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Virtual globe-based integration and sharing service method of GeoSpatial Information

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How to integrate and disseminate globally distributed multi-source and heterogeneous spatial information is an open problem in integration and sharing service of geographic information. Here we propose a new service architecture suitable for integration and sharing of distributed multi-source geographic information. We also propose a global virtual pyramid model, which can be applied in 3D virtual globes. In view of the difficulty of web multi-node geographic information sharing service, we propose a web multi-node service aggregation method, integrated in our autonomously developed virtual globe platform GeoGlobe and introduced in the National Platform for Common GeoSpatial Information Services named "TIANDITU". It achieves 2D and 3D integration for geographic information service.

virtual globe, service aggregation, National Platform for Common GeoSpatial Information Services

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With the rapid development of network technology, earth observation technology, and geographic information technology, a rapid capture of global multi-resolution remote sensing image and construction of 3D virtual globe system under the network environment has become an important symbol of the contemporary geographic information technology. Thanks to globally distributed server system, efficient spatial data transmission, and 3D real-time visualization approach, anyone can get access to global multi-scale geospatial information anywhere at any time [1, 2].

The most representative 3D virtual globe system is Google Earth, launched by Google company in 2005, which supports effective integration, organization, management of multi-source satellite remote sensing images, terrain data, vector data, and city 3D models on a global scale. At the same time, Google applies its highly efficient search engine technology in Google Earth, which can meet the demand of data query, location, and spatial analysis functions [3]. Then the Microsoft company also launched similar virtual globe platform Virtual Earth, which supports the WMS service. With the help of Microsoft Live Local service, one can search out any map image in global arbitrary areas and get the rendered 3D pictures in a partial region [4]. The US National Aeronautics and Space Administration (NASA) designed a 3D virtual globe platform World Wind as well, which supports the WMS-based image data display mainly from NASA and USGS (U.S. Geological Survey). Moreover, World Wind has an open architecture with good expandability [5].

The above typical 3D virtual systems adopt different spherical partition models, spherical encoding method, and global spatial reference. As a result, it is difficult to achieve data integration and sharing among different 3D virtual globe systems, and so is the case between 3D virtual globe system and professional geographic information system.

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Many domestic and foreign scholars have launched extensive research on Discrete Global Grids and Web geographic information integration and sharing. Discrete Global Grids (DGGs) have features of hierarchy, uniqueness and consistency, suitable for display of multi-resolution spatial data [6]. They provide a basic 3D spherical model structure for the construction of 3D virtual globe, so as to lay the foundation for effective organization, management, and expression of massive global multi-scale spatial data.

In the research of DGGs based on regular polyhedron grid, Fekete et al. [7] proposed Spherical Quaternary Triangle (SQT) model, Dutton [8] proposed Quaternary Triangular Mesh model, Bai et al. [9] proposed hierarchical partition of WGS-84 ellipsoidal facet based on QTM, and White [10] proposed recursive diamond subdivisions of the surface of an octahedron or icosahedron. The above DGGs have excellent properties such as good hierarchy, approximate rules, similar shape and size, global addressability, and data independence. However, because the mapping relationship computation from regular polyhedron to sphere is complicated, grid boundaries are not consistent with meridians and parallel circles, causing it difficult to utilize existing geographic data in all kinds of coordinate system.

In the research of DGGs based on latitude-longitude grid, it is convenient for data organization, storage and processing, as the corresponding relationship between the grid model and geographic coordinates is simple enough [11], which is widely used in World Wind, Google Earth, and Virtual Earth. In addition, in order to make the grid cell in the same level share approximate shape and size, a series of improvements on latitude-longitude grid have been proposed. The related research is called adjusted latitude-longitude grid. Ma et al. [12] developed a discrete square global grid system based on the parallels plane projection. Although its most grid cells meet the constraints about area and shape, there are still cracks in polar region. Ellipsoidal Quad-trees (EQT) proposed by Ottoson et al. [13] takes the actual earth shape into account and adopts the WGS84 ellipsoid as partition foundation. It ensures the approximate cell area, but the shape difference remains great. Beckers et al. [14] introduced azimuthal projection into hemisphere adjusted latitude-longitude grid to build equal-area cells, but the longitude-latitude changing rule is too complicated for analysis and calculation. Compared with the global latitude-longitude grid, the above adjusted latitude-longitude grid methods have their advantages on consistent area, but this optimization comes at the cost of irregular grid shape and complicated grid adjacency [15]. Moreover, the grid lacks hierarchy, nesting levels, and related grid encoding, which are essential for global multi-resolution data seamless organization and expression.

In addition, based on conclusion of the previous grid division methods at home and abroad, Li et al. [16] developed the Spatial Information Multi-Grid (SIMG) and provided the transfer rules between the grid code and the geographic coordinates. After analyzing the shortcomings of Discrete Global Grids and Image Pyramid, Cheng et al. [17] introduced the model of Image Subdivision Pyramid and proposed the construction strategy.

The above research work focuses on Discrete Global Grids systematically, which has laid the good foundation for the data organization of 3D virtual globe system. At the same time, web geographic information service methods have been discussed based on different service standards and service chains. Among them, the OGC and ISO/TC211 service specifications and criterions are basic guarantee of multi-source and heterogeneous geographic information sharing service. Nevertheless, the above research work did not realize integration and sharing services about distributed multi-source and heterogeneous geographic information.

In this paper, based on heterogeneous virtual globe collaborative services and multi-node geographic information integration service, we mainly discuss the following points: (1) In view of characteristics of professional geographic information management and web integration and sharing services, we design the system architecture integrating professional spatial data management and distributed integration and sharing services in virtual globe system. (2) On this basis, according to the heterogeneous data integration requirements in virtual globe system architecture, we develop the multi-source and heterogeneous data integration method in 3D virtual globe. (3) Moreover, in consideration of requirement of multi-level and multi-node geographic information integration services, we propose a geographic information integration and sharing method based on the multi-level nodes service aggregation model, following the geographic information service standard and unified service interface. (4) In this section, the above approaches are applied in National Platform for Common GeoSpatial Information Services "TIANDITU" and specific applications are introduced.

1 Web geographic information integration and sharing services system architecture

In view of hierarchical and multi-scale management of geographic information resources, along with distribution, heterogeneity and multi-source characteristics of geographic information services, we design a distributed multi-level system architecture of web geographic information integration and sharing service, as is shown in Figure 1.

It is a vertical multi-level service structure based on characteristics of geographic resources management, which is designed as national, provincial, and municipal geographic information service node, separately providing geographic information online services in different levels. Through geographic information multi-level aggregation services, geographic information service nodes distributed

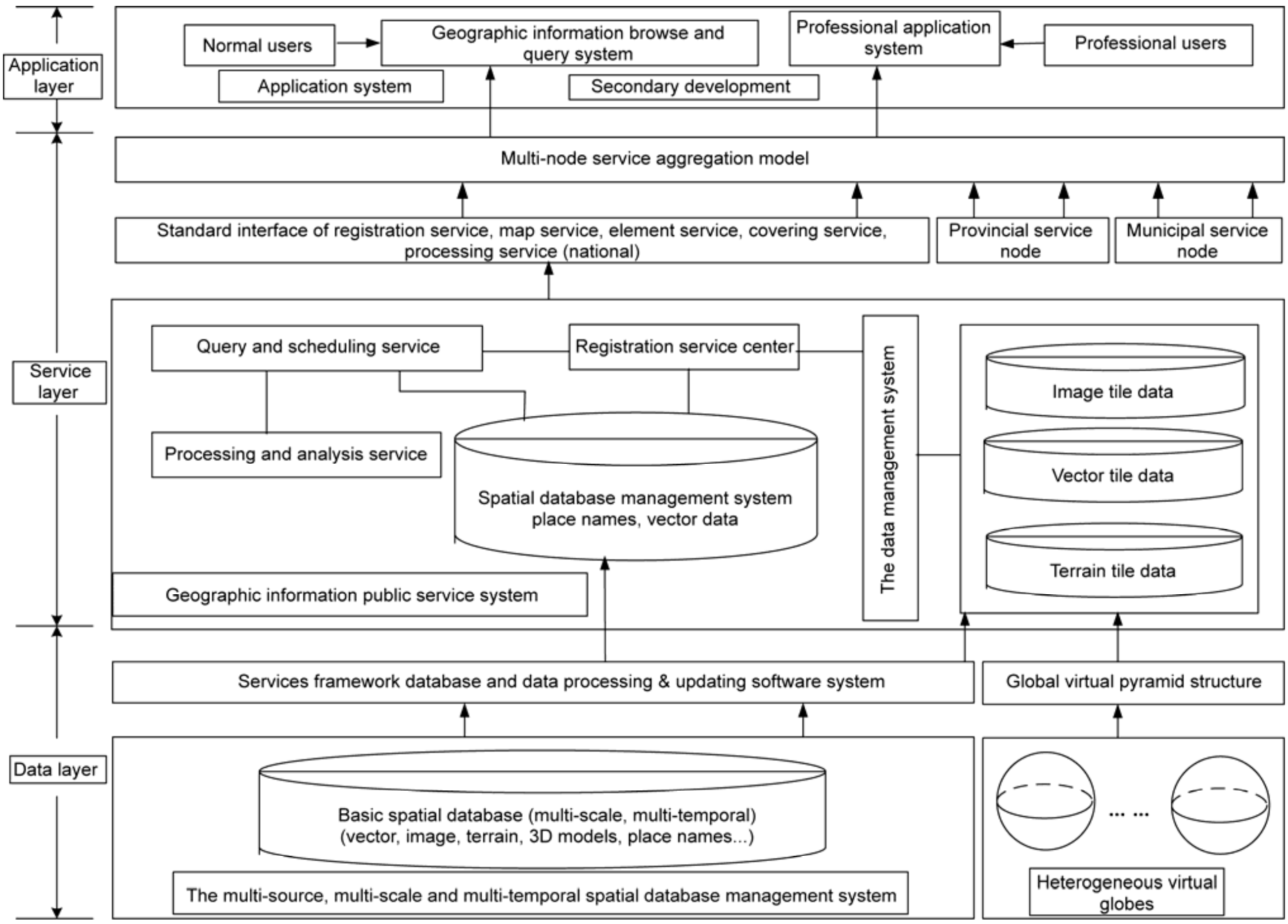

Figure 1 Geographic information integration and sharing service system architecture.

all over the country can be connected into a coordinated operation system, so as to provide comprehensive integration and online services about geographic information. At the same time, this architecture is a multi-level structure, whose service nodes are divided into data layer, service layer, and application layer.

(1) Data layer. This layer is responsible for the management of multi-source, multi-scale and multi-temporal spatial database and maintenance of the basic geographic data. The framework database is extracted in a certain way. With the help of data update system, the present situation of the data can be guaranteed and service-oriented spatial database framework can be generated. Besides, we can get access to multi-source heterogeneous virtual globe data such as Google Earth.

(2) Service layer. This layer is the core layer of the system architecture, whose data sources are geospatial database management system and heterogeneous tile data management system. The tiles are divided into blocks and layers with the global multi-scale pyramid structure data organization. The service layer can provide information query, processing and analysis functions based on geographic information service requirements. In addition, service interfaces of registration services, map services and elements services are provided, so that all levels of service nodes can be integrated into heterogeneous virtual globe.

(3) Application layer. In this layer, multi-scale, multi-temporal geographic information aggregation services in different nodes are provided to both ordinary users and professional users according to the multi-level nodes aggregation models.

2 Heterogeneous data integration methods in virtual globes

2.1 Global virtual pyramid model

Different data organization methods in virtual globes often use different types of pyramid structure according to different DGGs. In order to satisfy global multi-resolution massive spatial data effective storage and organization requirements, here we present a global virtual pyramid model, so as to integrate spatial data from different 3D virtual globes, as is shown in Figure 2.

Global virtual pyramid model consists of several different types (terrain, image, models, etc.) of child pyramid models. For each type of pyramid model, it consists of several layers in accordance with continuous resolution numbers. And for each data layer, it consists of several tiles with certain subdivision rules. As the smallest unit in global virtual pyramid models, a tile contains several properties such as specific resolution, spatial range, and coded row & column index. Since image files are texture attributes for terrain tiles, they keep one-to-one mapping relationship, as is the case in other different types of tiles. The above mapping relationship lays a foundation for connecting different data layers from distinct pyramid structures. The following is specific data structure for model objects.

(1) Global virtual pyramid model *VPGlobalPyramid*

```
Struct VPGlobalPyramid{
    VPTypeGroup * mImageGroup;    // Image Pyramid
    VPTypeGroup * mTerrainGroup;    // Terrain Pyramid
    VPTypeGroup * mModelGroup;    // Model Pyramid
    ……
    int    m_GroupsCount;    //Numbers of Different Types
    BOOL    m_bInitialized;    //If Initialized or Not
};
```

(2) Type-dependent child pyramid structure *VPTypeGroup*

```
Struct VPTypeGroup{
    std::vector< VPTypeSet * >    mSetArray;
    // Dataset Object Set
    int    mLevelCount;    // Numbers of Layers
    in a Single Pyramid
    typedef  struct    Region{
            double        m_dWest;
            double        m_dEast;
            double        m_dNorth;
            double        m_dSouth;
        }GroupRegion;                //Spatial Range
        Struct
    ……
    BOOL    m_bInitialized;        // If Initialized or Not
};
```

(3) Hierarchical data structure *VPLayerTiles*

```
Struct VPLayerTiles{
   int    m_nLevel;                    //Level Index
   int    m_nTileCount;                // Numbers of Tiles in a
   Layer
   std::map<LONGLONG, VPTile*>      m_HashTiles;
                          //Hash Table Constructed by Tiles
   ……
   BOOL      m_bInitialized;          // If Initialized or Not
};
```

In each Layer structure, a hash table is used for tiles maintenance and management. It offers access to corre-

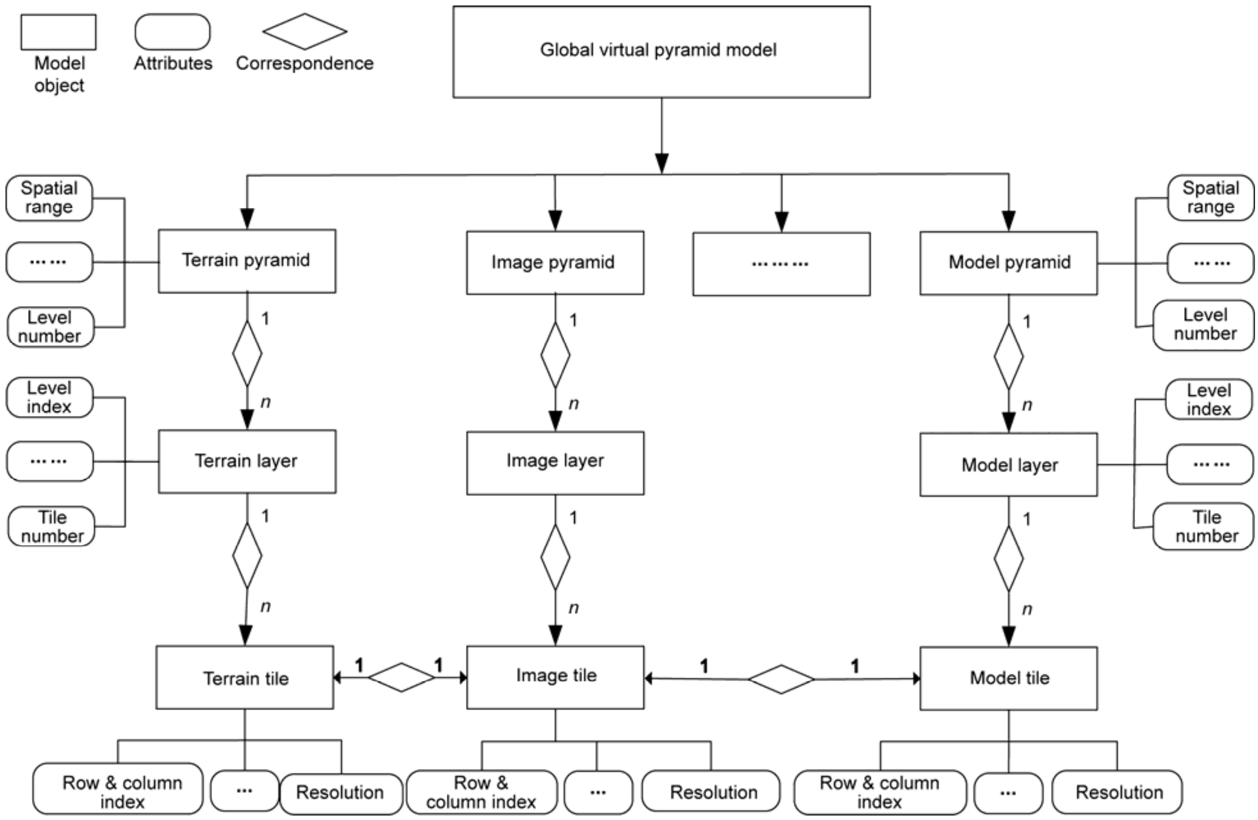

Figure 2 Global virtual pyramid model.

sponding tiles by the Key Value, so as to speed up access and query efficiency.

(4) Tile structure *Tile*

```
Struct VPTile{
    int m_nRow;              // Row Index of the Tile
    int m_nColumn;           // Column Index of the Tile
    int m_nLevel;            // Level Index of the Tile
    CBoundingBox    m_BoundingBox;
                             //Bounding Box of the Tile
    typedef struct tagVertex{
            float x,y,z;         // Space Coordinates
            float Tu,Tv;         // Texture Coordinates
        }CustomVertex_PosTex;
            //Struct of Space and Texture Coordinates
   CustomVertex_ PosTex *    m_pNorthWestVertices;
   CustomVertex_ PosTex *    m_pSouthWestVertices;
   CustomVertex_ PosTex *    m_pNorthEastVertices;
   CustomVertex_ PosTex *    m_pSouthEastVertices;
                             // Child-node Coordinate Struct
   ……
    BOOL   m_bInitialized;       // If Initialized or Not
}.
```

For each tile, a bounding box is defined by spatial range of this tile, so as to decide if the tile is visible during the data scheduling phase. Then we define a struct *CustomVetex_PosTex* used to preserve its corresponding geometry and texture coordinates. Each tile contains four child-nodes according to the quadtree structure, and each child-node contains a *CustomVetex_PosTex* pointer object, therefore each tile rendering is divided into four tiles separate rendering in the child nodes.

This data structure defines the spatial references, subdivision methods, and geocoding rules for global spatial data organization and lays a good foundation for integration of heterogeneous 3D virtual globes.

2.2 Integration rules of heterogeneous 3D virtual globes

Since heterogeneous 3D virtual globes involve different spatial references, subdivision methods, and geocoding rules, it is necessary to give a unified definition of the above three characteristics to generate the integration rules.

(1) Spatial reference. The popular spatial reference in virtual globes is WGS84 coordinate system whereas the most popular map projection is the Mercator projection. In Mercator projection, all of the meridians and parallels are perpendicular and both horizontal and vertical distance will get longer with the latitude increasing, so that the distortion ratio almost remains the same and it keeps shape and angle of the surface features invariable [18]. Moreover, if tiles in virtual globes share the same size, the tiles quantity will reduce by half. In view of the above advantages of Mercator projection, the spatial reference of heterogeneous virtual globes data integration will adopt the Mercator projection.

(2) Spherical subdivision. As virtual globes orient global spatial data organization and management, the spherical subdivision method determines the space index, tile shape, and unit size. In spherical subdivision research, in order to obtain accurate subdivision results, the most common way is to achieve infinite subdivision. When subdivided to a certain degree, the grid can simulate the earth surface very well, with the subdivision models such as regular tetrahedron, octahedron, dodecahedron and so on. Although it has advantages in sphere fitting, the texture mapping is usually too complicated and projection transformation is difficult when using global image data for virtual globe rendering, resulting in low index-efficiency. At present the virtual globes are not yet mature enough for applications. Therefore, in order to balance the efficiency of query and visualization, it often adopts plane models to subdivide the spherical surface in existing 3D virtual globes. The regular grid and mixed grid are the most widely used. The former covers projected sphere surface with regular grid cells. The grid cells are usually square and the ratio between different resolution levels is multiples of 2, so as to make it easier for calculation. Considering the existing subdivision methods in virtual globes, we adopt global latitude-longitude regular grid plane models in integration of heterogeneous virtual globes.

(3) Geocoding. In order to achieve better integration of temporal information, we construct global virtual earth geocoding methods based on Morton coding in global virtual pyramid model. In view of spherical subdivision models, the row & column indices of global tile data are transformed to binary format, which shall be put into the Morton codes alternately and generate one-dimensional address codes. At the same time, the temporal information is added to output spatial-temporal codes and corresponding indices, whose positioning algorithm complexity is equal to only O(1).

2.3 Integration methods of heterogeneous 3D virtual globes

As the logic pyramid structure data model, global virtual pyramid model provides a logic view of heterogeneous virtual globe integration. Subsequently the mapping relationship between the logic view and global virtual pyramid model is created by the integration rules, so that we can obtain integration data from heterogeneous virtual globes. The integration framework is shown in Figure 3 as follows.

When constructing the global virtual pyramid model, one pyramid model is divided into several child pyramid models. The logic ranges of the geographic data in the child pyramid models can be connected to a whole range of tiles in the successive layers of the main pyramid, so as to keep the consistency of the data structure. Each child pyramid model is a subset of the heterogeneous 3D virtual globes pyramid model. Based on spatial reference, subdivision method, and geocoding rules, the mapping relationship is created be-

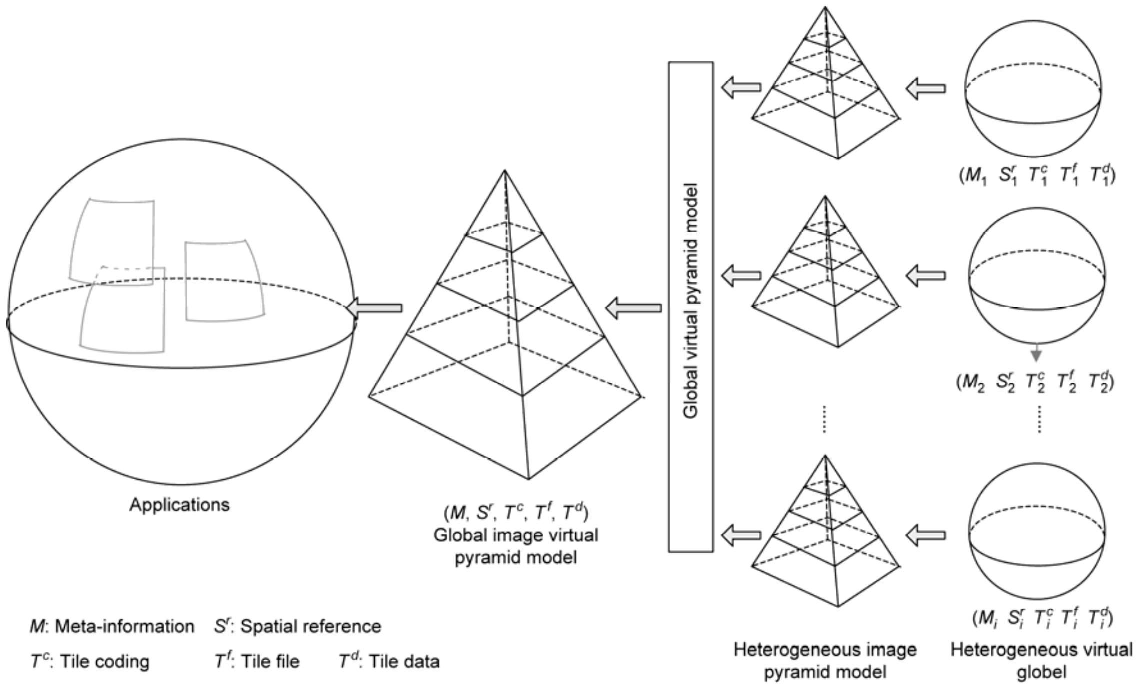

Figure 3 Integration framework of heterogeneous 3D virtual globes.

tween the global virtual pyramid model and each heterogeneous virtual pyramid model. At the same time, multi-source spatial data in heterogeneous 3D virtual globes is transformed to unified spatial tile data structure defined in global virtual pyramid model, so as to realize seamless data integration of multi-source heterogeneous virtual globe data.

The above integration methods of heterogeneous 3D virtual globes are applied into the open 3D virtual globe integration and sharing platform GeoGlobe, so that spatial data can be integrated in different virtual globe platforms such as GeoGlobe, Google Earth, and World Wind. Take data integration of GeoGlobe and Google Earth for example. After real-time data processing with online heterogeneous virtual globe integration methods, we can transform the Google Earth data into tiles and load them in GeoGlobe. Figure 4 shows the rendering of 0.6 m resolution satellite remote sensing image in Shanghai area accessed from Google Earth, whereas Figure 5 shows the data integration of GeoGlobe and World Wind, where 90 m resolution SRTM terrain data accessed from World Wind is loaded in GeoGlobe.

3 Geographic information integration and sharing method of multi-level nodes service aggregation

3.1 Multi-level nodes service aggregation model

The multi-source, multi-scale, and multi-temporal geographic information is usually stored in geographic information systems at all levels. Due to the independence of the systems and the heterogeneity of the structures, each system has become an independent information island, and it is difficult to share services. Based on the system structure of the web geographic information integration and sharing service that the paper presents, in accordance with requirements of geographic information online integration and sharing service in national, provincial and municipal levels, on the foundation that spatial data organization at all levels of nodes follows a uniform spatial reference datum and the organizational mechanism of global virtual pyramid data model, we propose a multi-level nodes service aggregation model and realize the integration and sharing of multi-level, multi-scale geographic information.

From the viewpoint of the object-oriented method, the multi-level nodes aggregation model (M) is a collection of node objects at all levels. As eq. (1) shows, N_{ij} is an abstract representation of a service node object and it represents the Node j in Level i.

$$M=\{N_{11},\cdots\cdots,N_{1m},N_{21},\cdots\cdots,N_{2n},\cdots\cdots,N_{ij},\cdots\cdots\}, \quad (1)$$

where m, n, i, j are positive integers.

Each node object (N) contains four basic elements: identifier of the object (ID^s), spatial data (D^s), meta-information data (D^m), and a collection of methods (M^s). It is shown in eq. (2).

$$N=\{ID^s,D^s,D^m,M^s\}. \quad (2)$$

The node object (N) meets the definition of object. It consists of three parts, which are identifier of the object (ID), status (S) and the collection of methods (F).

Figure 4 Rendering for data integration of GeoGlobe and Google Earth.

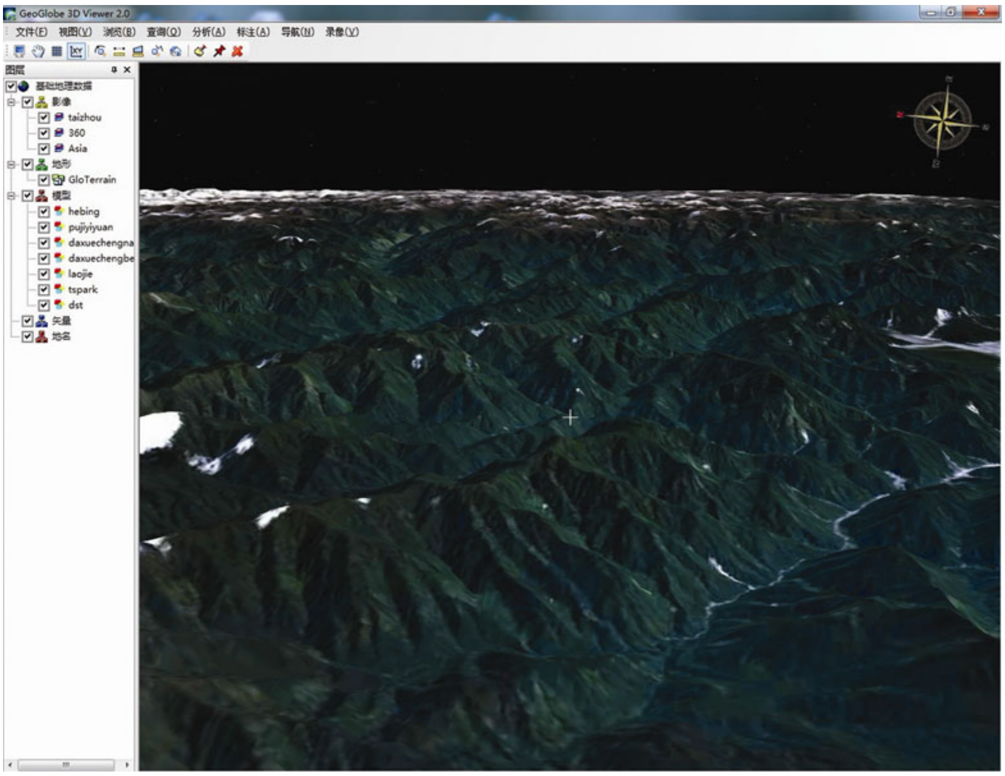

Figure 5 Rendering for data integration of GeoGlobe and World Wind.

$$ID(N) = ID^s,$$
$$S(N) = D^s \cup D^m,$$
$$F(N) = M^s.$$

ID^s, the unique identification of the object, is the service address. D^s, the spatial data of the object, includes multi-scale, multi-temporal spatial data such as vector, image, terrain, 3D model, place names and so on, and it also includes tile data in image, terrain and vector format. D^m, the meta-information data of the service node, includes unified descriptor meta-information such as the service address, geographic range, maximum resolution, the levels of map, data formats, and tile size of each data set in the node. M^s, the collection of methods provided by the node object, defines the collection of operation methods and the connection relationship among the objects and also between an object and the multi-level nodes service aggregation model. It is shown in eq. (3):

$$M^s = \{M_i^s, M_o^s\}. \quad (3)$$

M_i^s is the collection of methods among the node objects. It can be achieved through the operation on meta-information data (D^m) and spatial data (D^s) of node objects (N), such as getting the service address and levels of services of global multi-scale geographic data and spatial data of tiles in this node. M_o^s is the WMTS interface and API function for the multi-level nodes services aggregation model or external interface to call the node object (N). It can provide the meta-information data of this service node to the outside and return the spatial data of corresponding tiles according to the request parameter.

The node objects defined in eq. (1) have similar properties and methods but they also have certain differences. Their mutual relationship is described as follows: ① No intersection exists between sibling nodes ($N_{ij} \cap N_{ik} = \Phi$, i, j, k are positive integers and $j \neq k$). Sibling nodes are paratactic in the administrative level. Each of them has a clear geographic range. There are no relations of inclusion or being included between them. ② The geographic range of a service node is the union of the geographic range of its sub-service node ($N_{ij} = N_{(i+1)1} \cup N_{(i+1)2} \cdots N_{(i+1)k}$, i, j, k are positive integers).

Multi-level nodes service aggregation model (M) is a collection of every node object (N). Its definition needs to meet the following preconditions:

(1) The scales of the global geographic data stored on the service nodes at all levels are continuous. The tile spatial data organization follows the data organization structure of global virtual pyramid model. For example, The data of national nodes are in Level 0–i, then the data of provincial nodes are in Level i+1–j and the data of municipal nodes are in Level j+1–k (i, j, k are integers and $i < j < k$).

(2) Each service node follows WMS and WMTS Interface Specification and provides the interface API function for tile spatial data service.

3.2 Multi-level nodes service aggregation method

Based on the model mentioned above, the geographic information integration architecture of multi-level nodes service aggregation is shown in Figure 6. N_{11} is the national node while N_{2i} is the provincial node and N_{3k} is the municipal node. Besides, $i \geqslant 2$, $j \geqslant 2$, $k \geqslant 3$, $h \geqslant 4$ (i, j, k, h are positive integers).

This architecture diagram includes the national, provincial, and municipal nodes. Each node can include some child nodes (except the municipal nodes) but only one parent node (except the national node). Every node contains four parts, i.e., the spatial data, meta-information, API functions, and WMTS service interface. In this architecture, all nodes are linked through a multi-level nodes service aggregation model. Users obtain the required data from each node through this aggregation model. The geographic information integration process of service aggregation can be described as follows:

(1) Users send data requests to the multi-level nodes service aggregation model by API interface or WMTS service, according to the spatial range $R(L_1, B_1, L_2, B_2)$, resolution (r), temporal information (t) and other information of the geographic information that needs to be aggregated.

(2) Multi-level nodes service aggregation model (M) searches the meta-information (D^m) of each node (N) and then obtains several nodes which have intersection with the current geographic range (R). The result data can be indicated as eq. (4):

$$M_R = \{N_1, N_2, N_3\}. \quad (4)$$

M_R indicates the search method of multi-level nodes service aggregation model based on the geographic range. N_1 is national node. N_2 is provincial node. N_3 is municipal node. Each level node contains at least one object.

(3) Multi-level nodes service aggregation model (M) searches nodes which have the corresponding resolution with the result from (2) according to resolution (r). The result data can be shown as eq. (5):

$$M_r = \{N_{i1}, \cdots, N_{ij}\}. \quad (5)$$

In this equation, i=1, 2, 3 and $j \geqslant 1$. M_r is the search method of multi-level nodes aggregation model based on the resolution. N_{ij} is a node of a certain level. And so is the temporal information (t).

(4) Multi-level nodes service aggregation model (M) sends data requests to every node with the method shown in eq. (3). The node interior performs the operation such as request parsing and data acquisition through the method M_i^s and then sends the result data to M.

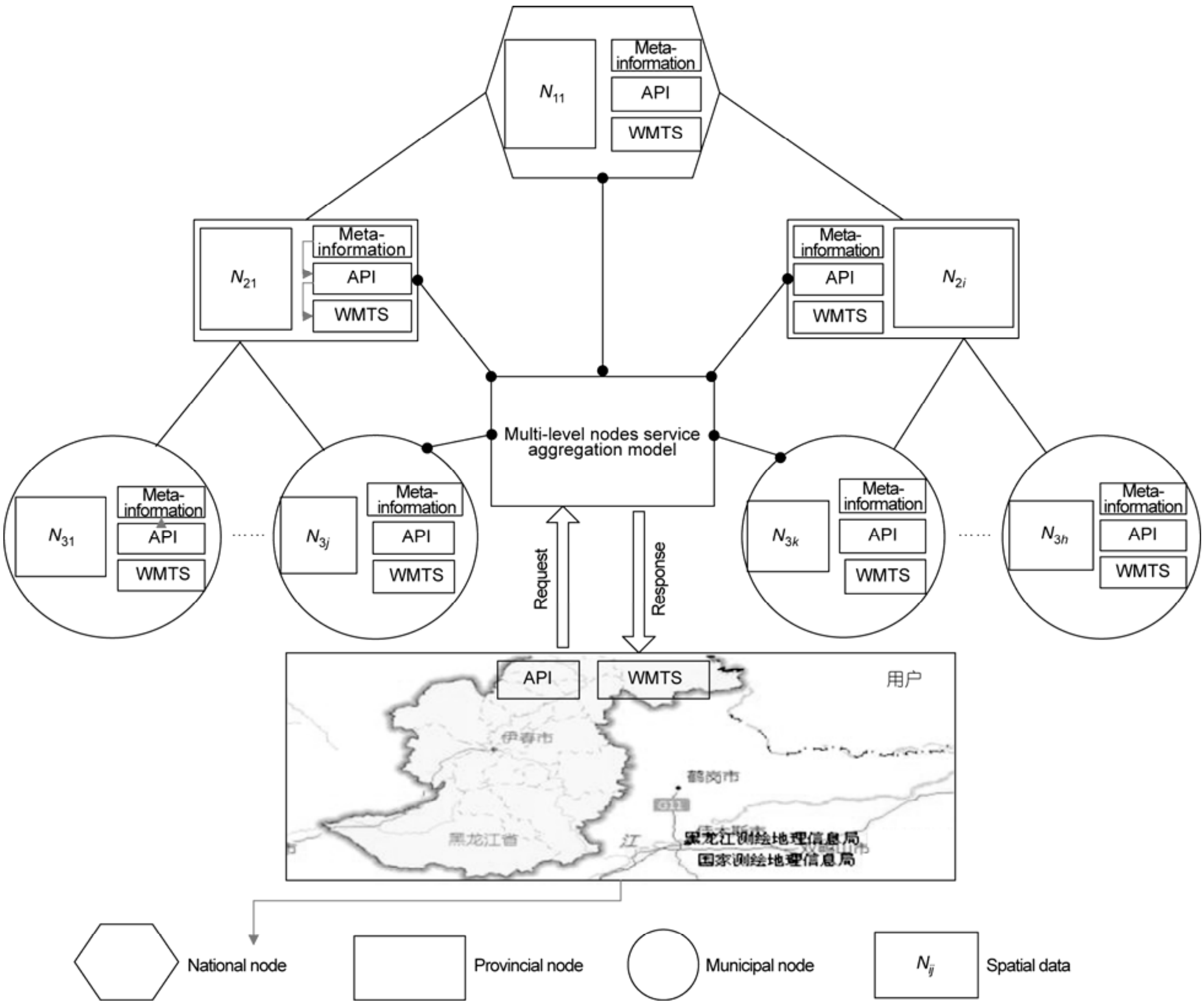

Figure 6 Geographic information integration architecture of multi-level nodes service aggregation.

(5) Multi-level nodes service aggregation model (*M*) aggregates the data returned by every node according to its geographic position by certain methods (M_p) and then return the aggregation result to users for display. The result can be shown as eq. (6):

$$\mathrm{Re} = M_p(N_{i1}, \cdots, N_{ij}). \quad (6)$$

(6) If partial areas within the display range of the screen have no current resolution data, use the data of higher level $(N_{(i+1)j})$ instead. So there is a need to aggregate the service of two level nodes. And multi-level nodes data are also needed to be aggregated during operations of zooming in and zooming out. Eq. (7) shows this process:

$$\mathrm{Re} = M_p(N_{i1}, \cdots, N_{ij}, N_{(i+1)j}). \quad (7)$$

3.3 Experiments and discussion

Experiments have been done for the multi-level nodes service aggregation method, based on the National Platform for Common GeoSpatial Information Services “TIANDITU”. Heilongjiang Provincial Platform for Common GeoSpatial Information Services “TIANDITU-Heilongjiang” and municipal node of Yichun City, Heilongjiang Province “TIANDITU-Yichun”. First, enter the portal of “TIANDITU-Yichun”. In the small scale range of Yichun City, there is only the geographic information service of Yichun municipal boundaries in provincial and municipal node service of Heilongjiang Province and Yichun City, which is used to indicate the geographic range of Yichun. The information aggregating national “TIANDITU” and Yichun municipal boundaries is shown in Figure S1 (www.springerlink.com/scp).

As the scale increases, the services of provincial nodes are needed to be aggregated in a certain scale condition. The following is a comparative experiment. Figure S2 (www.springerlink.com/scp) is a schematic diagram of Yichun in national “TIANDITU”. Figure S3 (www.springerlink.com/scp) is a schematic diagram of service aggregation of Heilongjiang provincial nodes and national node. Figure S3 retains the railway, water systems, and other surface features in national node. The other elements show the element information in the provincial node because the geographic information of the provincial node is more detailed than that of national node.

When the scale increases to a particular degree, there will be a need for service aggregation of municipal nodes. Figure S4 (www.springerlink.com/scp) is a schematic diagram of service aggregation of Heilongjiang provincial nodes and Yichun municipal nodes on the basis of Figure S3. It is clear that scale and content of geographic feature information in Figure S4 are much richer than those in Figure S3.

What can be seen from the experiments and the diagrams above is that multi-level nodes aggregation model can aggregate geographic information of multi-level nodes such as national node, provincial node, and municipal node automatically according to the geographic range and the scale of visualization to meet the user's requirements of multi-scale geographic information services. Compared with the existing models and methods of geographic information services, this model focuses on integration and sharing of web geographic information. In accordance with user's requests, it can search and discover geographic information of specific nodes and scale which meets the conditions and aggregation is carried out under the rules of global unified data organization. Meanwhile, each node has the ability to provide data sharing services to the external.

In the experiments, some geographic features such as water systems and railways span a large range and have different means of expression in different scales in the multi-level nodes service aggregation. The solution is the unified treatment in the service-oriented framework databases of national, provincial, and municipal levels. National databases manage and serve interprovincial geographic features and provincial databases manage and serve intercity geographic features. This can ensure the consistency of expression of the geographic features which cross multi-level nodes when conducting aggregation of multi-level geographic information services.

4 The application of geo-spatial information integration and sharing service-"TIANDITU"

We apply the above distributed system architecture, multi-level node service aggregation, and the integration method of heterogeneous virtual globes to the open virtual globe integration and sharing platform GeoGlobe. And National Platform for Common GeoSpatial Information Services (Public edition) "TIANDITU" is built on the basis of GeoGlobe.

"TIANDITU" is an important part of the construction of the "Digital China". The beta version began test run on October 21, 2010. There are nearly 19 million people from 210 countries and regions visited it just over one month. The public can easily browse multi-scale geographic information data of both two-dimensional and three-dimensional, locate by searching the place names, measure the distance and area, mark points of interest, and print the screenshot through the web portal. Figure S5 (www.springerlink.com/scp) shows it.

Now, the national master node mainly manages the 1:100 000 vector data and satellite imagery with the resolution of 500 m with global coverage, 1:250000 map data in public version covering the whole country, navigation electronic map data, satellite imagery with the resolution of 15 m and 2.5 m, satellite imagery with the resolution of 0.6 m which covers more than 300 prefecture-level cities of the country and other geographic information data. The provincial nodes are mainly responsible for the management and updating service of the multi-scale spatial data within provincial level. The municipal nodes are mainly responsible for the management and updating service of the multi-scale spatial data within municipal level. And it can form a multi-level management model through the network.

On this basis, the national node of "TIANDITU" defined a standard of service-oriented framework databases and a triangulation principle based on the latitude and longitude grid. It uses the data service organization mode in multi-scale pyramid structure with the resolution from low to high on a global scale. By this means, it converts the basic spatial data managed by national, provincial and municipal nodes into service-oriented framework data and provides two-dimensional or three-dimensional online web geographic information services in accordance of the framework databases by rasterizing vector data, data extraction and resampling, with the principle in which the resolution is close to a certain level in the multi-level resolution, as shown in Figure S6 (www.springerlink.com/scp).

In terms of the service mode, it can connect the national, provincial, and municipal geographic information service agencies to provide different levels of online geographic information services in the longitudinal direction and connect geographic information systems of different departments in the same level to provide online geographic information services about different themes or different areas in the transverse direction through the web portals at all levels of the "TIANDITU". It can make distributed geographic information service nodes a whole with cooperation in order to achieve distributed storage management, vertical and horizontal system linkage and online services.

In addition, commercial websites, government departments at all levels and other relevant departments can share the geographic information service resources of "TIANDITU", develop value-added service functions or integrate, manage and publish their own information through the web geographic information sharing service interface WFS, WCS, WMS, WMTS and map tiles service interface of "TIANDITU". This can save the cost of collecting, updating and maintaining geographic information and avoid duplicate construction of the thematic geographic information systems. For example, Network Center of the State Seismological Bureau can use the data sharing service interfaces provided by "TIANDITU" to schedule multi-scale geographic information online, integrate earthquake information with geographic information, and provide online topics service about earthquake information. This is shown in Figure S7 (www.springerlink.com/scp).

5 Conclusions and outlook

This paper first analyzed the related researches, application background, and technical difficulties of the three-dimensional virtual globe and web geographic information services. And then in order to be geared to the needs of heterogeneous virtual globes collaboration services and the requirements of multi-level, multi-node integrated geographic information services, it designed a system architecture for web geographic information integration and sharing service platform and proposed a data integration method of heterogeneous virtual globes and a multi-level nodes service aggregation model. Finally, it applied the above method to National Platform for Common GeoSpatial Information Services "TIANDITU" and realized the two-dimensional and three-dimensional integration of geographic information integration services. The application shows that the method this paper proposed can meet the requirement of the linkage services mode of distributed storage management, vertical and horizontal system linkage and online services. With the development and application of the technology of Internet of things, the integration of geographic information common service platform based on virtual globe, platform for cloud computing and the technology of Internet of things will surely promote the development of "Digital Earth" to "Smart Planet".

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