Concepts and Techniques of an Online 3D Atlas
– Challenges in Cartographic 3D Visualization

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Abstract.
To meet the challenges of future digital atlas publication, a concept for an online 3D atlas platform (APS) has been developed. This framework should have the potential for combining interactive thematic cartography with real-time 3D atlas technology. As to system design, the APS will consist of extensible modules for *spatial navigation, map visualization and information retrieval*, integrated in a *Web application user interface*. The modules will be developed gradually; *core functionality* will be implemented first and can be extended according to user needs.

Currently, work is done on the *visualization core module*, allowing for 2D and 3D mapping by means of the Virtual Globe engine *osgEarth*. The visualization engine is capable of handling large amounts of geographical data and web services. Essentially, the system offers 2D and 3D visualization of raster data (DTMs, imagery, etc.), vector data (choropleths, univariate symbols and diagrams, POIs), and even 3D objects.

Keywords: Atlas cartography, 3D atlas, 3D geovisualization, visualization engine

1 Introduction

During the last two decades numerous interactive atlas systems and maps have been published, featuring a variety of mainly statistical 2D map types like choropleths, point symbols and diagrams and – in some cases – also 3D maps like panoramic views and block diagrams. These systems usually include a bundle of functions for spatial and temporal navigation (zooming, panning, timeline, etc.), map representation (e.g. coloring), and layer management.
Today, atlas systems have to compete with a variety of freely available map services, Geoportals and Virtual Globes. At the same time, the popularity of geodata and geo-related applications offers a unique chance to digital atlas products as to activate new user groups and to animate them for collaboration. Thus, also the development of atlases has to strive for new horizons.

adfa, p. 1, 2011.

A detailed survey on current products of geovisualization points out that the majority of up-to-date applications are dedicated and conceived for web and mobile use (Hurni et al. 2011). The attractiveness of such applications is primary based on the immediate benefit in everyday life and on the actuality/timeliness of the data. In addition, applications using 3D concepts and Virtual Globes are persuading users by their intuitive navigation and spatial clarity (Bodum 2002). However, these applications are rather heterogeneous concerning content handling and cartographic quality.

The major challenge for digital atlases will be to merge the three main issues of *3D visualization, online mapping and mobile applications* with *cartographic design and atlas-specific functionality.* While 2D maps and atlases and their benefits are well documented, 3D atlas cartography lacks even basic concepts.

The *SwissAtlasPlatform (APS)* project has been launched to deal with the unsolved questions of 3D cartography, aiming to set up a general 3D atlas configuration, mainly for use in an online web environment (Sieber et al. 2011). Based on this APS, the new product line of the *Atlas of Switzerland* and affiliated atlases will be developed. The remainder of this paper describes the overall system design of the APS and its modular components, focusing on conceptual and technical requirements and on the realization of a cartographic 3D visualization module by means of a Virtual Globe engine. It shows the high potential of such an approach to bring atlas cartography as close as possible to the user.

2 Trends in the field of geovisualization

Within the past years, the basic conditions in the field of geovisualization have undergone a substantial – yet positive – change. The ever-increasing capacity of Internet connections, technical innovations concerning online mapping, and smart mobile devices have altered the users' expectations towards cartographic products and geographic data. Nowadays, digital atlases have to compete with freely available map services like *OpenStreetMap* or *Google Maps,* national Geoportals as e.g., *www.map.geo.admin.ch,* and with virtual 3D globes (*GoogleEarth, NASA World Wind*). In general, three major technological trends are affecting atlas cartography: online mapping, mobile mapping, and 3D mapping.

2.1 Web mapping 2.0

While twenty years ago the first maps appeared in the form of static images on the Internet, innovative Web mapping technology (e.g. HTML5, AJAX, OGC standards) and APIs facilitate the production and use of online maps nowadays. Services like *Google Maps, Bing Maps,* and *OpenStreetMap* offer simple tools to build efficient map applications without much programming knowledge. In combination with high-capacity Internet connections and mobile devices, the number of online map users has multiplied in the last few years – maps are ubiquitous.

These technical developments go along with the popularity of Web 2.0 services like *Facebook, Twitter* or *Flickr*. As a characteristic property of the Web 2.0, the wide public is able to produce, combine and broadcast media content, thus omitting the barrier between (map) author and user. As a prime example, the *OpenStreetMap* project can be mentioned, where volunteers generate content for a freely available map of the world.
Due to these circumstances, maps and cartography have gained an ever increasing audience and a considerable relevance in everyday life. On the other hand, the wide participation in the production and dissemination of maps raises concerns about reduced map quality, either in terms of graphical design, geometrical accuracy, or data completeness. Atlas cartography can benefit from the situation by offering collaboration and map standards.

2.2 Mobile technologies for mapping

The popularity of geo-aware applications is also based on another important initiative: The liberalization of the GPS system as a high-precision tool for public use in 2000. This step revolutionized the geo-market with regard to affordability of products and technical applications. With the introduction of GPX as a universal exchange format, GPS is not only used for navigation, but also for the production of spatial data (Haklay et al., 2008). Geo-referencing has become an easy task for everyone and geo-referenced data provides the basis for many of the online map applications and mash-ups (Fischer, 2008).
Also with regard to devices, the trend to mobile and ubiquitous use of (geo-) information is apparent. Since 2008, small portable computers – netbooks and tablets/pads – denote a rapidly increasing market share. In 2011, vendors shipped close to 488 million smartphones, 63 million tablets and 29 million netbooks compared to 210 million notebooks and 112 million desktop PCs (Canalys, 2012; **Fig. 1**). Most notably, the market for tablets is booming: Analysts estimate about 185 million pads sold (RBC Capital Markets) in 2014; 248 million are expected for 2015 (Transparency Market Research).

Worldwide smart phone and client PC shipments
Shipments and growth rates by category, Q4 2011 and full year 2011

Category	Q4 2011 shipments (millions)	Growth Q4'11/Q4'10	Full year 2011 shipments (millions)	Growth 2011/2010
Smart phones	158.5	56.6%	487.7	62.7%
Total client PCs	120.2	16.3%	414.6	14.8%
- Pads	26.5	186.2%	63.2	274.2%
- Netbooks	6.7	-32.4%	29.4	-25.3%
- Notebooks	57.9	7.3%	209.6	7.5%
- Desktops	29.1	-3.6%	112.4	2.3%

Source: Canalys estimates © Canalys 2012

Fig. 1. Smartphone and client PC shipments 2011 and annual growth rate worldwide (Canalys, 2012).

The ubiquitous availability of wireless technologies and cheap mobile devices has raised user needs, which also need to be fulfilled by classic geographical applications like atlases. A web atlas should be conceptually and technically designed in a way to allow a migration to mobile platforms. Thereby, the functionality and visualization of data as well as the GUI components have to be adapted to small (touch-) screen displays.

2.3 3D Geovisualization

3D visualization is a huge trend in the entertainment and game industry. Cinema, TV, smartphones, and gaming consoles have become 3D capable. By using standards like WebGL and XML3D many of the common Web browsers do natively support 3D applications (Völkl, 2010). 3D mapping has become big business for enterprises. Only recently, Nokia launched *NokiaMap 3D* with WebGL browser technology, while Apple iOS6 comes along with a MapApp based on C3 mobile technology. Amazon has decided to join 3D map services with an UpNext-App for mobile application (**Fig. 2**). *UpNext* has spent the past years developing detailed 3D maps for iOS and Android. One of the biggest players on the 3D map market is Google; while *Google Maps* is running with WebGL technology, the virtual 3D globe *GoogleEarth* is still based on a plug-in.

Fig. 2. 3D geovisualization on mobile devices: Apple C3 maps (Apple, 2012) / UpNext HD maps (Amazon, 2012)

In 3D geovisualization, focus is currently laid – both on the data production and the application side – on image resolution and photorealistic presentation. Concerning atlas cartography, basic questions need to be answered as to how cartographic 3D visualizations of thematic data can create secondary information for the user. Although there is a tendency towards 3D representations in cartography, many questions on effectiveness and usefulness remain unsolved (Bleisch et al., 2008).

3 Web atlas cartography and Virtual Globes

3.1 Web Atlases

Desktop-based digital atlases have reached a sophisticated and mature stage regarding 2D map representation technology and interactive functionality (Hurni et al., 2011). In the past few years, the evolution of thematic atlases has shown a strong tendency towards freely available, interactive Web applications. An overview on the characteristics of thematic Web atlases can be found in Sieber et al. (2011).

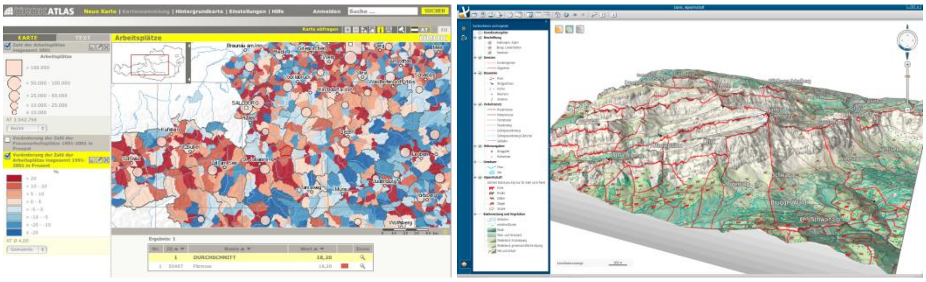

Fig. 3. Statistical 2D map (ÖROK-Atlas Online) / 3D block diagram (Schweizer Weltatlas interaktiv, 2011)

Most of the Web atlases are designed for the portrayal of 2D map views, and are mature in the fields of spatial 2D navigation and visualization. Besides seamless zooming and panning they often offer temporal navigation and animation for statistical data. The visualization includes choropleth maps and univariate symbol maps; sporadically, more complex diagrams like pie charts are realized. Sophisticated 2D Web atlases use vector data, allowing for adapting the classification and the coloring. Sometimes, tools for feature selection or spatial selection are available.

Technologically, there is a tendency towards pre-built frameworks like *Géoclip*, offering a standardized palette of functions and some limited possibilities of GUI design. These frameworks are mostly use to publish statistical atlases. Other applications like the *Tirol Atlas* and the *ÖROK Atlas* (**Fig. 3**) are fully based on Open Source solutions, ensuring compatibility with common standards and data formats. As with the *Atlas of Canada*, Web Mapping Services (WMS) are addressed to incorporate external map sources. Most of these atlases are freely accessible at no charge and can be used in any browser without additional installations or downloads.

Overall, the functionality of Web atlases is much less comprehensive compared to desktop-based systems like the *Atlas of Switzerland 3.0* (Sieber et al., 2011). In most cases, online atlases face problems of limited Internet capacity to handle large data sets and interactivity. Three-dimensional representations are not often featured in Web atlases; only the *Schweizer Weltatlas interaktiv* contains a Virtual Globe and a block diagram module (**Fig. 3**). Therefore, the major challenge for future atlas development is to combine the advantages of Web-based and desktop-based systems into a sole Web atlas platform.

3.2 Virtual Globes

Virtual Globes (VGs) are custom media for real-time visualization of large data sets in a 3D environment. The first VGs were published in 2005 when *NASA World Wind*, *GoogleEarth* and later on Microsoft's *Virtual Earth / Bing Maps 3D* emerged. Nowadays, commercial and non-commercial VGs are numerous (e.g., *Nokia Map 3D, osgEarth, i3d OpenWebGlobe, SkylineGlobe Pro, ESRI Arc Globe*); they are either used as stand-alone applications or as GIS visualization frontends. VGs are realized as a browser solution, in combination with a specific browser plug-in, or as a downloadable desktop application. In addition, versions for mobile devices are available. A fundamental criterion for using VGs as a visualization frontend in atlases is open access to the VGs source code (Open Source). While Closed Source VGs (e.g., *GoogleEarth, Nokia Map 3D, SkylineGlobe Pro*) are suited to work with predefined structures or to present geographical content solely, only Open Source VGs such as *osgEarth* or *i3d OpenWebGlobe* allow for atlas-specific extensions in the VGs' core.

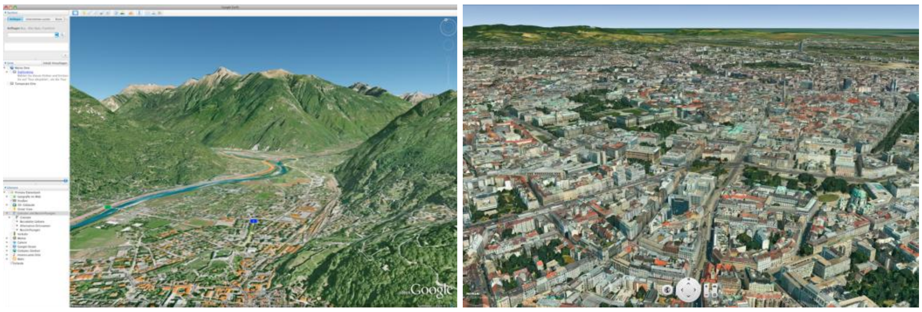

Fig. 4. 3D geovisualization on desktop devices: GoogleEarth (Google, 2012) and NokiaMap 3D (Nokia, 2012)

Because of the visual attractiveness and the practicability in everyday life, 3D globes gained enormous attention from the broad public, the mass media (e.g. in TV news programs) and the geospatial community. Large amounts of freely accessible satellite data and maps facilitate to reproduce and explore nearly every corner of the earth on computer screens (**Fig. 4**). Altogether, VGs mark another evolutionary step in modern Internet cartography (Gartner & Schmidt, 2010). However, VGs are not yet widely applied as interactive 3D viewers in cartography (Web maps, atlases, Geoportals). An online survey by Nebiker et al. (2008) on the potential of VGs and 3D Geoportals states that these can be "seen as vast global distribution channels for existing geodata, which could help reach new markets and customer groups. They are also seen as offering the potential for new applications and uses, such as geospatial collaboration within a shared and interactive (national) 3D geodata infrastructure."

In summary, contemporary *geovisualization techniques* allow for Web atlas development on desktop platforms and moreover on mobile devices. It has to be considered that mobile apps should differ from desktop solutions in both the handling of information (gesture-driven navigation) and in the kind of information displayed (location-based).

Concerning *cartographic visualization*, 2D mapping techniques are well established in atlas cartography, while 3D thematic mapping is rarely implemented. Only recently, attempts of 3D thematic mapping have been undertaken (Sandvik, 2008; Panchaud, 2012). Challenges for visualizing thematic properties with 3D mapping systems are still manifold: first of all, 3D representations of map features lack even basic concepts and strategies of map design. Another point to be considered is the handling of large quantities of statistical, geographical and image data for a coherent compilation at different map scales. Thus, an interactive mapping system should be developed, supplying 3D techniques for visualizing multi-scale maps, and tools for accessing thematic properties – based on sound 3D theoretical findings. Virtual Globes, allowing for intuitive navigation in large spatial data sets, are very well qualified to render cartographic data within a 3D atlas framework.

4 Design of an Online 3D Atlas

The next generation of digital atlases should benefit from the ongoing technological development in geovisualization. According to the current trends in atlas cartography and related fields, the need of an *online solution* is obvious. Furthermore, the new field of application has to be defined: An online atlas can be realized either for desktop computers or for mobile devices, and using more server-based or more client-based scenarios. Likewise, the decision to follow a pure *3D cartography approach* is also incisive: It substantially influences the approach of atlas makers as well as the technical solutions concerning system design, map display, and navigation.
In the following, the concept, design, and first implementations of an online 3D atlas will be sketched in an exemplary way by means of the next generation of the Atlas of Switzerland.

4.1 General Concepts and Methods

3D atlas cartography.
The concept of 3D-based cartography will be pursued, where a 2D map is considered as a special case of a 3D map situation. While most of the data and geometry should be useable in both “worlds”, the hypothesis for visualization states that special rules have to be developed for 3D representations. In order to assess the complex nature and characteristics of thematic geodata like data related to climate and weather, geology, traffic etc., not only static 2D maps, yet often a multi-dimensional, dynamic context is necessary. While 2D mapping techniques are quite well established, there is still a lack of (cartographic) knowledge concerning 3D representations and relating interactive methods (Räber & Sieber, 2012). Research has to be done to determine whether 3D-based visualizations can supersede 2D maps. Techniques for 3D visualization could incorporate floating sub- and supra-terrain layers, billboard concepts for point symbols and charts, and symbol representation at different scales or distances with a single master geometry (Asche, 2009). When using multi-scale maps, atlases are also confronted with aspects of spatial and temporal granularity and the level of

detail problem (LOD). These conceptual considerations are technically based on a 3D visualization engine, preferably a Virtual Globe.

Interactive atlas cartography.

As interactivity will play an important role in online 3D atlases, research and development should also concentrate on new methods and user-friendly tools for interactive navigation, map graphics and layer handling, and explorative analysis. As a precondition, maps and data have to be prepared for interactive use, by relying on vector graphics, and enhanced with relevant variables – a time-consuming but very important editorial task.

Navigation in 3D space and time should essentially allow for an intuitive map access with easy-to-use tools (and gestures). For spatial navigation, the concept of travelling by different means of transportation (airplane, helicopter, car, etc.) can be adapted from the gaming industry. Auxiliary tools for spatial and temporal orientation, for search and localization, and for visual tracking in a 3D environment are needed.

Interaction on cartographic 3D visualization should allow for individual map design within concise guiding limits. Functionality could cover re-classification of map data and re-symbolization of map geometry for altering the map graphics. The concept of a modular map is followed, thus creating new map content by a combination of complementary map layers. While this concept is not new to the cartographic community, special focus will be laid on usable layer handling and on smart combination of different map themes. In addition, interaction should also include possibilities to present different map views and to smoothly switch from 3D to 2D and vice versa.

Map analysis in atlas systems is in most cases offered in the form of explorative data analysis, information retrieval, and terrain analysis. The main aim of such interactive functionality is to detect and highlight hidden structures and processes without altering the original data. Analysis tools can work – in a spatial or temporal context – either on a global level of the map or selectively on individual map elements. Map analysis will concentrate on graphical data brushing (Andrienko, 2009) offering spatial and statistical selection criteria. Map comparison and map animation in combination with 3D information is also of great interest. In the field of 3D terrain analysis, questions concerning movement have to be faced, as e.g. the behavior of terrain visibility for moving objects (car ride, daily exposure to sunlight).

While research activities on atlas cartography will thus concentrate on methods and techniques in the two fields of 3D cartography and interactivity, concepts of an online / mobile distribution channel have to be considered on the technical development side.

Online atlas cartography.

Online atlases are state-of-the-art in digital atlas cartography; the integration with the Web is a must for today's geographic and atlas information systems. A Web-based architecture of an atlas application has many advantages compared to an offline media distribution: It can be continuously updated for both map data and functionality. The cyclic expandability enables a quick adaptation to thematic and technical short-term trends. In addition, the online connection facilitates contacts with the user community: Preferences and suggestions for map topics, atlas functionality, and bug reporting as well as information about user behavior and atlas usability can be gathered. Moreover, it can take advantage of the potential of remote data sources and various cartographic web services like WMS or WFS (Iosifescu-Enescu, 2011).

To focus on an online application is closely related to the decision to store and access data by means of cloud computing. Both data and geometry is organized in a spatial database and optionally in file systems (tiled vector and image raster data), all stored in a scalable cloud system. The use of a cloud guarantees the scalability of the atlas, meaning that the system is able to handle large numbers of access requests.

Mobile atlas cartography.

Mobile atlases are just a variation of online atlases, yet rather different in content, functionality, and handling. The concept for mobile solutions should vary from desktop atlases because of the typical use of mobile services in connection with outdoor activities. Concerning atlas content, mobile solutions should be dedicated to location-based information retrieval and display; answering e.g. the question about the geological structure of the mountain in front of the user. Compared to the functionality of desktop applications, the amount of functions and their complexity has to be reduced, mainly because of the limited screen size and CPU of mobile devices. Also, the functions need to be adapted to tasks of absolute and relative positioning using GPS, delivering on-site information, and displaying real-time data. Tablet computers (and smartphones) follow a new GUI design concept, because most of the interactions are performed by gesture commands. Regarding technical design, mobile applications usually require a proprietary development for each platform (iOS, Android, etc.). Moreover, a mobile atlas should also offer offline operation and data storage mode (data caching).

4.2 Atlas Framework: The SwissAtlasPlatform

Within the project of the Atlas of Switzerland (AoS), the above concepts will be applied in the atlas framework *SwissAtlasPlatform (APS)*, from which a next online/ mobile generation of the Atlas of Switzerland will be derived and published in the coming years.

The APS system architecture is designed as a Web atlas framework, allowing for different client-server relations (Sieber et al., 2011). It will be based preferably on standardized interfaces and non-proprietary formats. In general, it consists of an *atlas core* and *additional atlas extensions* (**Fig. 5**).

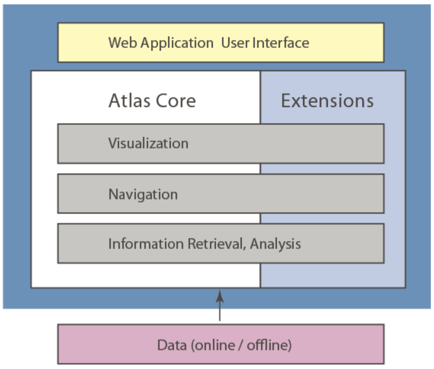

Fig. 5. Conceptual design of the SwissAtlasPlatform (APS)

The APS core modules offer basic functionality for 3D and 2D visualization, spatial and temporal navigation, as well as query and analysis of map elements. As a visualization engine, a 3D Virtual Globe technology is applied complying with the requirements of the overall atlas concept. Atlas functionality is provided to the user by means of a Web-application interface.

To define the appropriate basic atlas functionality for the APS core an internal online survey on the use and usability of AoS3 functions was accomplished in 2011 (Hollenstein, 2011). The main results in short: too much functionality is confusing for the user, a lot of functions remain unused (although cartographically reasonable), and the 3D panorama map mode is most attractive and most used. The aim of the APS core is therefore to create a 3D atlas with easy-to-use functionality, embedded in a slim GUI. Considering the facts of this survey and of other user response, the planned basic APS functions can be determined as follows:

- *General Atlas Functions:* Language, Tooltips, Help, Preferences, Contact, Exit, Home, Imprint, Print map, Export map, Map services (WMS), Full screen (switch GUI on/off)
- *Spatial Navigation:* Zoom (with Full view), Pan, Free navigation (Flight mode), Reference map (current position), Object search (Index), Camera position, Geographic position (Coordinates, Height)
- *Temporal Navigation:* Timeframe, Timeline (Start/Stop)
- *Thematic Navigation:* Theme list (hierarchic organization), Active themes, Theme search (Index)
- *Information Retrieval:* Map element/object query (Picking), Labeling (map objects), Legend, Thematic info (including Web links)
- *Map Analysis:* Measuring (Distance, Area), Terrain profile
- *Map Visualization:* Base map manipulation (altering the map), Transparency (global or layer-specific), Highlighting (map elements), Extruded footprints (choropleths, 3D objects), Lighting (linked with day-time), Sky (sun, stars)
- *Map Views (Atlas modes):* 3D globe, 3D block diagram, 2D maps

- *Visualization Types:* Raster: images, grids (queryable); Vector: choropleths, points (abstract, pictorial), symbols (univariate, diagrams), billboards, lines, 3D objects (only simple geometry).

The above list of APS functions shows clearly that in the basic framework, the most attention is given to navigation and visualization aspects.

In future, the APS core will be extensible in two ways: for internal add-ons in the context of the Atlas of Switzerland project, and also for collaboration with external atlas partners.
Internal extensions will comprise advanced navigation tools, as e.g. backtracking or additional tools for precise localization. Mature visualizing functions may include tools for custom symbolization, or the creation of various atmospheric effects. Additionally, multivariate mapping will be realized. Analysis tools will provide possibilities for map comparison and data brushing.
External extensions may contain specific functions for affiliated atlases. Thus, for both the Hydrological Atlas of Switzerland and the Historical Atlas of Switzerland, advanced spatio-temporal tools for data analysis are of importance. By means of external extensions, also the cartographic presentation of hydrological real-time data could be solved later on.
Currently, development work focusses on the 3D visualization module and – coherently – the navigation module of the atlas core. The reasons for concentrating on visualization first are mainly twofold: on the one hand, 3D is a relative new field for cartographic applications. On the other hand, finding a visualization engine – capable of managing the requirements as to data type and data volume as well as to visualization types – is critical for the APS and the AoS project.

5 3D Visualization Engine

5.1 Requirements and Criteria for 3D Atlas Operation

As motivated in previous sections, a viewer application with current 3D Virtual Globe technology will be set up within the 3D visualization module. Basically, there are various qualified products that could be integrated into the APS core (Nebiker et al., 2010); nevertheless, only few of them meet the essential criteria for use in an atlas. These requirements were defined as follows:

- High geodetic quality: geoid or ellipsoid, instead of a simple sphere (to ensure geometric accuracy even at large scale)
- Support of several geodetic reference systems (WGS84, UTM, etc.) and cartographic projections
- Free perimeter setting of the region displayed (geographic area limitation, focus)
- Unlimited number of data processed
- Dynamic/progressive streaming of geodata, high performance visualization
- Interface to integrate Web services (WMS, WTS, WFS)

- Elevation data: multi-resolution terrain level of detail (LOD definition)
- Combination of multiple DTMs with different spatial resolutions
- Data types: raster and vector integration
- Interactive grid and vector data handling
- Real 3D objects
- Points of Interest (POI)
- Map layer operations: replacement of layers (when zooming), switching layers on/off
- Real-time navigation
- Labeling: label placement, occlusion
- Data management: DBMS connection
- Integration of additional symbolization, functions and tools for thematic cartography
- Web enablement: running directly / by means of a plug-in in the browser
- Use of Open Source frameworks
- Investment and operating costs (commercial/non-commercial providers)

Twenty existing Virtual Globes, e.g. *GoogleEarth, Nokia Maps 3D, NASA World Wind, i3D Open Globe, osgEarth, Skyline Globe Pro, ERDAS Titan, XNavigator, and ossimPlanet* were verified on these criteria. Critical features were the geodetic quality, multiple DTM and vector data handling, free access to the source code, and finally also financial and support considerations. The Open Source framework *osgEarth,* released and maintained by Pelican Mapping, Fairbanks VA (USA), fulfills most of the criteria cited above and was selected as a 3D visualization engine for the APS.

5.2 The 3D Visualization Engine osgEarth

osgEarth is a free open source terrain rendering toolkit for OpenSceneGraph (OSG) applications, creating XML-based 2D and 3D maps (**Fig. 6**). Its internal design reflects the focus on real-time data: Raster and vector data sources are generally structured into tile hierarchies to optimize fast serving over the web and real-time display. As a characteristic, osgEarth incorporates the concept of separated but connected drivers, a means to handle each of the data sources effectively. osgEarth supports drivers for imagery and elevation data (Image/Elevation Drivers), for vector and 3D model geometry (Model and Feature Drivers), for tile caching (Cache Drivers), and optionally for terrain rendering implementation (Terrain Engine Drivers).
Image/Elevation Drivers are capable of adding and combining a number of image or elevation layers of different sizes and resolutions. Thus, scalable imagery and terrain models – either offline, or dynamically at run-time – can be created.
Model and Feature Drivers use a model data source to incorporate and display any vector feature data (e.g. choropleths), and to place external 3D models (e.g. buildings). Models work independently of osgEarth's image/elevation tiling system. A Model Driver is responsible for its own level-of-detail and data paging (screen updating) management.

Vector feature symbology controls the display of vector map layers. A vector feature consists of a geometry file and an associated list of attributes. The geometry can be symbolized either by means of styles and stylesheets for point, line, polygon, altitude, extrusion, marker, skin, and text, or by means of expressions. Styles and stylesheets are composed of graphical variables for symbols (size, fill and stroke color, opacity, texture, etc.) and positional attributes (offset, height). Expressions make use of feature attribute values to calculate a symbol property dynamically. Since symbology exists separately from the content, vector feature symbology can be re-used and applied to different feature data sets.

Cache Drivers allow for caching tiles on disk in order to avoid downloading/processing tiles multiple times and thus to maximize performance.

osgEarth's *Terrain Engine Driver* is by default based on OSGs osgTerrain library. It is able to render maps either in a geocentric view (globe) or in a projected view (flat projection). As an addition, it enables even to re-project data on the fly among different coordinate reference systems.

Following the concept of *Multiple Image Layers,* osgEarth supports maps with multiple image sources, assembling different imagery, elevation, and vector data sources on the fly. It is also possible to integrate locally stored data with web-service-based data, since access to open-standard services like WMS, WCS, or TMS is realized.

To summarize, the concept and implementation of osgEarth as a 3D visualization engine seems to be convincing. Although being a mature Open Source project, osgEarth needed to be examined and reviewed with data of cartographic relevance.

Fig. 6. Rendering of raster data and 3D objects with osgEarth (Pelican Mapping)

5.3 First Cartographic Results with osgEarth

To produce a first series of 2D and 3D maps by the osgEarth engine, test data from the AoS3 atlas project and from the Swiss mapping authority Federal Office of Topography (swisstopo) were used. Since the osgEarth engine is already equipped with basic functionality for spatial navigation, layer management, and information query, a provisional GUI was set up for testing purposes.

The main intention of these tests was to evaluate the current performance and capability of the system, as well as the future potential of the 3D environment. Elevation models, raster data, vector data, and 3D objects were tested under different rendering conditions. While elevation and raster data are technically relatively simple to handle, display problems and performance issues were encountered in the processing of vector data.

Elevation models from the worldwide data sets SRTM30plus [200m] and GLS-DEM [90m] were processed and tested. To cover Switzerland and its surroundings in more detail, two additional DEMs, DTM25 [25m] and DTM-AV [2m], were added as elevation layers. After time-consuming preprocessing to build a LOD tile structure (TMS), a multi-layered elevation model for the whole world resulted, which was integrated into the atlas prototype.

Raster data (pixel maps, aerial and satellite images, shaded reliefs) were run through a tile building pre-process to speed up display as well. The integration of pixel maps, satellite images and photographs in osgEarth needs indication of the reasonable zooming range. For an analytically shaded relief, the four data sets Natural Earth [50mio. / 10mio.], SRTM30plus, and GLS-DEM were combined. For Switzerland, the same data sets as for building the DEM, the DTM25/Ferranti mosaic and DTM-AV, were used. Raster images can also be integrated by means of Web map services WMS (**Fig. 9**); this channel allows for display of applicable maps from external data sources.

The representation of *vector data* (choropleths, lines, point symbols and univariate diagrams, POIs) is essential for cartographic purposes (**Fig. 8**). Yet, the display of vector data in a 3D online environment is still challenging. Especially for the rendering of linear features according to cartographic standards, 3D technology has to be improved. With osgEarth, univariate cartographic symbols can be generated, even as extruded objects (**Fig. 7**). However, osgEarth lacks of a kind of cartographic toolbox with methods for thematic mapping, especially for the representation of (3D) point and line diagrams. *Billboard techniques* were successfully applied for object labeling as well as for point symbols; Hence, labels and POIs are evident features to be implemented in the planned 3D atlas.

Real *3D objects* can be integrated in osgEarth in nearly real-time. Tests with a total of 1.8 mio. buildings in Switzerland (Vector25 dataset) in the form of 3D models and as extruded polygon footprints have proved to be successful with regard to display quality and speed (**Fig. 10**).

The range of application listed above shows the great potential of osgEarth as a 3D visualization engine for an interactive online atlas.

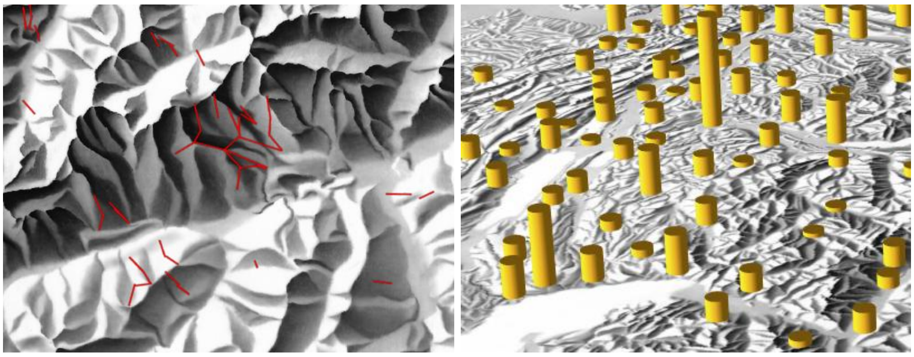

Fig. 7. left: 2D map with polylines, orthogonal view [cable ways] / right: 2D map with extruded symbols, tilted view [population]

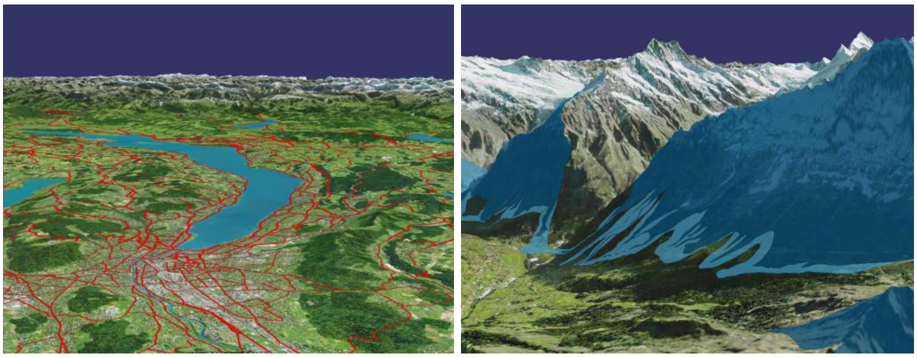

Fig. 8. left: 3D map with polylines [road network] / right: 3D map with polygons [glaciers]

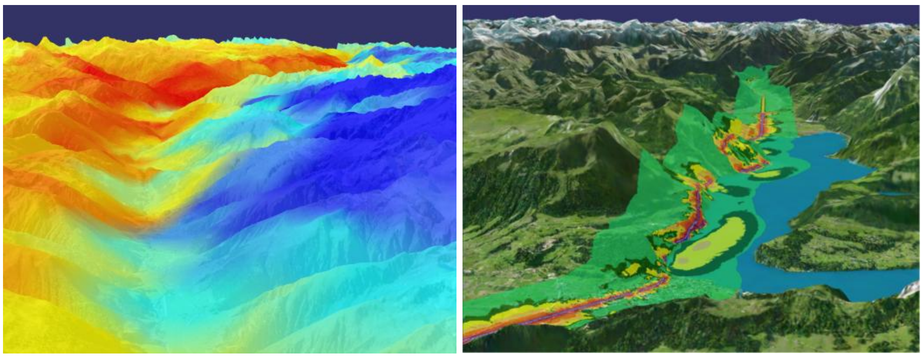

Fig. 9. left: 3D map with raster data [precipitation] / right: 3D map with WMS service (geo.admin.ch) [railroad noise at daytime]

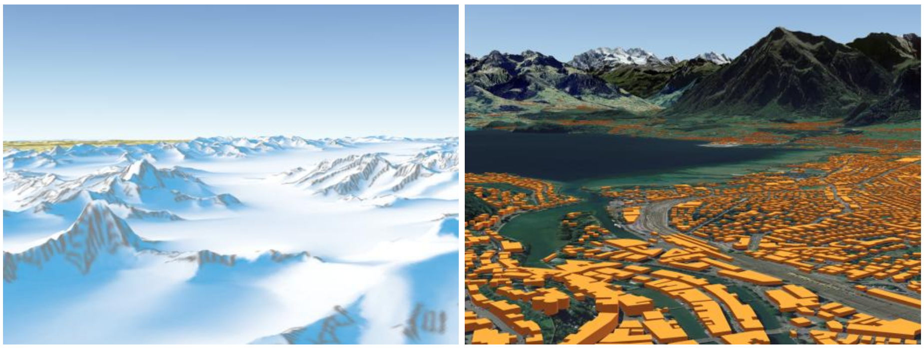

Fig. 10. left: 3D map with elevation data [Last Glacier Maximum] / right: 3D map with extruded footprints [buildings]

6 Conclusions and Outlook

The new generation of the national Atlas of Switzerland will be designed as a Web-based 3D application. It will incorporate an atlas framework (APS) for the generation of 3D and 2D atlas components with real-time visualization. The key benefits of the APS are the modular structure of the functionality (APS core with basic features, APS extensions), and the use of a Virtual Globe as a cartographic 3D visualization engine. First extensive tests have proven that the Virtual Globe engine osgEarth offers the tools to process and combine divers data sources like elevation models, raster and vector data sets, 3D objects, and Web map services. osgEarth is able to handle online, massive data at real-time and with satisfactory display quality. Nevertheless, one has to be aware that the quality of cartographic representations achieved by means of a Virtual Globe will never come up to traditional 2D map rendering techniques.

Future work will focus on the extension of the 3D engine osgEarth in order to further cartographic needs, e.g., symbolization and display quality of vector data and elevation data, adaptive zooming and LOD. There are also some technical challenges to be faced concerning the design of a user interface for multi-platform online use and optimized caching techniques, to mention just a few. Cartographic research will mainly concentrate on the fields of 3D visualization and interactivity for atlas applications. Closely related to the ongoing atlas development, experiments have to be conducted to meet the users' requirements concerning the usability of cartographic 3D representations and interactive tools.

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