

DISTRIBUTED SYSTEM-BASED CONCURRENT CONSTRUCTION METHOD FOR MASSIVE DEM PYRAMID TILES

5 **Technical Field**

The present invention relates to the technical field of parallel processing for geospatial data, and in particular to a distributed system-based concurrent construction method for massive DEM pyramid tiles.

10 **Background**

At present, with the increasing demand for DEM (digital elevation model), the volume of high-accuracy and high-resolution DEM data is increasing at geometric level, and the theory and method of DEM pyramid slicing are also becoming mature. However, how to efficiently segment the massive DEM data into tiles is a key problem that needs to be solved urgently in
15 the wide application of DEM. With the rapid development and maturity of parallel computation and distributed computing platforms, it provides efficient computing power for parallel computation of massive DEM pyramid tiles. Combining parallel computation with mature DEM sampling algorithm and quadtree based segmentation algorithm to realize the concurrent construction method for DEM pyramid tiles can improve the efficiency of DEM data
20 calculation.

In recent years, scholars at home and abroad have begun to focus on the distributed computation and analysis of massive spatial data. In the construction of DEM pyramids, they generally focus on the thread parallel strategy, mainly combining with high-performance computers to build massive DEM pyramid tiles with multi threads. This method can give full play to the
25 performance of the machine. However, if the volume of DEM data is high, the general computer memory cannot bear it, and the effect of computation cannot be achieved. There are also some

patents on DEM analysis and computation. Chinese patent document 089098709949.5 discloses a parallel digital terrain analysis-oriented massive DEM deploying and scheduling method, which solves the efficiency of terrain analysis of massive DEM, and this patent does not involve the content of DEM pyramid tiles. Chinese patent document CN201710107308.X discloses a DEM-based inland lake catchment area demarcation method, which comprises the steps that DEM data of a digital elevation model in a set region is acquired, and the DEM data are cut to obtain basic DEM data; a ridge line in the set region is established according to the basic DEM data; segmentation computation of spatial grid data is performed on spatial units. This patent does not involve the parallel or DEM pyramid algorithms. Chinese patent document 201410687961.4 discloses a structured multi-scale reconstruction method suitable for regular grid DEM, which likewise does not involve the pyramid establishment and parallel methods. Chinese patent document 201410788404.1 discloses a self-adaption image pyramid slicing method for relational database extension, in which a self-adaption image slicing model is provided, and the image tile size is selected in a self-adaption manner according to the self-adaption image slicing model. Image slicing involves the null value of the imaging element, and does not involve the method of DEM tile splicing. In terms of software, commercial GIS software mainly has the function of DEM pyramid slicing. These methods mainly use different sampling algorithms to segment DEM, without realize distributed DEM pyramid tiles.

Therefore, it is necessary to develop a distributed system-based concurrent construction method for massive DEM pyramid tiles, which can parallelize and segment the pyramid tiles of large-scale or massive DEM, and can carry out distributed computation in the high-performance computer cluster environment, reduce the time of pyramid construction and improve the computation efficiency. Meanwhile, the value of DEM tile edge can be calculated by combining the method of near average value to solve the smooth transition between adjacent tiles.

Summary

The technical problem to be solved by the present invention is to provide a distributed system-based concurrent construction method for massive DEM pyramid tiles, which can parallelize and segment the pyramid tiles of large-scale or massive DEM, and can carry out distributed
5 computation in the high-performance computer cluster environment, reduce the time of pyramid construction and improve the computation efficiency. Meanwhile, the value of DEM tile edge can be calculated by combining the method of near average value to solve the smooth transition between adjacent tiles

To solve the above technical problem, the technical solution of the present invention is: a
10 distributed system-based concurrent construction method for massive DEM pyramid tiles, specifically comprising the following steps:

S1, acquiring metadata of a source DEM;

S2, establishing a local coordinate system of the source DEM, segmenting the source DEM into
several tiles that may be concurrently calculated (the segmenting is to cut a DEM into many
15 small pieces of the same size); calculating an index value of each of the tiles as key according to parameters of the source DEM, forming a linked list <Key, Tile> that stores the metadata of the source DEM with the key value pair <Key, Tile> as the calculation unit, and distributing the <Key, Tile> to different computing nodes according to the index value key for calculation;
S3, setting or calculating the maximum level MaxZoom according to whether to define the
20 maximum level MaxZoom, and setting required parameters of the output tiles; and then calculating the parameters of the output tile according to the set coordinate system and the segmentation rule, wherein the parameters of the output tile include the length, width, resolution, etc. of the tile;

S4, performing concurrent construction on a distributed key value pair <Key, Tile> by a
25 computing node, and merging the elevation value at the same computing node according to the index value key; calculating the bounding rectangle Extend of the corresponding tile according to the length, width and resolution of the output tile based on the index value key, calculating

the coordinates of each grid cell in the input tile, and then calculating the coordinates of each grid cell in the output coordinate system according to the set output coordinate system; calculating the index value key of the output tile where the corresponding grid cell is located according to the coordinates of each grid cell, and adding it to a map to form a map

5 <key,List<cell>>, where key represents the index value of the tile, List represents the linked list, and cell represents the grid cell;

S5, merging linked lists <cell> of the same index value key on the computing node; merging linked lists <cell> at all computing nodes according to the index value key, to form a key value pair <key, List<cell>>;

10 S6, calculating the coordinates of the grid cell of the output tile according to the parameters and coordinate system of the output tile, and then calculating the elevation value of the grid cell from the merged key value pair <key, List<cell>> according to the sampling method;

S7, correcting the edge elevation value of the output tile by using an eight neighborhood algorithm; circularly obtaining four side grid cells of each tile and eight tiles adjacent thereto

15 according to the generated linked list <Key, Tile>, and taking the average elevation value of the grid cells of the adjacent tiles as the elevation value of the corresponding grid cell to achieve the smooth splicing of the tiles;

S8, determining whether the current level Zoom meets the termination conditions, and if the termination conditions are met, the process ends; if the termination conditions are not met, the

20 width and height of the bounding rectangle Extend of the next level and the tile of the next level are calculated according to the previous level. The calculation method is: $NZ = CZ - 1$, $W = EW/2(NZ+1)$, $H = EH/2(NZ+1)$, where NZ represents the next level, CZ represents the current level, EW and EH represent the width and height of the original DEM, and W and H represent the width and height of the tile;

25 S9, according to the tile of the previous level and the sampling algorithm, generating the tile of the next level and the index value key by parallel computation; calculating the index value key of the next level corresponding to the current level tile according to the index value key, the

next level and the parameters of the tile, sampling the elevation value of the tile of the next level from the current level tile by using the sampling algorithm to form the sub-tile and index value key of the tile of the next level, and merging the same index value key on each node to form a key value pair <key,List<tile>>; then, according to the index value key, merging the tiles of the same index value key on all nodes to form the tile of the next level, and then performing step S7; and

S10, circularly executing steps S8~S9, until the level Zoom is determined to meet the termination conditions which are: if the minimum level MinZoom is set, determining whether the current level Zoom reaches the set minimum level MinZoom, if yes, terminating, and if the minimum level MinZoom is not set and the current level zoom is less than 0, terminating.

Where tile represents the tile, key represents the index value of the tile, Value represents the elevation value, List represents the linked list, cell represents the grid cell, Zoom represents the level, Map represents the map, and Extend represents the bounding rectangle of the source DEM; the above technical solution is adopted to obtain the metadata of the source DEM to be segmented as the basis for data segmentation and projection transformation; a coordinate system is established in which the upper left corner of the source DEM is the origin and the lower right direction is the positive direction; the source DEM map sheet is segmented according to the width and height of the default tile; the index value key is formed according to the row and column numbers of the preliminarily segmented tiles, and a key value pair is constructed with the index value key as the key and the tile as the value; the key value pairs are distributed in different computing nodes for the following computations: according to the set MaxZoom or the calculated MaxZoom, as well as the set width and height of the output tile, the coordinate system and the sampling algorithm, each computing node performs segmentation computation on the allocated input tile, and outputs the index value key and a linked list containing the grid cell; then merging the grid cells of the same index value on each computing node; finally merging cells of the same index value key on different computing nodes to output a plurality of key/Value pairs; calculating the eight adjacent index values key according to the

index value, obtaining the edge elevation values of the adjacent tiles and the current tile, and taking the average value of the corresponding edge values as the edge value of the current tile, so as to achieve the smoothness when the tiles are spliced; then circularly calculating the level Zoom of the next level, width and height of the tile, and calculating the linked list <Key, Tile> of the next level with the output linked list <Key, Tile> of the previous level as the input; the circular termination condition is that the current level Zoom is less than the set MinZoom or 0; and the sampling method is to use the sampling algorithm for sampling. The sampling algorithm can be the nearest pixel method, bilinear interpolation method, cubic convolution method, etc., which are all prior arts.

As the preferred technical solution of the present invention, the metadata in step S1 comprise original resolution, coordinate system, and bounding rectangle extent data of a source DEM under the original coordinate system. The purpose of acquiring the metadata of the source DEM is to meet the needs of subsequent calculations. These calculations include preliminary segmentation of the source data to facilitate the parallelization of subsequent calculations.

As the preferred technical solution of the present invention, step S2 of establishing a local coordinate system of the source DEM specifically comprises: establishing a coordinate system with the upper left corner of the source DEM as the origin and the lower right direction as the positive direction; according to the width and height of the set tile, the source DEM data is segmented into a plurality of tiles; in order to preliminarily segment the source DEM to form the linked list <Key, Tile>, the calculation method of the index value key is given below:

$$\text{Key} = C + \text{"_"} + R, C = (x - XMin) / TW, R = (y - YMin) / TH$$

where, C, R represent the row and column numbers of the tile, x and y represent the coordinates of the tile at any point of the tile, XMin represents the minimum X of the bounding rectangle extent of the source DEM, YMin represents the minimum Y of the bounding rectangle extent of the source DEM, TH is the height of the initial tile, and TW is the width of the initial tile.

As the preferred technical solution of the present invention, in step S3, if the level MaxZoom is not set, it is necessary to calculate the level MaxZoom according to the coordinates of the

lower left point and the upper right point of the bounding rectangle Extend of the source DEM through projection transformation on the coordinates of the lower left point and the upper right point, with the coordinate of the lower left point of (SLon,SLat) and the coordinate of the upper right point of (ELon, ELat); and then the level MaxZoom is calculated according to the formula

5 given below:

$$\begin{aligned}
 dLat &= ((ELat - SLat) / 180.0) \bullet \pi \\
 dLon &= ((ELon - SLon) / 180.0) \bullet \pi \\
 lat1 &= (SLat / 180.0) \bullet \pi \\
 lat2 &= (ELat / 180.0) \bullet \pi \\
 a &= (\sin(dLat / 2) \bullet \sin(dLat / 2)) + (\sin(dLon / 2) \bullet \sin(dLon / 2) \bullet \cos lat1 \bullet \cos lat2) \\
 dist &= R \bullet 2 \bullet \arctan\left(\sqrt[2]{a} / \sqrt[2]{1-a}\right) \\
 MaxZoom &= (\log(2\pi R / dist - tileSize) / \log(2))
 \end{aligned}$$

where, MaxZoom is the maximum level, dLat represents the latitude difference, dLon represents the longitude difference, lat1 represents the radian of SLat, lat2 represents the radian of ELat, a represents the calculated median, dist represents the distance between two points, tileSize represents the maximum side length set by tile, and R represents the semi-major axis of WGS84 ellipsoid, $R = 637817$. To calculate the extend of the output tile, it is necessary to be appropriately expanded to avoid such problems as cracks in the output tile splicing.

As the preferred technical solution of the present invention, for the grid cell=<x,y,Value> in step S4, where x,y is the coordinate of the tile, and Value is the elevation value.

15 As the preferred technical solution of the present invention, in step S4, the tile is input by parallel computation, and the DEM value of the input tile is divided into different output tiles according to the parameter of the output tile; first the bounding rectangle Extend of tile is calculated according to the index value key of the input tile, and the calculation formula is given below:

$$\begin{aligned}
 MinX &= ExMinX + col \bullet W \\
 MinY &= ExMinY + row \bullet H \\
 MaxX &= ExMinX + (col + 1) \bullet W \\
 MaxY &= ExMinY + (row + 1) \bullet H
 \end{aligned}$$

where, MinX, MinY, MaxX, MaxY represent the minimum and maximum XT coordinates of the bounding rectangle Extend, col, row are the row and column number of the input tile, ExMinX, ExMinY represent the minimum X, Y coordinates of the bounding rectangle Extend of the source DEM, H represents the height of the tile, and W represents the width of the tile.

5 As the preferred technical solution of the present invention, in step S7 of correcting the elevation value of the edge of the tile by using an eight neighborhood algorithm, the adjacent tiles are calculated in parallel for the output linked list <Key, Tile>, the cell values of the adjacent grid cells around except for the intersection points are taken, and the values of the top, bottom or left and right cells are taken, and the average value of the obtained cell values is taken
10 as the elevation value of the specified grid cell; the elevation values of the four corners are calculated by taking the values of the other three tiles adjacent to the tile and the corresponding corners, and taking the average value as the elevation value of the corresponding grid cell.

Compared with the prior art, the present invention has the following beneficial effects: the distributed system-based concurrent construction method for massive DEM pyramid tiles has
15 following advantages: the parallelization of building DEM pyramid tiles for large-scale DEM data is realized by using the high-performance computing cluster, which can reduce the time of building DEM pyramid and improve the computing efficiency; and the edge elevation value of the tile is smoothed by 8 neighborhoods to avoid the smoothing of DEM visualization, analysis and computation.

Brief Description of the Drawings

Fig. 1 is a work flow diagram of a distributed system-based concurrent construction method for massive DEM pyramid tiles according to the present invention;

Fig. 2 is a schematic diagram of a local coordinate system segmenting DEM by using a
25 distributed system-based concurrent construction method for massive DEM pyramid tiles according to the present invention;

Fig. 3 is a computing diagram of a single computing node by using a distributed system-based concurrent construction method for massive DEM pyramid tiles according to the present invention;

Fig. 4 is a schematic diagram of merging a plurality of computing nodes by using a distributed system-based concurrent construction method for massive DEM pyramid tiles according to the present invention;

Fig. 5 is a schematic diagram of edge smoothing by using a distributed system-based concurrent construction method for massive DEM pyramid tiles according to the present invention; and

Fig. 6 is a visualization diagram of a distributed system-based concurrent construction method for massive DEM pyramid tiles according to the present invention.

Where: Fig. (a) is a 17-level diagram; Fig. (b) is a 17, 16-level embedded display diagram; Fig. (c) is a 17-level Wireframe diagram; Fig. (d) is 17, 16-level embedded Wireframe diagram.

Detailed Description

The technical solutions in the embodiments of the present invention will be clearly and completely described below in conjunction with the drawings in the embodiments of the present invention.

Embodiment: as shown in Figs. 1~6, the distributed system-based concurrent construction method for massive DEM pyramid tiles comprises the following specific steps:

Where tile represents the tile, key represents the index value of the tile, Value represents the elevation value, List represents the linked list, cell represents the grid cell, zoom represents the level, Map represents the map, the Extend represents the bounding rectangle of the source DEM, <Key, Tile> represents the key value pair;

S1, using the source DEM data with a resolution of 30m and a part of high-accuracy source DEM data in tif format, with the set coordinate system being WGS84; developing pyramid tile programs based on Flink distributed platform; and

obtaining the metadata of the national 30m source DEM, including the original resolution, coordinate system WGS84 and Extend.

S2, establishing a local coordinate system for the input source DEM data, setting the height and width of the initial divided tile to 126 (grid), using the sliding window method to segment the source data, then calculating the key according to the row and column numbers of tile in the local coordinate system, building a series of <Key, Tile> key value pairs, and distributing the key value pair data to different computing nodes for calculation according to Flink's algorithm; and establishing a coordinate system with the upper left corner of the source DEM as the origin and the lower right as the positive direction; where the calculation method of the index value key is given below:

$$\text{Key} = C + \text{"_"} + R, C = (x - XMin) / TW, R = (y - YMin) / TH$$

where, C, R represent the row and column numbers of the tile, x and y represent the coordinates of the tile at any point of the tile, XMin represents the minimum X of the bounding rectangle extent of the source DEM, YMin represents the minimum Y of the bounding rectangle extent of the source DEM, TH is the height of the initial tile, and TW is the width of the initial tile.

S3, setting or calculating the maximum level MaxZoom according to whether to define the maximum level MaxZoom, and calculating the parameters of the output tile according to the set coordinate system and segmentation rule; the parameters of the output tile include the length, width, resolution of the tile; if the maximum level MaxZoom is not set, it is necessary to calculate the maximum level MaxZoom according to the coordinates of the lower left point and the upper right point of the bounding rectangle Extend of the source DEM through projection transformation on the coordinates of the lower left point and the upper right point, with the coordinate of the lower left point of (SLon,SLat) and the coordinate of the upper right point of (ELon, ELat); and then the maximum level MaxZoom is calculated according to the formula given below:

$$\begin{aligned}
dLat &= ((ELat - SLat) / 180.0) \cdot \pi \\
dLon &= ((ELon - SLon) / 180.0) \cdot \pi \\
lat1 &= (SLat / 180.0) \cdot \pi \\
lat2 &= (ELat / 180.0) \cdot \pi \\
a &= (\sin(dLat / 2) \cdot \sin(dLat / 2)) + (\sin(dLon / 2) \cdot \sin(dLon / 2) \cdot \cos lat1 \cdot \cos lat2) \\
dist &= R \cdot 2 \cdot \arctan\left(\sqrt[2]{a} / \sqrt[2]{1-a}\right) \\
MaxZoom &= (\log(2\pi R / dist - tileSize) / \log(2))
\end{aligned}$$

where, MaxZoom is the maximum level, dLat represents the latitude difference, dLon represents the longitude difference, lat1 represents the radian of SLat, lat2 represents the radian of ELat, a represents the calculated median, dist represents the distance between two points, tileSize represents the maximum side length set by tile, and R represents the semi-major axis of WGS84 ellipsoid, $R = 637817$.

To calculate the extend of the output tile, it is necessary to be appropriately expanded to avoid such problems as cracks in the output tile splicing. In step S3, the parameters of the output tile are set as: 65 for the width and height (grid), WGS84 coordinate system, naming of the index value key according to TMS standard.

S4, performing concurrent construction on a distributed key value pair <Key, Tile> by a computing node, and merging the elevation value at the same computing node according to the index value key; calculating the bounding rectangle Extend of the corresponding tile according to the length, width and resolution of the output tile based on the index value key, calculating the coordinates of each grid cell in the input tile, and calculating the preliminarily segmented tiles, respectively; first calculating the Extend of tile according to the index value key; calculating the coordinates of each grid cell in the input tile, where cell=<x,y,Value>, where x,y is the coordinate in the tile, and Value is the coordinate of the elevation value; calculating the coordinates of the cell in the output coordinate system according to the set output coordinate system WGS84, calculating the index value key of the output tile where the cell is located according to the calculation result, and adding it to the Map to form a Map <key,list < cell>>; and merging linked lists <cell> of the same index value key on the computing node, with the

principle as shown in Fig. 3. In step S4, the tile is input by parallel computation, and the DEM value of the input tile is divided into different output tiles according to the parameter of the output tile; and first the bounding rectangle Extend of tile is calculated according to the index value key of the input tile, and the calculation formula is given below:

$$\begin{aligned} MinX &= ExMinX + col \bullet W \\ MinY &= ExMinY + row \bullet H \\ MaxX &= ExMinX + (col + 1) \bullet W \\ MaxY &= ExMinY + (row + 1) \bullet H \end{aligned}$$

where, MinX, MinY, MaxX, MaxY represent the minimum and maximum XT coordinates of the bounding rectangle Extend, col, row are the row and column number of the input tile, ExMinX, ExMinY represent the minimum X, Y coordinates of the bounding rectangle Extend of the source DEM, H represents the height of the tile, and W represents the width of the tile.

S5, merging linked lists <cell> on all the computing nodes according to the index value key. Since the input tiles are distributed on different computing nodes, and the output tiles may contain different input tiles, that is, the data of the output tiles may be in different computing nodes, and it is necessary to pull these data to the same node for merging, that is, Flink's Reduce operation, with the principle as shown in Fig. 4.

S6, calculating the coordinates of the grid cell of the output tile according to the parameters and coordinate system of the output tile, using the set sampling method to calculate the elevation value of cell from the merged <key,List<cell>>, with the nearest sampling algorithm used in the present embodiment.

S7, correcting the elevation value of the edge of the tile by using an eight neighborhood algorithm; circularly obtaining four side grid cells of each tile and eight tiles adjacent thereto according to the generated linked list <Key, Tile>, and taking the average elevation value of the grid cells of the adjacent tiles as the elevation value of the corresponding grid cell to achieve the smooth splicing of the tiles; and according to the output key value pair <Key, Tile>, calculating the eight tiles adjacent to each tile according to the TMS naming rules of the index

value key, taking the cell values of the adjacent tiles, and taking the average value as the

corresponding cell value to achieve the smoothness of tile splicing, with the principle as shown in Fig. 5.

S8, determining whether the current level Zoom meets the termination conditions, and if the termination conditions are met, the process ends; and if the termination conditions are not met, the width and height of the bounding rectangle Extend of the next level and the tile of the next level are calculated according to the previous level. The calculation method is: $NZ = CZ - 1$, $W = EW/2(NZ+1)$, $H = EH/2(NZ+1)$, where NZ represents the next level, CZ represents the current level, EW and EH represent the width and height of the original DEM, and W and H represent the width and height of the tile.

S9, according to the tile of the previous level and the sampling algorithm, generating the tile of the next level and the index value key by parallel computation; calculating the index value key of the next level corresponding to the current level tile according to the index value key, the next level and the parameters of the tile, sampling the elevation value of the tile of the next level from the current level tile by using the sampling algorithm to form the sub-tile and index value key of the tile of the next level, and merging the same index value key on each node to form a key value pair $\langle \text{key}, \text{List} \langle \text{tile} \rangle \rangle$; and then, according to the index value key, merging the tiles of the same index value key on all nodes to form the tile of the next level, and then performing step S7, with the nearest sampling algorithm used in the present embodiment.

S10, circularly executing steps S8~S9, calculating the List $\langle \text{Key}, \text{Tile} \rangle$ of the next level until the current level Zoom is determined to meet the termination conditions which are: if the minimum level MinZoom is set, determining whether the current level Zoom reaches the set minimum level MinZoom, if yes, terminating; and if the minimum level MinZoom is not set and the current level Zoom is less than 0, terminating.

The foregoing are only better embodiments of the present invention and are not intended to limit the present invention. Any modification, equivalent replacement, improvement, etc. made within the spirit and principles of the present invention shall be covered within the scope of protection for the present invention.

Claims

1. A distributed system-based concurrent construction method for massive DEM pyramid tiles, comprising the following specific steps:

5 S1, acquiring metadata of a source DEM;

S2, establishing a local coordinate system of the source DEM, segmenting the source DEM into several tiles that may be concurrently calculated; calculating an index value of each of the tiles as key according to parameters of the source DEM, forming a linked list <Key, Tile> that stores the metadata of the source DEM with the key value pair <Key, Tile> as the calculation unit,
10 and distributing the <Key, Tile> to different computing nodes according to the index value key for calculation;

S3, setting or calculating the maximum level MaxZoom according to whether to define the maximum level MaxZoom, and setting required parameters of the output tiles; calculating the parameters to output tiles according to the set coordinate system and segmentation rule;

15 S4, performing concurrent construction on a distributed key value pair <Key, Tile> by a computing node, and merging the elevation value at the same computing node according to the index value key; calculating the bounding rectangle Extend of the corresponding tile according to the length, width and resolution of the output tile based on the index value key, calculating the coordinates of each grid cell in the input tile, and then calculating the coordinates of each
20 grid cell in the output coordinate system according to the set output coordinate system; calculating the index value key of the output tile where the corresponding grid cell is located according to the coordinates of each grid cell, and adding it to a map to form a map <key,List<cell>>;

S5, merging linked lists <cell> of the same index value key on the computing node; merging
25 linked lists <cell> at all computing nodes according to the index value key, to form a key value pair <key, List<cell>>;

S6, calculating the coordinates of the grid cell of the output tile according to the parameters and coordinate system of the output tile, and then calculating the elevation value of the grid cell from the merged key value pair <key, List<cell>> according to the sampling method;

S7, correcting the edge elevation value of the output tile by using an eight neighborhood algorithm; circularly obtaining four side grid cells of each tile and eight tiles adjacent thereto according to the generated linked list <Key, Tile>, and taking the average elevation value of the grid cells of the adjacent tiles as the elevation value of the corresponding grid cell to achieve the smooth splicing of the tiles;

S8, determining whether the current level Zoom meets the termination conditions, and if the termination conditions are met, the process ends; if the termination conditions are not met, the width and height of the bounding rectangle Extend of the next level and the tile of the next level are calculated according to the previous level. The calculation method is: $NZ = CZ - 1$, $W = EW/2^{(NZ+1)}$, $H = EH/2^{(NZ+1)}$, where NZ represents the next level, CZ represents the current level, EW and EH represent the width and height of the original DEM, and W and H represent the width and height of the tile;

S9, according to the tile of the previous level and the sampling algorithm, generating the tile of the next level and the index value key by parallel computation; calculating the index value key of the next level corresponding to the current level tile according to the index value key, the next level and the parameters of the tile, sampling the elevation value of the tile of the next level from the current level tile by using the sampling algorithm to form the sub-tile and index value key of the tile of the next level, and merging the same index value key on each node to form a key value pair <key, List<tile>>; then, according to the index value key, merging the tiles of the same index value key on all nodes to form the tile of the next level, and then performing step S7; and

S10, circularly executing steps S8~S9, until the level Zoom is determined to meet the termination conditions which are: if the level MinZoom is set, determining whether the current

level Zoom reaches the set level MinZoom, if yes, terminating, and if the level MinZoom is not set, and the current level zoom is less than 0, terminating.

2. The distributed system-based concurrent construction method for massive DEM pyramid tiles according to claim 1, wherein the metadata in step S1 comprise original resolution, coordinate system, and bounding rectangle extent data of DEM under the original coordinate system.

3. The distributed system-based concurrent construction method for massive DEM pyramid tiles according to claim 1, wherein step S2 of establishing a local coordinate system of the source DEM specifically comprises: establishing a coordinate system with the upper left corner of the source DEM as the origin and the lower right direction as the positive direction; according to the width and height of the set tile, the source DEM data is segmented into a plurality of tiles; in order to preliminarily segment the source DEM to form the linked list <Key, Tile>, the calculation method of the index value key is given below:

$$\text{Key} = C + \text{"_"} + R, C = (x - XMin) / TW, R = (y - YMin) / TH$$

where, C, R represent the row and column numbers of the tile, x and y represent the coordinates of the tile at any point of the tile, XMin represents the minimum X of the bounding rectangle extent of the source DEM, YMin represents the minimum Y of the bounding rectangle extent of the source DEM, TH is the height of the initial tile, and TW is the width of the initial tile.

4. The distributed system-based concurrent construction method for massive DEM pyramid tiles according to claim 3, wherein in step S3, if the level MaxZoom is not set, it is necessary to calculate the level MaxZoom according to the coordinates of the lower left point and the upper right point of the bounding rectangle Extend of the source DEM through projection transformation on the coordinates of the lower left point and the upper right point, with the

coordinate of the lower left point of (SLon,SLat) and the coordinate of the upper right point of (ELon, ELat); and then the level MaxZoom is calculated according to the formula given below:

$$\begin{aligned}
dLat &= ((ELat - SLat) / 180.0) \bullet \pi \\
dLon &= ((ELon - SLon) / 180.0) \bullet \pi \\
lat1 &= (SLat / 180.0) \bullet \pi \\
lat2 &= (ELat / 180.0) \bullet \pi \\
a &= (\sin(dLat / 2) \bullet \sin(dLat / 2)) + (\sin(dLon / 2) \bullet \sin(dLon / 2) \bullet \cos lat1 \bullet \cos lat2) \\
dist &= R \bullet 2 \bullet \arctan\left(\frac{\sqrt[2]{a}}{\sqrt[2]{1-a}}\right) \\
MaxZoom &= (\log(2\pi R / dist - tileSize) / \log(2))
\end{aligned}$$

where, MaxZoom is the maximum level, dLat represents the latitude difference, dLon represents the longitude difference, lat1 represents the radian of SLat, lat2 represents the radian of ELat, a represents the calculated median, dist represents the distance between two points, tileSize represents the maximum side length set by tile, and R represents the semi-major axis of WGS84 ellipsoid, $R = 637817$.

5. The distributed system-based concurrent construction method for massive DEM pyramid tiles according to claim 3, wherein for the grid cell= $\langle x,y,Value \rangle$ in step S4, where x,y is the coordinate of the tile, and Value is the elevation value.

6. The distributed system-based concurrent construction method for massive DEM pyramid tiles according to claim 5, wherein in step S4, the tile is input by parallel computation, and the DEM value of the input tile is divided into different output tiles according to the parameter of the output tile; first the bounding rectangle Extend of tile is calculated according to the index value key of the input tile, and the calculation formula is given below:

$$\begin{aligned}
MinX &= ExMinX + col \bullet W \\
MinY &= ExMinY + row \bullet H \\
MaxX &= ExMinX + (col + 1) \bullet W \\
MaxY &= ExMinY + (row + 1) \bullet H
\end{aligned}$$

where, MinX, MinY, MaxX, MaxY represent the minimum and maximum XT coordinates of the bounding rectangle Extend, col, row are the row and column number of the input tile, ExMinX, ExMinY represent the minimum X, Y coordinates of the bounding rectangle Extend of the source DEM, H represents the height of the tile, and W represents the width of the tile.

5

7. The distributed system-based concurrent construction method for massive DEM pyramid tiles according to claim 5, wherein in step S7 of correcting the elevation value of the edge of the tile by using an eight neighborhood algorithm, the adjacent tiles are calculated in parallel for the output linked list <Key, Tile>, the cell values of the adjacent grid cells around except for the intersection points are taken, and the values of the top, bottom or left and right cells are taken, and the average value of the obtained cell values is taken as the elevation value of the specified grid cell; and the elevation values of the four corners are calculated by taking the values of the other three tiles adjacent to the tile and the corresponding corners, and taking the average value as the elevation value of the corresponding grid cell.

15