A New Spatial Framework for Digital Earth: Sphere Shell Space 3D Grid

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Abstract. Discrete Global Grid data model has been widely used in digital earth. But it is only confined to the surface, and then it can not reach to the inside and outside of the earth surface. The Sphere Shell Space 3D Grid (SSSG) proposed here sets up a new spatial reference framework for the whole earth 3D space. The subdivision and coding model of SSSG is designed and carried out, which is called as extended-Octree (e-Octree) model. At last, the prototype system of SSSG is realized, in which SSSG has been used to implement global terrain visualization, space orbit objects representation. These typical applications experiments show that SSSG is a new methodology for global change researches and earth system science. Furthermore, it could not only be used for representation, but also be used for dynamic simulation and spatial index.

Keywords: Digital Earth, Global Spatial Grid, Octree, Sphere Shell Space

1. Introduction

The range of human spatial activities has been promoted to various levels of earth space that from underground, land, sea, air to space, and spatial observation scope has been enlarged to every sphere shell of earth systems, while spatial exploration ability is being enhanced persistently. More and more scientific research, military and economic activities have shown their characteristics of global three-dimensional distribution, multi-spatial level, multi-spatial-temporal scale, non-gap organization. As a result, it is essential to construct the global uniform space framework in order to integrate various earth sphere shells' information.

Traditional GIS data models are mainly focused on medium- and small-scale problems, in which the map projection is used for mapping spatial-temporal phenomena from solid space to planar space, and spatial data have been organized according to map scale and map sheet, and geographic

objects modeling, analysis, representation is carried out in Euclidean space. As a result, traditional GIS data models have been challenged in this trend. And then, new concepts such as Digital Earth, Global Information Grid, appeared in recent twenty years, and also these GIS software such as ArcGlobe/GeoFusion, Google Earth, World Wind and Virtual Earth. In these research scopes, Global space grid is the core (Goodchild, 2000).

Sphere surface grid models, such as Lat-Lon Grid, Platonic Polyhedral Grid (Sahr et al. 2003), Voronoi Grid (Lukatela 1987) and Hybrid Grid (GeoFusion), have been proposed and used as the uniform global space framework. Although the limitations of map projections, map scales and map sheets have been broken through, sphere surface grid models is only confined to the surface, and have not replied to the problem about earth radial solid space modeling, so there is no rigorous description and expression of tridimensional entities and process. These solid objects could be transformed to sphere surface by dimensional reduction process, but results in problems such as disorder data organization, difficulties in multi-source data integration, confusion in understanding, and so on.

Therefore, the construction of new global 3D grid becomes an important problem. In recent years, Sphere Lat-Lon Grid, Yin-Yang Grid (Kageyama A. & Tetsuya S. 2004), Cubed-Sphere Grid (Tsuboi S. et al. 2008), Adaptive-Mesh Refinement Grid (Stadler et al. 2010), Sphere Degenerated Octree Grid (YU & WU 2009), etc, have been proposed. These sphere grid models have been used in macro-scale earth system simulation principally.

But there exist two problems in existing global space grid models. First, the relationship between surface grid and solid grid is dissevered, and there is no effective spatial information integration of different space level. Second, the sphere shell structure character has not been reflected in current grid models' design. But the surface is the main space level of human activities, and there are distinct differences in spatial information granularity of different space level.

In order to adapt to the global spatial information organization requirement, Sphere Shell Solid 3D Grid (SSSG) is proposed. The sphere shell structure character is reflected in this model design (Section 2). The surface and radial subdivision and coding of SSSG is unitive (Section 3). In Section 4, the prototype system is realized, and two typical applications experiments show that SSSG is a new 3D spatial reference model for digital earth and a new methodology for global change researches and earth system science

2. Sphere Shell Space 3D Grid

2.1. Sphere Shell Space

In geography science, Sphere Shell Structure is the main character of the earth. But sphere shells in geography are fuzzy in boundary, and intersect one another and even overlap. Therefore, sphere shells in geography could not be used in the global 3D grid design directly. Then, in this paper, sphere shell space is defined in geometry (Fig. 1).

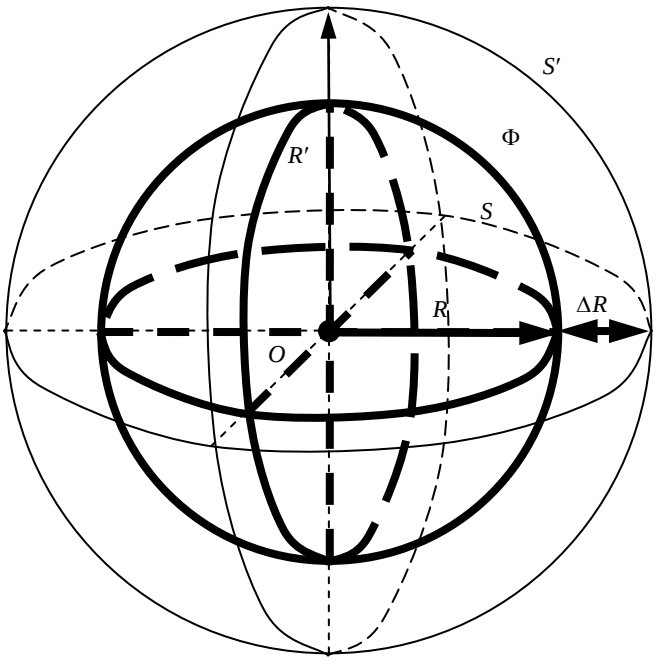


Figure 1. Sphere shell space geometric structure.

Each sphere shell space could be regarded as two concentric spheres (S and S'), their centre points is O. The inner sphere radius is R, and the outer sphere radius is R', so the thickness of this sphere shell space (Φ) is $\Delta R = R - R'$. In this definition, sphere shell space is clear-cut, and its shape is inerratic.

2.2. Sphere Shell Space 3D Grid Design

The basic idea of subdivision of SSSG is that, the earth spherical surface is set as starting surface; the whole earth has been divided into several homocentric datum sphere shells along the radial direction, and then the grid subdivision of each datum sphere shell has been taken place.

The basic construction flow of Sphere Shell Space 3D Grid is as below:

(1) The whole earth solid space is partitioned into several sphere shell spaces by sphere shell surfaces.

(2) The earth surface *S* is called as origination surface, and numbered as 0. Then these inner surfaces are ascendingly numbered as -1, -2, ... , and correspondingly, these outer surfaces are descendingly numbered as 1, 2, ... All these surfaces are called as datum surfaces.

(3) The sphere shell solid space between two datum surfaces is called as datum sphere shell. These datum sphere shells are then divided and coding according to e-Octree model (Section 3).

3. e-Octree Subdivision and Coding Model

The subdivision and coding model of SSSG is extended-Octree (e-Octree) model. There are three subdivision mechanisms, which consist of regular octree subdivision (ROS), degraded octree subdivision (DOS) and adaptive octree subdivision (AOS). DOS and AOS are extensions based on standard octree structure.

3.1. Subdivision

The subdivision process is carried out both on the surface and radial (Fig. 2).

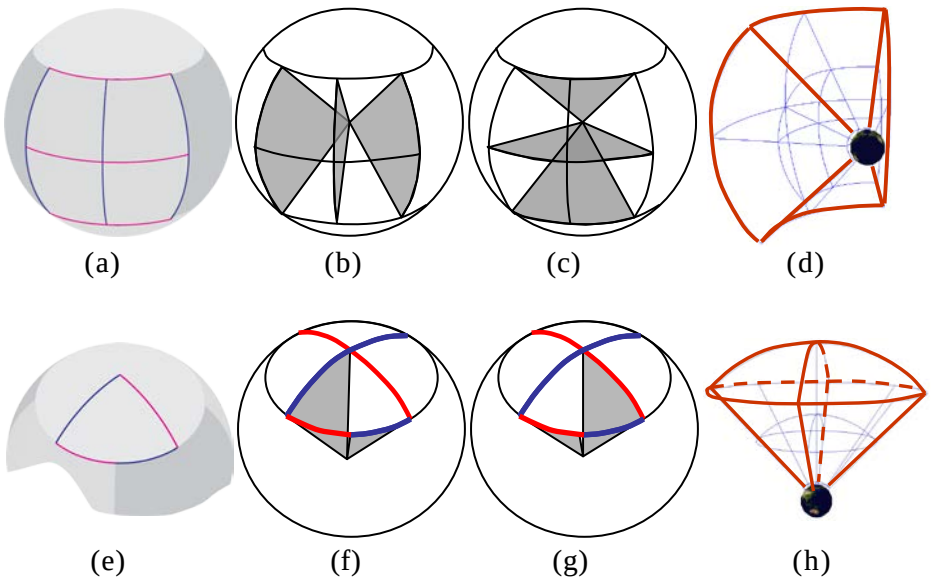


Figure 2. e-Octree subdivision model.

(1) the surface subdivision is Hybrid Grid. In Fig. 2, (a) and (e) show the surface division of low latitude region and high latitude region respectively, and the red and blue lines are called as iso-latitude line and iso-longitude line.

(2) The radial division tool is iso-latitude surface (Fig. 2(b) (f)) and iso-longitude surface (Fig. 2(c) (g)). The solid space is divided into solid cells (Fig. 2(d) (h)) using iso-latitude surface and iso-longitude surface. Fig. 3 shows level 1 ~ 3 grid in ROS and DOS.

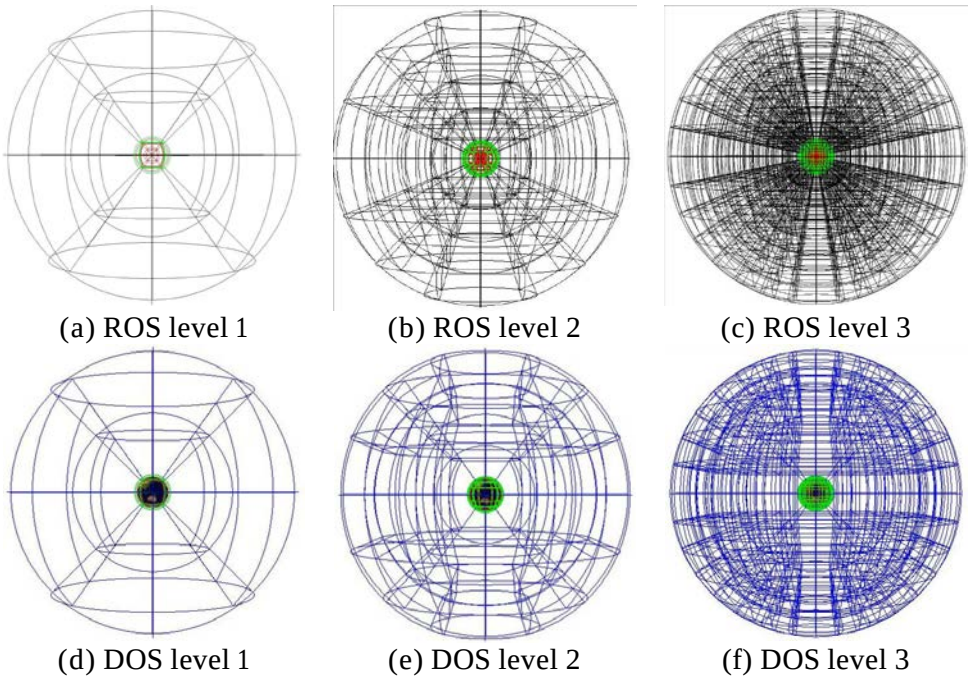


Figure 3. ROS and DOS subdivision results of level 1, 2 3.

3.2. Coding

The coding method is based on the surface and radial subdivision.

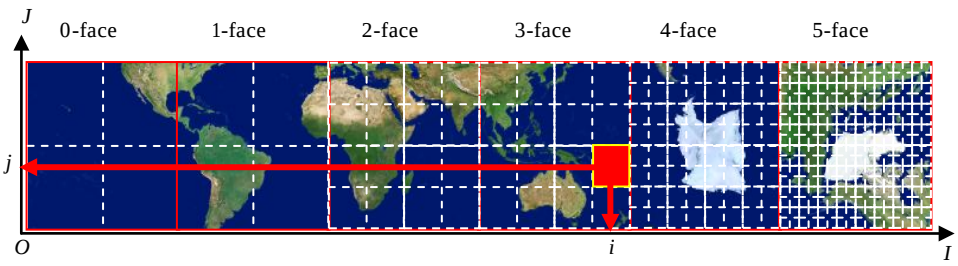


Figure 4. Surface coding.

(1) The coding of surface grid cell is in the *i-j* form, in which *i* denotes the number of current grid cell in horizontal orientation, and *j* denotes the number of current grid cell in vertical orientation (Fig. 4).

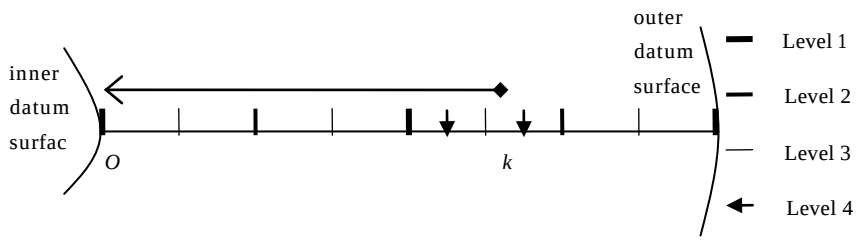


Figure 5. Radial coding.

(2) The coding of radial grid cell is in the *k* form, in which *k* denotes the number of current grid cell in radial orientation (Fig. 5).

4. The Prototype system

The prototype system of SSSG is realized. And then it has been used to implement global terrain visualization, space orbit objects representation. Both examples run on a laptop with Core2 Duo CPU 2.0GHz, 8600M GT, 1280×800, Microsoft Visual Studio 2005，OpenGL 2.0.

(1) Global terrain visualization

In this example, testing data include SRTM elevation (30 senconds resolution, 3.56GB), BlueMarble Image (30 senconds resolution, 3.6GB) and vector map (1:4,000,000, National Borderline 1.1MB, Province Borderline 1.7MB, Roadway and Railway 17MB). Fig. 6 and 7 show Sphere Shell Space 3D Grid over the whole earth and local region.

(2) Space orbit objects representation

In this example, the orbit is represented using SSSG grid cells (Fig. 8), and the satellite position is described in SSSG grid code form dynamicly (Fig. 9).

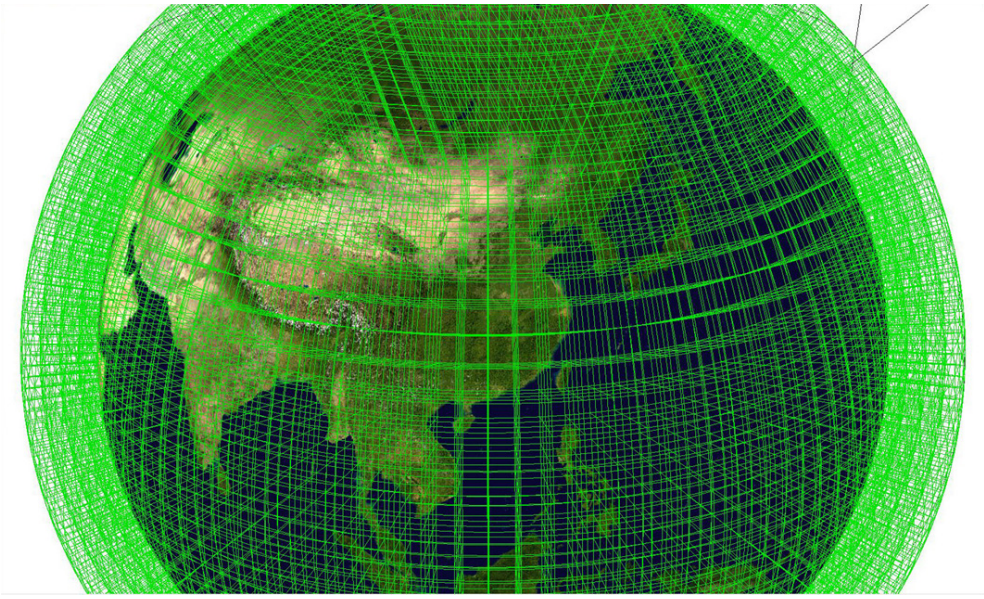


Figure 6. Sphere Shell Space 3D Grid (green wire frame) over the whole earth.

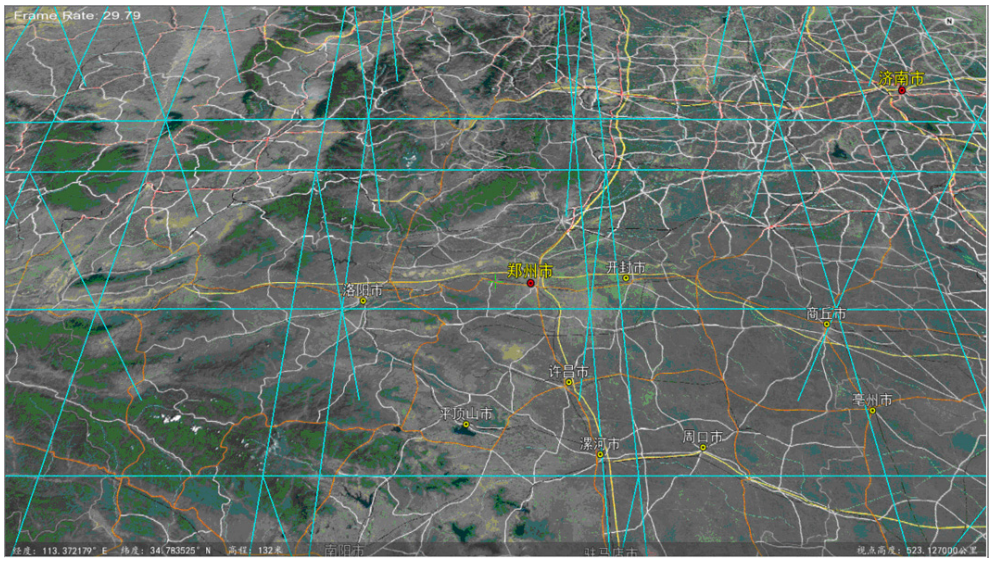


Figure 7. Sphere Shell Space 3D Grid (blue wire frame) over local region.

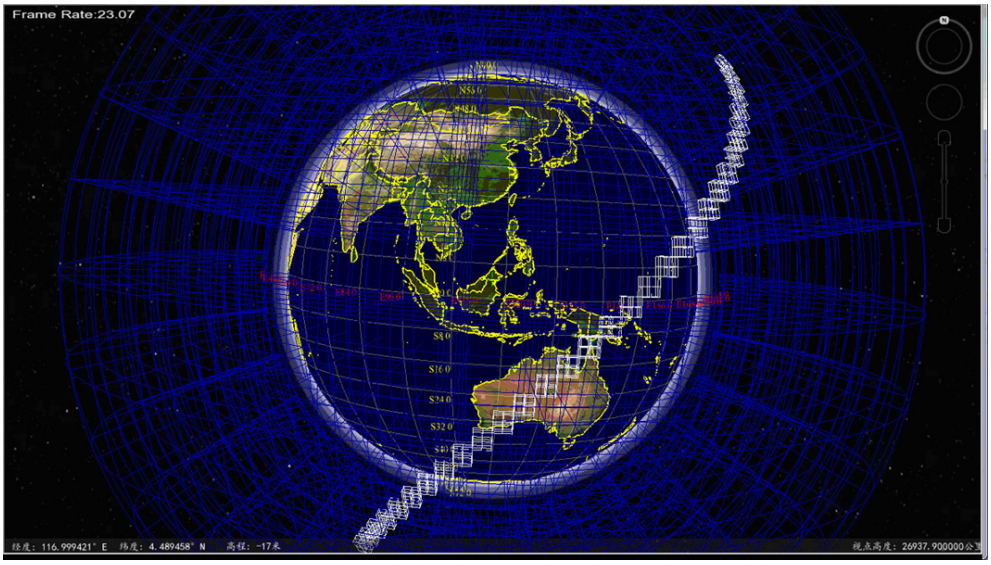
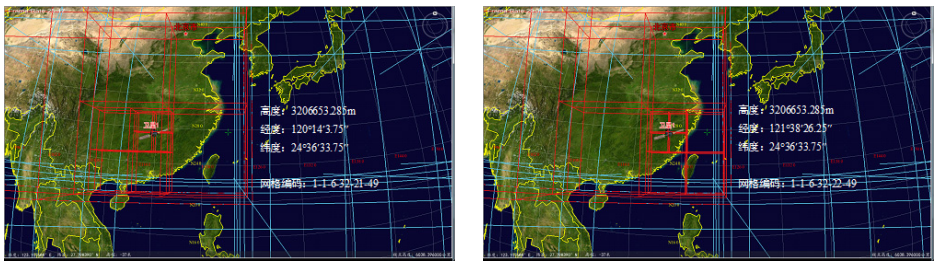


Figure 8. An arbitrary orbit (white wire frame) in the Sphere Shell Space 3D Grid.



(a) (b)

Figure 9. One moving satellite in the Sphere Shell Space 3D Grid.

These typical applications experiments show that SSSG is a new 3D spatial reference model for digital earth and a new methodology for global change researches and earth system science.

5. Conclusion

The Sphere Shell Space 3D Grid (SSSG) proposed here sets up a new spatial reference framework for the whole earth 3D space for Digital Earth. It is able to represent spatial objects distributed from underground, land, sea, air to space within a uniform framework, and also uniformly organize various kinds of spatial information in each earth sphere shells. Furthermore, it can not only be used for representation, but also be used for dynamic simulation and spatial index.

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