Research on the Construction of Global Spatial Multi-Grid Model Considering the Geographic Features of China

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Abstract. According to the subdivision principles of global grid, the advantages and disadvantages of classical spherical grid generation method at home and abroad are analyzed and compared. Considered with the spatial characteristics of China and the current standards of Geographical data, this paper proposes a global spatial multi-grid subdivision method that could adapt to the characteristics of global space and take into account the geographical features of China. And on the basis of this, a global unified spatial multi-grid coding model has been established and the corresponding neighborhood search algorithm and coordinate transformation formula have been derived, which provided theoretical supports for global grid positioning and information sharing.

1. Introduction
In 1998, former US Vice President Gore gave a speech on "Digital Earth" at the opening ceremony of the California Scientific Research Center. At the end of 1999, the "Digital Earth Beijing Declaration" was published successfully, which marked that Digital Earth construction work would be officially promoted worldwide. Spatial information multi-grid is the carrier of Geo-spatial data and it is a unified platform for organization, expression and sharing of Geo-spatial data. The core issue is how to cut the sphere, how to code the grid, how to search for the neighboring grid of the same level, and how to build coverage relationships for different levels of grids and how to convert grid coding and spherical latitude and longitude coordinates, etc.

At present, a lot of researches have been done on the global multi-grid model based on spherical coordinates at home and abroad. There are roughly four kinds of splitting schemes, including equal latitude and longitude latitude grid, variable latitude and longitude grid, adaptive grid and regular polyhedral grid.

For the advantages and disadvantages of the above four grid models, this paper develops a new set of Geo-spatial partitioning schemes that conform to current data specifications, has relatively simple scheduling algorithms and small data redundancy with considering the actual situation of China and the current characteristics of the finished spatial information, which can meet the global multi-scale, multi-temporal, multi-source spatial information products under the unified management, efficient retrieval and seamless integration of this model.

2. Global Space Grid Splitting Scheme

2.1. Global Grid Subdivision Principle
For different application requirements and service background, Global spatial could be divided by a variety of ways. Goodchild and Kimerling have successively proposed several evaluation criteria for
evaluating the merits of the global grid, and Clarke later conducted a comprehensive analysis of these standards. Studies have shown that multi-level hierarchical structure and homogeneous grid approximation have simple connection with common coordinates, and the versatility and scalability of the grid are the general standards that should be followed in global segmentation [6]. However, it is impossible to design a splitting scheme that conforms to all standards in reality, so we can only make reasonable choices according to their respective application requirements, and balance the standards and reality as much as possible. Considering the regional spatial characteristics and national geographic data characteristics in China, this paper proposes the basic criteria for grid subdivision:

- Take into account the curvature of the earth. Achieve continuous, seamless, global coverage.
- The grid has the characteristics of multiple levels, nesting and dynamic, and it should be suitable for multi-resolution expression.
- The grid should be as compatible as possible with the current series of basic scales (such as Table 1) in China, which is convenient for the collection, integration and sharing of a large amount of existing Geo-spatial information.
- Normative trellis coding and simple decoding. Be convenient to perform roaming and scheduling of the same level or upper and lower layers of the grid.
- Simple conversion relationship between grid coding and the global framework spatial reference datum.

The division of the grid should be versatile, and users can arbitrarily subdivide it according to the application requirements.

### Table 1. Latitude and Longitude Range Corresponding to Different Scale Maps

| Frame scale      | 1:100000 0 | 1:50000 0 | 1:25000 0 | 1:10000 0 | 1:5000 0 | 1:25000 | 1:10000 |
|------------------|------------|-----------|-----------|-----------|---------|--------|--------|
| Longitude range  |            |           |           |           |         |        |        |
| (wide)           | 6°         | 3°        | 1°30’     | 30’       | 15’     | 7°30”  | 3°45”  |
| Latitude range   |            |           |           |           |         |        |        |
| (high)           | 4°         | 2°        | 1°        | 20’       | 10’     | 5’     | 2°30”  |

Considering the above criteria, adopting latitude and longitude interval method combined with the latitude and longitude range of China’s basic scale in the mid-latitude region can be better compatible with our traditional map framing mode. It is beneficial for collection and organization of existing geographic data. In polar area, the Spherical deformation becomes serious. Triangulation scheme with “positive polyhedron” can express spherical characteristics better and reduce data redundancy greatly as shown in Figure 1.

![Figure 1. Level-0 Subdivision of Global Grid](image-url)
Considering the compatibility of existing maps in China and the regularity of the grid itself, this paper defines 60°S to 60°N for mid-latitude regions (China's geographical range is 4°N–53°N, covering the entire Chinese territory). Splitting is performed by equal latitude and longitude interval method in this area. The area of southern 60°S and northern 60°N is defined as polar region and the triangular splitting scheme is used in this area. The world is longitudinally split at 60° longitude. The middle and low latitudes are laterally split at 60° latitude to form the global basic grid, which is the 0th level grid, as shown in Figure 1. The basic grid has a total of 24 elements. The middle and low latitudes area and the polar regions are divided into squares and equilateral triangles with a side length of 60°, which conform to the basic criteria of grid.

2.2. Grids Splitting in the Middle and Low Latitudes Area
In Middle and low latitudes area, quadrilateral splitting is performed according to the latitude and longitude range of Table 1. The north-south direction is recorded as "S" and "N" respectively. Taking the basic grid N00 in the middle and low latitudes of the northern hemisphere as an example, the N00 grid is divided according to 15*10, and 150 grid units with a latitude difference of 4° and a difference of 6° are obtained, which corresponds to China's 1:100 million basic scale range. Then use the lower left corner (the southern hemisphere is the upper left corner) as the starting point to encode them separately by row and column numbers, as shown in Figure 2.

![Figure 2. Level-1 Subdivision of the Basic Grid](image)

Similarly, according to the latitude and longitude range shown in Table 1, the basic grid is divided step by step, which can get 1:1,000,000, 1:500,000, 1:250,000, 1:100,000, 1:50,000, 1:25,000 and 1:10,000. As shown in Figure 3.
From the eighth level to the next subdivision, it strictly divides the quadtree according to the equal latitude and longitude interval. Each level of trellis coding uses a two-digit code to indicate its number of rows and columns. As the level continues to increase, the grid resolution is also increased by an integer multiple of 4, when divided into 26 levels, the grid accuracy can reach less than 2 cm.

2.3. Grids Splitting in Polar Regions
For the polar regions, expand it with the pole as the center. Starting from the 180° warp with the pole as the apex, 60° as the apex angle, triangulation from west to east, the six meridians divide the north and south latitude 60° weft coils into six equilateral triangles. And the bottom edge of the triangle forms a seamless connection with the basic grid in the middle-low latitude area, and the north-south orientation of the triangle is distinguished by the additional codes '1' and '0' respectively, as Figure 4.
In order to reduce the deformation of the spherical triangle when performing the Quaternary division, this paper uses the "latitude and longitude division method" to subdivide step by step, the basic method is: For each spherical triangle, average them according to the latitude and longitude coordinates of three vertices. Take the midpoint of the three sides, the midpoint line divides the spherical triangle into four equally similar small triangles. So on and so forth; polar regions can be divided into hierarchical multilevel triangular grids.

3. Global Spatial Information Grid Coding Model
The Global Spatial Information Grid Coding Model (GSIG-ID) uniquely encodes each grid element of each level of grid. Grid coding is the unique identifier of a grid unit. According to the global grid's splitting plan, in the middle and low latitudes area, the "equal latitude and longitude interval method" is used to generate a quadrilateral grid. The polar regions use the "latitude and longitude division method" to generate an equilateral triangle grid. It is worth noting that this paper combines the Arctic basic grid and the Antarctic base grid to form six diamond-shaped basic grids, so that the polar region grid has a shape similar to that of the middle and low latitude regions, as shown in Figure 4. Therefore, it is possible to encode using a uniform encoding rule. In this paper, the variable length coding mechanism is adopted. Starting from the basic grid, the grid coding length is increased step by step with two digit codes, as shown in Figure 5.

4. Neighborhood Search for Global Space Grid
Neighbor relationship is one of the most important spatial relationships in spatial grids. It is also an essential part of building a digital model of space grids. It will play an important role in cross-grid adjacency analysis such as indexing, scheduling, and aggregating massive amounts of data.
4.1. Neighborhood Search in Middle and Low Latitude Areas

The grids of the middle and low latitudes are coded according to the equal latitude and longitude interval method. It can be known from the middle and low latitude coding formula that the odd-numbered bit Bi implies its latitude information (line number), and the even-numbered bit Li implies its longitude information (column number). Therefore, the adjacent trellis coding in the middle and low latitudes area can be obtained by simple binary addition and subtraction of (B, l) (0<\text{b}<B, 0<l<L). Taking grid 0011 as an example, the four adjacent grid codes are (b+1, l), (b-1, l), (b, l-1), (b, l+1). The adjacent angular grid codes are (b+1, l-1), (b-1, l+1), (b-1, l-1), (b+1, l+1), as shown in the figure. 6.

![Figure 6. Edge Neighborhood Search and Angular Neighborhood Search in Mid-low Latitudes Area](image)

4.2. Neighborhood Search in Polar Regions

After the spherical triangle grid of the polar region is merged into a diamond block, it can draw on the advantages of neighborhood search algorithms in low-and-mid-latitude regions. The neighborhood search based on diamond blocks is divided into three cases: neighborhood search for inner diamond blocks (white), neighborhood search for edged diamonds (blue), a neighborhood search with a corner diamond (green), as shown in Figure 4. The neighborhood search algorithm of the inner diamond block is consistent with the algorithm principle of the middle and low latitude regions. The neighborhood search of the edge diamond block spans the boundary of the base diamond block. Take the diamond block on the left side as an example, I and J of 2-corners-adjacent diamond block located in the base diamond block on the left side are (B, B-b-1), (B, B-b+1) or (B-l-1, L), (B-l+1, L), I and J of one side adjacent to the diamond block are (B, B-b) or (B-l, L). The horn-shaped block includes north-south diamond block and an east-west diamond block. The horn-shaped block is divided into a north-south diamond block and an east-west diamond block. Take the north diamond block (B, 0) as an example, there are 2 edge neighboring blocks and 2 corner neighboring blocks respectively located on the left and right sides of the base block, which are (B, 0), (B, 0) and (B, 1), (B-1, 0), 1 respectively. The angular adjacent (B, 0) block is located in the opposite base block. Other neighboring blocks located in the same block have the same principle as the inner diamond block search, and similarly, B and L of other neighboring blocks can be obtained, and then the adjacent diamond lattice coding can be obtained by substituting the coding formula. The neighborhood search of a triangle includes an upward triangle and a downward triangle. The diamond adjacent block search method can be used to obtain the corresponding adjacent diamond block. Then delete it as needed to get it. Taking the upward triangle as an example, each triangle consists of three sides adjacent to the triangle and nine corners adjacent to the triangle as shown in Figure 7.
5. The Relationship between Grid Coding and Geographic Coordinates

Under the same spatial reference, each grid unit uniquely corresponds to a range of regions of the surface. Conversely, any coordinates on the surface map corresponds to multiple grids nested in layers in the global spatial information grid model. Therefore, there is a mutual transformation relationship between grid coding and geographic coordinates.

5.1. Conversion Algorithm of Middle and Low Latitude Area

Since the grid in the middle and low latitudes area is divided by the equal latitude and longitude interval method, there is a certain conversion relationship between grid coding and ground latitude and longitude.

5.1.1. From Latitude and Longitude to Grid Coding. Knowing the latitude and longitude (L, B) coordinates of a point on the surface, finding a certain level of grid coding corresponding to this point is called encoding.

\[
L = \text{int} \left( \frac{180° - L - \sum_{i=4}^{\infty} L_{i-1} \times W_i}{W_i} \right), 0° \leq L \leq 360°
\]

, L is longitude (if L is east longitude, then L = -L)

\[
B = \text{int} \left( \frac{B - \sum_{i=4}^{\infty} B_{i-1} \times H_i}{H_i} \right), 0° \leq B \leq 60°
\]

, B represents latitude

L and B are the latitude and longitude coordinates of a given point respectively, n represents the number of stages of the grid, and Li and Bi represent the longitude information and the latitude information (row and column number) of the i-th level respectively, Wi and Hi represent the longitude difference and the latitude difference of the i-th grid respectively, and the values are:

\[
W_i = \begin{cases} 
0°, & i < 0 \\
6°, & i = 0 \\
6°, & i = 1 \\
30°, & i = 4 \\
30°, & i > 4 
\end{cases}
\]

\[
H_i = \begin{cases} 
0°, & i < 0 \\
60°, & i = 0 \\
60°, & i = 1 \\
4°, & i = 4 \\
2°, & i = 4 \\
20°, & i > 4 
\end{cases}
\]

For example, find the secondary grid coding of P (108°W, 29°N):

B0=int[(29°-0°)/60°]=0, L0=int[(180°-108°-0°)/60°]=1;
B1=int[(29°-0°*60°)/4°]=7, L1=int[(180°-108°-1°*60°)/6°]=2;
B2=int[(29°-0°*60°-7°*4°)/2°]=0, L2=int[(180°-108°-1°*60°-2°*6°)/3°]=0.

Therefore, the secondary grid code corresponding to P (108 ° W, 29 ° N) is: code=N017200.

5.1.2. From Grid Coding to Latitude and Longitude. If you know the encoding of a grid, get the latitude and longitude corresponding to the lower left corner of the grid is called decoding.

\[ L = 180 - \sum_{i=0}^{n} L_i \times W_i, \]  
\[ B = \sum_{i=0}^{n} B_i \times H_i, \]

where \( L \) is positive for the west longitude, denoted by W; negative value for the east longitude, denoted by E.

The first digit of the code N indicates the northern hemisphere, S represents the southern hemisphere.

L and B are the latitude and longitude coordinates corresponding to the lower left corner of the grid respectively, n represents the number of levels of the grid, \( L_i \) and \( B_i \) represent the longitude information and the latitude information (row and column number) of the i-th level, \( W_i \) and \( H_i \) represent the longitude difference and the latitude difference of the i-th grid respectively. For example, the grid N017200 is a three-level grid, and the latitude and longitude of the lower left corner is: (108°-1°*60°-2°*6°-0°)W, (0°*60°+7°*4°+0°)N.

5.2. Conversion Method of Polar Region

The conversion algorithm in the polar regions is more complicated. Firstly, starting from B1L1 (codes 4th to 5th), compare the size of \( B_i \) and \( L_i \) to determine the hemisphere area where the grid is located. As shown in the following formula, (1) and (3) represent the Northern Hemisphere and the Southern Hemisphere, respectively. (2) refers to a diamond shaped block that crosses the equator. A triangle with an additional code of 0 belongs to the northern hemisphere. A triangle with an appendage of 1 is located in the southern hemisphere.

\[
\begin{align*}
B_1 \cdots B_n &> L_1 \cdots L_n, \quad n \geq 1 \quad \text{(1)} \\
B_1 \cdots B_n &= L_1 \cdots L_n, \quad n \geq 1 \quad \text{(2)} \\
B_1 \cdots B_n &> L_1 \cdots L_n, \quad n \geq 1 \quad \text{(3)} 
\end{align*}
\]

Taking case (1) Northern Hemisphere as an example, as the value of B increases, its latitude value also increases. Similarly, as the L value increases, the grid longitude increases simultaneously. Referring to the principle of the conversion algorithm in the middle and low latitude regions, the mutual conversion formula between the grid coding and the geographical coordinates in the polar regions can be obtained. No further details will be repeated here.

6. Summary

The digital model of global space grid based on multi-level partitioning is of great significance to the organization management and dynamic scheduling of massive spatial data. According to the spherical characteristics of the Earth, different dissection schemes are adopted in the middle and low latitudes and polar regions, and the seamless splicing is achieved, as shown in Figure 8.
Using the coding model to uniquely encode the grids at all levels, it can realize the neighborhood search and coordinate transformation of the global grid, and quickly index all kinds of spatial information and attribute information within the grid. It provides great convenience for data scheduling, analysis and mining, and enables sharing of resource information on a global scale.

7. Reference
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