service. However describing them all would require a separate study.

2.5. Web Map Tile Services on MapCache

WMS service provided by Visualization Service as described on previous chapters has currently no public interfaces. Generally as topographic maps are used mostly as background layers for other user interface elements WMS is not very optimal solution when considering performance.

Even if NLS of Finland still has some legacy WMS services for external API customers the focus on web map interfaces has clearly moved to WMTS based services. MapCache software on a clustered server infrastructure is now used to implement a WMTS service that was published on 2013 (NLS of Finland 2013). Since then usage loads have been steadily growing and expectation is that this trend is going to continue. For example *Paikkatietoikkuna*, a public and free website containing geographic and SDI information in Finland, is using this WMTS service on its map user interface:

http://www.paikkatietoikkuna.fi/web/en > Map Window

Tile matrix set recommended to be used on national services in Finland is based on Transverse Mercator projection with metric coordinate system (JHS180, 2011). This set is geographically defined by binding it to the Equator and the meridian of a UTM zone 35 intersecting the area of Finland. There are 16 resolution levels officially defined, top level 0 with resolution of 8192 meters/pixel and the most accurate level 15 with resolution of 0.25 meters/pixel as described on *Table 1*.

level	m/pix	level	m/pix	level	m/pix	level	m/pix
0	8192	5	512	8	32	12	2
1	4096	5	256	9	16	13	1
2	2048	6	128	10	8	14	0.5
3	1024	7	64	11	4	15	0.25

Table 1. Resolution levels on the tile matrix set recommended to be used in Finland (JHS180, 2011).

Map tiles for digital map products introduced on chapter 2.4 are all cached on file storages of MapCache servers. MapCache uses internal GeoServer based WMS service layer of Visualization Service to fetch map tiles to a cache. Most popular map products are statically pre-populated and caches updated using custom batch processes. For example if static population is processed on levels 0 to 13 (that is up to resolution of 1 meter/pixel) there are about 10 million tiles hitting the area of Finland. Using the system one map product can currently be fully repopulated for levels 0 to 13 on less time than a day.

This WMTS service is now very efficient, especially for tiles already cached, and MapCache software has been very stable. The performance is achieved by running MapCache on servers with file systems capable of handling hundreds of millions of file nodes. It's good to have enough CPU and memory too but the focus should be on file system design.

If map tiles for some products or resolutions are not pre-populated and GeoServer WMS must be called dynamically to draw map tiles then the opposite is true when optimizing servers. Servers running GeoServer and PostGIS seems to be very CPU and memory consuming when rendering topographic maps with a lot of feature type layers having different styles.

2.6. Raster Map Products

Topographic database and small scale vector map databases are available on vector formats with Open data license in Finland (NLS of Finland, 2012). This allows customers to use topographic data in almost any way they need.

However there is still demand also for large and small scale raster maps with map visualization pre-rendered to raster files. The production pipeline to generate these raster files was renewed to use Visualization Service as rendering engine. Products generated from the new pipeline were published end of 2014 (NLS of Finland, 2014).

Before this properties of raster maps were not fully aligned with those used on web map services. However new product specifications were defined so that raster file resolutions match with resolutions of the tile matrix set introduced on previous chapter. Raster file map sheet divisions still follows national variant of UTM grid (NLS of Finland 2003). For example large scale Basic map raster files are generated on 12x12 km map sheets with resolution of 1 meter/pixel and Topographic map raster 1:250 000 on 96x96 km map sheets with resolution of 32 meter/pixel. Also map visualizations are now harmonized between raster map products and WMTS based web map services.

The raster file format is now PNG with geographic map orientation information delivered on related PGW files. As for map tiles on WMTS also these PNG files are encoded with 8 bit palette of 256 colors. This optimizes file sizes significantly compared to true color encoding. However as palette support on GeoServer have had some bugs (GeoServer, 2014) extra file format conversion phases were needed to enable different palettes on different products and also to ensure 8 bit palette color order keeping the same on raster files of a same map product.

Most of raster map products are now generated as anti-aliased PNG files. A user survey (NLS of Finland, 2014) suggested that there are both customers needing non-anti-aliased raster files (for example if further processing was applied by a customer) and those that are wanting them anti-aliased (for viewing purposes). Because of harmonization of map products with web map services it was decided that the main principle shall be anti-aliased raster files but for Basic map raster both versions are offered.

Raster map products are updated weekly (for map sheets with changes on topographic data) and distributed to customers via freely available Open data download service with Atom feeds notifying changes to customers.

2.7. Coming Next: On-Demand Printing

Currently NLS of Finland has separate solutions for producing PDF file originals for printed maps and creating map printouts on different GIS applications. In beginning of 2015 a project was started to continue the renewal of the architecture described on this article. The focus on this project is to extend the architecture by bringing also pipelines of printed maps and printouts to the same system.

The main aim is to reach on-demand printing capability also for printed maps products, Basic map 1:25 000 and Topographic map 1:50 000.

There are still a lot of issues for the project to solve. Suitable large format and cost effective printer devices and services (digital press or fine quality inkjet printers) must be compared, product definitions for printed maps and printouts need to be adjusted and extensions to Visualization Service software modules shall be developed.

The idea is also to utilize same GeoServer based SLD visualizations as web map services and raster map production now use. GeoServer can output styled maps also as vector PDF files. These files would then be modified by adding map frame information like headers, map scale, coordinate grids, map legend, index map etc. items that are needed on printed maps or printouts.

3. Key Benefits

3.1. Streamlined Pipelines

Perhaps the most important benefit for NLS of Finland obtained from the new architecture is that same map layers and visualization definitions can be shared for all product pipelines. If on-demand printing plans can be implemented also then there's a full range of map products from online web services to raster maps and printed map products that can be served using the same solution, called Visualization Service as described in previous chapters.

Simultaneously there has been development in Europe for building the European Location Framework (http://www.elfproject.eu/). As one part of it there are plans to build European wide web map services for a Base Map product. National mapping agencies would be responsible for the region of their country. For NLS of Finland the solution would probably use parts of Visualization Service on the implementation.

Some of the modules of Visualization Service have also been successfully piloted on a cloud platform in a project called *Geodata service platform* (JulkICTLab 2014) that was piloting WFS, WMS and WMTS services for topographic data. One conclusion was that while it was rather easy to setup same server modules also on a cloud infrastructure data update processes are much more challenging compared to an environment discussed on chapters 2.2 and 2.3.

3.2. Up-to-Date Map Products

For large scale topographic map products the update cycle is now one week. This is achieved for both WMTS services and raster map products. Small scale map databases are updated only once a year as data changes on smaller scales are not as crucial.

The system is triggered to handle data updates through the whole chain of data processing. Production environment extracts GML files daily that are used by a PostGIS data loader also each day. This loader database is replicated once a week to PostGIS database instances of GeoServer cluster and finally WMTS service can start repopulating its tiles or map raster production environment updating raster files. Tuning this chain is quite complex development task.

3.3. Performance and Monitoring

Online web map services can be monitored by an online tool called Spatineo Monitor that is monitoring also the WMTS service of NLS of Finland (see the service status page at http://directory.spatineo.com/service/12048/). The availability of the WMTS service has been 99.9% or better. Stability and also average response times has been orders of magnitude better compared to legacy WMS services still used by NLS of Finland.

3.4. Enhanced and Consistent Map Styles

Besides achieving consistency on map styles by streamlining product pipelines there has not been any major changes on cartography of topographic maps in NLS of Finland.

However some enhancements has been achieved as a result of renewing map rendering engines. Using GeoServer maps are now scaled better to any resolution without rasterization, map generalizations are harmonized and antialiasing has made maps visually more appealing. Also with GeoServer SLD configurations it's now easier to define multiple style variants for same map layers. For example for topographic map data there are multiple styles for different purposes (see figures on *Appendix I*).

3.5. Supporting Standards and Recommendations

For the renewal of the architecture the most important national recommendation has been the one defining the tile matrix set to be used in Finland as described on chapter 2.5. This specification is now successfully adopted by WMTS services provided by NLS of Finland. Resolution levels from the specification are now also used on raster map products to ensure some level of consistency with WMTS map tiles. However as raster map files uses UTM based map sheet division map tiles on the national tile matrix set and raster map files do not share same pixel space grids on all resolution levels.

In Europe national mapping agencies must also support the implementation of INSPIRE directive (Infrastructure for Spatial Information in the European Community). One step towards implementation was taken by providing some partial element layers of Basic map raster with some relation to INSPIRE data themes (see *Figure 3e* and *Figure 3f* in *Appendix I*). Also ELF project mentioned on chapter 3.1 is advancing the implementation of INSPIRE.

4. Conclusion

As a summary the new architecture for NLS of Finland discussed on this article has streamlined processes needed for providing web map services like efficient WMTS tiled map services and producing digital map products like raster maps. Technological choices to build the architecture based on Open Source software like PostGIS, GeoServer and MapCache has proved to be a working solution. Adaptation of national recommendation for tile matrix set has been successful. New map visualizations for topographic maps were not introduced but consistency for map styles between different map product pipelines was achieved.

There is still potential for extending the architecture. In 2015 on-demand map printing capabilities shall be investigated. Even new visualizations could be added to map services if just needed. Dynamic WMS services based on the new architecture may replace legacy WMS services in future. Also web map services based on GeoServer raster file publishing (ie. elevation model visualizations) may be developed.

Appendix I - Style variants for topographic map data

Figure 3a. Basic map raster - color scheme for printing.

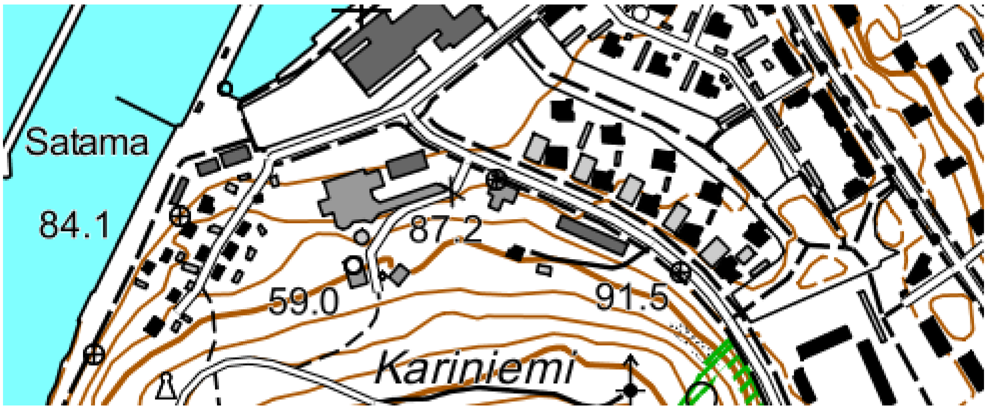

Figure 3b. Basic map raster - color scheme for background map usage.

Figure 3c. Background map series - scale 1:10 000.

Figure 3d. Basic map raster - another color scheme for background map usage.

Figure 3e. Basic map raster - thematic layers; Buildings and Geographical names.

Figure 3f. Basic map raster - thematic layers; Elevation and Transport networks.

References

GeoServer (2013) GeoServer improvement issue (GEOS-6207). Truncate labels on border. http://jira.codehaus.org/browse/GEOS-6207. Accessed 10 April 2015

GeoServer (2014) GeoServer bug issue (GEOS-6474). Problem using different palettes. https://jira.codehaus.org/browse/GEOS-6474. Accessed 10 April 2015

JHS180 (2011) "JHS 180 Paikkatiedon sisältöpalvelut". Recommendation text in Finnish. First published 2011, updated 2013. See the link, on a page 14 there is an overview grid illustration of the recommended tile matrix set in Finland. http://docs.jhs-suositukset.fi/jhs-suositukset/JHS180/JHS180_liite1.pdf. Accessed 10 April 2015.

JulkICTLab (2014) Geodata service platform. http://julkictlab.fi/en/pilot-projects/geodata-service-platform/. Accessed 10 April 2015.

Leskinen T (2009) Geographic names register as a part of the spatial data infrastructure. http://icaci.org/files/documents/ICC_proceedings/ICC2009/html/nonref/12_1.pdf. Accessed 10 April 2015.

NLS of Finland (2003) "UTM Lehtijako". Map sheet division based on UTM zone 35. http://www.maanmittauslaitos.fi/sites/default/files/UTM_lehtijakopdf.pdf. Accessed 10 April 2015.

NLS of Finland (2012) National Land Survey topographic data now freely available. Press release 2012-05-03. http://www.maanmittauslaitos.fi/en/tiedotteet/2012/05/national-land-survey-topographic-data-now-freely-available. Accessed 10 April 2015.

NLS of Finland (2013) "Uusi rajapintapalvelu tarjoaa sovelluksille kartat entistä helpommin". In Finnish. About WMTS service that was published on 2013 by NLS of Finland. http://www.maanmittauslaitos.fi/tiedotteet/2013/10/uusi-rajapintapalvelu-tarjoaa-sovelluksille-kartat-entista-helpommin. Accessed 10 April 2015.

NLS of Finland (2014) "Rasterikartat muuttuvat - tutustu muutoksiin". In Finnish. http://www.maanmittauslaitos.fi/tiedotteet/2015/01/rasterikartat-muuttuvat-tutustu-muutoksiin. About renewed raster map products published on 2014 by NLS of Finland. Accessed 10 April 2015.