Visualization of Alternative Future Scenarios for Forest Ecosystems Using Animated Statistical Surfaces

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***Abstract*—Rising uncertainties associated with climate change make it important to include forest ecosystem simulations into forest management planning. The output of such models can be visualized in two-dimensional time-series animation, which is often too complex to provide a spatio-temporal overview. This contribution describes a novel method, called animated three-dimensional statistical surfaces, that aims at improving the perception of change in animated time-series. The method visualizes attribute values as surfaces, which are interpolated and animated over time; the attribute surfaces are combined with color-coding and contour lines to support absolute and relative height judgment as well as faster perception and better location of change. A design study and prototypical implementation of the visualization method is described in this contribution. The method is not limited to ecological model output; it can be used to create three-dimensional animations of arbitrary time-series where parameters are supplied in regular raster format.**

Keywords—GIScience; animated maps; forest ecosystems; LANDIS-II; 3D visualization; geo-visual analytics

I. Introduction

Rising uncertainties associated with climate change make it important to include forest ecosystem simulations into forest management planning. Without considering the effects of climate change using modeling, forest plans may suggest the use of management that leads to undesirable outcomes. By comparing various forest management alternatives under different future climate scenarios, forest managers can make a more accurate long-term estimate of the consequences resulting from actions taken today or in the years to come.

Small budgets and short-term planning may constrain the creativity of forest managers to acknowledge a multitude of possible management regimes. This includes management regimes that could be rewarding and sustainable if considered over the next 100 years. Simulation and examination of future alternative scenarios can thus assist in thinking-out-of-the box.

While the advantages of integrating ecosystem modeling into forest management decision-making are obvious, effective and user-friendly spatial visualization software that makes simulation output more accessible to forest managers and modelers is still rare. In this contribution, the user-friendly visualization of future alternative scenario datasets produced by LANDIS-II [1], a commonly used modeling tool in forest ecology, is discussed. LANDIS-II is a landscape model designed to simulate forest succession, climate change, seed dispersal and disturbances, including fire, wind, harvesting, and insects, for landscapes of 10,000 to 20,000,000 ha. Typical future scenario output consists of geo-referenced regular rasters at different time-steps that encompass a large number of forest ecosystem parameters.

A typical approach for visualizing such datasets is to color output rasters using a GIS (geographical information system) and to align the resulting maps in temporal sequence, thus creating an animation. While cartographic animation has a long tradition as visualization method for spatio-temporal datasets, a number of challenges are encountered when applying this method. In the following sections, the challenges of cartographic animation for spatio-temporal data and the concept of statistical surfaces are described. A design study is then presented that explores how the concept of animated statistical surfaces can be useful in compensating for some of the disadvantages of cartographic time-series animation while profiting from the advantages of animated 3D techniques. A prototypical implementation of animated three-dimensional statistical surfaces is described, showing an alternative future scenario dataset generated with LANDIS-II.

II. Time-series Animation and Statistical Surfaces

A. Potential and Challenges of Time-series Animation

Compared to static maps, animated maps use time as additional representational dimension. When a sequence of maps is shown in rapid succession, the observer may perceive changes as a fluid motion. It is this emphasis on the change between moments [2] and the possibility of showing a temporal as well as spatial overview of a dynamic phenomenon [3], [4], which highlights the strengths of animation.

However, cartographic animation is not a suitable representation method for datasets where little change occurs, and it can be difficult to interpret when the datasets are very

This work was funded in part by the USDA AFRI program (Grant # 226280).

complex. Complex animations cause high cognitive loads, where observers quickly exhaust their cognitive resources and are not able to convert the information shown on animated maps into chunks of meaning that can be remembered [5]. Different complexities can be identified in animation, including animation length (long run time exhausts short-term visual memory), complexity of spatial patterns (spatial heterogeneity) and complexity of the patterns of change (temporal heterogeneity) [5]. Selective attention to specific elements of an animation, e.g., a counting task given to the observer, may lead to change blindness, where elements that were not part of the task go unnoticed [6]. Flickering transitions between time steps can even extend change blindness to large changes [7], and observers often over-estimate their abilities to detect changes in map animations [8].

B. Three-dimensional Statistical Surfaces

The third dimension is often used in landscape representation to show terrain, i.e., continuous variation of elevation over an area. The third dimension can also represent a continuous parameter that does not have an immediate physical equivalent in geographic space: two spatial coordinates are combined with a third coordinate expressing relative height proportional to an attribute value at that 2D location, e.g., biomass computed by LANDIS-II shown as a 3D surface. If such statistical surfaces express the attribute value by height, they are referred to as three-dimensional (3D) statistical surfaces in this contribution.

Comparative studies largely concentrate on comparing static 2D with static 3D cartographic representations, but the findings are inconclusive regarding which one is superior. Animated 3D representations have received little attention. There are problems associated with static 3D representations, which very likely extend to animated statistical surfaces, including occlusion of background elements by foreground elements and inability to accurately judge size. Some studies suggest faster user performance, better orientation and user enjoyment with 3D displays (for an overview of comparative 2D versus 3D representation studies see [9]).

III. Statistical Surface Animation Method

A. Prototype Design Reflections

The complexity of spatial patterns and patterns of change of animated time-series data created with LANDIS-II is high. This makes it difficult for the observer to guide attention to where major change is happening as well as to form a temporal and spatial overview of the shown dynamic phenomena. Therefore, we combined 2D temporal animation (Figure 1 left) with the three-dimensional statistical surface concept (Figure 1 middle) with the intention of drawing attention to locations where important changes are occurring. In animated three-dimensional statistical surfaces, change is expressed by varying the height of the surface proportional to the attribute value at the current time-step.

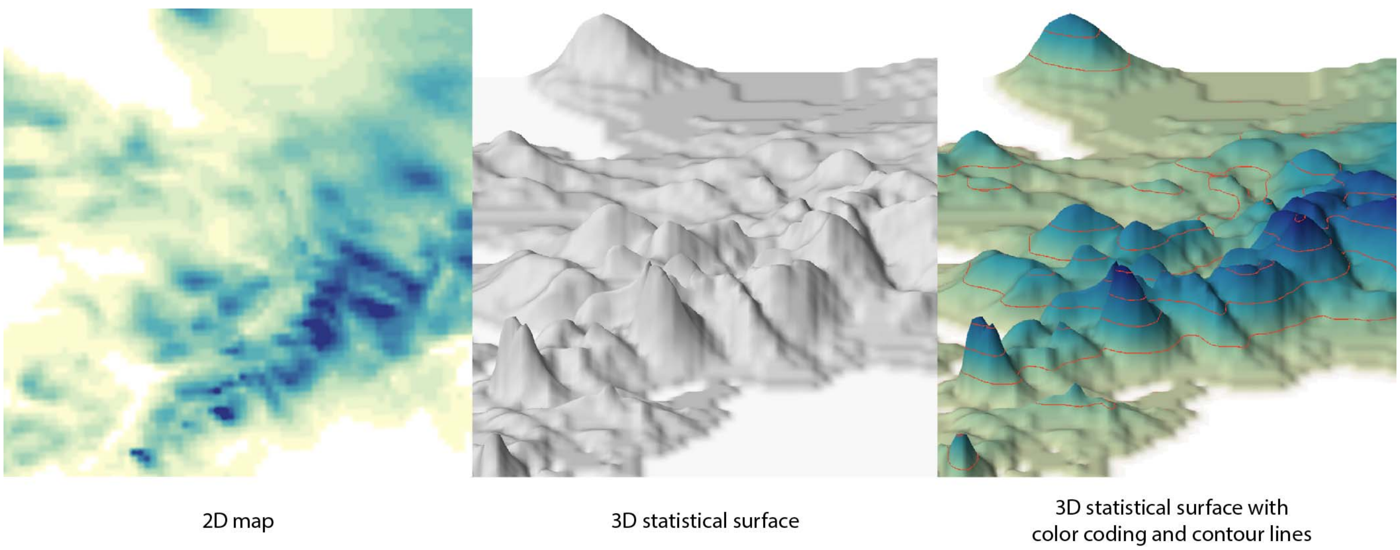

Figure 1: Comparison of attribute value representations: color-coded two-dimensional map (left), height-coded three-dimensional statistical surface (middle), combination of attribute value encoding by color, contours and height (right). Data: precipitation forecast for Central Switzerland in mm, January 21, 2010, midnight.

The following paragraphs describe the motivation for specific design choices for the animated statistical surface prototype and how these choices are founded on research findings for either 2D animation or 3D static representation. By capitalizing on the advantages of both representations, we aimed to create a superior visualization method for change perception and location in spatio-temporal datasets:

1) Increased attention to change through motion

Reference [10] argues that coherent motion helps identify cluster patterns more easily and quickly in animated representations compared to multiple static representations, and it has been shown that humans can very well discern micro-motions [11]. In the prototype for animated statistical surfaces a value increase or decrease results in an up- or down-movement of the statistical surface while in a standard 2D animation, changes are expressed solely via color changes.

2) Faster user performance with 3D display

Reference [12] found that observers would perform certain tasks faster using static schematic 3D representations compared to static 2D schematic representations, though whether this is generalizable to dynamic surface representations has not yet been proven. In time-series animation, the quick perception of change is especially important as individual animation frames can only be shown for a limited time to sustain the impression of temporal flow as well as the memory of previous time-steps. The animated 3D representations at the core of the prototype are expected to positively influence change detection.

3) Smooth 3D animation flow

Reference [13] speculates that interpolating smooth transitions between 2D animation frames visually prepares users to detect small changes. They also found that participants tended to watch smoothly interpolated 2D animations at higher speed. The presented prototype implements interpolation of 3D statistical surfaces at different time frames to provide smooth animation flow in three dimensions and time.

4) Intuitive relative size and spatial trend judgment

In the three-dimensional statistical surface prototype, spatial differences in value can be perceived as direction (e.g., stair steps for gradual change), which may be more intuitive to interpret and possibly faster to perceive than changes in color gradient. While accurate size judgment can be negatively influenced by 3D central perspective projection (see 5) below), relative visual comparison of values represented by height may be more intuitive and analogous to routine spatial tasks than comparing colors in 2D, especially under time pressure.

5) Choice between central and parallel perspective

Foreshortening of background elements due to central perspective projection can negatively influence size judgment. Same size elements are drawn on the display smaller in the background than in the foreground. However, reference [11] argues that the observer of 3D representations can perceive background objects at the actual size (size constancy) if a satisfactory set of depth cues (e.g., shading, occlusions) is used in the representation. This allows the user to apply size constancy to 3D representations just as to objects perceived in real life.

The developed prototype shows attribute values as a shaded surface. It allows the user to switch between central perspective projection and parallel oblique projection. The latter shows same size elements in the foreground and background at same display size, which is also helpful when low-height background values would be reduced beyond recognition in central perspective projection.

6) Multiple visual encoding of attribute value

In addition to encoding attribute value as height, height is combined with color and contour lines in the prototype (Figure 1 right) to better support relative size judgment as well as absolute size judgment for reasons given in 5).

B. Related Work

The use of three-dimensional representations for the purpose of forest landscape ecosystem visualization appears to be mostly geared at terrain and individual tree representation. At a regional scale, output of forest ecosystem landscape models is often visualized as 2D land-use maps or as shaded terrain draped with 2D land-use textures; at a more local scale, miniature photorealistic 3D models of trees are common to be placed on terrain and species distribution appears to be the most often visualized content [14],[15]. Forest ecosystem model output is often presented in form of multiple static 2D maps at different time steps rather than as animated time-series.

Reference [16] uses static three-dimensional statistical surfaces combined with terrain to visualize natural hazard parameters in an alpine environment. Reference [9] evaluated the static combination of 2D bar charts and 3D. Reference [17] comes closest to the method described in this contribution by dynamically visualizing diurnal population change. Their method does not allow for interpolated time-step transitions.

C. Implementation

1) Rendering of 3D statistical surfaces and interactivity

Customized software was developed to implement animated statistical surfaces. The software is written in Java and builds on JOGL [18], a Java interface for OpenGL [19] for building interactive views of statistical surfaces. OpenGL is a standard application-programming interface for generating 2D and 3D computer graphics.

Using the prototype, the user loads a series of regular raster grids from LANDIS-II containing attribute values where each raster grid represents a time-step. One grid at a time is displayed as shaded three-dimensional surface, starting by default with year zero. The user can choose to play a sequence of smoothly changing surfaces or stop at a specific time-step. When the animation is stopped, the user can zoom in and out of the surface display, can rotate it and change shading parameters.

2) 3D Texture interpolation for smooth animation flow

A regular raster containing attribute values is interpreted by the software as height values (z-coordinate) and translated into a three-dimensional surface. This is illustrated in Figure 2b, where the largest value in the raster (red dot) is interpreted as highest point of the surface.

To avoid abrupt, incoherent visual changes between larger time-steps, a 3D texture is used for interpolation. If one imagines stacking geo-referenced regular output rasters of LANDIS-II in temporal order on top of each other, the result is a space-time cube where the up direction represents the progression in time (Figure 2a). This data structure is called a 3D texture. By specifying a point in time on the temporal axis of the 3D texture, the algorithm can identify the raster corresponding to that time-step. The rasters in the 3D texture represent the spatial distribution of attribute values over time, e.g., biomass at every valid data location in the test site area computed in two-year time-steps over a decade. In the example in Figure 2a, the 3D texture cube contains six rasters. If a time is selected, for which a model-computed raster does not exist (e.g., year seven), the values of the raster cells are linearly interpolated to provide smooth-looking transitions in the three-dimensional animation. The openGL vertex shader, an element of the graphics processor, uses the values of the 3D texture to

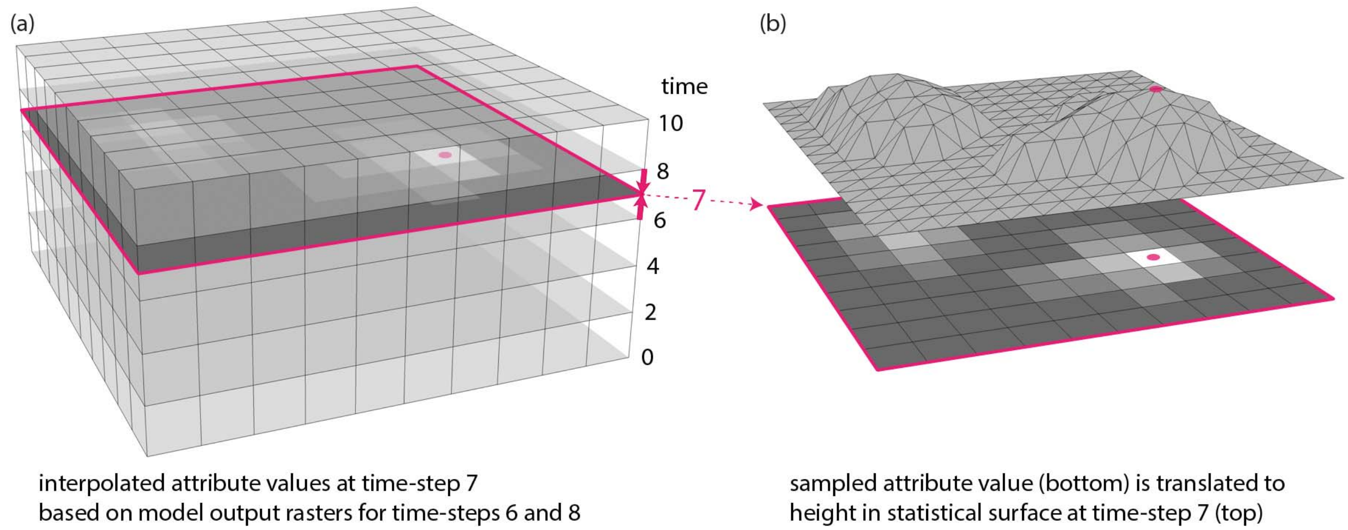

Figure 2a: 3D Texture and smooth interpolation of time steps; 2b: Translation of attribute raster values to heights in a triangle mesh of statistical surface.

adapt the height coordinate of each geometry vertex in the three-dimensional statistical surface at the given time-step of the animation.

3) Attribute value color-coding, contour lines, and choice of projection

To help the user judge relative and absolute attribute value represented by height, two additional ways of encoding attribute value were added to the animated three-dimensional surfaces: color-coding and contour lines. For color coding the user can select a color ramp (colors and class boundary), which is used by the OpenGL fragment shader to assign color to the statistical surfaces. This is analogous to hypsometric color-coding of terrain. Research suggests that diverging user attention from the animation to a legend may break observed animation flow [5]. For this reason, contour lines were added to the statistical surfaces using an algorithm described by [20] so that users can better estimate attribute values without having to move their gaze away from the statistical surface.

It is difficult to estimate if the individual user receives enough depth cues to accurately judge relative height in central perspective projection as explained in section 3A5). For this reason, in addition to central perspective projection, parallel oblique projection was implemented as a choice. The user can toggle the view between the two projections.

IV. Results

Figure 3 shows three snapshots at time-steps 0, 50, and 100 years using the described animated three-dimensional statistical surfaces method. The method produces a three-dimensional animation only partly documented via static snapshots for this contribution. The parameter shown by the statistical surfaces is the distribution and quantity of biomass (kg) of yellow birch over time per 4 ha site. This is only one example of the many parameters produced by the LANDIS-II model. As LANDIS-II provides output data only for forested areas, the visualized data shows many spikes where the surface is disrupted by no data values set to 0.

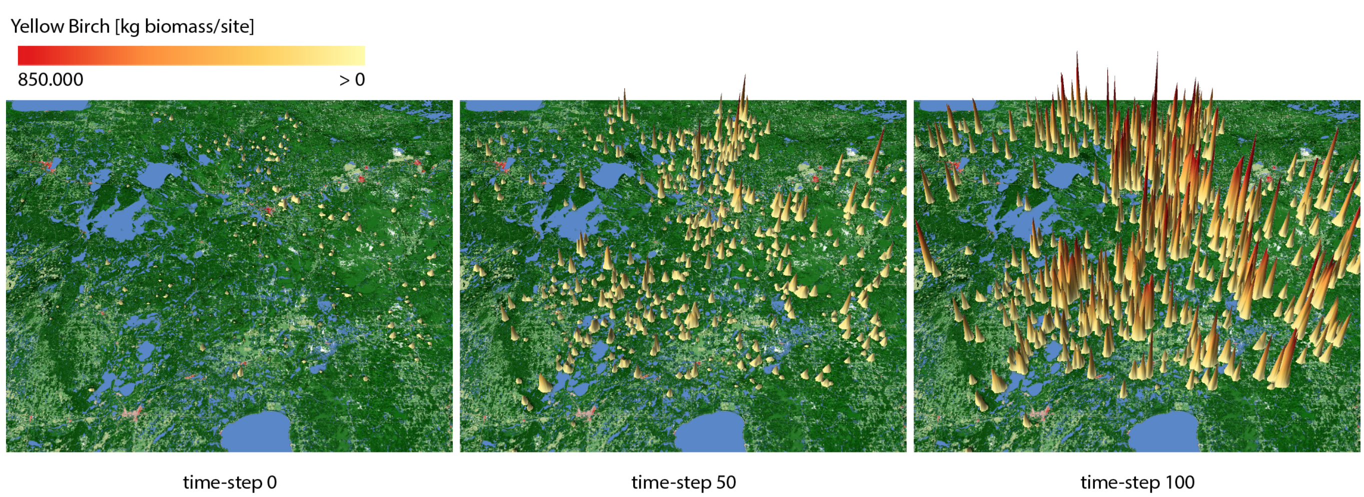

Figure 3: Snap-shots of animated three-dimensional statistical surfaces showing the distribution and quantity of Yellow Birch (in kg biomass per 4 ha site) over time in Northern Minnesota; statistical surface based on time-series rasters computed with LANDIS-II; reference map texture based on USGS National Landcover Database.

V. CONCLUSION AND FUTURE WORK

We described a novel method and prototypical implementation, which combines the concepts of animation and three-dimensional statistical surfaces to improve visual awareness and location of change in complex time-series. The prototype is user-friendly, and the method can be applied to arbitrary time-series data encoded as regular rasters; possible applications of the method thus go beyond visualizing forest landscape model output.

Future work will include a formal user evaluation of the presented method and prototype. Occlusions of background elements by foreground elements are generally a challenge for three-dimensional representations. While occlusion cannot be completely avoided, it would be helpful to automatically alter the viewpoint of the observer while the three-dimensional statistical surface animation runs, so that regions of greatest change are always visible. However, this would require assisting the user with spatial orientation during changes of viewpoint. Attention guidance through cueing and saliency reinforcement has recently become a focus of research in two-dimensional animation and could be adapted to guide user attention in this three-dimensional statistical surface animation. We would also like to investigate how alternative future scenarios for forest ecosystems can be compared. Possible approaches include using several animated statistical surfaces or animated surfaces showing relative differences between scenarios.

REFERENCES

[1] R.M. Scheller, J.B. Domingo, B.R. Sturtevant, J.S. Williams, A. Rudy, D..H. Mladenoff, and E.J. Gustafson, “Design, development, and application of LANDIS-II, a spatial landscape simulation model with flexible temporal and spatial scales,” Ecological Modelling, vol. 201, 2007, pp. 409–419.

[2] M. P. Peterson, Interactive and Animated Cartography. Englewood Cliffs, NJ: Prentice Hall.

[3] P. J. Ogao and M.-J. Kraak, “Defining visualization operations for temporal cartographic animation design,” Int. J. of App. Earth Observation and Geoinformation, vol. 4(1), 2002, pp. 23–31.

[4] D. Dorling, “Stretching Space and Splicing Time: From Cartographic Animation to Interactive Visualization,” Cartography and Geographic Information Systems, vol. 19(4), 1992, pp. 215–227.

[5] M. Harrower and S. Fabrikant, “The Role of MapAnimation for Geographic Visualization,” in Geographic Visualization: Concepts, Tools, and Applications, M. Dodge, M. McDerby and M. Turner, Eds. Chichester, UK: Wiley, 2008, pp. 49–65.

[6] D.J. Simons and C.F. Chabris, “Gorillas in our midst: sustained inattentional blindness for dynamic events,” Perception, vol. 28, 1999, pp. 1059–1074.

[7] R. Rensink, J.K. O’Regan and J.J. Clark, “To See or not to See: The Need for Attention to Perceive Changes in Scenes,” Psychological Science, vol. 8 (5), 1997, pp. 368–373.

[8] C. Fish, K.P. Goldsberry and S. Battersby, “Change Blindness in Animated Choropleth Maps: An Empirical Study,” Cartography and Geographic Information Science, vol. 38(4), 2011, pp. 350–362.

[9] S. Bleisch, Evaluating the appropriateness of visually combining abstract quantitative data representations with 3D desktop virtual environments using mixed methods, PhD dissertation, London: City University London, 2011, 208 pages.

[10] A.L. Griffin, A.M. MacEachren, F. Hardisty, E. Steiner and B. Li, “A Comparison of Animated Maps with Static Small-Multiple Maps for Visually Identifying Space-Time Clusters,” Annals of the Association of American Geographers, vol. 96(4), 2006, pp. 740–753.

[11] C. Ware, Information Visualization: Perception for Design, 3rd ed., Morgan Kaufmann, 2012, 536 pages.

[12] K. Risden, M.P. Czerwinski, T. Munzner and D.B. Cook,”An initial examination of ease of use for 2D and 3D information visualizations of web content,” Int. J. Human-Computer Studies, vol. 53, 2000, pp. 695–714.

[13] T. Shipley, S.I. Farbikant and A.-K. Lautenschuetz, “Creating Perceptually Salient Animated Displays of Spatiotemporal Coordination in Events,” in Cognitive and Linguistic Aspects of Geographic Space, M. Raubal, D.M. Mark and A.U. Frank, Eds., Springer Berlin Heidelberg, 2013, pp. 259–270.

[14] A. Zamuda, A., J. Brest, N. Guid and V. Zumer, "Modelling, Simulation, and Visualization of Forest Ecosystems," EUROCON, 2007. The International Conference on Computer as a Tool, 2007, pp. 2600–2606.

[15] A. O. Falcão, M. Próspero dos Santos and J.G. Borges, “A real-time visualization tool for forest ecosystem management decision support,” Computers and Electronics in Agriculture, vol. 53(1), pp. 3–12.

[16] M. Kunz, Interactive visualizations of natural hazards data and associated uncertainties, PhD dissetation, Zurich: ETH Zurich, 2011, 89 pages.

[17] T.Kobayashi, R.M. Medina, T.J. Cova, “Visualizing Diurnal Population Change in Urban Areas for Emergency Management,” The Professional Geographer, vol. 63(1), 2011, pp. 113–130.

[18] JOGL - Java™ Binding for the OpenGL® API, last accesssed June 24, 2013 at https://jogamp.org/jogl/www/.

[19] OpenGL - The Industry's Foundation for High Performance Graphics, last accessed June 24, 2013 at www.opengl.org.

[20] P. Cozzi and K. Ring, 3D Engine Design for Virtual Globes , 1st ed., CRC Press, 499 pages.