Master's thesis

Integrating High Fidelity Mapping Services Into Public Presentations

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Abstract

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Chapter 1

Introduction

Scientific visualization of space research, also known as astro-visualization, becomes increasingly important for scientists to communicate their work in exploring the cosmos. 3D computer graphics has shown to be an efficient tool for bringing insights from geological and astronomical data, as spatial and temporal relations can intuitively be interpreted through 3D visualizations.

Researching and mapping out celestial bodies other than the Earth is an important part of expanding the space frontier and virtually rendering these globes using real gathered map and terrain data is a natural part of any scientifically accurate space visualization software.

Two important parts of a software for visualizing celestial bodies are terrain and atmosphere. The focus of this thesis is put on terrain rendering on globes using high fidelity geographical data such as texture maps and digital terrain models. The globe rendering feature with the research involved was implemented for the software OpenSpace. The implementation was separated enough from the main program to avoid dependencies and make the thesis independent of specific implementation details.

1.1 Background

1.1.1 OpenSpace

OpenSpace is an open-source, interactive data visualization software with the goal of bringing astro-visualization to the broad public and serve as a platform for scientists to talk about their research. The software supports rendering across multiple screens, allowing immerse visualizations on tiled displays as well as in dome theatres [1].

With a real time rendering software such as OpenSpace, the human curiosity involved in exploration easily becomes obvious when the user is given the ability to freely fly around in space and near the surface of other worlds and discover places they probably never can visit in real life. This is also true for public presentations where researchers such as geologists can go into details about their knowledge in these places.

An important part of the software is to avoid the use of procedurally generated data. This is to express where the frontier of science and exploration is currently at, and how it progresses through space missions with the goal of mapping the Universe. A general globe browsing feature provides a means of communicating this progress through continuous mapping of our planets and moons.

1.1.2 Globe Browsing

1.2 Tesselating the Ellipsoid

Triangle models are still the most common way of modeling renderable objects in 3D computer graphics softwares, even though other rendering techniques such as volumetric ray casting also can be considered for terrain rendering [2].

A triangle mesh, or more generally a polygon mesh, is defined by a limited number of surface elements. This means that ellipsoids need to be approximated by some sort of tessellation or subdivision surface when modeled as a polygon mesh. There are several techniques for tessellating an ellipsoid. Some of them are covered in this section.

1.2.1 Geographic Grid Tessellation

Tessellating the ellipsoid using a geographic grid is a very straightforward approach. Ellipsoid vertex positions can be calculated using a transform from geographic (latitude and longitude) space to a cartesian coordinate space. An implementation of such a transform is implemented and described by Cozzi and Ring [2, p. 25]. Figure (fisk) shows three geographic grid tessellations of ellipsoids with constant number of latitudinal segments of 2, 4 and 8 respectively. A common issue with this approach is something referred to as polar pinching. At both of the poles, segments will be pinched to one point which leads to an increasing amount of segments per area. This in turn results in oversampling and visual artifacts in texture mapping due to the very thin quads.

Chapter 2

Theoretical Background

A sophisticated globe rendering system needs to rely on some mathematical foundations. These foundations together with different theories and algorithms developed for globe rendering works as a base for the research of this thesis.

2.1 Modelling Globes

We will discuss different proposed methods used for modelling and rendering of globes. The globe can be modelled either as a sphere or an ellipsoid and there are different tessellation schemes for meshing the globe. Different map projections can also be considered and it all ties together with a choice of level of detail algorithm.

2.1.1 Globes as Ellipsoids

Planets, moons and asteroids are generally more accurately modelled as ellipsoids than as spheres. Planets are often stretched out along their equatorial axes due to their rotation which causes the centripetal force to counter some of the gravitational force acting on the mass. This effect was proven in 1687 by Isac Newton in Principia Mathematica [14]. The rotation causes a self-gravitating fluid body in equilibrium to take the form of an oblate ellipsoid, otherwise known as a biaxial ellipsoid with one semimajor and one semiminor axis. Globes can be modeled as triaxial ellipsoids for more accuracy when it comes to smaller, more irregularly shaped objects. For example Phobos, one of Mars's two moons, is more accurately modeled as a triaxial ellipsoid with radii of $27 \times 22 \times 18$ km [2].

The World Geodetic System 1984 (WGS84) standard defined by National

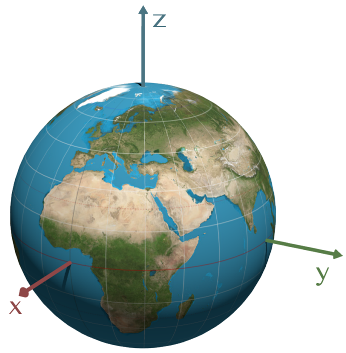

Figure 2.1: The WGS84 coordinate system and globe.

Geospatial-Intelligence Agency (NGA) models the Earth as a biaxial ellipsoid with a semimajor axis of 6,378,137 m and a semiminor axis of 6,356,752.3142 m [2]. This is what is known as a reference ellipsoid; a mathematical description that approximates the geoid of the earth as closely as possible. The WGS84 standard is widely used for GIS and plays an important role in accurate placements of objects such as satellites or spacecrafts with position coordinates relatively close to the Earth's surface. In the WGS84 coordinate system, the x-axis points to the prime meridian, the z-axis points to the north pole and the y-axis completes the right handed coordinate system, see figure 2.1.

2.1.2 Tesselating the Ellipsoid

Triangle models are still the most common way of modeling renderable objects in 3D graphics softwares, even though other rendering techniques such as volumetric ray casting also is possible for terrain rendering (src).

A triangle mesh, or more generally a polygon mesh, is defined by a limited number of surface elements. This means that ellipsoids need to be approximated by some sort of tessellation or subdivision surface when modeled as a polygon mesh. There are several techniques for tessellating an ellipsoid. Some of them are covered in this section.

Geographic Grid Tessellation

Tessellating the ellipsoid using a geographic grid is a very straightforward approach. Ellipsoid vertex positions can be calculated using a transform from geographic coordinates to cartesian model space coordinates [2, p. 25]. Figure 2.2 shows three geographic grid tessellations of ellipsoids with constant number of latitudinal segments of 4, 8 and 16 respectively.

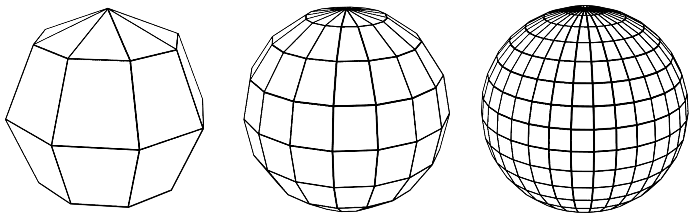

Figure 2.2: Geographic grid tesselation.

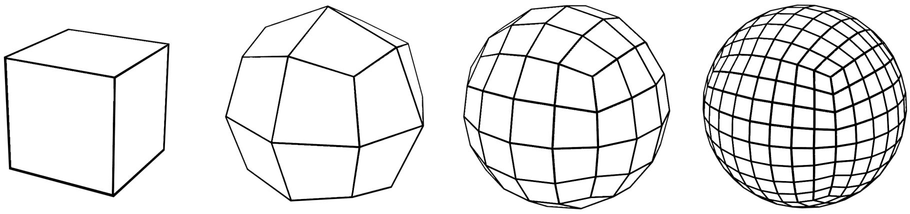

Figure 2.3: Quadrilateralized spherical cube tessellation.

A common issue with geographic grids is something referred to as polar pinching. At both of the poles, segments will be pinched to one point which leads to an increasing amount of segments per area. This in turn results in oversampling in textures as well as possible visual artefacts in shading due to the very thin quads at the poles as well as possible performance penalties for highly tessellated globes.

Quadrilateralized Spherical Cube Tessellation

Another common tessellation method for spheres which can be generalized to ellipsoids is the quadrilateralized spherical cube tessellation. The standard approach is to subdivide a cube centered in the origin and then normalize the coordinates of all vertices to map them on a sphere. There are also other more complicated schemes designed to work with specific map projections [4].

To model an ellipsoid from a sphere, the vertices can be linearly transformed with a scaling in the x, y, and z directions individually. Figure 2.3 shows a tessellated spherical cube of four different detail levels.

Hierarchical Triangular Mesh

The hierarchical triangular mesh (HTM) is a method of modeling the sky dome as a sphere proposed by astronomers in the Sloan Digital Sky Survey [10]. Instead of uniformly dividing cube faces, an alternative option is to subdivide a normalized octahedron by, in each subdivision step, split every

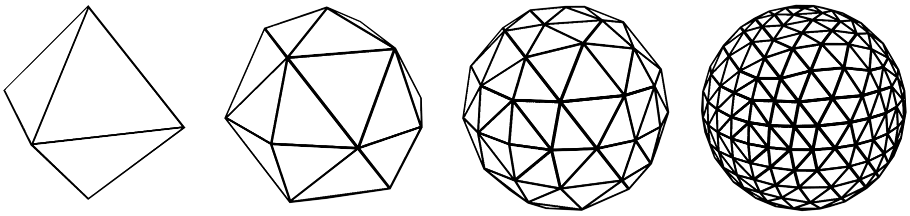

Figure 2.4: Hierarchical triangular mesh tesselation.

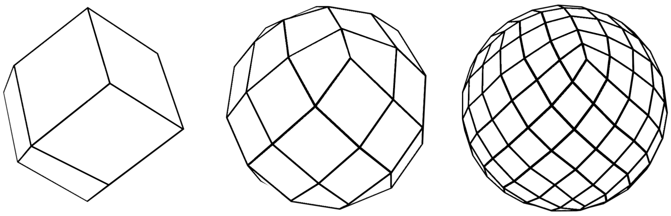

Figure 2.5: HEALPix tesselation.

triangle into four new triangles, see figure 2.4. An ellipsoid can be created from the sphere by normalizing the coordinates and linearly rescaling them the same way that can be done for the spherical cube tessellation.

Hierarchical Equal Area IsoLatitude Pixelation

Hierarchical Equal Area IsoLatitude Pixelation (HEALPix) is spherical tessellation scheme with corresponding map projection. The base level of the tessellation is built up of twelve quads, similar to a rhombic dodecahedron, which each can be subdivided further. The tessellation in figure 2.5 shows how the vertices in the HEALPix tessellation leads to curvilinear quads.

Geographic Grid Tessellation With Polar Caps

In their description of the ellipsoidal clipmaps method, Dimitrijević and Rančić introduces polar caps to avoid polar issues related to geographic grids [4]. The polar caps are simply used as a replacement of the problematic, oversampled regions around the poles. The caps can be modelled as grids projected onto the ellipsoid surface in their own georeferenced coordinate systems. One obvious issue with polar caps is the edge problem that occurs due to the fact that the caps are defined as separate meshes with vertices that do not coincide with the geographic vertices of the equatorial region, see figure caps. Dimitrijević and Rančić solves the issue by using a type of edge blending between the equatorial and polar segments [4]. Figure 2.6 shows a sphere tessellated with one equatorial region and two polar regions.

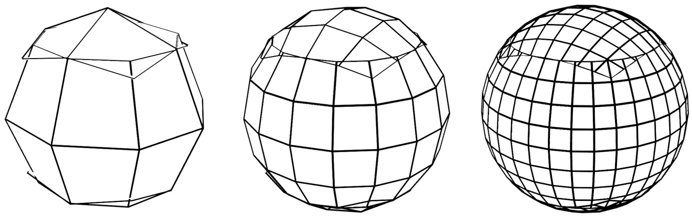

Figure 2.6: Geographic tessellation of an ellipsoid with polar caps.

2.1.3 2D Parameterisation for Map Projections

A map projection P defines a transformation from cartesian model space coordinates to georeferenced (projected) coordinates, as in equation 2.1. The inverse projection P^{-1} is used to find positions on the globe surface in model space given georeferenced coordinates as in equation 2.2.

$$\begin{pmatrix} \phi \\ \theta \end{pmatrix}_{georeferenced} = \vec{P}(x, y, z), \tag{2.1}$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix}_{modelspace} = \vec{P}^{-1}(\phi, \theta), \tag{2.2}$$

Where $(x, y, z)^T$ is the cartesian coordinates of a point on the ellipsoid surface. The parameters ϕ and θ are georeferenced coordinates defining all positions on the globe. The georeferenced coordinates can have different definition range depending on which projection is used.

The globally positive gaussian curvature of any ellipsoid makes it impossible to unproject it on a flat 2D surface without any distortions. Different projections are used for different purposes. Equal-area projections preserve the size of a projected area as $\partial\phi\partial\theta / \partial\phi_0\partial\theta_0 = 1$, while conformal projections preserve the shape of projected objects as $\partial\phi / \partial\theta = 1$; ϕ_0 and θ_0 are coordinates at the center of the projection with no distortion. No global projection can be both area-preserving and conformal [4].

There are several possibilities for defining a coordinate transform for map projections. A common approach is to project the ellipsoid onto another shape that allows for being flattened out without distortion, such as a cube, a cylinder or a plane. These types of shapes are known as developable shapes and have zero gaussian curvature.

Choosing a map projection is tied together with the choice of ellipsoid tessellation. This is because the map often needs to be tiled up when rendering. Each tile has its local texture coordinate system which need to have a simple transform from the georeferenced coordinate system for texture sampling. If the tiles can be affinely transformed to the geo referenced coordinate system, texture sampling can be done on the fly; otherwise the geo referenced coordinates need to be reprojected which may be computationally heavy or impossible for real time applications.

The European Petroleum Survey Group (EPSG) has defined several standards for map projections of the Earth. Many of these are mentioned when discussing the different projections.

Geographic Projections

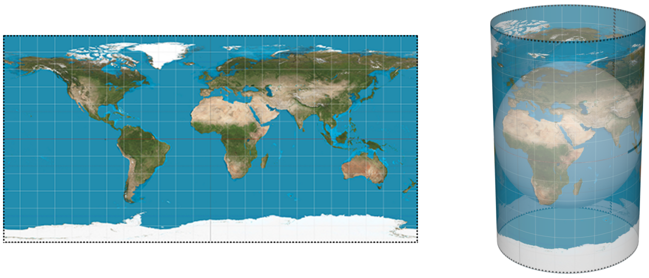

Figure 2.7: Geographic map projection.

Geocentric projection asd

Geodetic projection asd

Geographic Projections

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Geographic Projections

Chapter 3

implementation

3.1 <Section title>

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Figure 3.1: <Caption here>

3.1.5 <Sub-section title>

3.2 <Section title>

Chapter 4

Results

Chapter 5

Discussion

Chapter 6

Future Work

<Future work here>

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Chapter 7

Appendices