

VISUALIZATION AND ANIMATION OF MOUNT EVEREST

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ABSTRACT:

In the year 1988 a new topographical map 1:50'000 of the Mount Everest region was published by the National Geographical Society. The full map content was derived from aerial images of scale 1:35'000, acquired in a 1984 photogrammetric flight. This highly acclaimed topographical map, produced with Swiss photogrammetric and cartographic know-how, serves until nowadays as an important work of reference. We took the analogue data (images, contours), converted them into digital form through scanning, and produced a texture-mapped 3D computer model. With a DTM of 10 m grid size and natural texture pixel size of 1 m this model is currently the best dataset available for an area of 25 by 25 km² around the summit of Mount Everest. The basic data has been used for diverse scientific purposes and in a number of TV specials and Magazine reports. This paper reports briefly about the production procedure of the model and discusses some issues related to the interactive real-time visualization of such an extended high resolution photorealistic dataset.

1. INTRODUCTION

A photogrammetric mapping project of Mount Everest was sponsored by the National Geographic Society and the Boston Museum of Science and produced in 1988 a highly acclaimed topographical map 1:50'000. In the National Geographic Magazine, Vol. 174 No.5 (Washburn, 1988) a report was given describing some technical aspects and the tremendous organizational efforts, which were necessary to make such a project a success. More detailed information about the project can be found in Altherr and Grün (1990a,b), Jeanrichard (1990) and Grün (1990).

Nowadays, the technology is available to produce and visualize in real-time 3D models of high quality, both in terms of geometrical resolution and textural detail and of fairly large dimensions. Therefore, we decided to produce a high resolution photorealistic 3D model of Mount Everest, as an example to demonstrate the capability of modern photogrammetric techniques for 3D model building and to study the specific modelling and visualization problems associated with very steep terrain. We took the available primary data (aerial images and photogrammetric contour line plots) and turned them into a high resolution model, both with respect to DTM and phototexture resolution. We produced a model extending over 25x25 km² with a pixel size of 1 m in Black/White. We even have a smaller area around the summit of the mountain available at 50cm colour texture resolution. We have described the procedure of virtual model generation and the results in Gruen, Murai, 2002.

This contribution briefly addresses some of the key aspects of model generation, shows the highly realistic visualization products and an animation, which was derived from the model data. However, our main emphasis will be on the discussion of the performance of some popular commercial software packages with respect to the interactive visualization of hybrid terrain models.

The generation of a 3D model such as Mount Everest would be a purely academic exercise if it could not be used for many different purposes. One is cultural and natural heritage protection. The UNESCO World Heritage List includes a number of mountains. Some of them even are considered

“sacred mountains” by the local people and as such rank high as natural, cultural and religious sites to be protected.

Mount Everest is part of the Sagarmatha (“Mother of Universe”) National Park, Nepal, a UNESCO World Heritage Site (Bernbaum, 2001). This is an exceptional area with dramatic mountains, glaciers and steep valleys, dominated by Mount Everest. The park shelters several rare species, such as snow leopard and the lesser panda. The presence of Sherpas, with their unique culture, adds further interest to this site.

Nowadays, the heavy pressure from tourism has placed large demands on natural resources and even introduced problems with waste disposal.

The demand for construction timber and firewood has destructed the forests to an alarming degree. Consequent soil erosion has made reforestation difficult. Pastures at lower altitudes are overgrazed and even water is becoming unfit for drinking. This is a situation, which applies to many high mountain areas worldwide. Therefore, environmental protection and conservation, together with the preservation of cultural heritage, are becoming pressing issues for these regions.

The recording of the current situation and the monitoring of ongoing processes are prerequisites for analysis and the establishment of sustainable measures of protection.

Computer-based models of the environment play an ever increasing role in this context.

This year (2003) we celebrate the 50th anniversary of the first ascent of the Mount Everest summit by Edmund Hilary and Tensing Norgay. On this occasion many media events honoring this achievement will be organized worldwide. It is interesting to see that the media productions make increasingly use of the virtual Everest model.

The internet is full of information on Mount Everest (e.g. www.mnteverest.net/, www.everestnews.com). Our own project information can be accessed via www.photogrammetry.ethz.ch/research/mounteverest.

2. PRIMARY DATA

In the years 1981 and 1984 Bradford Washburn, former Director of the Boston Museum of Science, received from the Chinese and Nepalese governments the permission to organize a photogrammetric flight over the Everest region. The project planning and execution was the responsibility of Swissair Photo&Surveys Ltd, Zurich (Altherr and Grün, 1990a,b; Jeanrichard, 1990). On the cloud-free day of 20 December 1984 the weather and snow conditions were ideal to have a Learjet 35, equipped with a WILD RC-10 camera, $c = 152$ mm, collect 160 aerial B/W images during a 3.5 hours mission. Flying height above sea level was 13'100 m and produced an average image scale of 1:35'000 (Figure 1 left). The very strong jet stream blowing with 240 km/h caused some problems with the required flight velocity such that all flight lines had to be flown in east-west direction. On 22 December 1984 a second flight covered the colour image program.

For navigation support a 1:100'000 enlargement of an ESA Metric Camera (MC) image from a 2 December 1983 Space shuttle mission flyover was used. These space images were also used for the generation of ground control points (GCPs) for the triangulation of the aerial photographs (Figure 1 right). Data processing for the topo map 1:50'000

The aerial images were collected with the production of an analogue 1:50'000 map in mind. The processing involved the stages aerial triangulation, contour plotting, planimetric features plotting, cartographic editing and printing. The only unconventional procedure was the acquisition of ground control points (GCPs) for aerial triangulation via orientation and measurement of a Metric Camera (MC) space image stereomodel. This was necessary because we did not have permission to measure a sufficient number of GCPs on-site. Also the required effort for this work would have been tremendous.



Figure 1: Left: Full aerial image of Mount Everest (B/W, original scale 1:35'000)
Right: Section of a colour infrared ESA MC image over Mount Everest (original scale 1:800'000). The summit is at the center of the picture under a thin layer of clouds

For details see Altherr and Grün (1990a,b), Gruen (1989), Grün (1990), Jeanrichard (1990), Washburn (1988).

The determination of control points by terrestrial surveying was not possible for several reasons. Therefore we extracted them from a stereopair of ESA's Metric Camera (MC) colour infrared images, produced during the Space Shuttle mission STS-9 Columbia on 2 December 1983.

The measurement of model coordinates and the adjustment of the model block was made by Swissair Photo&Surveys Ltd, Zurich. 77 models were used, arranged in 8 strips with 60% forward overlap and 35% sidelap. The photogrammetric plotting of contours (20 m interval) and planimetric features was done on a WILD A8, supported by a RAP system at scale 1:10'000. The comparison with older maps revealed many substantial differences, which justified the production of this new map.

The cartographic editing and finishing was done at the Federal Office of Topography, Bern. The map is published in Washburn (1988) and drew much appraisal from many Everest retirees, among them Sir Edmund Hillary.

3. DIGITAL REMAPPING

For the generation of the 3D computer model it was decided to restrict the area to a 25x25 km² region around the summit (the full map sheet covers a larger area).

We took 9 sheets of the original photogrammetric plot 1:10'000 and had them digitized with a 40 m contour interval at the Asian Institute of Technology (AIT), Thailand. The digitized contours were converted into a raster Digital Terrain Model with our own DTM modelling software DTMZ. The quality was checked by re-deriving the contours from the raster model and comparing them with the original contour plans. No significant deviation was found.



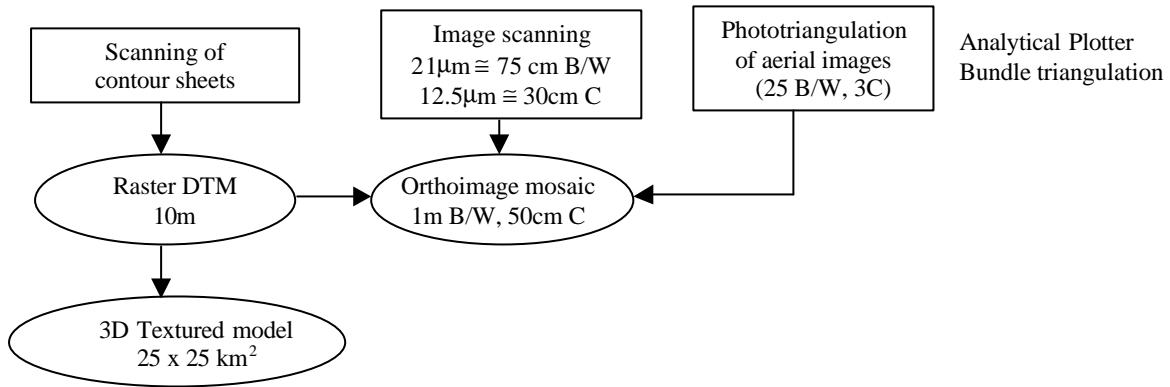


Figure 2: Procedure for the production of the photo textured 3D computer model

The selected area is covered by 5 strips with 8 aerial B/W images each at 60% and 80% forward overlap and 35% sidelap. Since the original triangulation results of the full image block were lost we had to re-triangulate again, using more or less the same GCPs and tie points as before. This time the image measurements were made on the Analytical Plotter WILD AC-3 and the adjustment was done by the bundle method. The precision of $\sigma_{\text{sigma}0} = 4.7$ micron was more than sufficient for the purpose at hand.

The automated triangulation would have failed in this case because of huge parallaxes and insufficient texture in many portions of the images. Automated image matching for DTM generation was also not possible for the same reasons.

For the production of a digital orthomosaic 40 photographs were scanned on a DSW 300 scanner with a resolution of 21 micron pixel size, which translates into an average footprint of 75 cm in the object. In addition 3 colour images around the summit were scanned with 12.5 micron resolution in order to create an ultra high resolution 3D model with 50 cm footprint in colour (procedure and results in Bumbacher, 2001).

The B/W orthomosaic was produced with 1 m footprint, covering an area of 25x25 km², thus generating 600 MB image data uncompressed (Figure 4). The underlying DTM was generated with a raster width of 10 m, in total 6.25 Million points.

For visualization purposes the orthomosaic can be draped over the DTM (Figure 5)

4. HIGH RESOLUTION PHOTOREALISTIC VISUALIZATION

4.1 Basic considerations

The 3D model of Mount Everest can be used in various forms. One is for photorealistic visualization. For this purpose it can be overlaid with all kind of additional information, like ascent routes, location of camps, places of danger, etc.

Visualization tools and software are available in manifold forms.

In http://www.Tec.army.mil/TD/survey/survey_toc.html for example we can access a list of about 550 software packages just for terrain visualization. More packages are probably lingering in various research labs.

Although the conceptional aspects of computer graphics algorithms are quite straightforward, it is always the implementation and the quality of the key components of the computer platform which define the performance.

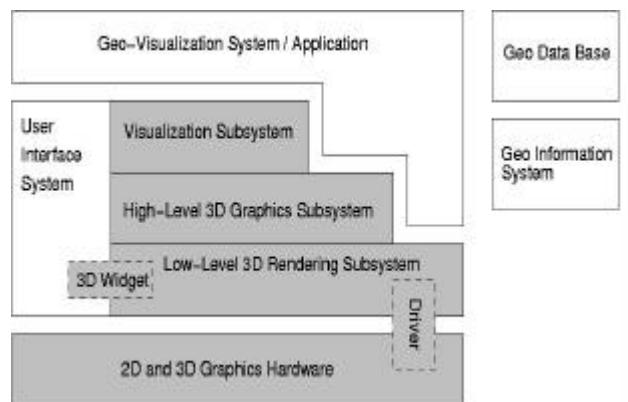


Figure 3: Principle software architecture of geovisualization software (courtesy J. Döllner, 2002)

Geovisualization systems are complex software systems, with strong dependencies on the hardware as well. Figure 3 shows the principle architectural setup of geovisualization software. In order to represent an efficient system, all components have to perform well individually, but also their interaction must be solved in an acceptable manner. For more details see Döllner, 2002.

When analysing visualization software a major consideration is whether real-time performance is required or not. The fascination of real-time performance is intriguing enough so that most users, once they have been exposed to it, will not want to do without it. Also, for many analysis applications, real-time performance is just a must for the sake of economy and efficiency of operation.

Actually one can classify visualization software on the basis of its real-time performance, given a certain computer configuration. In this context one can distinguish high-end, middle class and low-end systems (e.g. Skyline <http://www.skylinesoft.com>, IMAGINE VirtualGIS <http://www.erdas.com/software/ProductModules.asp>, and Cosmo Player <http://cai.com/cosmo>, in this order).

While low-end software is increasingly available as freeware over the Internet, the other levels of quality can only be reached by paying, in parts dearly, for the product.

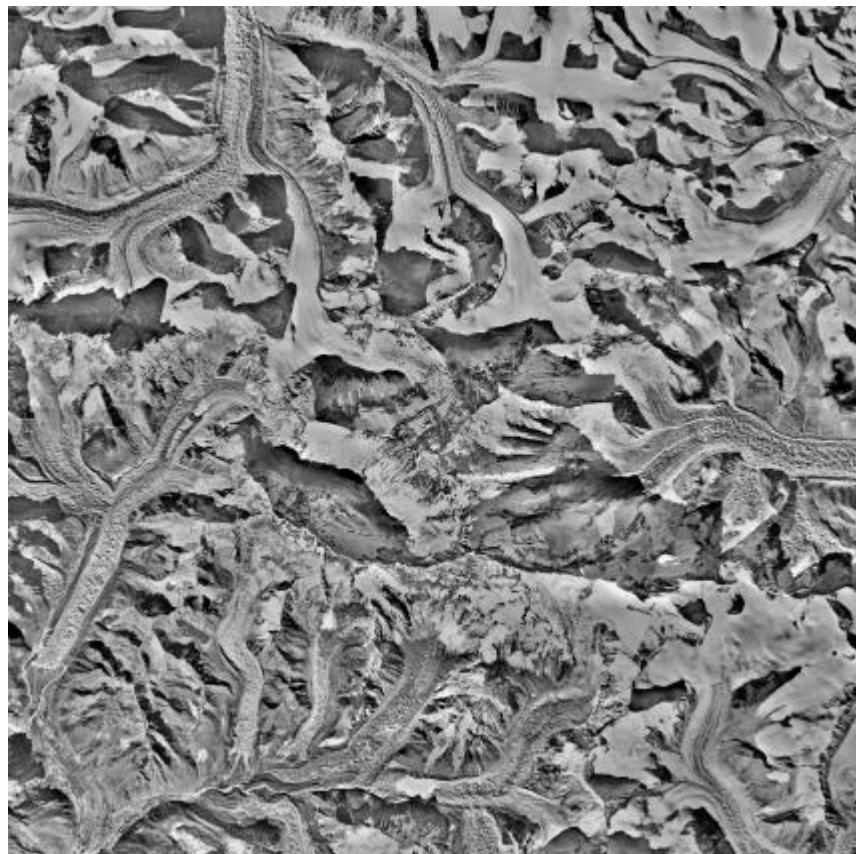


Figure 4: The orthomosaic of the Everest area ($25 \times 25 \text{ km}^2$ at 1 m pixel size)

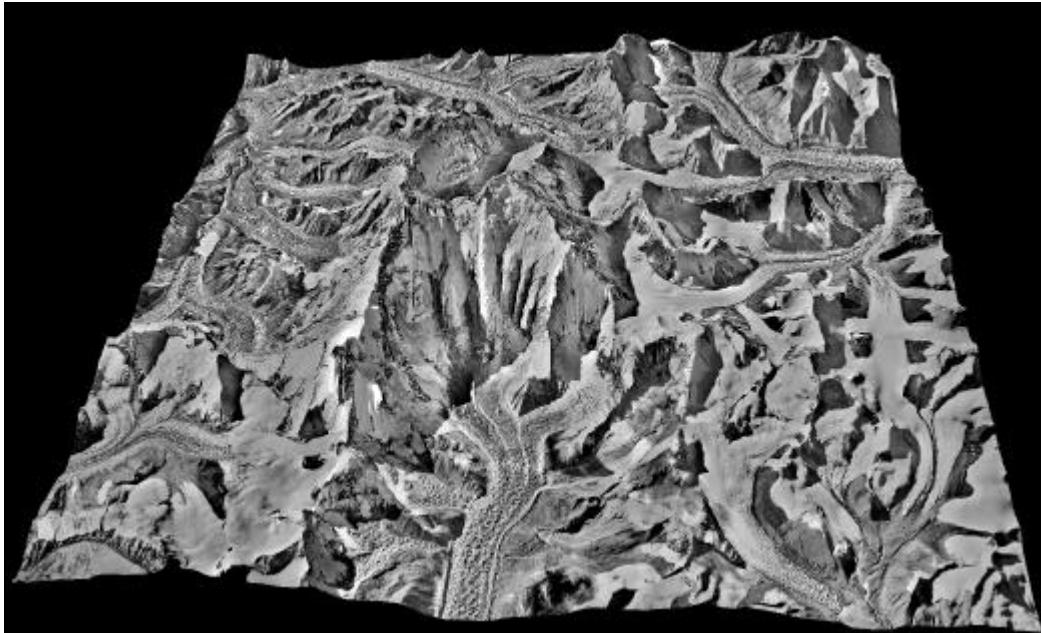


Figure 5: Orthomosaic draped over the DTM, visualized with ERDAS IMAGINE VisualGIS. View from the East at an elevation of 31'372 m. Foreground: Kangxung Glacier; centre: Everest Summit

There are many more quality criteria which can be applied, like acceptance of public data formats for input, rendering quality of geometry and texture, shading model, anti-aliasing, trajectory definition, illumination and animation functions, video/DVD production capabilities, etc. Observing that

computer power and graphics board performance is increasing dramatically over the last years one can nowadays expect even from laptops a rendering performance which was unheard of only 2-3 years ago. High-end performance of phototextured 3D models can be obtained on laptops if the

software supports that. One critical parameter here is the Level-of -Detail (LoD) property. LoD capability ensures that at each and every frame of an image sequence only the foreground portion of the 3D model is represented at highest resolution. Other zones of model depth are represented at lower resolution. This reduces the amount of computations substantially, an advantage, which becomes the more prominent the bigger the model is. This LoD property applies both to vector and image raster data. The interested user should also pay attention to the fact whether the different resolution layers can be produced effortlessly by himself or whether a major economic effort is needed.

Since our Everest dataset has the respectable size of ca 1 GB, it requires high-end visualization software for use in an interactive mode. Currently we employ primarily Skyline from IDC AG, Luzern, Switzerland as a high-end tool for real-time demos, VirtualGIS as a middle class package for the production of videos and our own software DTMZ-PPViz for the generation of very high resolution still images in parallel projection. In the following investigations we have also included Maya and Cosmo Player for comparison.

4.2 Experiences with commercial visualization software

Table 1, on the next page, shows an overview of the characteristics of some visualization software packages used in our environment.

It is obvious that there are large differences between those packages which we would like to explore with a practical approach by using our Mount Everest model of ca. 850 MB total size (250 MB vector and 600 MB image data).

In the following we will report about the experiences gained with these packages:

4.2.1 ERDAS Virtual GIS 8.4

This software was tested on a PC, equipped with Pentium 3 at 600 MHz, 512 MB RAM. The graphic card was an ELSA Gloria XXL 3D with 40 MB acceleration memory, running under Windows NT 4.0 operating system.

The Everest 10 meter DTM was imported in Virtual GIS from the digital photogrammetric station Socet Set. First, the data from Socet Set internal DTM format was converted into a GRID surface for Arc Info, then the DTM was converted within the Arc interface into an Arc GRID binary file, which was then imported into Virtual GIS.

The imagery used in Virtual GIS for texturing the model was initially created in Socet Set as an orthophoto (1m resolution) in TIFF format. This image format came without geo-reference information, which was retrieved from the internal orthophoto file from Socet Set. This information includes the lower left corner coordinates (in ground system) and the pixel size in meters on the ground.

The orthophoto was imported in ERDAS and during the import operation, the lower left corner coordinates and the pixel size were given to place the imagery on top of the model. At this stage we were able to visualize the textured model and perform interactive, or pre-defined flythrough animations. It is possible to set the desired level of detail, but it is statically applied to the whole scene. In order to facilitate dynamic levels of detail, the user must construct a "Virtual World" as the software calls it. The user selects the number of sectors in which the model will be divided, and then the software builds the separate pyramids of detail for the DTM and the corresponding image data, for every sector.

The result is the ability to navigate through the scene, viewing each part of the textured model, by adapting its detail according to the distance from the viewer. This is done both in

interactive and pre-defined flythrough mode. In interactive mode the data has to be reduced significantly (in case of image data down to 5%), with the related loss of resolution, in order to be able to work efficiently. In this case there was no additional vector data to be imported, such as buildings or roads. It is important to note that in such vector layers it is not possible to apply real textures on such additional vector data, and only the option to alter the material colour is provided. A further note concerns the offline rendering into video sequences. We have not found a way to avoid aliasing effects that appear in animations. Edges of the polygonal models appear jagged, due to the absence of correct sampling prior to rendering. In scenes as the Everest dataset, the absence of man-made objects made the effect less intensive, yet still noticeable.

4.2.2 Terra Builder - Skyline

This software was tested on a PC, equipped with Pentium4 1.80 GHz, 512 MB RAM. The graphic card was a Nvidia Quadro 2 Pro with 64 MB acceleration memory, and the operating system Windows 2000.

The DTM of Everest was imported into Terra Builder in the form of ASCII text, where the three spatial coordinates for every measured point are listed. This form has the disadvantage of large file size, but when the data is imported, it is converted into binary grid, consuming considerably less disk space. An alternative is importing the DTM as ASCII elevation grid, an export option available in Socet Set - the software where the measured surface came from. The TIFF plugin for Terra Builder handled the import operation for the imagery.

The file size reduction scheme of Terra Builder managed to reduce the total data size by a factor of 4, resulting in a size of approximately 250 MB, starting from a total of 1 GB of imported material. After creating the internal file (MPT) the inspection of the textured model showed satisfying results from the aspects of speed and efficiency in handling the detail, during interactive navigation.

Certain mismatches were witnessed after the import stage. The DTM appeared to have erroneous triangles (artefacts) on all sides of the modelled area. We were not able to detect the source of this problem, and the solution that we used, was to shift by a small amount the boundaries of the displayed area inwards, and use a smoothing/feathering function supplied from the software to diminish these artefacts. There was a noticeable reduction in the image quality, in comparison with the original imagery.

Interactive and offline animations that were generated show that there exist aliasing artefacts originating from the absence of a resampling method for rendering polygons. Polygon edges appear jagged, but the textures do not present aliasing effects due to the efficient resampling for the LoDs. After the creation of a flight path, for the generation of a video sequence, the control of the camera rotations is not exact and in some cases quick rotations between two key positions create an unpleasant visual result.

4.2.3 Alias | Wavefront Maya 2.5

This software was tested on a Silicon Graphics Onyx 2 workstation, with 4 R10000 processors and 2 GB of RAM. Graphic processor was a Infinite Reality 2 with 64 MB.

The system was running under IRIX 6.5 UNIX operating system.

Parameters	Cosmoplayer	Virtual GIS 8.4	TerrainView	Skyline	Maya 2.5
Rendering	Interactive only. Supplies Gouraud shading, texturing, pre-defined view points. Viewer navigates through the scene using mouse input	Interactive and offline. Supplies Gouraud shading, texturing, vector model layers, environment sky and atmospheric effects (fog). Viewer can navigate manually, or by recording flight paths. Offline rendering outputs: Snapshot images and video sequences	Interactive and offline. Supplies Gouraud shading, texturing, shadows, weather simulation with volumetric clouds and vector model layers. Viewer can navigate manually, or by recording flightpaths. Offline rendering outputs: Snapshot images and image sequences	Interactive and offline. Supplies Gouraud shading, texturing, vector model layers, environment sky. Viewer can navigate manually or by recording flight paths. Offline rendering outputs: Snapshot images and video sequences	Offline only. Flat shading, Gouraud shading and texturing. Supplies diffuse, specular and anisotropic (Phong, Blinn) light models. Shadow calculation using depth-buffer or ray tracing. Rendering outputs: Snapshot images and video sequences
Antialiasing	No antialiasing for geometry or textures	No antialiasing for geometry or textures	Interactive and online. Based on the antialiasing methods available on the graphics hardware.	No antialiasing for geometry or textures	Fully controlled antialiasing for geometry and textures. Adjustable sampling method, number of iterations and motion blur. All parameters defined before rendering.
Levels of Detail (LoD)	Not available	User can set desired constant LoD for whole scene (geometry and texture), or dynamic adjustment of detail according to viewing position, during animation	Fully automatic LoDs, based on quadtree structure, for terrain geometry and texture. Three levels of detail for vector models (e.g. buildings) and their texture	User can set desired constant level of detail for whole scene (geometry and texture), or dynamic adjustment of detail according to viewing position, during animation	Not available for geometry. Constant level of detail can be set for textures prior to rendering
File Format	VRML ASCII text, standardized and platform independent. Disadvantage is the large disk space needed . Separate conversion programs exist to import/export into other 3D formats (DXF, 3DS, Maya, OpenFlight)	Internal binary file format (IMG). Features good file size reduction. Additional information on reference datum and map projection can be included. Several import and export capabilities (Arc coverages, 2D DXF, ASCII text, VRML)	Internal binary file format for DTM is based on wavelet compression and uses the Terrapage API. Buildings are imported in OpenFlight format into binary format (vtc) from CG2. Import options include OpenFlight and VT format from CG2. VRML option is under construction. No export options	Internal file format (MPT). Achieves very good reduction of file size. In our case the imagery (600 MB) and the model (360 MB) were compressed into a single multi-resolution file of 250 MB. Import options include ASCII/binary elevation grid and ASCII XYZ coordinates	ASCII and binary . Occupies half space in comparison with ASCII VRML, but includes also animation data. Import/export capabilities include 3D Studio, IGES, DXF, VRML, and MOVE animation curves
Additional Characteristics	Widely available and free of cost. Ease of use through the Web, but file size limitations	Close connection with photogrammetric and remote sensing applications	Handles large terrain data in interactive render mode. DTM compression reaches a factor of 25. Performance decreases in the presence of vector models (buildings) and their textures. Requires special software for building LoDs for terrain	Designed to handle large datasets. Has options for including additional visual information (maps, labels)	High control of rendering and animation parameters. Offers very high quality results, but only offline. Rendering times depend on preferences and scene complexity, but are generally high

Table 1: Characteristics of some visualization software packages

The most significant issue in importing the Everest dataset into Maya was the absence of the variety in import options, available in the other packages. This package is rather oriented towards computer animation and not geo-visualization. The result was that only VRML and DXF formats were available to work with. We rejected the DXF format because of the large file size that is generated, and the lack of support for texture files.

We tried first to import the model and imagery straight into Maya, but we found it difficult to import the VRML version in one piece. The orthophoto in its original resolution occupies 600 MB (TIFF), and the import operation failed due to insufficient memory, according to the operating system report. In order to solve this problem, we decided to break down the model in pieces and the image in corresponding tiles and loaded the parts into the software, rather than as a whole. The model was converted into VRML format, using the corresponding export option from Virtual GIS 8.4. The model is broken into small tiles, whose number depends on the desired level of image detail in Virtual GIS. A low level of detail (5%) in the raster image will result in a model tiled into a few pieces (~10), which are texture-mapped with corresponding image tiles at the LoD's resolution. On the contrary, a high level of image detail results in a big number of tiles (~200) that compose the model.

The file size of the data in VRML format increased significantly, as Maya accepts VRML files which describe the coordinates in X, Y, Z columns, rather than height grid. This fact multiplied the VRML file size by a factor of 6, since we had to apply the same change to texture coordinates. This resulted into a VRML text file little larger than 1 GB, but after importing the model into Maya, the internal file size was reduced into 500 MB.

This approach seems to be effective in transferring the dataset into Maya, in contrast to the straightforward method, but we noticed a significant error. The material properties (texture file name) were automatically included in the internal file and the model with the textures appeared correct when it was inspected in preview. In the final rendering, though, the texture colour seemed to be lost. Through manual editing, we

managed to reload the textures and restore the texture colour for a part of the model, yet this is not an efficient solution due to the large number of tiles and textures.

4.2.4 Cosmoplayer

This software was tested on a PC platform, equipped with Pentium4 1.80 GHz, 512 MB RAM. The graphic card was a Nvidia Quadro 2 Pro with 64 MB acceleration memory, and the operating system Windows 2000.

Within the software package Virtual GIS, we were able to export a VRML version of the model. This file format can be used to view and inspect interactively the 3D textured model using VRML viewers, such as Cosmoplayer, through the Web.

There are restrictions in the scene size that can be viewed interactively. In our case the whole scene occupies 250 MB of disk space and the texture 600 MB. We should note at this point that the texture was not loaded in one piece, but split into tiles, as described in the Maya 2.5 import procedure.

The viewer performed inadequately even when the data was stored locally on the computer. Loading time for the scene was approximately 3 minutes and a flight through the model could not be performed at all.

Because of the above-mentioned low performance we consider the VRML visualisation solution inappropriate for such large textured dataset.

Figures 6 and 7 show two views onto the 3D model, produced with VirtualGIS.

For further reading on the visualization of Mt. Everest we recommend Jacob (2002) and our own web page: <http://www.photogrammetry.ethz.ch/research/mounteverest>.

Under <http://dsc.discovery.com/convergence/everest/interactive/interactive.html> a Quicktime animation, produced for Discovery Channel with our DTM, can be downloaded, showing the ascent route over the Khumbu Glacier and South Col.

We also scanned the National Geographic 1:50'000 topo map, including the printed ascent routes and overlaid it to the raster DTM. Figure 8 shows a view onto this 3D mode



Figure 6: View from West. Foreground: Khumbu Glacier; background centre: Everest Summit; background to the right: Lhotse Summit. Northface and Southface are both visible

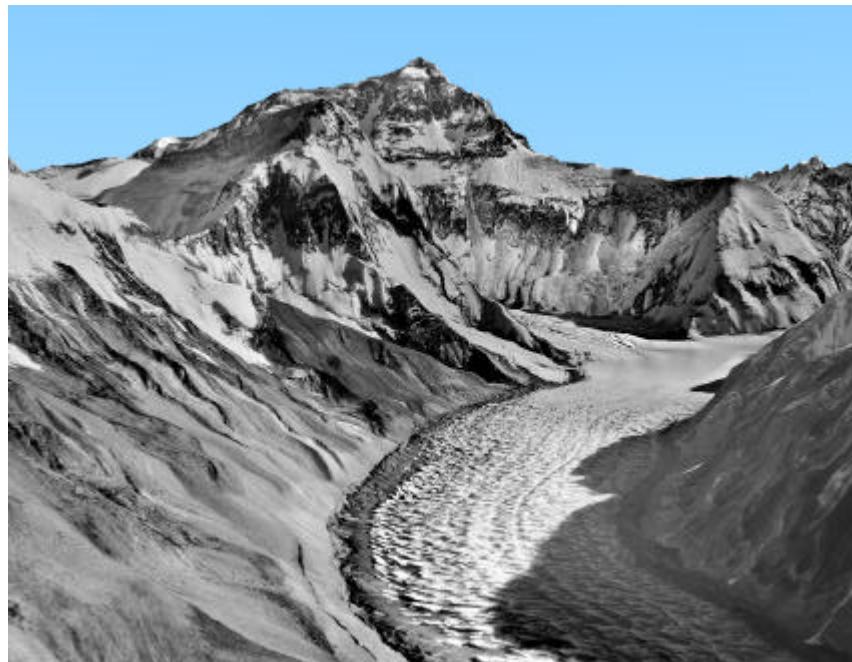


Figure 7: View from North-Northeast. Foreground: Dong Rongpu Glacier; center: Everest Summit with Northface

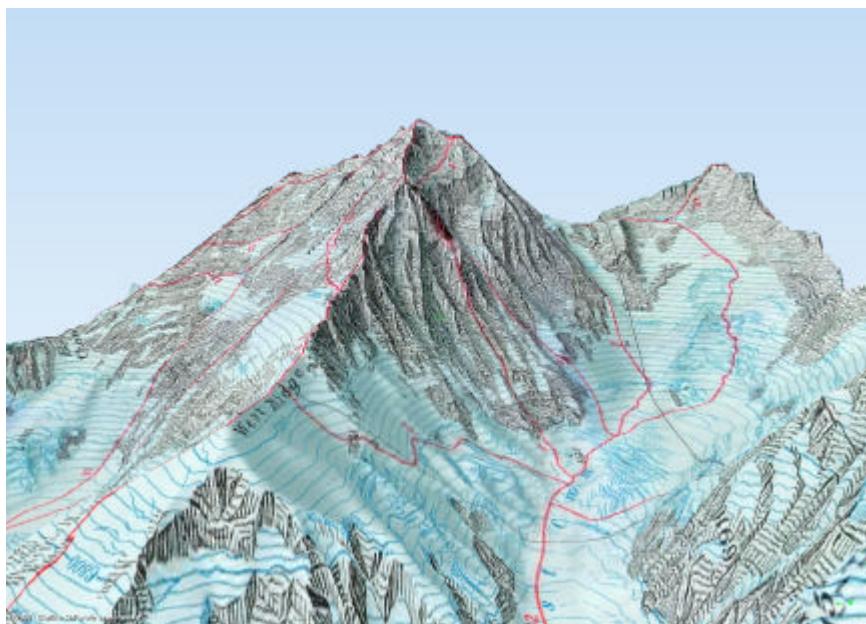


Figure 8: 3D model with overlaid topo map content, including major ascent routes
(produced with Skyline)

5. CONCLUSIONS

We have presented a very high resolution photorealistic 3D model of Mount Everest, produced from metric aerial images. The required quality of the model did not allow us to use automated procedures for triangulation and DTM generation. Therefore, there was much manual effort involved, which was offset by the amazing result: A dataset of very high quality, which can be used for many purposes.

An important function in all kind of applications of such 3D models is visualization. There is still a lack of inexpensive software for high quality real-time visualization of such very large datasets as presented here.

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